

## Temperament and emotion regulation: The role of autonomic nervous system reactivity

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### **Abstract:**

The aim of the present study was to examine the moderating role of parasympathetic and sympathetic nervous system functioning on the relationship between child temperament and emotion regulation. Sixty-two 4.5-year olds (31 females) were rated by their parents on temperamental surgency. Respiratory sinus arrhythmia (RSA) and pre-ejection period (PEP) were measured at baseline and in reaction to an interaction with an unfamiliar person and a cognitive test. The preschoolers' ability to self-regulate emotion was assessed in response to a disappointment. Results revealed little or no PEP reactivity to the unfamiliar person to be related to poorer emotion regulation for children high in surgency, indicating that the lack of sympathetic activation may be a risk factor for behavioral maladjustment. Reciprocal sympathetic activation, or increases in sympathetic activity accompanied by decreases in parasympathetic activity, was associated with better regulation of emotion for all levels of temperamental surgency supporting previous work that reciprocal activation is an adaptive form of autonomic control.

**Keywords:** temperament | autonomic nervous system | parasympathetic reactivity | sympathetic reactivity | emotion regulation

### **Article:**

## **INTRODUCTION**

Emotion regulation is a developmentally significant accomplishment. Learning to control one's emotions to frustrating or fear-inducing situations is essential to positive social adjustment and attenuates conditions related to poor developmental outcome. In young children, successful emotion regulation leads to better peer relations (Calkins, Gill, Johnson, & Smith, 1999), prosocial behavior (Eisenberg, Fabes, Guthrie, & Reiser, 2000), and fewer problem behaviors

(Supplee, Skuban, Shaw, & Prout, 2009). Moreover, emotion regulation has an important role in school readiness, and moderates risks associated with economic disadvantage (Raver, Garner, & Smith-Donald, 2007; Shields et al., 2001).

Children's ability to regulate emotions may vary depending upon their temperament. Variations in temperamental approach, for example, generate different emotions that may require regulation. Children who are characterized by high temperamental approach, referred to as surgent, exuberant, or uninhibited, exhibit more approach to novelty, intense pleasure, and impulsivity (Rothbart & Bates, 2006). Because of their approach motivations, these children may experience more frustration and anger to blocked goals, which in certain contexts would need to be regulated. Similarly, children who are low in temperamental approach, referred to as behaviorally inhibited or shy children, are characterized by their low tolerance for novelty and high levels of fearfulness and may also require skills to regulate their emotions—specifically their fear (Kagan, Reznick, & Snidman, 1987).

The importance of the self-regulation of emotion to children of varying approach tendencies may be best explained by their developmental outcomes. In several studies, surgent or exuberant children have been found to be at risk for externalizing behaviors (Berdan, Keane, & Calkins, 2008; Gunnar, Sebanc, Tout, Donzella, & van Dulmen, 2003; Stifter, Putnam, & Jahromi, 2008). On the other hand, extremely inhibited children are more likely to develop internalizing behaviors (Biederman et al., 2001), specifically anxiety (Chronis-Tuscano et al., 2009; Feng, Shaw, & Silk, 2008). The inability to regulate the predominant emotions associated with their temperamental dispositions may be the mechanism by which children high or low in approach develop problem behavior. Indeed, recent evidence indicates that exuberant or surgent children who have difficulty regulating their emotions are more likely to develop externalizing problems (Rubin, Coplan, Fox, & Calkins, 1995; Stifter et al., 2008). For example, preschoolers high in surgency but low in regulation were more likely to be aggressive which in turn was related to peer rejection (Gunnar et al., 2003). Interestingly, this combination of surgency and regulation was also predictive of elevated levels of salivary cortisol, indicating that children's surgency is not only associated with their behavior, but also how they respond physiologically.

As the behaviors of inhibited (low approach) children are by definition regulatory, for example, they avoid or withdraw from situations, which heighten their fear, few studies have found differences in emotion regulation among this temperament group. The handful of studies that have examined the regulatory capacity of inhibited children suggest that if they are continuously inhibited across childhood (e.g., inability to regulate fear) their outcomes are poorer than if they demonstrated less fear reactivity or better regulation. (Eisenberg, Shepard, Fabes, Murphy, & Guthrie, 1998; Hill-Soderlund & Braungart-Rieker, 2008; Stifter, Cipriano, Conway, & Kelleher, 2009).

In addition to relations with behavioral responses, the ability to regulate emotions and behavior has been related to differences in cardiac physiology in infants, toddlers, and preschoolers, specifically activity in the parasympathetic branch of the autonomic nervous system (Blair, 2003; Calkins, Dedmon, Gill, Lomax, & Johnson, 2002; Hastings et al., 2008; Porges, Doussard-Roosevelt, Portales, & Greenspan, 1996; Stifter & Jain, 1996). In general, these studies have demonstrated that high levels of baseline parasympathetic activity as measured by respiratory

sinus arrhythmia (RSA) and/or the ability to suppress parasympathetic activity are related to more accomplished emotion regulation and developmental outcomes reflecting effective self-regulation of emotion. For example, children who exhibited stable suppression of parasympathetic activity to challenge tasks from 2 to 4.5 years of age were more likely to possess better social and emotion regulation skills and to have fewer behavior problems (Calkins & Keane, 2004).

According to the polyvagal theory of Porges (Porges, 1995, 2007), while baseline measures of parasympathetic activity index the capacity to respond to the environment, variations in the suppression of parasympathetic input on the heart reflect the organism's ability to engage and disengage with the environment. Porges contends that changes in parasympathetic input to the heart gives rise to increases in metabolic output sufficient for participating in social interactions. Under conditions of perceived threat, however, Porges proposes that suppression of parasympathetic input may not be enough and activation of the sympathetic system will be necessary for mobilization. Thus, we might expect that individuals will vary to the degree to which they evoke sympathetic reactivity (Beauchaine, 2001; Kagan, 1994).

Historically, increases in heart rate (HR) have been used as a measure of sympathetic input to the heart. Increases in HR to fearful stimuli and contexts, for example, are well documented in the developmental (Kagan, 1994), and adult (Cacioppo, Klein, Berntson, & Hatfield, 1993) research literature. HR, however, is autonomically controlled by both the sympathetic and parasympathetic branches of the autonomic nervous system and thus is not a good estimate of sympathetic activation. For instance, HR reactivity to fearful contexts for some individuals may be due to withdrawal of parasympathetic input to the heart rather than sympathetic reactivity. This may be particularly true for those who are high in temperamental approach as they may be less physiologically aroused by fearful stimuli. In order to examine temperamental differences in physiological reactivity and its relation to emotion regulation a more accurate measure of sympathetic activation is required.

Pre-ejection period (PEP), the sympathetically mediated time between the beat of the heart and ejection of blood into the aorta, has been validated in adults as a viable measure of sympathetic activity (Berntson et al., 1994), and most recently studied in children and adolescents (Matthews, Salomon, Kenyon, & Allen, 2002; McGrath & O'Brien, 2001; Quigley & Stifter, 2006). PEP has also been studied in relation to developmental outcomes. Decreased sympathetic reactivity, as measured by PEP, has been linked to externalizing behavior in 6–7 year olds (Boyce et al., 2001) and distinguished adolescents co-morbid for hyperactivity attention disorder (ADHD) and conduct disorder from those with ADHD only and from controls (Beauchaine, Katkin, Strassberg, & Snarr, 2001). On the other hand, PEP measures of increased sympathetic reactivity was related to the freezing behavior of toddlers during interactions with a stranger (Buss, Davidson, Kalin, & Goldsmith, 2004) and children's increased memory for a mildly stressful event (e.g., fire alarm; Quas, Carrick, Alkon, Goldstein, & Boyce, 2006). To date, no study has examined the relationship between temperament and PEP in young children.

Recent psychophysiological models have called for the integration of sympathetic and parasympathetic control in understanding behavioral and affective reactivity and regulation (Berntson, Cacioppo, & Quigley, 1991). Historically, the activity of both branches of the

autonomic nervous system was believed to be coupled and reciprocal whereby increases in one branch would be accompanied by decreases in the other. Berntson et al. (1991), however, suggest that reactivity in both branches can also act independently (uncoupled) or together (nonreciprocal) resulting in nine different patterns of autonomic modes of control (parasympathetic and sympathetic reciprocal activation, uncoupled parasympathetic and sympathetic withdrawal, uncoupled parasympathetic and sympathetic increases, coinhibition, coactivation, and no reactivity). More importantly, they propose, and research has confirmed (Berntson et al., 1994; El-Sheikh et al., 2009), that the pattern of reciprocal sympathetic activation (increases in sympathetic activity coupled with decreases in parasympathetic activity) is more adaptive when under stress, whereas reciprocal parasympathetic activation would predominate during calm states. Moreover, consistent with Porges' polyvagal theory (Porges, 1995), parasympathetic decreases with no sympathetic activation (uncoupled parasympathetic withdrawal), would be necessary only under mild challenge. Recently, studies have considered activation in both branches in children and adolescents (Alkon et al., 2003; Quigley & Stifter, 2006; Salomon, Matthews, & Allen, 2000). The results from those studies that examined social and behavioral outcomes have revealed reciprocal activation to be related to positive environments and outcomes (El-Sheikh et al., 2009; Salomon et al., 2000) while nonreciprocal coactivation (increases in both parasympathetic and sympathetic activation) or coinhibition (decreases in parasympathetic and sympathetic activation), to be related to negative outcomes such as externalizing disorders (Boyce et al., 2001; El-Sheikh et al., 2009). None of these studies considered individual differences in temperamental approach, a temperament dimension that has implications for physiological reactivity.<sup>1</sup>

## THE PRESENT STUDY

In the present study we examined the cardiac physiology of preschool children who varied on temperamental approach and whether parasympathetic reactivity as measured by changes in RSA or sympathetic reactivity as measured by changes in PEP contributed independently or in combination to the ability to regulate emotion when disappointed. We used a parent-rated instrument to assess temperament. Specifically, we examined variations in surgency, a construct that includes intense pleasure, impulsivity, (low) shyness, and activity level.

As context is important in understanding the biological foundation of temperament we assessed cardiovascular reactivity by measuring RSA and PEP during two tasks; an interview with an unfamiliar person and a cognitive assessment. We expected the interview with an unfamiliar person to be mildly threatening and thus would be more likely to elicit changes in sympathetic activation, particularly in children rated as lower in temperamental approach. The cognitive assessment, which has been used in previous research as a context for measuring RSA suppression (see Porges et al., 1996), was expected to be more sensitive to parasympathetic changes indicative of social and affective regulation. The person who administered the cognitive assessment participated in warm-up activities with the child prior to the test and therefore was not considered to be as stressful as the interview with an unfamiliar person.

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<sup>1</sup> The term "surgency" is an abbreviation of the dimension "extraversion/surgency" drawn from the Child Behavior Questionnaire (Rothbart et al., 2001), which was used in the present study. We chose this briefer label as it is most commonly used in the developmental literature and is less cumbersome for the reader.

To assess emotion regulation, we examined emotional reactions to a mild disappointment. This task, designed initially to evoke display rules, has been proposed to also require the regulation of emotion in young children (Cole, Martin, & Dennis, 2004) and is supported by research demonstrating a link between the ability to regulate disappointment and expected outcomes of emotion regulation such as externalizing behavior (Cole, Zahn-Waxler, & Smith, 1994; Stifter et al., 2008).

Based on the theoretical and empirical literature, we developed several hypotheses that guided our study. Our primary hypothesis was that physiological reactivity would moderate the relationship between temperament and emotion regulation but in different ways. Specifically, we hypothesized that (1) children rated higher in surgency who demonstrated increases in sympathetic reactivity during the interview with an unfamiliar person would be more regulated. This hypothesis is based on previous research with children and adolescents, which showed that increases in HR to a stressor to be a protective factor against psychosocial maladjustment (Ortiz & Raine, 2004; Raine, Venables, & Williams, 1995). On the other hand, (2) we expected that children rated lower in surgency who exhibited greater sympathetic reactivity during the interview with an unfamiliar person would be less able to regulate their disappointment. Because inhibited children (low surgency) already have active sympathetic systems (Kagan et al., 1987) greater sympathetic reactivity to novelty might impede their ability to develop regulatory strategies (Hill-Soderlund & Braungart-Rieker, 2008). (3) Although, we did not expect parasympathetic reactivity to moderate the temperament-emotion regulation relationship, we did hypothesize that children who demonstrated decreases in parasympathetic activation during a cognitive assessment would be better regulated during disappointment than children who did not decrease parasympathetic activity, regardless of their temperament. This hypothesis is based on the findings from studies in early childhood demonstrating positive relationships between RSA and emotion and self-regulation. (4) Finally, we explored whether highly surgent preschoolers who exhibited reciprocal parasympathetic or sympathetic activation would be more likely to be better regulated than those who exhibited co-inhibition or co-activation of both branches. Recent research has shown reciprocal activation to be related to positive developmental outcomes (El-Sheikh et al., 2009) but no study, to date, has examined whether this physiological pattern of reactivity is moderated by the child's temperament.<sup>2</sup>

## **METHOD**

### **Participants**

Ninety children (43 female) were re-recruited from two completed, longitudinal studies examining the development of emotion regulation, emotion expression, and temperament in infancy and toddlerhood when children were 4.5 years old. Participants were predominantly White, educated, and middle class. Parental average age was 35.1 years (range = 20–47 years) for mothers and 37.6 years (range = 25–50 years) for fathers. Maternal average years of education was 15.7 years (range = 11–21 years) and paternal average years of education was 16.2 years (range = 12–28 years). The highest percentage of families (31.9%) reported an average yearly income of \$50,000–\$75,000. Of the 90 participants, 62 had complete data available on all the

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<sup>2</sup> Autonomic modes of control (Berntson, Cacioppo, & Quigley, 1993) were attempted but the sample size was too small to fill each cell with enough subjects.

study variables. Reasons for missing data included problems with the ECG recording equipment during the baseline, emotion interview, or PPVT, refusal of children to have the electrodes placed on their body, or incomplete temperament questionnaire data.

## Procedures and Measures

When children were 4.5 years of age they came to the laboratory twice, once with their mother and once with their father. During both laboratory visits, children participated in several tasks designed to assess self- and emotion regulation abilities as well as a cognitive assessment (Stifter et al., 2008). Prior to the tasks, the child participated in several warm-up activities (~15 min) to acclimate them to the lab and the experimenters, one of whom administered the cognitive assessment. Additionally, children's parasympathetic and sympathetic physiology was collected during a baseline and three tasks. Parents completed several questionnaires, which included a report of their child's temperament. The physiological recordings (baseline, interview with an unfamiliar person, cognitive assessment) and a disappointment task were used in the present study and are described in greater detail below. All tasks were administered at a child-sized table and were videotaped for later off-line coding.

## Physiologic Recordings

Baseline and task electrocardiograms (ECG) and impedance cardiograms were recorded. After the 15-min warm-up period and attachment of the electrodes, a baseline period during which children ranked toys to be used in the disappointment paradigm (see below) was recorded. After the baseline period, cardiac physiology was recorded while children viewed 12 min of various emotional scenes, for example, neutral, happy, fear, anger, from the *Wizard of Oz*, answered questions about the movie clips posed by an unfamiliar female, and participated in a cognitive assessment. In line with theory and research on parasympathetic and sympathetic reactivity, only change in RSA and PEP during the interview with an unfamiliar person and the cognitive assessment were used in the present study.

Three electrodes were placed in a triangular pattern on the distal end of the right clavicle, lower left rib cage chest, and the lower abdomen. Cardiac impedance was collected using a four spot electrode configuration. Electrodes were placed on the back of the neck on the C4 vertebrae, at the top of the sternum, over the xiphisternal junction, and on the back over the thoracic spine (Sherwood et al., 1990). The two current electrodes were approximately 2 cm above and below the recording electrodes. Basal thoracic impedance ( $Z_0$ ), the first derivative of the change of thoracic impedance ( $dZ/dt$ ), and the ECG were measured using a Minnesota Impedance Cardiograph (Model 304B) connected to a laptop computer which was equipped with data collection hardware and software (Mindware Technologies, Westerville, OH).

To quantify the HR data, the ECG and impedance signals were passed through an A/D converter with ECG and  $dZ/dt$  sampled at 1,000 Hz and  $Z_0$  sampled at 500 Hz. RSA, or HR variability that occurs within the respiratory frequency, was used in the study to assess parasympathetic reactivity. RSA values were derived from the interbeat interval series and were resampled at 25 ms to create a stationary wave form. The integral of the power in the RSA band (.24–1.04 for children) was extracted and the natural logarithm of this measure was the RSA statistic. Visual

inspection of movement artifact was conducted and artificial heart beats were interpolated to retain the time series. PEP, a measure of sympathetically mediated cardiac contractility, is derived by taking the time between the onset of the ECG Q wave and dZ /dt B point (beginning of the ejection). PEP is negatively related to sympathetic activation, such that lower values represent increases in sympathetic activity while higher values indicate decreased sympathetic activity.

Mean RSA and PEP were calculated for each 30 s of the baseline and reactivity tasks. In cases of movement artifact, data were edited manually. For ease of interpretation of the study hypotheses, RSA and PEP change scores were calculated so that both parasympathetic suppression and sympathetic reactivity were in a positive direction. That is, change in RSA ( $\Delta$ RSA) was calculated by subtracting mean RSA during the interview and cognitive task from the baseline RSA mean such that *positive scores represented parasympathetic suppression with larger change scores indicating greater suppression* . Change in PEP ( $\Delta$ PEP) was calculated by subtracting the mean PEP during the interview and cognitive task from the mean PEP during baseline such that *positive scores indicated sympathetic reactivity with larger change scores signifying greater reactivity* .

#### Interview With an Unfamiliar Person

After the child watched a video of several selected scenes from the *Wizard of Oz* , an experimenter the child had not met or seen previously entered the room and interviewed the child about how she/he felt when she/he watched a particular scene. The experimenter also presented cards with emotion faces (happy, angry, sad, fear) printed on them and put them in front of the child to allow the child to indicate which face matched how she/he felt when she/he saw the scene. The experimenter noted which emotion and which emotion face the child used to answer the questions during the interview. If the child said “okay,” “not bad,” “bad,” “I don't know,” or any other nondescript term, the experimenter prompted the child with “Did you feel Happy? Sad? Mad? or Scared?” The interview lasted approximately 5 min.

#### Cognitive Assessment

The Peabody Picture Vocabulary Test-Third Edition (PPVT; Dunn & Dunn, 1981) measures the child's receptive language ability. The PPVT was administered according to standardized procedures by an experimenter who was familiar to the child. The child was presented with four pictures and the experimenter told the child to point to the picture that matched the word that the experimenter said. Raw scores were converted to age-adjusted standardized scores from published norms. The task lasted approximately 15 min.

#### Disappointment Task

The disappointment task was used to assess children's self-regulation of emotion (Cole, 1986). At the start of the laboratory visit, the child was shown a tray of six toys, and the experimenter asked the child to choose the toy she/he liked best. Once this toy was identified, the experimenter put the toy aside and then asked the child to choose the toy she/he liked the least. This procedure continued until all six toys were ranked. After participating in a number of tasks, and ending

ECG/impedance recording, the experimenter thanked the child and told the child that s/he would receive a prize. The experimenter left the room and returned with a wrapped prize, which contained the toy the child ranked as his/her least favorite.

The experimenter handed the child a wrapped gift and while the child unwrapped the gift, the experimenter sat across from him/her (experimenter-present condition). The experimenter remained in the room for 30 s after the child unwrapped the gift, attended to paperwork and did not engage with the child. After the 30 s passed, the experimenter left the room for 60 s (experimenter-absent condition). A second experimenter returned to the room after the 60 s to interview the child about the gift (how she/he felt about the prize, did she/he know that she gave him/her the wrong gift). When the second experimenter completed the interview, the mother entered the room and remained with the child for 60 s (mother-present condition). The first experimenter then returned to the room and gave the child the opportunity to exchange the gift for any other gift on the tray.

Children's facial and vocal affect during the disappointment task were coded from videotaped recordings. Children's facial expressions were coded using an adapted version of Ekman and Friesen (1978) Facial Affect Coding System (FACS) as a guide. Coders were trained to continuously code for the onset and offset of expression indicative of low/moderate positive, high positive, low/moderate negative, and high negative facial affect. A more detailed description of the coding scheme can be obtained from the first author. Coders maintained 84% agreement on 24% of the sample.

Children's verbalizations were transcribed from the videotapes and then coded for content and tone. Negative verbalizations were coded from the transcripts when the child used negative emotion words (e.g., "angry") or made negative comments about the prize. Positive verbalizations were coded when children used such words as "happy" and "love." The emotional tone of the children's verbalizations was also coded. Hostile, demanding, or whiney tones were coded as negative whereas pleasant, cheerful, or appreciative vocalizations were coded as positive. Verbalizations were then combined in the following manner: if either the tone or content was positive, then a low positive code was applied. If both the tone and content were positive, then a high positive code was applied. The same compositing was done for negative verbalizations. All other verbalizations were coded as neutral. Reliability was calculated on 28% of the subjects and was .91 (Cohen's kappa).

Composite scores were created for positive, neutral, and negative affect by averaging the proportion of time children expressed each emotion facially and vocally during the experimenter-present and experimenter-absent conditions. Only emotions expressed during the experimenter-present condition were considered in the present study because this condition, during which the children had to regulate their disappointment in the presence of another person, was considered more challenging to the children's emotion regulation system. Finally, to reflect the ability to regulate his/her disappointment in a way that followed culturally appropriate display rules, a composite was created by summing the proportion of positive and neutral affect during the experimenter-present condition. Although strongly inversely related ( $r = .70, p < .001$ ), this



variable and the proportion of time the child expressed negative affect, an indicator of the inability to regulate disappointment, were considered separately in the present study.<sup>3</sup>

### Parent-Report of Child Temperament

The Child Behavior Questionnaire Short Form Version 1 (CBQ; Rothbart, Ahadi, Hershey, & Fisher, 2001) was sent to the homes of the participants and completed by the mother and father. The CBQ is a child temperament questionnaire that consists of items asking parents to respond to statements describing their child's reactions to a number of situations. Mothers and fathers rated their child on a seven-point scale for each statement (1 = *extremely unlike your child* to 7 = *extremely true of your child*). For the purposes of the present study, the extroversion/surgency superfactor was used and included the following subscales (alphas for mother, father): activity level ( $\alpha = .69, .65$ ), impulsivity ( $\alpha = .59, .66$ ), shyness, (negatively loaded,  $\alpha = .86, .83$ ), and high intensity pleasure ( $\alpha = .45, .46$ ). As mother's and father's ratings were strongly related,  $r = .66, p < .001$ , an overall “surgency” score was computed by averaging the subscale scores for the mothers and fathers ( $\alpha = .79$ ). High scores reflect higher surgency while low scores on surgency were hypothesized to reflect inhibited-like behavior.

## RESULTS

### Preliminary Analyses

All study variables were tested for gender differences. No significant gender differences were revealed for temperamental surgency, the physiological measures (baseRSA, basePEP,  $\Delta$ RSA interview,  $\Delta$ PEP interview,  $\Delta$ RSA cognitive, and  $\Delta$ PEP cognitive) and the emotion regulation outcome variables. Descriptive statistics for all study variables can be found in Table 1.

Intercorrelations were computed among all study variables prior to conducting our primary analyses. Of the 28 possible correlations, only 7 were significant. As expected, baseRSA was positively related to the  $\Delta$ RSA during the interview,  $r = .353, p < .01$ . BasePEP was negatively related to the  $\Delta$ PEP interview,  $r = -.378, p < .01$ , and positively correlated with  $\Delta$ PEP during the cognitive test,  $r = .253, p < .05$ . Also,  $\Delta$ RSA interview was significantly related to  $\Delta$ RSA cognitive,  $r = .228, p < .05$ , and  $\Delta$ PEP interview was significantly correlated with  $\Delta$ PEP cognitive,  $r = -.413, p < .001$ . Surgency was negatively related to  $\Delta$ RSA cognitive,  $r = -.270, p < .05$ , suggesting that high surgent children were less likely to exhibit vagal suppression during the cognitive test. Finally, children high in surgency were more likely to show high levels of regulation (more positive/neutral affect) during the disappointment task,  $r = .234, p < .05$ .

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<sup>3</sup> To confirm that preschoolers were disappointed when they did not receive the gift that they ranked as most liked, we first examined change in positive/neutral and negative affect from the experimenter-present to the experimenter-absent condition. *t*-tests indicated that there were significantly higher levels of positive/neutral affect in the experimenter-present than experimenter-absent condition,  $t(1, 89) = -5.807, p < .001$ . However, while children showed higher levels of negative affect in the experimenter-absent condition, these differences were not statistically significant,  $t(1, 89) = 1.195, p = .235$ . Secondly, children should also trade the gift they received for any of the other toys. All but one of the children traded their gift. The one girl who kept her least favorite gift (baby rattle) stated that she wanted to give it to her baby brother.

**Table 1.** Descriptive Statistics for the Study Variables

	<i>N</i>	Mean	SD	Range
Predictors				
Surgency <sup>a</sup>	78	4.50	0.70	2.74–5.98
Mean RSA baseline	83	5.78	1.06	3.28–8.71
Mean PEP baseline	82	74.27	16.05	41.33–110.33
Mean RSA interview	82	5.81	1.08	3.23–8.32
Mean PEP interview	81	73.08	15.39	42.29–108.25
Mean RSA cognitive	80	6.12	1.17	4.12–9.01
Mean PEP cognitive	77	72.36	17.00	42.00–114.00
ΔRSA interview <sup>b</sup>	81	−.03	.78	−1.54–4.38
ΔPEP interview <sup>c</sup>	80	−1.06	10.00	−37.57–20.67
ΔRSA cognitive <sup>b</sup>	78	−.35	.62	−2.29–1.25
ΔPEP cognitive <sup>c</sup>	76	2.17	12.14	−26.00–38.67
Outcome				
Proportion of positive and neutral affect during disappointment	90	.76	.27	.02–1.0
Proportion of negative affect during disappointment	90	.13	.18	.0–.74

<sup>a</sup> Seven-point scale.

<sup>b</sup> Positive scores represent decreases in RSA (vagal suppression).

<sup>c</sup> Positive scores represent increases in PEP (sympathetic activation).

### RSA/PEP Descriptives

As can be seen in Table 1, children's physiological responses to the interview and cognitive test ranged from RSA decreases (positive scores) to RSA increases. Similarly, a wide range of responses were observed for PEP reactivity to the interview and cognitive test. Interestingly, the majority of children did not show the expected direction of change in RSA. Only 31% of children showed parasympathetic suppression to the cognitive test while 40% showed parasympathetic suppression to the interview. The majority of children did, however, show the expected changes in PEP with 53% during the cognitive test but only 46% showing a decrease in PEP (sympathetic reactivity), during the interview with the unfamiliar person.

A test of mean differences between the baseline measures and the RSA/PEP recorded during the interview with an unfamiliar person and the cognitive test revealed only one significant change and it was in the opposite direction than expected. RSA during the cognitive test was significantly higher than baseline RSA,  $t(1, 77) = -5.017, p < .001$ . Although not significant, the lower PEP values measured during the interview and cognitive test indicate that children exhibited more sympathetic activation during the tasks than baseline.

### Primary Analyses

The goal of the present study was to examine whether children's physiology moderated the relationship between children's temperamental surgency and their ability to regulate emotions. To test our hypotheses, multiple regression analyses were performed to examine the main effects of surgency and each of the moderating variables (baseRSA, basePEP, ΔRSA interview, ΔPEP interview, ΔRSA cognitive, and ΔPEP cognitive), as well as their interactions, on the emotion regulation outcome variables. We also examined the three-way interactions between surgency, ΔRSA, and ΔPEP.

Predictor variables were centered and then multiplied to create interaction terms. In each model, the predictor variable of parent-reported surgency was entered in the first step. Because baseline measures were significantly correlated with physiological reactivity ( $r$ 's = .25–.38), we controlled for the respective baseline levels in the multiple regression analyses in the second step. The physiological reactivity variables were entered in the third step, and the two-way interactions between child surgency and the physiological variables were entered in the third step. In this step, we also entered the two-way interactions between the reactivity variables ( $\Delta$ RSA  $\times$   $\Delta$ PEP). Finally, in the fourth step the three-way interaction, surgency  $\times$   $\Delta$ RSA  $\times$   $\Delta$ PEP, was entered. Follow-up tests of significant interactions were conducted following Aiken and West (1991).

Four multiple regression analyses were performed. Two analyses examined the moderating effect of physiological reactivity to the interview on the relationship between surgency and children's proportion of positive/neutral affect and negative affect during the Disappointment task. The second set of analyses examined the moderating effect of the RSA and PEP obtained during the cognitive assessment in predicting positive/neutral affect and negative affect to disappointment. All analyses that included the three-way interaction between surgency,  $\Delta$ RSA, and  $\Delta$ PEP were not significant so we reported the analyses without the three-way interaction. None of the significant findings were changed.

#### Moderating Effects of RSA/PEP During the Interview on Positive/Neutral Affect to Disappointment

The results of the multiple regression analysis testing the moderating effects of  $\Delta$ RSA interview and  $\Delta$ PEP interview on the relationship between surgency and children's proportion of positive/neutral affect during the Disappointment task are reported in Table 2. This model was significant with an  $R^2$  of .340. None of the main effects were significant. However, three significant interaction effects with surgency emerged—surgency  $\times$  baseRSA,  $t(10, 56) = 2.46$ ,  $p < .05$ , surgency  $\times$  basePEP,  $t(10, 56) = 2.23$ ,  $p < .05$ , and surgency  $\times$   $\Delta$ PEP interview,  $t(10, 56) = 3.83$ ,  $p < .001$ . Additionally, there was a significant interaction effect for  $\Delta$ PEP interview and  $\Delta$ RSA interview,  $t(10, 56) = 2.024$ ,  $p < .05$ .

Following guidelines recommended by Aiken and West (1991), the simple effects of the interaction between surgency and baseRSA were examined at  $-1$  SD and  $+1$  SD of surgency. At low levels of surgency, baseRSA and disappointment regulation (high levels of positive/neutral affect) were significantly negatively related,  $\beta = -.405$ ,  $t = -2.629$ ,  $p < .05$ . As can be seen in Figure 1, low surgent children who presented with higher levels of baseline RSA showed less positive/neutral affect to disappointment than low surgent children with low levels of baseline RSA. At high levels of surgency this relationship was not statistically significant.

Follow-up analyses of the significant interaction effect for surgency and basePEP, which examined the simple effects at low and high levels of surgency (Aiken & West, 1991) revealed that at  $-1$  SD level of surgency, basePEP and disappointment regulation were not significantly related. At high levels of surgency, basePEP and disappointment regulation were marginally significantly related,  $\beta = .325$ ,  $t = 1.822$ ,  $p < .10$ .

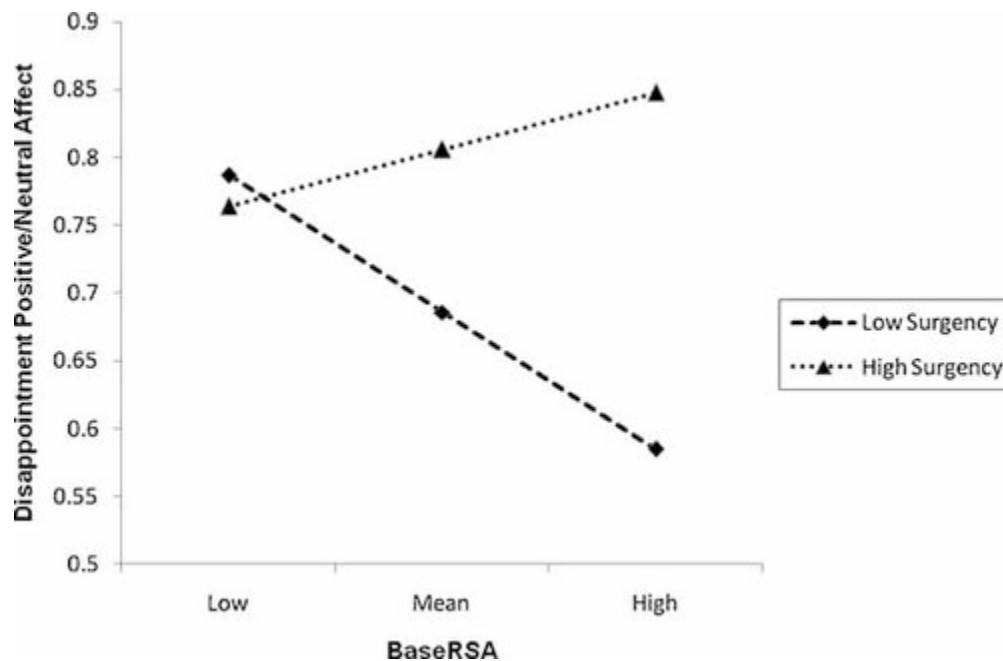
**Table 2.** Multiple Regression Analyses for Surgency, RSA/PEP Baseline and RSA/PEP Reactivity to the Interview in Predicting Positive/Neutral Emotions to Disappointment

	<i>B</i>	SE ( <i>B</i> )	$\beta$	<i>F</i>	<i>R</i> <sup>2</sup>
				2.547**	.337
Surgency	.084*	.044	.226		
Mean RSA baseline	-.028	.031	-.114		
Mean PEP baseline	.000	.002	.001		
$\Delta$ RSA interview	-.046	.049	-.140		
$\Delta$ PEP interview	.004	.003	.152		
Surgency $\times$ RSA baseline	.101**	.041	.316		
Surgency $\times$ PEP baseline	.007**	.003	.295		
Surgency $\times$ $\Delta$ RSA interview	-.146	.105	-.193		
Surgency $\times$ $\Delta$ PEP interview	.022***	.006	.537		
$\Delta$ RSA interview $\times$ $\Delta$ PEP interview	.008**	.004	.311		

\*  $p < .10$ .

\*\*  $p < .05$ .

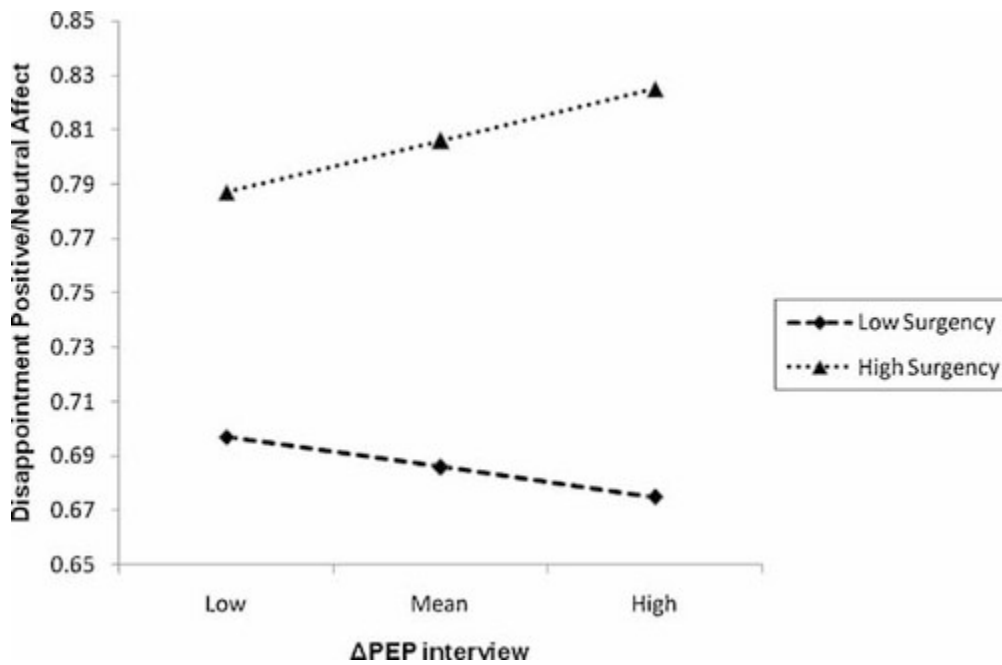
\*\*\*  $p < .001$ .



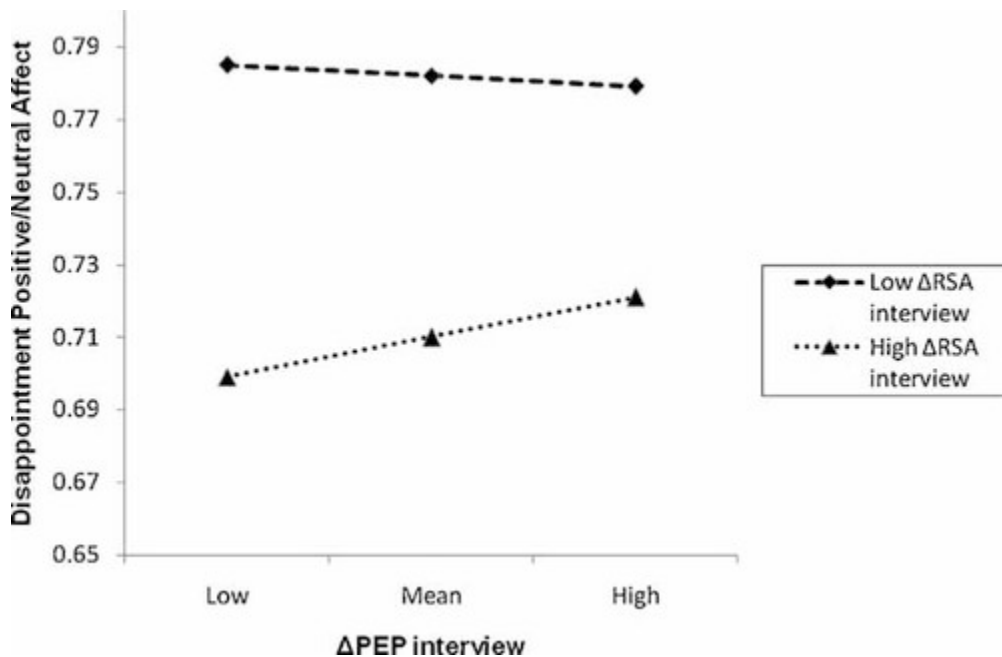
**Figure 1.** The moderating effect of BaseRSA on the relationship between child surgency and positive/neutral affect during disappointment at  $\pm 1$  SDs of surgency.

The significant interaction effect for surgency and  $\Delta$ PEP interview can be seen in Figure 2. Following the procedures of Aiken and West (1991), the simple effects of the interaction were probed.  $\Delta$ PEP interview and disappointment regulation were significantly negatively related at low levels of surgency,  $\beta = -.434$ ,  $t = -2.381$ ,  $p < .05$ . On the other hand, at high levels of surgency,  $\beta = .744$ ,  $t = 3.446$ ,  $p < .001$ ,  $\Delta$ PEP interview and disappointment regulation were positively related. As hypothesized, when being interviewed by an unfamiliar person, high surgent children who increased in sympathetic activation were better at regulating their emotions than high surgent children who responded with less sympathetic reactivity. Also confirming our

hypothesis, the data indicate that low surgent children who exhibited increased sympathetic input relative to low surgent children who showed less sympathetic reactivity were less able to regulate their disappointment.



**Figure 2.** The moderating effect of  $\Delta$ PEP interview on the relationship between child surgency and positive/neutral affect during disappointment at  $\pm 1$  SDs of surgency.



**Figure 3.** The moderating effect of  $\Delta$ RSA interview on the relationship between  $\Delta$ PEP interview and positive/neutral affect during disappointment at  $\pm 1$  SD of surgency.

Finally, the significant interaction between  $\Delta$ RSA interview and  $\Delta$ PEP interview can be seen in Figure 3. The simple effects of the interaction were probed such that the relationship between  $\Delta$ PEP interview and emotion regulation were examined at low ( $-1$  SD) and high ( $+1$  SD) levels of  $\Delta$ RSA interview (Aiken & West, 1991). At  $+1$  SD of  $\Delta$ RSA interview,  $\Delta$ PEP interview and disappointment regulation were significantly positively related,  $\beta = .411$ ,  $t = 2.242$ ,  $p < .05$ . As hypothesized, children who demonstrated more reciprocal sympathetic activation, that is, sympathetic reactivity accompanied by parasympathetic suppression, during the interview were more likely to regulate their disappointment. At  $-1$  SD of  $\Delta$ RSA interview,  $\Delta$ PEP interview, and disappointment regulation were not significantly related.

#### Moderating Effects of RSA/PEP During the Interview on Negative Affect to Disappointment

The results of the multiple regressions testing the interaction between surgency and RSA/PEP reactivity to the interview with an unfamiliar person in predicting negative affect to the Disappointment task mirrored the results for positive/neutral affect. As can be seen in Table 3, no main effects were revealed. However, three significant interaction effects with surgency emerged—surgency  $\times$  baseRSA,  $t(10, 56) = -2.53$ ,  $p < .05$ , surgency  $\times$  basePEP,  $t(10, 56) = -2.33$ ,  $p < .05$ , and surgency  $\times$   $\Delta$ PEP interview,  $t(10, 56) = -2.70$ ,  $p < .001$ . In addition, the same interaction between  $\Delta$ RSA and  $\Delta$ PEP revealed in the previous analysis was found,  $t(10, 56) = -2.37$ ,  $p < .05$ . Follow-up analyses were conducted as recommended by Aiken and West (1991), and the simple effects of each interaction between surgency and baseRSA were examined at  $-1$  SD and  $+1$  SD of surgency. The interactions were plotted but graphs are not included as they are similar (but in the opposite direction) to those for positive/neutral affect.

**Table 3.** Multiple Regression Analyses for Surgency, RSA/PEP Baseline, and RSA/PEP Reactivity to the Interview in Predicting Negative Emotions to Disappointment

	<b>B</b>	<b>SE (B)</b>	<b><math>\beta</math></b>	<b>F</b>	<b>R<sup>2</sup></b>
				2.377**	.298
Surgency	.026	.028	.113		
Mean RSA baseline	.014	.019	.092		
Mean PEP baseline	-.001	.001	-.131		
$\Delta$ RSA interview	.057*	.031	.286		
$\Delta$ PEP interview	-.005**	.002	-.328		
Surgency $\times$ RSA baseline	-.066**	.026	-.334		
Surgency $\times$ PEP baseline	-.005**	.002	-.322		
Surgency $\times$ $\Delta$ RSA interview	.119*	.066	.255		
Surgency $\times$ $\Delta$ PEP interview	-.010***	.004	-.387		
$\Delta$ RSA interview $\times$ $\Delta$ PEP interview	-.006**	0.003	-0.369		

\*  $p < .10$ .

\*\*  $p < .05$ .

\*\*\*  $p < .001$ .

Follow-up analyses for the significant interaction between surgency and baseRSA revealed that at low levels of surgency, there was a significant relation between baseRSA and negative affect during disappointment,  $\beta = .394$ ,  $t = 2.51$ ,  $p < .05$ , such that as baseline RSA increased for low surgent children, negative affect increased. Complementing the above findings, low surgent

preschoolers who exhibited high levels of baseline RSA were less regulated, that is, showed more negative affect to disappointment, than low surgent preschoolers with low baseline RSA. There was no significant relation between baseRSA and negative affect for high surgent children.

Results from a simple effects analysis of the interaction between basePEP and negative affect during disappointment revealed a significant effect for high surgency,  $\beta = -.469$ ,  $t = -2.603$ ,  $p < .05$ , but not low surgency. For children rated as high in surgency, higher PEP at baseline was related to less negative affect to being disappointed than if high surgent children had lower baseline PEP.

The significant interaction effect for surgency and  $\Delta$ PEP interview was probed following the procedures of Aiken and West (1991) and revealed a significant relation between  $\Delta$ PEP interview and negative affect,  $\beta = -.753$ ,  $t = -3.413$ ,  $p = .001$ . High surgent children who demonstrated greater sympathetic reactivity to the interview with the unfamiliar person were less likely to display negative affect when disappointed than high surgent children who showed a lower sympathetic response. The relation between  $\Delta$ PEP interview and negative affect was non-significant for low surgent children.

#### Moderating Effects of RSA/PEP During the Cognitive Assessment on Positive/Neutral Affect to Disappointment

The regression model with  $\Delta$ RSA cognitive and  $\Delta$ PEP cognitive as the moderators between surgency and disappointment positive/neutral affect was not significant,  $F(10, 53) = 1.45$ ,  $p > .10$ . There were no significant main or interaction effects.

#### Moderating Effects of RSA/PEP During the Cognitive Assessment on Negative Affect to Disappointment

Similarly, the multiple regression analysis examining the interaction between  $\Delta$ RSA cognitive/ $\Delta$ PEP and surgency on negative affect to the disappointment revealed no main or interactions effects  $F(10, 53) = 1.30$ ,  $p > .10$ .

To summarize, high surgent children who were able to mount a sympathetic response to the interview with a novel person were better regulated to a disappointment as illustrated by their high levels of positive/neutral affect and low levels of negative affect when compared to their high surgent peers who could not increase sympathetic reactivity to the interview. In contrast, low surgent children who showed increases in sympathetic reactivity to the interview were less regulated as evidenced by their low positive/neutral affect and high negativity. Less regulated low surgent children also exhibited high RSA at baseline. No moderating effects of sympathetic reactivity, and, contrary to hypothesis, parasympathetic reactivity to the cognitive assessment were found. Finally, children, regardless of temperament, who showed reciprocal sympathetic activation were better regulated than those children who exhibited coinhibition of sympathetic and parasympathetic activity.

## DISCUSSION

Differences in parasympathetic functioning have been studied extensively in young children. Baseline measures of parasympathetic input as measured by RSA have been associated with adaptive behaviors such as positive reactivity and temperamental approach. Likewise, parasympathetic reactivity, specifically parasympathetic suppression, to cognitive and emotional challenges, are associated with better emotion regulation, supporting Porges' (1995, 2007) polyvagal theory that social engagement/disengagement is dependent upon the functioning of the myelinated vagus. Although it is recognized that the parasympathetic branch of the ANS predominates phylogenetically and functionally, the activity of the sympathetic branch, particularly when environments are deemed “unsafe,” should also be informative about the developmental and behavioral outcomes of children. Until recently, very little research has measured sympathetic reactivity that is not confounded with parasympathetic influence. The goal of the present study was to examine both parasympathetic and sympathetic activation in preschoolers within two contexts and the role that the autonomic nervous system plays in moderating the relationship between temperamental surgency and emotion regulation to disappointment. Our findings indicate that the degree of sympathetic reactivity as measured by PEP during a stressful interview interacts with surgency, such that children rated as higher in surgency show improved emotion regulation, that is, more positive/neutral and less negative affect to being disappointed, as PEP levels increase, while those with lower surgency showed no such relationship.

The results on both baseline PEP and PEP reactivity during the interview with an unfamiliar person suggest that high surgent children may benefit from both higher sympathetic tone as well as greater sympathetic reactivity, specifically to a situation that may be interpreted as unsafe to some children. The lack of sympathetic tone or reactivity has been implicated in several studies, most done with children at risk for antisocial behavior. The results have shown that these children show low HR either at rest or in reaction to tasks designed to elicit sympathetic arousal (e.g., El-Sheikh, Ballard, & Cummings, 1994; Raine, Venables, & Sarnoff, 1997). Indeed, a meta-analysis of 40 studies of children ranging in age from 3 to 18 years found an effect size of  $-.44$  linking low resting HR to externalizing behaviors such as antisocial, oppositional, conduct disorder, and aggressive behavior (Ortiz & Raine, 2004). Moreover, an analysis of nine studies examining HR reactivity and antisocial behavior revealed an effect size of  $-.76$ , indicating that these children and adolescents do not react sympathetically to stressors that typically increase HR (Ortiz & Raine, 2004). HR, however, is the product of both parasympathetic and sympathetic input and thus not an accurate index of sympathetic activation. In the present study, we examined sympathetic activation in preschoolers using a more accurate measure—PEP. We hypothesized that high-surgent children who have been shown in past research to exhibit high levels of externalizing behaviors (Berdan et al., 2008; Stifter et al., 2008) would show lower levels of emotion regulation, a marker for externalizing problems, if they were not able to mount a sympathetic response than high surgent children who reacted sympathetically, particularly during a situation that may require the “fight or flight” response (for example, interacting with an unfamiliar person). Our hypothesis was supported and our findings confirm earlier studies that indicate that low sympathetic arousal may be a risk factor for later problem behavior. In contrast, increases in sympathetic output may act as a type of alarm system that alerts the child that a particular behavior is problematic. Or, sympathetic activation may reflect a degree of fear/anxiety, which would function to restrain the child from participating in negative behaviors.



The ability to mount a sympathetic response, therefore, may protect high surgent children from developing externalizing problems.

We also aimed to explore whether reciprocal sympathetic or parasympathetic activation interacted with surgency to predict better emotion regulation and that coinhibition or coactivation would relate to poorer regulatory ability dependent upon the level of surgency. Our findings showed that regardless of temperament, children who showed reciprocal sympathetic activation (parasympathetic suppression/increased sympathetic reactivity) during the interview with an unfamiliar person exhibited better emotion regulation than those who showed coinhibition (parasympathetic suppression/decreased sympathetic reactivity). These data join a growing body of evidence that reciprocal activation is a marker for behavioral adjustment (El-Sheikh et al., 2009; Salomon et al., 2000). Our finding suggests that when both the parasympathetic and sympathetic systems work in a reciprocal manner to increase arousal to an emotionally challenging situation (interacting with an unfamiliar person) this synergistic action may provide a physiological context for learning to regulate. That is, increases in physiological arousal within a challenging social context indicates the ability of the ANS to respond appropriately, and may reflect a physiological system that is responsive to the socialization of rules and standards of conduct (e.g., always be thankful when you get a gift even if you did not want it). Importantly, this finding was for all children regardless of temperament, further supporting the generalizability of reciprocal activation.

This result also revealed that children who exhibited coinhibition (parasympathetic withdrawal with little or no sympathetic activation) were less able to produce positive/neutral expressions and more likely to display negative expressions of emotion when receiving an undesired gift. Berntson et al. (1991) has suggested that coinhibition as well as coactivation reflect opposing rather than coordinated action across the ANS and thus may not support an organized response to an emotion-eliciting event such as regulating disappointment. Previous research has shown coinhibition to be related to clinical levels of externalizing behaviors (Boyce et al., 2001) and to be a risk factor for children exposed to marital conflict (El-Sheikh et al., 2009). Our findings extend this work and suggest that a possible mechanism through which coinhibition is related to poorer behavioral adjustment may be through the children's ability to regulate their emotions. Indeed, Beauchaine (2009) has suggested that children who display coinhibition may be a target group for emotion regulation intervention.

Finally, our hypothesis that children demonstrating decreases in parasympathetic activation, particularly during a cognitive assessment, would be better at regulating their disappointment, regardless of their temperament, was not confirmed. Previous research has shown suppression of parasympathetic activation (decrease in RSA) during mental tasks to be related to positive outcomes including emotion regulation (e.g., Stifter & Corey, 2001), however, most of these findings were for infants. The one study with preschoolers that did measure change in RSA to the PPVT, which was used in the present study, found a relationship between RSA suppression and approach motivation (Blair, Peters, & Granger, 2004). As this study was done with low-income children, the cognitive test may have been more challenging and thus elicited the expected response. The preschoolers in the present study were from middle class families and scored well, on average ( $M = 111.50$ ,  $SD = 12.44$ ) thus, the PPVT may have been less likely to produce a significant change in RSA in this sample. It may be that with development, changes in

parasympathetic activation to a cognitive task such as the PPVT do not make significant demands on the autonomic nervous system. Perhaps, more challenging tasks such as those that require working memory will provide a better assessment of RSA suppression in preschoolers. Indeed, several studies with preschool age children that have examined RSA change to more challenging cognitive tasks (problem solving, effortful control) have found RSA suppression to be related to positive developmental outcomes (Calkins, Graziano, & Keane, 2007; Graziano, Keane, & Calkins, 2007).

Our findings did reveal a significant interaction with baseline RSA, which was counter to expectation. While the research suggests a positive outcome for higher baseline RSA, low surgent children who exhibited higher baseline RSA were more likely to have poorer emotion regulation than low surgent children with lower RSA. This counterintuitive finding may be related to the regulatory strategies that typify low surgent children. Studies have shown that fearful or inhibited children tend to seek out comfort/regulation from caregivers (Mangelsdorf, Shapiro, & Marzolf, 1995; Parritz, 1996). Thus, while their high RSA would signify better regulatory skill, low surgent children may be unable to regulate in contexts where the caregiver is not available, which was the case with the disappointment task used in the present study. Future research might consider examining the relationship between ANS functioning, temperamental surgency, and emotion regulation across a number of different tasks that vary in the availability of the caregiver.

This study was not without limitations. For one, the research design was cross-sectional and as such the direction of effects could not be established. Two, our measure of surgency was based on parent report of temperament, a method known to have a subjective component (Stifter, Willoughby, & Towe-Goodman, 2008). Multiple measures of children's temperament would increase the reliability of this construct. As the present study only examined children's emotion regulation to disappointment, future research might also consider other emotion-eliciting situations, in particular those that evoke emotions specific to variations in surgency such as anger and fear. Another limitation was that our sample was quite homogenous; thus our results may not generalize to other ethnic/racial groups. Likewise, the study's small sample size may have restricted our ability to find significant results, particularly for the three-way interactions. We were also unable to examine autonomic profiles due to the small sample. Future research with larger samples would be able to test whether the relationship between reciprocal or nonreciprocal activation and emotion regulation was specific for high surgent children and might address whether autonomic profiles found in adults map onto those in children.

In summary, previous research has indicated that children high in surgency benefit from the development of regulatory skills as their tendency toward novelty-seeking, impulsivity, and high intensity pleasure puts them at risk for problem behaviors. Our results indicate that the ability to mount a sympathetic response that is adaptive (e.g., in response to an uncertain or "unsafe" situation) may protect high surgent children by contributing to the ability to regulate disappointment. Moreover, our findings showed that all young children who demonstrate a coordinated physiological response (reciprocal sympathetic activation) to the same situation also demonstrate better emotion regulation. By examining both branches of the ANS using more accurate measures that target the same organ, the findings of the present study add to the

growing body of research on the importance of the autonomic nervous system functioning in developmental outcomes.

## NOTES

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