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Respiratory sinus arrhythmia, parenting, and externalizing behavior in children with autism spectrum disorder

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Abstract

Children with autism spectrum disorder exhibit significant difficulties with emotion regulation. Respiratory sinus arrhythmia is a biomarker for processes related to emotion regulation, with higher baseline rates linked to beneficial outcomes. Although reduction in respiratory sinus arrhythmia in response to challenge can index adaptive processes in community samples, excessive withdrawal may suggest loss of regulatory control among children with clinical concerns. Psychophysiological risk for problems may be protected against or exacerbated by parenting environments more or less supportive of the development of children's regulatory competence. Respiratory sinus arrhythmia was examined in 61 children with autism spectrum disorder ages 6–10 years in relation to externalizing behavior, and parenting was considered as a moderator. Respiratory sinus arrhythmia was obtained during laboratory tasks, and positive parenting, negative parenting, and children's externalizing behaviors were each indexed through multiple methods. Respiratory sinus arrhythmia reactivity interacted with negative, but not positive parenting. Higher respiratory sinus arrhythmia reactivity was associated with more externalizing behavior under conditions of higher negative parenting, but with lower externalizing behavior at lower levels of negative parenting. Similarly, negative parenting was only associated with externalizing behaviors in the context of high child respiratory sinus arrhythmia reactivity. Implications for our understanding of emotion regulation in children with autism spectrum disorder, and for related interventions, are discussed.

Keywords

autism spectrum disorder, emotion regulation, externalizing behavior problems, parenting, psychophysiology, respiratory sinus arrhythmia

Autism spectrum disorder (ASD) is a neurodevelopmental condition characterized by deficits in social communication and the presence of restricted and/or repetitive behaviors (American Psychiatric Association, 2013). Although externalizing behaviors (e.g. non-compliance, aggression, disruptiveness) are not included in the diagnostic criteria for ASD, these challenges are common in children with ASD (McClintock, Hall, & Oliver, 2003) and cause significant distress for both the children and the adults supporting them (Caplan, Feldman, Eisenhower, & Blacher, 2016; Lecavalier, Leone, & Wiltz, 2006; Shawler & Sullivan, 2017). Externalizing problems can interfere with learning opportunities, impair functioning, and lead to more restrictive educational environments for children with ASD (Koegel, Koegel, & Surratt, 1992; Lauderdale-Littin, Howell, & Blacher, 2013).

Although many factors can contribute to the development of externalizing problems, these behaviors in children with ASD are often thought to be related to underlying challenges with emotion regulation (Mazefsky, Pelphrey, & Dahl, 2012; Samson, Hardan, Lee, Phillips, & Gross, 2015). Indeed, children with ASD exhibit more behaviors reflective of emotion dysregulation, fewer strategies

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considered beneficial for regulation, and diminished effects of regulatory efforts compared to children without ASD (Jahromi, Meek, & Ober-Reynolds, 2012; Mazefsky & White, 2014; Samson et al., 2015).

Respiratory sinus arrhythmia (RSA)

Autonomic nervous system activity is one route to better understand the biological underpinnings of reactivity and regulation in children with ASD (see Benevides & Lane, 2015). This system is comprised of the sympathetic nervous system (SNS) and the parasympathetic nervous system (PNS). SNS activity is often referred to as the "flight or fight" response, which involves an increase in arousal related to risk assessment, reward motivation, and/or inhibitory efforts (Beauchaine, 2001). The PNS is the arousal "brake," slowing heart rate and reducing arousal through increased output of the vagus nerve (Beauchaine, 2015a; Benevides & Lane, 2015). In this way, PNS activity is a substrate and psychophysiological index of emotion regulation (Beauchaine, 2015b). PNS activity is typically measured through RSA, as indexed by high-frequency heart-rate variability related to respiratory patterns.

RSA is commonly measured as a baseline level or through reduction in RSA in response to a challenge (RSA *reactivity*). Higher baseline RSA is thought to index better emotion regulation abilities and is associated with a host of desirable child outcomes, whereas lower baseline RSA is observed across several forms of psychopathology (Beauchaine, 2015b). RSA *reactivity* is more complicated in its interpretation, and may depend upon the population studied and the nature of the challenge (Beauchaine, 2015a; Beauchaine et al., 2019; Graziano & Derefinko, 2013; Obradović, Bush, & Boyce, 2011). RSA reactivity (i.e. reduction in RSA) in response to a challenge is often considered beneficial in community samples, in that this process allows for an efficient and incremental increase in arousal to address the demands of the situation, as well as greater SNS activation when needed (Graziano & Derefinko, 2013). Alternatively, higher RSA reactivity (higher withdrawal) in response to challenge may reflect a loss of regulatory control, particularly for children with clinical concerns, resulting in behavior more heavily driven by the SNS (Beauchaine, 2015a; Beauchaine et al., 2019).

Although the evidence is somewhat mixed, several studies have found lower baseline RSA as a function of ASD status (Benevides & Lane, 2015). In one of the few studies to examine RSA reactivity in ASD, Vaughan Van Hecke et al. (2009) found higher RSA reactivity to a video of an unfamiliar person in children with ASD relative to peers without ASD. The few studies that have examined RSA and individual differences *among* children with ASD have linked higher RSA baseline to better social skills (Bal et al., 2010; Guy, Souders, Bradstreet, DeLussey, & Herrington, 2014).

RSA and externalizing behavior

Several studies have linked lower baseline RSA with externalizing behavior in children without ASD (see Beauchaine, 2015b; Beauchaine, Gatzke-Kopp, & Mead, 2007). The only identified study to date that has examined RSA in relation to externalizing behavior in children with ASD was conducted by Neuhaus, Bernier, and Beauchaine (2014). However, the association between baseline RSA and externalizing behavior, which was low and not statistically significant, was presented only for the entire sample, which included children without ASD. Moreover, in a regression involving the full sample in which social skills were controlled, externalizing behaviors exhibited an unexpected positive relation to baseline RSA.

The current study examined RSA in children with ASD between the ages of 6 and 10 years. This age range represents an important period for parental influence on emotion regulation in children both with ASD (Fenning, Baker, & Moffitt, 2018) and without ASD (Morris, Silk, Steinberg, Myers, & Robinson, 2007), and falls within the ages included in previous examinations of the effects of physiology on externalizing behavior in this population (e.g. J. K. Baker, Fenning, Erath, et al., 2018; Neuhaus et al., 2014; Vaughan Van Hecke et al., 2009). Based upon the literature, it was hypothesized that higher baseline RSA would be associated with lower externalizing behavior, and that higher RSA reactivity would be associated with higher externalizing behavior. To the extent that children with ASD experience challenges with regulation and may have relatively low baseline RSA, higher RSA reactivity (i.e. reduction in RSA) could yield very low levels of RSA that reflect loss of regulatory control among these children.

RSA × parenting interactions

Several theories propose person-by-environment processes wherein certain developmental outcomes are a function of interactions between child characteristics and parenting. The *dual-risk* perspective, also known historically as the *diathesis-stress* perspective, proposes that some children are more vulnerable to poor environments than others based upon biological risk factors (Heim & Nemeroff, 1999; Roisman et al., 2012). *Differential-susceptibility* theory not only suggests that certain children have biological profiles that sensitize them to poor environments but also argues that these same profiles allow children to take advantage of supportive environments (Belsky, Bakermans-Kranenburg, & van IJzendoorn, 2007; Roisman et al., 2012). Boyce and Ellis (2005) proposed the *biological-sensitivity-to-context* model, which is

consistent with the differential-susceptibility hypothesis, but more specifically identifies psychophysiological reactivity as a key index and mechanism of sensitivity to both adverse and advantageous environmental conditions.

Consistent with person-by-environment models, interactions between SNS reactivity and parenting have predicted child externalizing behavior in several studies of children with ASD (J. K. Baker, Fenning, Erath, et al., 2018; J. K. Baker, Fenning, Howland, & Huynh, 2018) and without ASD (Erath, El-Sheikh, Hinnant, & Cummings, 2011; Kochanska, Brock, Chen, Aksan, & Anderson, 2015). *RSA* reactivity and parenting have also interacted in research on children with neurotypical development. Dyer, Blocker, Day, and Bean (2016) found that, among boys, the highest rates of externalizing problems were observed when high RSA reactivity was combined with more authoritarian maternal parenting styles. Similarly, Obradović et al. (2011) found that high RSA reactivity to a cognitively based stressor appeared to strengthen the relation between exposure to marital conflict and children's externalizing problems. No published studies have tested interactions between RSA reactivity and parenting in children with ASD.

The current study

The current study tested interactions between RSA reactivity and both positive and negative aspects of parenting in children with ASD. We hypothesized that higher RSA reactivity would be less positively related to externalizing behavior in the context of more optimal parental support (i.e. higher positive and lower negative parenting) and, likewise, that stronger associations between parenting and externalizing behavior would be found for children with higher RSA reactivity. Including positive and negative environmental conditions allowed a more complete comparison of dual-risk and biological-sensitivity-to-context models than most prior studies that included only measures of adverse environmental conditions.

In examining RSA reactivity, it is important to be attentive to the nature of the stressor (Beauchaine, 2015b; Beauchaine et al., 2019). In a learning context, high reactivity to frustration when attempting to complete a requested task may elicit disruptive behaviors in children with ASD (Mohammadzaheri, Koegel, Rezael, & Bakhshi, 2015). As such, we measured RSA reactivity during a task that specifically involved asking the child to engage in a frustrating activity—in this case, tracing a star using only a mirror image as a guide (El-Sheikh, 2005).

The current study was also concerned with robust, multi-method assessment of the variables of interest. We included multiple indices of positive parenting, each of which involved careful coding. Parental co-regulatory scaffolding has proven to be a powerful factor in the development of children with developmental disabilities (e.g. J. K. Baker, Fenning, Crnic, Baker, & Blacher, 2007; Fenning & Baker, 2012), and has been identified as a moderator for links between SNS risk and externalizing behavior in children with ASD (J. K. Baker, Fenning, Erath, et al., 2018). Parental warm attitudes, as coded through a parent speech sample, are negatively associated with externalizing problems in children (J. K. Baker, Fenning, Howland, et al., 2018) and adults with ASD (Woodman, Mailick, & Greenberg, 2016). Similarly, we utilized both coding and questionnaire data in our composite of negative parenting. Critical parent attitudes, as coded during the aforementioned speech sample, have been established as a fairly reliable correlate of externalizing behavior in children with ASD (J. K. Baker, Fenning, Howland, et al., 2018), with evidence for a causal pathway from criticism to behavior problems (rather than vice versa) in adolescents and adults with ASD (Greenberg, Seltzer, Hong, & Orsmond, 2006). Harsh parenting, as measured by questionnaire, has been examined in numerous studies of psychophysiology and externalizing problems in samples without ASD (e.g. Erath et al., 2011). Finally, consistent with the only other previous study examining RSA in relation to externalizing behavior in ASD (Neuhaus et al., 2014), we utilized parent report on a child behavior checklist (CBCL) for our main outcome measure, and this measurement was augmented with a symptom count from a structured diagnostic interview for clinical symptoms of oppositional defiant disorder (ODD), which co-occurs with ASD at rates as high as 37% (Kaat & Lecavalier, 2013).

Method

Participants

An initial sample of 77 children with ASD ages 6–10 years and their primary caregivers participated in a laboratory visit that included child assessment, psychophysiological data collection, structured parent–child tasks, parent interview, and parent completion of questionnaires. Children with an existing ASD diagnosis provided by a physician or psychologist were recruited from the community and from local service providers via flyers. Exclusionary criteria for the child included the presence of a genetic disorder of known etiology and significant motor impairment that would prevent task engagement.

Of the original 77 children, 11 refused the electrodes for measurement of RSA, and RSA data were determined to be artifactual for 5 additional children (e.g. noise or loss of signal due to pulling on electrode wires). Missing data analyses revealed no significant differences between the 16 children without usable RSA data and those included in the study except that missing data occurred more frequently for males (25% missing) as compared to females (0%), $\chi^2 = 4.89$, $p = 0.03$, and for children with higher ASD

Table 1. Descriptive statistics and correlations among variables of interest ($n = 61$).

	1	2	3	4	5	6	7	*M* (*SD*)
1. Age in years	—							7.95 (1.48)
2. IQ	–0.23†	—						80.02 (20.68)
3. ASD symptom level	–0.06	–0.11	—					7.21 (2.06)
4. RSA baseline	0.36**	–0.25†	0.04	—				5.96 (1.17)
5. RSA reactivity	–0.02	–0.00	0.06	0.00	—			0.00[a] (0.73)
6. Positive parenting	0.01	–0.02	–0.15	0.01	–0.07	—		0.01[b] (0.62)
7. Negative parenting	–0.09	0.08	–0.04	–0.19	0.14	–0.05	—	–0.01[b] (0.80)
8. Externalizing composite	–0.26*	0.26*	–0.08	0.03	0.03	–0.10	0.17	0.01[b] (0.91)

SD: standard deviation; ASD: autism spectrum disorder; RSA: respiratory sinus arrhythmia.
[a]Scores represent residuals from a regression.
[b]Composites were generated by averaging standardized scores.
†$p < 0.10$; *$p < 0.05$; **$p < 0.01$.

symptom scores, $t = 2.43$, $p = 0.02$, $d = 0.63$. Missing data were not significantly related to estimated IQ, $t = -1.59$, $p = 0.18$, $d = 0.41$.

The remaining sample of 61 children (74% male) was diverse with regard to intellectual ability and ASD symptom levels (see Table 1), with estimated IQ ranging from 47 to 121. The majority of the families identified their children as Hispanic (47%), 33% were Caucasian non-Hispanic, 5% were Asian American, 5% were African American, 3% identified as "other," and 8% identified as "multi-ethnic/racial." The median annual family income was between US$50,000 and US$70,000. The majority of primary caregivers were married (71%) and 3% of the primary caregivers were fathers. Nineteen (31%) of the children were taking medication, most commonly for attention problems/hyperactivity (13%), asthma (8%), allergies (7%), or seizures (5%). No children were reported to be taking selective serotonin reuptake inhibitors (SSRIs), which are sometimes related to RSA measurements (Beauchaine et al., 2019).

Procedures

All procedures were approved by our institutional review board. Parents consented for themselves and for their children, and assent was obtained from children.

RSA data collection. Following consent, the children were seated at a table that faced a small television on a stand in front of them. A wall was to the children's left and a temporary partition was placed to the children's right, behind which the parent eventually was seated. The electrodes were placed on the child by a female research assistant with the help of the parent. Electrodes were placed on the lower ribs and on the right clavicle. A short adjustment period occurred during which the data acquisition systems were checked for appropriate signal and then a 3-min baseline procedure was performed. This baseline involved viewing a series of nature slides on the television that included scenes of trees, water, mountains, and so on (Erath, Bub, & Tu, 2016). Parents were asked beforehand if they felt that their children had any particular interests in, or fears of, these types of stimuli, and none were reported. A video camera mounted high above the television recorded the child for later data assurance and allowed the parent to view the child from behind the partition. The child then engaged in the 3-min challenging task. As in previous studies that utilized this task to elicit physiological arousal related to negative emotion (e.g. El-Sheikh, 2005), the children were given a pencil and a structure was placed in front of them that allowed them to attempt to trace a star with only an indirect view of their hand and the paper by way of a mirror. This process reverses the directionality of the image, making the task difficult to perform. Despite the large range of cognitive functioning present in our sample, every child was judged to have understood the request for basic tracing, and each child demonstrated sufficient motor skills to engage with the task.

Scaffolding task. Following the RSA data collection, the parents and children were asked to engage in a series of interactive tasks, including one from which the measure of parental scaffolding was obtained. In this task, which has been used several times by our laboratory and others with children with ASD and related disabilities (J. K. Baker et al., 2007; J. K. Baker, Fenning, Erath, et al., 2018), the dyad was provided with colorful block tiles and a photo of a completed puzzle. The child was instructed to make the structure depicted in the photo. The parent was asked to let the child try it on his or her own, and then to provide any help that the parent deemed necessary. The experimenter returned after 5 min.

Parent speech sample. A 5-min speech sample was completed with the parent in a separate room from the child (Daley & Benson, 2008). The experimenter asked the parent to speak uninterrupted for 5 min about the child and his or her relationship with the child. The speech was audiotaped and coded for warmth and criticism.

Parent interview and forms. Parents reported on their children's externalizing behavior problems using a CBCL, and were also interviewed individually about their children's symptoms of ODD using a module from a structured diagnostic interview.

Measures

Diagnostic confirmation and ASD symptom level. Diagnostic confirmation was primarily based upon the existence of an ASD diagnosis by a community physician or psychologist and evidence that the child met the criterion for an autism spectrum classification on our laboratory administration of the Autism Diagnostic Observation Schedule–2 (ADOS-2; Lord et al., 2012). The ADOS-2 is a semi-structured assessment that facilitates observation and recording of child behaviors related to language, social communication, play, repetitive behaviors, and restricted interests and was performed by assessors certified as research reliable in the system. Most children (66%) received Module 3, 26% were tested with Module 2, and 8% received Module 1. The ADOS-2 comparison score was used to characterize the sample according to overall ASD symptom severity and to provide a robust measure of ASD symptom levels for consideration as a covariate. The comparison score allows for examination of symptom levels across different modules, with 1 indicative of minimal to no evidence of ASD-related symptoms and 10 reflecting a high level of symptoms.

Five children did not meet the ADOS-2 criterion for an ASD classification, but were retained in the current sample following completion of an in-depth, multi-method clinical best estimate by a licensed clinical psychologist with research reliability in the ADOS-2 and significant expertise in ASD assessment. All five children met clinical criteria on the Social Responsiveness Scale–2 (SRS-2; Constantino & Gruber, 2012), a widely used parent report measure of ASD symptoms, and all but one also met criteria on the Social Communication Questionnaire, Lifetime Version (SCQ; Rutter, Bailey, & Lord, 2003), a screening instrument based on the Autism Diagnostic Interview–Revised (ADI-R; Rutter, Le Couteur, & Lord, 2003).

Child IQ. An estimate of child IQ was obtained using the Stanford-Binet 5 ABIQ (Roid, 2003). The ABIQ is comprised of two subscales with high loading on the general intelligence factor: a Matrix Reasoning task that assesses non-verbal fluid reasoning and a Vocabulary task that evaluates expressive word knowledge. The Stanford-Binet 5 has sound psychometric properties and has been used previously for children with ASD (Matthews et al., 2015; Roid, 2003).

RSA. RSA was measured with a MindWare data acquisition system (MindWare Technologies, Inc., Gahanna, OH, USA). Electrocardiography data were collected through disposable Ag-AgCl electrodes placed on participants' right clavicle and lower left and right ribs. Data were sampled at 500 Hz, and RSA scores were quantified using spectral analysis (Berntson et al., 1997) with MindWare HRV analysis software (version 3.0.22) as the natural log of the variance in heart period within age-adjusted respiratory frequency bands (e.g. 0.27–0.50 Hz for 9-year-old children, 0.25–0.50 Hz for 10-year-old children; see Shader et al., 2018, for additional ranges). RSA was expressed in units of $\ln(ms^2)$. Possible artifacts were flagged by an algorithm that detects improbable interbeat intervals, allowing visual inspection and editing when necessary; relatively few artifacts were detected and these were corrected manually (Berntson et al., 1997). RSA reactivity was calculated as the residual of the regression of RSA during the star-tracing period on RSA during the baseline period (Burt & Obradović, 2013). Residualized change scores were multiplied by −1 so that higher RSA reactivity scores indicated greater reductions in RSA (i.e. greater withdrawal) from the baseline to the star-tracing period.[1]

Warmth and criticism. Parental warmth and critical comments were each coded in accordance with the guidelines from the Autism Five-Minute Speech Sample (AFMSS) (Daley & Benson, 2008). Warmth was indexed by the intensity of the feeling expressed by the parent about the child as represented by a positive and enthusiastic tone; spontaneous expressions of affection, love, appreciation, and so on; and signs of concern and empathy, and was coded 1 (*low*), 2 (*moderate*), or 3 (*high*). Critical comments were measured through a frequency count of statements that criticize or find fault with the child. These comments include a present-tense negative description of the child's personality or an account of problematic behavior delivered with a harsh tone or an indication of strong dislike or dissatisfaction. Psychometric support for this system has been provided in the form of high test–retest and interrater reliability, and associations with relevant child and family factors (J. K. Baker, Fenning, Howland, et al., 2018; Benson, Daley, Karlof, & Robison, 2011). Reliability for the current sample, based upon 47% of cases, was intraclass correlation (ICC; absolute agreement) = 0.82 for critical comments, and kappa = 0.85 for warmth.

Scaffolding. Parental support was coded from videotapes of the dyadic problem-solving task using the Parental Scaffolding Observation System (Hoffman, Crnic, & Baker, 2006). This system considers parents' ability to provide motivational, emotional, and technical support to their children during a challenging activity. Motivational scaffolding includes the ability of the parent to recruit the child's attention to the task, foster enthusiasm for the task, and refocus the child should he or she become distracted. Emotional scaffolding scores reflect a parent's ability to

provide co-regulatory emotional support to the child and to contribute to the child's feelings of accomplishment. Technical scaffolding evaluates the parent's ability to provide structure and support for the child with regard to the task through instruction, guidance, prompting, and/or modification of the task or goal. Each of these subscales is rated from 1 (*very low or absent support*) to 5 (*characteristically high support*). These subscales are highly positively correlated and the measure is most commonly used as an average overall score (J. K. Baker et al., 2007). Interrater reliability based on 25% of cases was ICC = 0.73.

Harsh discipline. Harsh discipline was measured with items from the Alabama Parenting Questionnaire (Frick, 1991). Our harsh discipline scale included two of the three items from the Corporal Punishment scale, with the item asking about hitting with a "belt, switch, or other object" omitted given its potential overlap with physical maltreatment, which we did not wish to capture. This item was replaced with the item reflecting harsh verbal discipline ("You yell or scream at your child when he or she has done something wrong."), in order to provide a more complete measure of harsh discipline. The alpha for this scale was 0.60.

Externalizing behavior. Externalizing behavior was partially indexed by parent report using the standardized Externalizing Scale *T* score from the age-appropriate version of the CBCL (Achenbach, 2009), a widely used measure with demonstrated validity in children with ASD (e.g. Pandolfi, Magyar, & Dill, 2012). Parents were also interviewed using the ODD subscale of the Diagnostic Interview Schedule for Children (DISC; Costello, Edelbrock, & Costello, 1985; Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000), a structured, computer-facilitated diagnostic interview based upon criteria from the *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; *DSM-5*; American Psychiatric Association, 2013). The DISC has been used in previous studies to assess comorbid behavior disorders in children with neurodevelopmental disabilities (B. Baker, Neece, Fenning, Crnic, & Blacher, 2010). The current study considered the total number of ODD symptoms endorsed. Only the ODD module was administered due to meta-analytic findings suggesting fairly low rates of conduct disorder among children with ASD (e.g. 4%) as opposed to ODD (about 30%–37%; Kaat & Lecavalier, 2013; Simonoff et al., 2008).

Data analysis plan

Composites for positive parenting, negative parenting, and child externalizing behavior were constructed on a theoretical basis regardless of the association between the relevant variables. Additional post hoc analyses were performed for any individual component variables that were not significantly related in the predicted direction. Bivariate correlations were then considered, followed by two hierarchical regressions used to test study hypotheses. The first regression tested hypothesized main effects of RSA baseline and reactivity, and whether RSA reactivity interacted with positive parenting. The second regression tested the interaction between RSA reactivity and negative parenting. Significant interactions were followed up with estimates of the relevant simple slopes at the mean of the moderator, as well as 1 *SD* below and 1 *SD* above the mean. Regions of significance (RoS) analyses were conducted to consider the degree to which the interactions suggested dual-risk or biological-sensitivity-to-context models (Roisman et al., 2012).

Results

Consistent with previous studies (J. K. Baker, Fenning, Howland, et al., 2018; Benson et al., 2011), most parents were rated moderate (63%) or high (30%) on warmth on the AFMSS. Similarly, average scaffolding was in the moderate to moderately high range ($M = 3.56$, $SD = 0.82$), and parents were relatively low on critical comments ($M = 2.28$, $SD = 2.36$) and harsh discipline ($M = 1.49$, $SD = 0.51$). Consistent with meta-analytical findings for negative emotion induction tasks (Beauchaine et al., 2019), children demonstrated significant RSA withdrawal as a group when moving from the baseline ($M = 5.96$, $SD = 1.17$) to challenge task ($M = 5.65$, $SD = 1.19$), $t = 3.17$, $p < 0.002$, $d = 0.41$. The current sample mean for externalizing behavior on the CBCL fell at the threshold for "borderline" clinical problems ($M = 59.62$, $SD = 9.44$), with almost a third (30%) falling within the clinical range. Similarly, and consistent with previous reports (Kaat & Lecavalier, 2013; Simonoff et al., 2008), 34% of the sample met criteria for ODD on the DISC ($M = 2.49$, $SD = 2.71$).

Parental critical comments and harsh discipline scores each exhibited some skew and were normalized through square-root transformation. These variables were positively correlated, $r = 0.33$, $p = 0.015$, and were standardized and averaged to generate the negative parenting composite. The association between parental warmth and scaffolding suggested an unexpected inverse association, $r = –0.23$, $p = 0.08$. Subsequently, analyses were performed not only for the overall positive parenting variable but also for warmth and scaffolding separately.[2] Scores for the children on the CBCL and the DISC ODD symptom scales were highly positively correlated, $r = 0.70$, $p < 0.001$, and were standardized and averaged for the externalizing behavior composite.

Lower child age and higher estimated IQ were each significantly related to higher externalizing behavior and were controlled in subsequent analyses (see Table 1). Medication use to treat inattention/hyperactivity was related to higher baseline RSA, $t = –2.62$, $p = 0.011$, $d = 0.68$; however, this variable was not related to any other variable of interest and did not alter results when controlled or when RSA scores were adjusted prior

Table 2. Hierarchical linear regressions predicting from RSA reactivity and parenting to externalizing composite.

	Positive parenting to externalizing composite						Negative parenting to externalizing composite					
	B	*SE*	β	*t*	*p*	R^2	*B*	*SE*	β	*t*	*p*	R^2
Step 1												
Age	–0.17	0.08	–0.29	–2.01**	0.049	0.150	–0.16	0.08	–0.27†	–1.99†	0.051	0.168
IQ	0.01	0.01	0.24†	1.88†	0.066		0.01	0.01	0.24†	1.88†	0.066	
RSA baseline	0.15	0.11	0.19	1.40	0.167		0.17	0.11	0.22	1.61	0.112	
RSA reactivity	0.04	0.16	0.03	0.27	0.792		0.02	0.15	0.02	0.13	0.898	
Parenting	–0.14	0.18	–0.10	–0.78	0.436		0.20	0.15	0.17	1.36	0.179	
Step 2												
Age	–0.16	0.08	–0.26†	1.93†	0.059	0.153	–0.17	0.08	–0.28*	–2.20*	0.032	0.257
IQ	0.01	0.01	0.24†	1.78†	0.080		0.01	0.01	0.24†	1.93†	0.059	
RSA baseline	0.15	0.11	0.20	1.44	0.156		0.17	0.10	0.21	1.65	0.105	
RSA reactivity	0.07	0.16	0.05	0.40	0.691		–0.05	0.15	–0.04	–0.31	0.759	
Parenting	–0.14	0.19	–0.09	–0.73	0.468		0.10	0.14	0.09	0.71	0.478	
RSA reactivity × Parenting	–0.14	0.28	–0.07	–0.49	0.624		0.64	0.25	0.32*	2.55*	0.014	

RSA: respiratory sinus arrhythmia.
Confidence interval for the significant interaction was 0.14–1.15.
†$p < 0.10$; *$p < 0.05$.

to analysis. No other demographic variable or aspect of medication status was related to either RSA measures or the outcome variable. All variables were mean-centered for inclusion in the regressions. Child age and estimated IQ were entered on the first step of the first regression, along with RSA baseline, RSA reactivity, and positive parenting (Table 2). The interaction between the latter two variables was added on the second step. Neither RSA baseline nor reactivity was significantly related to externalizing behavior, nor was the interaction between RSA reactivity and positive parenting. Analyses treating each of the positive parenting variables separately were similarly not significant for either warmth, $\beta = -0.27$, $p = 0.055$, or scaffolding, $\beta = 0.16$, $p = 0.386$.

In the second regression, negative parenting replaced positive parenting. RSA reactivity interacted with negative parenting in the prediction of the externalizing composite (Table 2). Follow-up analyses revealed that higher RSA reactivity predicted more externalizing behavior in the context of high negative parenting, $t = 2.04$, $p = 0.045$, $d = 0.53$; did not predict at medium levels, $t = -0.36$, $p = 0.717$, $d = 0.09$; and was associated with *fewer* externalizing behaviors at lower levels of negative parenting, $t = -2.07$, $p = 0.043$, $d = 0.53$ (Figure 1). RoS analyses suggested that the interaction was significant at levels of negative parenting higher than 0.075 and lower than −0.73 (each well within the observed range of scores). Considering RSA reactivity as a moderator of parenting, negative parenting was only related to higher externalizing behavior in the context of high RSA reactivity, $t = 2.84$, $p = 0.006$, $d = 0.73$, but not at medium, $t = 0.72$, $p = 0.474$, $d = 0.19$, or low levels of RSA reactivity, $t = -1.42$, $p = 0.161$, $d = 0.37$ (Figure 2). RoS analyses indicated that negative parenting related to externalizing behaviors at levels of RSA reactivity higher than 0.28 (within the range of observed scores).

Discussion

The current study examined relations between measures of RSA and externalizing behavior in children with ASD, and the potential for parenting to buffer or strengthen these associations. RSA reactivity to challenge interacted with negative parenting, but not positive parenting, in the prediction of child externalizing behavior. The significant interaction finding suggests slightly different interpretations depending upon which predictor is considered the moderator.

Follow-up analyses that considered parenting as the moderator suggested that variation in negative parenting alters the association between higher RSA reactivity and externalizing behavior. Lower levels of negative parenting may allow the increased child arousal reflected in RSA withdrawal to be channeled into task engagement, whereas higher levels of parental negativity in the context of higher child RSA reactivity may promote dysregulation, perhaps through further escalation of arousal or engagement in coercive exchanges (Beauchaine & Zalewski, 2016).

When RSA reactivity was considered as the moderator of environmental effects, there was some support for a biological-sensitivity-to-context/differential-susceptibility model. Variation in negative parenting was associated with externalizing behavior only for children exhibiting higher RSA reactivity. Moreover, while higher RSA reactivity was associated with higher externalizing behavior in the context of high levels of negative parenting, higher RSA reactivity actually predicted significantly *lower* externalizing behavior at the low end of negative parenting as well.

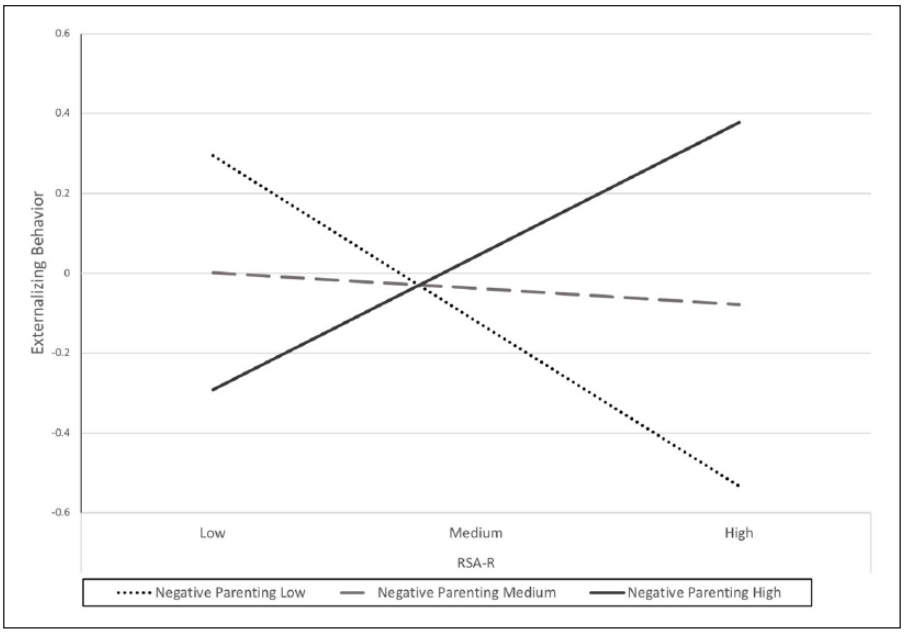

Figure 1. Negative parenting moderating the association between respiratory sinus arrhythmia reactivity (RSA-R) and externalizing behavior.

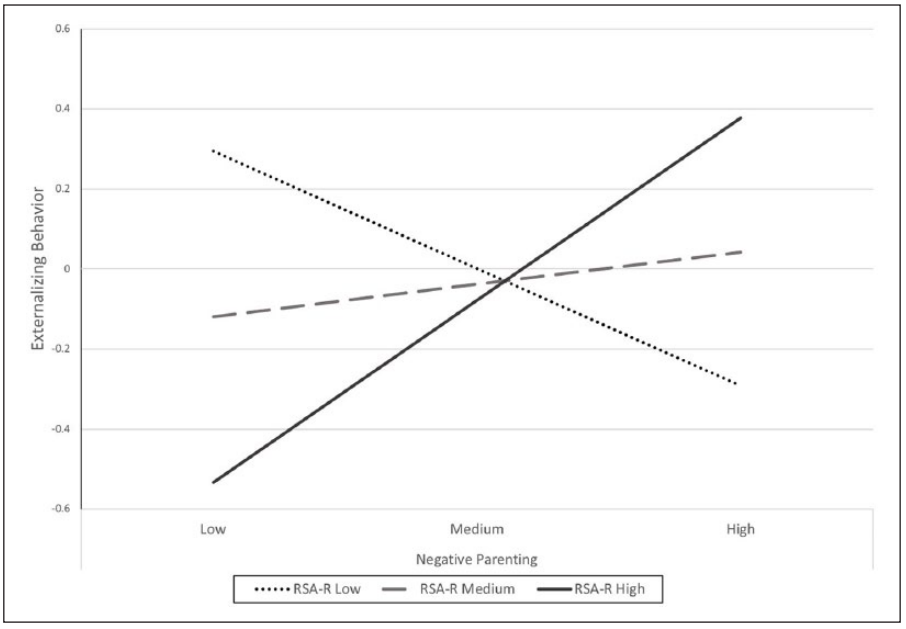

Figure 2. Respiratory sinus arrhythmia reactivity (RSA-R) moderating the association between negative parenting and externalizing behavior.

Effects of RSA reactivity at both high and low negative parenting suggest that high RSA reactivity may represent an increased sensitivity to environmental effects, for better *and* for worse (Belsky et al., 2007; Roisman et al., 2012). Of course, the lack of any significant interactions between RSA reactivity and positive parenting limit the evidence for biological sensitivity to variations in negative parenting only. Physiological sensitivity to the effects of negative parenting is consistent with recent findings that children with ASD who exhibited higher SNS reactivity appeared more susceptible to the effects of parental criticism than those with lower SNS reactivity; however, those findings suggested a dual-risk rather than a differential-susceptibility process (J. K. Baker, Fenning, Howland, et al., 2018).

It is important to recognize that no significant association between parenting and children's externalizing behavior was present for children with lower levels of RSA reactivity. These findings, along with the elevated externalizing scores for the sample as a whole, may validate the experience of parents of some children with ASD whose behavior problems persist despite the delivery of what is generally considered to be beneficial parenting.

The lack of a direct main effect of baseline RSA on child behavior in the current study could partially be due to challenges in obtaining a true baseline for children with ASD. Although we utilized a relatively common protocol, the proper paradigm for establishing baseline for psychophysiology among children with clinical difficulties is debated (see Beauchaine, 2015a; Beauchaine et al., 2019). For children with ASD in particular, a new and potentially intimidating laboratory setting may have already activated the psychophysiological processes of interest. It is therefore possible that the current baseline represented a "snapshot" of an already dynamic process.

The observed absence of a positive association between parental warmth and scaffolding was unexpected. It is possible, however, that parents' warm attitudes toward their children with ASD may be distinct from their scaffolding, which taps motivating, co-regulating, and teaching the child (Gottman, Katz, & Hooven, 1996; Grusec & Davidov, 2010). Positive parenting also did not moderate associations between RSA measures and externalizing behavior. A previous study found that higher quality scaffolding appeared to buffer the effects of SNS risk on externalizing problems in children with ASD (J. K. Baker, Fenning, Erath, et al., 2018). RSA may be more sensitive to parental socialization (Beauchaine et al., 2007; Bell, Shader, Webster-Stratton, Reid, & Beauchaine, 2018); thus, it is possible that this type of external co-regulatory support may serve as more of a contributor to the development of RSA than as a moderator of its effects.

Although the current sample is relatively large for investigations involving psychophysiology in ASD, replication would strengthen conclusions. As is the case for many studies of RSA in children with ASD (e.g. Neuhaus et al., 2014; Vaughan Van Hecke et al., 2009) and without ASD (e.g. Liew et al., 2011), we did not control for children's height, weight, or body mass index (BMI), which have been linked to RSA baseline (but not reactivity) in some community samples (e.g. El-Sheikh, 2005). However, these variables may be related to RSA measurement primarily at extreme levels (Fraley, Birchem, Senkottaiyan, & Alpert, 2005), and many studies have not found them to be related to RSA measurements (Calkins, Graziano, & Keane, 2007; Gentzler, Rottenberg, Kovacs, George, & Morey, 2012; Scarpa, Haden, & Tanaka, 2010). Similarly, we did not measure children's motor skills, which could have contributed to variation in children's responses to the challenge task; however, children with significant motor impairments were not included in the study, and it appears unlikely that motor skills were associated with our variables of interest in a manner that would confound the observed interaction findings.

Our sample exhibited significant ethnic diversity, but was not large enough to examine the degree to which the processes under consideration varied by ethnic group. Historically, investigations involving psychophysiology in ASD have excluded children with lower levels of intellectual functioning (see Lydon et al., 2016, for a review). Lower child estimated IQ did not appear to significantly compromise measurement in the current study, which we hope will encourage researchers to be more inclusive in extending psychophysiological measurement to a broader population of individuals with ASD.

Among children with ASD, who are characterized by regulation challenges, higher RSA reactivity was associated with higher levels of externalizing behavior under conditions of high negative parenting, but lower externalizing behavior in the context of lower parental negativity. These results suggest the utility of considering interactions between child psychophysiology and parenting when investigating how the environment can support children with ASD. Findings from the current study combined with previous studies of children with ASD (J. K. Baker, Fenning, Erath, et al., 2018) and without ASD (see Beauchaine et al., 2015) suggest the potential for tailoring parenting interventions based upon regulatory profiles. For example, previous work from our lab with a separate sample of children suggested that parent co-regulation may be particularly important for reducing behavior problems in children with low SNS arousal tendencies (J. K. Baker, Fenning, Erath, et al., 2018), while reduction in parental criticism might benefit those with high SNS reactivity (J. K. Baker, Fenning, Howland, et al., 2018). The present study suggests that children high in RSA reactivity may uniquely benefit from less negative parental attitudes and reductions in harsh discipline. Further clarity will be gained through investigations that consider both SNS and RSA tendencies simultaneously.

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Notes

1. Although the use of residual scores to calculate physiological reactivity is common, some researchers have utilized a difference score obtained by subtracting mean respiratory sinus arrhythmia (RSA) in baseline from RSA during the challenge task (or vice versa; Beauchaine et al., 2019). Each approach has its strengths and weaknesses and one is not clearly superior to the other for the current purpose (Burt & Obradović, 2013). Utilizing difference scores resulted in RSA reactivity scores that were very highly correlated with those from the residual-derived method used here, $r = 0.95$, $p < 0.001$.
2. Although the three-level ordinal scale for warmth was retained for combination with scaffolding (which produced a continuous variable), warmth was treated dichotomously (low/moderate = 0, high = 1) in the individual follow-up regression given the ordinal nature of the variable, the non-normal distribution, and low rate of "low" scores.

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