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Improvements in Negative Parenting Mediate Changes in Children's Autonomic Responding Following a Preschool Intervention for ADHD

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Abstract
Abnormal patterns of sympathetic- and parasympathetic-linked cardiac activity and reactivity are observed among externalizing children and mark deficiencies in central nervous system regulation of behavior and emotion. Although changes in these biomarkers have been observed following treatment, mechanisms remain unexplored. We used MEMORE—a new approach to analyzing intervening variable effects—to evaluate improvements in parenting as mediators of changes in sympathetic nervous system (SNS)- and parasympathetic nervous system (PNS)-linked cardiac activity and reactivity among 99 preschoolers with attention-deficit hyperactivity disorder who were treated using an empirically supported intervention. Decreases in negative parenting (criticism, negative commands, physical intrusions) were associated with increases in resting respiratory sinus arrhythmia (RSA) and pre-ejection period (PEP) reactivity to incentives from pre- to postintervention. Increases in positive parenting were not associated with changes in autonomic function. These findings suggest socially induced plasticity in peripheral biomarkers of behavior and emotion regulation and underscore the importance of reducing aversive interactions between parents and children when treating externalizing behavior.

Keywords
RSA, HRV, PEP, ADHD, externalizing, parenting, intervention, mediation

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Over the past 40 years, extensive research has elucidated socialization mechanisms through which emotional lability and emotion dysregulation are shaped and maintained in families of children with externalizing behavior disorders (Patterson, DeGarmo, & Knutson, 2000; Snyder, 1977; Snyder, Edwards, McGraw, Kilgore, & Holton, 1994). In many such families, dyad members escalate conflict because doing so effectively terminates aversive interactions. Such coercive exchanges occur thousands of times across development and negatively reinforce conflict escalation and associated emotional liability, since escape from highly aversive interactions provides relief (Beauchaine & Zalewski, 2016; Snyder, Schrepferman, & St. Peter, 1997).

Historically, research on family dynamics has been conducted at the behavioral level of analysis through painstaking coding of dyadic interactions. This research demonstrates that operant reinforcement is at play in the development of coercive relationships (Snyder, 1977; Snyder et al., 1994). More recent findings suggest that negative reinforcement of emotional lability also shapes and maintains patterns of physiological activity and reactivity that often characterize individuals with impulse control and emotion dysregulation problems (see Beauchaine, 2015a; Beauchaine, Gatzke-Kopp, & Mead, 2007; Beauchaine & Zalewski, 2016; Crowell et al., 2017).

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Family Dynamics and Parasympathetic Nervous System (PNS) Function

Respiratory sinus arrhythmia (RSA), defined by periodic increases and decreases in heart rate across successive respiratory cycles, is both a peripheral index of PNS efference to the heart and a useful biomarker of emotion regulation capabilities, *given appropriate stimulus conditions* (see, e.g., Beauchaine, 2001, 2015a, 2015b; Beauchaine & Thayer, 2015; Porges, 2007). As reviewed elsewhere (e.g., Shader et al., in press; Zisner & Beauchaine, 2016), a large literature demonstrates associations between RSA reactivity and emotion regulation specifically during emotion evocation tasks but not during tasks that assess other abilities such as attention allocation.

Children, adolescents, and adults who experience problems with emotion dysregulation often exhibit low resting RSA and/or excessive RSA reactivity (PNS withdrawal) to emotionally evocative stimuli (see Beauchaine, 2015a, 2015b; Beauchaine & Thayer, 2015; Crowell et al., 2005). Perhaps unsurprisingly given that emotion dysregulation is a hallmark of externalizing psychopathology, low resting RSA and excessive RSA reactivity are also observed among children and adolescents with conduct problems, delinquency, and associated mental health conditions (e.g., Beauchaine, Katkin, Strassberg, & Snarr, 2001, Beauchaine et al, 2007, 2013; de Wied, van Boxtel, Matthys, & Meeus, 2012). Such deficiencies in PNS-linked cardiac function among children with externalizing behavior problems are observed as early as the preschool years (Crowell et al., 2006) and predict responses to empirically supported interventions (Beauchaine et al., 2013). According to contemporary transactional models, emotion dysregulation and its physiological substrates are shaped and maintained among children at least in part through negative reinforcement mechanisms, as outlined above (Beauchaine et al., 2007; Beauchaine & Zalewski, 2016). This assertion is supported empirically among families of children with multiple adjustment problems (e.g., Crowell et al., 2013, 2014, 2017; Skowron et al., 2011).

Externalizing Psychopathology and Sympathetic Nervous System (SNS) Function

From preschool to adolescence, children with externalizing disorders also demonstrate compromised SNS-linked cardiac activity and reactivity (Beauchaine et al., 2001, 2013, 2015; Crowell et al., 2006). Cardiac pre-ejection period (PEP), quantified by the time between left ventricular depolarization and ejection of blood into the aorta, marks SNS reactivity via β-adrenergic mechanisms (Sherwood et al., 1990). In a series of papers, we have argued that PEP nonreactivity to monetary incentives marks central nervous system reward dysfunction, which confers vulnerability to a range of externalizing disorders (e.g., Beauchaine et al., 2013). Consistent with this perspective, lengthened PEP at rest and reduced PEP reactivity to incentives are observed among children with ADHD and children with conduct disorder and predict early initiation of alcohol and substance use (Beauchaine et al., 2001, 2013; Brenner & Beauchaine, 2011; Crowell et al., 2006). Moreover, deficiencies in PEP and RSA interact to predict especially poor outcomes among children with externalizing behavior problems (see Beauchaine et al., 2007; Pang & Beauchaine, 2013).

Transactional models of externalizing behavior suggest that for some, neurobiological vulnerabilities interact with environmental risk to promote increasingly intractable comportment outcomes across development (see Beauchaine & McNulty, 2013; Beauchaine, Zisner, & Sauder, 2017). Impulsive children, many of whom exhibit the autonomic characteristics described above, may be particularly vulnerable to developing severe externalizing behavior when exposed to environmental adversity, including coercive family processes. In this article, we evaluate (1) whether deficiencies in SNS- and PNS-linked cardiac activity/reactivity improve during treatment for externalizing behavior and (2) whether any such improvement is mediated by changes in parenting. Such findings would be consistent with research outlined above suggesting that parenting—specifically negative reinforcement of emotional lability—shapes and maintains children's physiological response patterns (Beauchaine & Zalewski, 2016; Beauchaine et al., 2007; Crowell et al., 2017). Although the notion that short-term interventions might alter children's psychophysiological function may seem implausible, such effects on other psychophysiological measures, including electrodermal responding, have been observed (e.g., Beauchaine et al., 2015; Raine et al., 2001).

Treating Externalizing Behaviors

Empirically supported psychosocial treatments for externalizing behaviors almost invariably include components that target coercive parenting (see, e.g., Eyberg, Nelson, & Boggs, 2008; Pelham & Fabiano, 2008). The *Incredible Years* (IY) intervention is a well-established treatment for conduct problems among children ages 4 to 12 years (see Beauchaine, Webster-Stratton, & Reid, 2005; Webster-Stratton, 2015). The program includes parent, child, and teacher components. Parents meet in small-group sessions, during which trained therapists discuss adaptive responses to children's impulsive and dysregulated behaviors. Parents also watch vignettes of behaviors that are typical of children with externalizing psychopathology and learn to issue clear, age-appropriate commands, avoid conflict escalation, and positively reinforce socially competent behaviors and emotion regulation. Child components include structured and unstructured group activities with trained therapists who teach anger management, emotional awareness, emotion regulation, and appropriate social behaviors. Together, parent and child components decrease coercion within families, teach prosocial skills to children, reduce conduct problems, and improve emotion regulation (Webster-Stratton, Reid, & Beauchaine, 2011). A randomized, waitlist control trial of IY conducted by our research group among preschool children produced pre-post treatment improvements in child externalizing behavior, child emotion regulation, self-report parenting behaviors, and observed positive parenting (Beauchaine et al., 2013; Webster-Stratton et al., 2011; Webster-Stratton, Reid, & Beauchaine, 2013). Reductions in negative parenting during both home visits and lab sessions were also observed. Moreover, treated children exhibited pre–post improvements in electrodermal responding (Beauchaine et al., 2015).

In this study, we evaluate changes in positive and negative parenting as mediators of changes in SNS- and PNS-linked cardiac activity and reactivity following treatment for ADHD. Although few studies have addressed such questions, Graziano, Bagner, Sheinkopf, Vohr, and Lester (2012) found that improvements in parenting following treatment for behavior problems predicted changes in RSA reactivity among children born prematurely. However, children in their study were younger and had fewer behavior problems. Moreover, they did not assess changes in SNS-linked cardiac reactivity.

Toward evaluating changes in parenting as mediators of changes in children's autonomic function, we apply the well-established Kraemer, Wilson, Fairburn, and Agras (2002) conceptual criteria for evaluating intervening variable effects. We test these effects statistically using MEMORE (Montoya & Hayes, 2016), a new method that uses bootstrap confidence intervals to test direct and indirect effects of mediation, as described in further detail below.

Method

Participants

Data were collected as part of a randomized controlled trial of the IY intervention (Webster-Stratton et al., 2011, 2013). Preschool-aged children (n = 99), ages 4 to 6 years (mean age = 5.36, SD = 0.92), with the hyperactive/impulsive or combined subtypes of ADHD, based on *Diagnostic and Statistical Manual for Mental Disorders* (4th ed., text rev.; *DSM–IV–TR*; American Psychiatric Association, 2000) criteria, were recruited. Participant children were 76% male, and 22% identified as ethnic minority, consistent with the Seattle population. The inattentive subtype was excluded, since it is distinct etiologically from the hyperactive/impulsive and combined subtypes (Adams, Derefinko, Milich, & Fillmore, 2008; Fair et al., 2013) and does not portend progression to more severe externalizing behaviors in later childhood and adulthood (e.g., Beauchaine, Ben-David, & Sela, 2017; Diamond, 2005; Lee, Burns, Becker, & Beauchaine, 2016).

Families were recruited through print advertisements placed in local publications and posted at schools and pediatricians' offices. Parents were invited to complete an initial phone interview if their child was ever diagnosed with ADHD. Trained research assistants completed phone interviews with 204 families and explained study procedures and inclusion criteria. Parents of children who still appeared to be eligible then completed the attention problems subscale of the Child Behavior Checklist (Achenbach & Edelbrock, 1991) and the hyperactive/impulsive and combined ADHD scales of the Child Symptom Inventory (CSI; Gadow & Sprafkin, 1997). Those who appeared to meet *DSM–IV* criteria for ADHD on the CSI and scored at or above the 95th percentile on the attention problems subscale of the CBCL were invited to the lab for an interview using the Diagnostic Interview Schedule for Children (DISC; Shaffer, Fisher, Lucas, Mina, & Schwab-Stone, 2000). Among 103 families who visited the lab, 99 had a child with ADHD and were enrolled in the study.

Intervention

All study procedures were approved by the local institutional review board. Families were randomized to immediate (n = 49) and delayed (waitlist control) intervention (n = 50) groups. Children in the immediate intervention participated with one or both parents in twenty 2-hr weekly sessions beginning after pretreatment assessment of behavioral and psychophysiological measures in which parents and children met in separate groups (see Webster-Stratton et al., 2011). As outlined above, parents learned effective problem-solving, adaptive emotion regulation, positive parenting techniques, and effective parenting responses to impulsive/disruptive child behaviors, among other topics. Children participated in the IY Dinosaur training program, in which trained therapists taught and coached emotion regulation skills during structured and unstructured activities. Therapists reinforced topics related to emotional awareness, anger management, teamwork, and problem-solving.

Families in the delayed intervention group started treatment following postassessments of immediate intervention participants, approximately 20 weeks after pretreatment assessments. Parents in the delayed condition received 10 sessions of IY parenting groups—half the dose of the immediate intervention condition. Children in the delayed condition received an equivalent dose of the IY Dinosaur program as those in the immediate intervention (approximately 40 hr). In this study, we combine participants into a single group for all analyses. This was necessary to attain an adequate sample size to address our main hypotheses, which required tests of statistical interactions (see below). Combining groups is justified in part given nonsignificant group differences on all but 10 of 136 parent and child behavioral outcome measures (about the number expected by chance; see Beauchaine et al., 2015). More importantly, the average effect size of these 136 group comparisons was quite small (d = 0.04).

Interventions were delivered by master's- and doctoral-level therapists who were certified to lead IY groups. Details about adherence and fidelity are reported elsewhere (Webster-Stratton et al., 2011, 2013). Pretreatment assessments for all participants (both the immediate and delayed conditions) were completed approximately 1 week after the diagnostic interviews, prior to the start of IY for the immediate condition. Posttreatment assessments were completed separately at the end of treatment for each condition.

Laboratory tasks

Psychophysiological measures were collected during the pretreatment assessment in 30-min laboratory sessions. Children participated in a protocol that began with a resting 5-min baseline in a noise-attenuated, distraction-free room. To evaluate incentive responding, children played a matching game to earn toy rewards, similar to tasks previously used to assess responses to reward in preschool children (Crowell et al., 2006). In this game, they are presented with shapes (e.g., circles, squares, triangles) on a computer screen and select matching shapes on an age-appropriate keyboard. Correct responses are paired with an image of a smiley face and a tone, whereas incorrect responses are paired with a blank screen and a different tone. Children are told that if they collect enough smiley faces, they can choose from a container of toys, all worth about $10. Following the task, children are allowed to keep a toy for "trying hard," regardless of their performance.

Next, children and their parent (mothers in all but one case) engaged in 7 min of free play, followed by a 2-min rest period, then a frustrating block building task. During the task, children were tethered to psychophysiological recording equipment and sat within a small marked area on the floor to reduce movement-related artifacts. Parents were instructed to retrieve and dump a container of large foam blocks on the floor. Without touching the blocks, parents coached their children to build progressively complex structures based on figures given to the parent. The task is difficult for 4 to 6-year-olds and is frustrating for both parents and children, as assessed by observations of dyadic conflict and expressions of negative affect (Beauchaine, Strassberg, Kees, & Drabick, 2002).

Psychophysiological measures

RSA. High-frequency spectral densities were calculated via fast Fourier transformation of R-R time series in Kubios 2.2 (Tarvainen, Niskanen, Lipponen, Ranta-Aho, & Karjalainen, 2014). Electrocardiographic (ECG) signals were sampled at 1 kHz by an HIC 2004 impedance cardiograph, using a spot electrode configuration (Qu, Zhang, Webster, & Tompkins, 1986). Accurate assessment of RSA requires appropriate specification of respiratory frequencies (Ritz, 2009; Shader et al., 2017), which vary considerably by age (see Zisner & Beauchaine, 2016). We therefore used FFT windows that were adjusted for ages of participants, based on published population values (Fleming et al., 2011; Wallis, Healy, Undy, & Maconochie, 2005). FFT windows were set to 0.33 to 0.50 Hz for 4-year-olds, 0.32 to 0.50 Hz for 5-year-olds, and 0.30 to 0.50 Hz for 6-year-olds. Of note, negligible respiratory-linked spectral power is observed above 0.50 Hz, regardless of age (see Shader et al., 2017). Resting RSA was calculated across the final 1 minute of the initial 5-minute baseline, whereas RSA reactivity to emotion evocation was calculated by subtracting resting RSA collected during the 2-minute baseline immediately before the block task from RSA collected during block building. Thus, as is customary in psychophysiological research, negative scores indicate RSA withdrawal (reduced PNS activity).

PEP. The HIC 2004 impedance cardiograph was used to collect both ECG and impedancecardiographic (ICG) waveforms. Cardiac data were segmented into 30-second epochs using Bio-Impedance Technology CopWin software, version 5.06 (Bio-Impedance Technology, Inc., 2001). PEP values were ensemble-averaged in 30-second epochs by trained research assistants, who inspected all data visually to ensure proper placement of the dZ/dt B-wave. Reactivity was calculated by subtracting ensemble-averaged PEP values during the final 1 min of the initial 5-min resting baseline from those collected during the incentive task. As is customary, negative values therefore indicate PEP shortening (increased SNS activity).

Complete psychophysiological data were available for 81% of children, and complete behavioral observation data (see below) were available for 85% of parents. Nine participant children did not return for the posttreatment clinic visit, and data from 11 participants were affected by excessive movement or problems with physiological recording. In addition, 15 participant families did not complete the posttreatment home visit. Missing data were replaced by averaging across 30 imputations following recommendations set forth by Graham (2009).

Behavior observations

Behavior observations were conducted during 30-min free play sessions in participants' homes. Parents and children were instructed to stay in one room with familiar toys and not to use electronics such as televisions or handheld gaming devices. Trained research assistants who were blind to condition and study hypotheses coded child and parent behaviors from videotapes of these sessions, using the *Dyadic Parent-Child Interaction Coding System* (DPICS; Robinson & Eyberg, 1981). The DPICS is a well-researched microanalytic coding system that assesses parenting behaviors including positive affect, critical statements, encouragement, and negative physicality. For purposes of this study, two parenting composites were formed, including positive/supportive parenting and negative/critical parenting. Scores on these behaviors were summed across the entire 30 min. Following from Reid, Webster-Stratton, and Hammond (2007), positive parenting included positive affect, positive physicality, praise, descriptive commenting, encouragement, and problem-solving. Negative parenting included critical statements, negative commands, commands with no opportunity for compliance, physical intrusions, and negative physicality. We have used these composite variables in several previous studies (e.g., Reid et al., 2007). Mothers who participate in the IY program use more positive parenting and less negative parenting than untreated controls. Although these changes are associated with improvements in child behavior and dyadic relationship quality (e.g., Webster-Stratton et al., 2011, 2013), no previous research has evaluated relations between treatment-induced changes in parenting in the home and children's physiological reactivity.

Pre-post changes in parenting, externalizing, and psychophysiological responding

Postintervention child outcomes, including mother, father, and teacher reports, are presented elsewhere (Beauchaine et al., 2013, 2015; Webster-Stratton et al., 2011, 2013) and are summarized in Table 1. In brief, mothers, fathers, and teachers all reported significant reductions in children's externalizing behaviors, including impulsivity, hyperactivity, and oppositionality. In addition, behavior observations indicated improvements in social competence. From pre- to postintervention, children's resting RSA increased, as did their RSA reactivity. Changes in PEP activity and reactivity were not found. Since sample-wide changes in dependent variables are not prerequisites for mediation, analyses were conducted as planned (see below).

As noted above, differences in children's behavioral outcomes between the immediate and delayed conditions were negligible. Furthermore, changes in their physiological responding did not differ across conditions, all ts(97) ≤ 1.48, all ps ≥ .142, all ds ≤ 0.30. In contrast, greater improvements in both positive and

Table 1. Descriptive Statistics for Child Outcomes

Variable	Pre mean (*SD*)	Post mean (*SD*)	$t(98)$	p	d
CBCL externalizing (*T*)	64.6 (8.8)	58.3 (1.3)	6.53	< .001	1.32
CPRS-R hyperactivity (*T*)	74.5 (8.7)	63.8 (15.4)	6.63	< .001	1.34
CPRS-R oppositionality (*T*)	67.7 (12.0)	59.0 (14.7)	5.03	< .001	1.02
Resting RSA (ln[ms^2])	5.49 (1.15)	5.87 (1.16)	2.75	.007	0.56
RSA reactivity (ln[ms^2])	−0.38 (0.95)	−0.75 (1.24)	−2.37	.020	−0.48
Resting PEP (ms)	80.55 (12.49)	79.35 (11.87)	−0.90	.373	−0.10
PEP reactivity (ms)	1.05 (3.76)	1.05 (3.71)	< 0.01	.999	0.00

Note: CBCL = Child Behavior Checklist (Achenbach & Edelbrock, 1991); CPRS-R = Conners' Parent Rating Scale Revised (Conners et al., 1998); PEP = pre-ejection period; RSA = respiratory sinus arrhythmia. All externalizing outcomes reported in this table are mother-reports. Data are collapsed across groups given nonsignificant differences of very small effect size on all outcomes (see text).

Table 2. Pre- to Postintervention Changes in Parenting for Participants in the Immediate and Delayed Conditions

	Immediate Intervention					Delayed Intervention				
Variable	Pre (*SD*)	Post (*SD*)	$t(48)$	p	d	Pre (*SD*)	Post (*SD*)	$t(49)$	p	d
Positive parenting	23.39 (18.45)	39.76 (24.74)	4.06	< .001	0.75	22.03 (13.12)	27.75 (16.94)	2.37	.022	0.38
Negative parenting	35.04 (23.42)	21.67 (12.44)	−4.48	< .001	−0.71	28.42 (20.39)	23.10 (12.57)	−1.73	.089	−0.31

Note: PEP = pre-ejection period; RSA = respiratory sinus arrhythmia.

negative parenting were observed for those in the immediate intervention condition. Thus, parents who received a larger dose of treatment improved more. As shown in Table 2, parents in the immediate intervention demonstrated improved positive and negative parenting, whereas parents in the delayed intervention condition showed increases in positive parenting, $t(49) = 2.37$, $p = .02$, $d = 0.38$, but nonsignificant reductions of small–medium effect size in negative parenting, $t(49) = -1.73$, $p = .09$, $d = -0.31$. Furthermore, compared to the delayed condition, parents in the immediate condition exhibited greater increases in positive parenting, $t(97) = 2.28$, $p = .03$, $d = 0.46$, and greater reductions in negative parenting, $t(97) = -1.88$, $p = .06$, $d = -0.38$.

It is important to note that such findings do not threaten the validity of mediation analyses using the combined sample. In fact, more variance in parenting outcomes could help in detecting mediated effects. Nevertheless, we chose to run tests of mediation within the combined sample first, then run separate follow-up tests in both the immediate and delayed intervention subsamples. These latter analyses were considered exploratory given low power to detect effects with smaller *n*s (see Whisman & McClelland, 2005).

Correlations among psychophysiological and parenting variables are presented in Table 3. PEP reactivity was correlated negatively with resting PEP, $r = -.28$, $p = .004$, and RSA reactivity, $r = -.29$, $p = .004$. No other variables were correlated significantly, all rs ≤ .16, all ps ≥ .05.

Table 3. Correlations Among Pretreatment Psychophysiological and Parenting Variables for Combined Immediate and Delayed Intervention Participants

Variable	1	2	3	4	5
1. Resting RSA	—				
2. RSA reactivity	.07	—			
3. Resting PEP	−.09	.04	—		
4. PEP reactivity	−.10	−.29*	−.28*	—	
5. Positive parenting	.16	−.02	−.02	.11	—
6. Negative parenting	.07	−.07	−.04	.16	.15

Note: PEP = pre-ejection period; RSA = respiratory sinus arrhythmia.
*$p \leq .01$.

According to Kraemer et al. (2002), "to show that M is a mediator of treatment, [1] M would have to measure an event or change occurring during treatment, and [2] then it must correlate with treatment choice, hence possibly be a result of treatment, and [3] have either a main or interactive effect on the outcome" (p. 879). As Table 1 indicates, the first criterion is met by virtue of improvements in positive and negative parenting—our putative mediators. Since everyone received an intervention, the second criterion requires that changes in parenting among the immediate intervention group following their treatment exceed any de novo changes in parenting among the waitlist intervention group during the waitlist period. These effects are carried in Treatment × Condition interactions, which were significant for both positive and negative parenting. Thus, changes in parenting among those in the immediate intervention condition exceeded changes in parenting during the waitlist period among those in the delayed intervention condition. Finally, the third criterion is met by testing the mediational effect statistically, as described below.

Mediation analyses

Historically, mediation analyses in intervention research have been tested using path analytic approaches, following steps set forth by Judd, Kenny, and McClelland (2001). In large samples, the Kraemer et al. (2002) criteria have been evaluated using structural equation modeling (e.g., Beauchaine et al., 2005). A new program, MEMORE, tests mediational effects in repeated-measures designs using path analytic regression (Montoya & Hayes, 2016). The advantage of MEMORE over traditional approaches is that it estimates bootstrap confidence intervals for direct and indirect effects, without relying on multiple tests to infer mediation. In simulations, the percentile bootstrap confidence interval provides a desirable balance between Type I error and power. In contrast, the causal steps approach is often

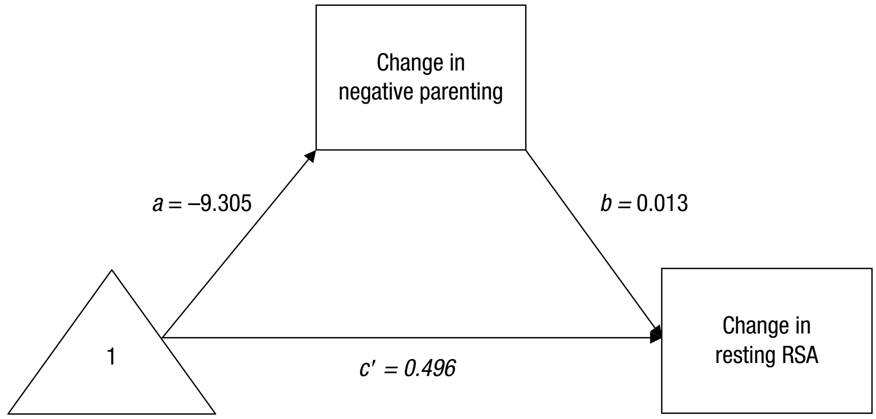

Fig. 1. Mediation of changes in resting RSA during treatment by changes in negative parenting. In the figure, 1 represents treatment, *a* represents the link between treatment and changes in parenting (the mediator), *b* represents the association between change in RSA (the dependent variable) as a function of changes in parenting (the mediator), and *c*′ represents the association between treatment and change in RSA. The $a \times b$ product quantifies the indirect effect of changes in parenting on changes in RSA.

too conservative (see Hayes, 2013; Montoya & Hayes, 2016).

Results

The test of mediation of changes in resting RSA through changes in negative parenting is shown in Figure 1. Sample-wide increases in resting RSA from pre–post intervention were mediated in part by reductions in negative parenting. The indirect effect of parenting on resting RSA was different from zero, with a 95% bias-corrected bootstrap confidence interval of [−0.290, −0.015] ($a \times b = -0.124$).[1] Reductions in negative parenting also mediated changes in PEP reactivity (b = 0.060), with a 95% bias-corrected bootstrap confidence interval of [−1.369, −0.070] ($a \times b = -0.560$). Thus, reductions in negative parenting were associated with greater PEP reactivity to incentives. Mediational effects of changes in parenting on changes in RSA reactivity and resting PEP were not significant (i.e., their confidence intervals included zero).

As outlined above, exploratory follow-up mediational analyses were conducted separately for the immediate and delayed treatment conditions to test whether significant effects from the pooled analyses were specific to either group. For resting RSA, mediational effects of parenting were not significant in either condition: immediate treatment 95% bias-corrected confidence interval of [−0.636, 0.040] ($a \times b = -0.253$) and delayed treatment 95% bias-corrected confidence interval of [−0.201, −0.029] ($a \times b = -0.06$). In contrast, the mediational effect of parenting on PEP reactivity was significant for the immediate treatment condition, 95% bias-corrected confidence interval of [−3.085, −0.033] ($a \times b = -0.124$), but not for the delayed treatment condition, 95% bias-corrected confidence interval of [−3.082, 0.039] ($a \times b = -0.124$).

Discussion

For the combined sample, reductions in negative parenting mediated pre- to posttreatment improvements in both PNS- and SNS-linked cardiac function, as indexed by resting RSA and PEP reactivity to incentives following an empirically supported intervention for ADHD. The IY series and similar interventions consistently yield improvements in parenting, children's externalizing behaviors, and children's emotion regulation (Beauchaine et al., 2005, 2013; Eyberg et al., 2008; Pelham & Fabiano, 2008). However, despite empirical findings linking physiological reactivity specifically to coercive relationship dynamics in cross-sectional studies (e.g., Crowell et al., 2014, 2017), almost no studies have evaluated effects of parenting on children's autonomic activity/reactivity in treatment–outcome contexts. In fact, this is the first study that we are aware of to evaluate mediating effects of parenting on changes on children's SNS- and PNS-linked cardiac activity and reactivity. According to Kraemer et al. (2002), effects that accrue during the course of an intervention and account for variance in outcomes are mediators of treatment response. Following transactional models, which suggest that coercive family processes reinforce emotional lability and emotion dysregulation (see Beauchaine & Zalewski, 2016; Snyder et al., 1997), we hypothesized that changes in parenting following the

IY series, which targets coercive, negative parenting behaviors, would mediate changes in children's autonomic function.

In support of this hypothesis, improvements in children's resting RSA and PEP reactivity were mediated by reductions in negative parenting in the combined sample. However, when analyses were conducted in the immediate and delayed treatment conditions separately, most of these effects were nonsignificant, which is likely a result of reduced statistical power (see above) given the relatively small number of children in each group (n = 49–50). It is well documented that tests of higher order interactions require larger samples than we had available for these subgroup analyses (e.g., Whisman, & McClelland, 2005). Given that failure to find mediational effects of parenting in three of the four subsample tests was likely attributable to low power, we discuss findings from the overall sample throughout the remainder of this discussion.

Although it may seem unlikely that changes in children's psychophysiological function would be observed following a brief intervention, preschool-aged children demonstrate considerable neuroplasticity (e.g., Anderson & Reidy, 2012; Tau & Peterson, 2010), and previous research with this sample revealed improvements in electrodermal responding, a different SNS measure (see Beauchaine et al., 2015). Findings reported by Raine et al. (2001) indicate that preschool interventions confer improvements in electrodermal responding into middle childhood.

Previous research implicates coercive, harsh, and invalidating parenting in shaping and maintaining emotional lability and emotion dysregulation and in conferring risk for progression to increasingly severe externalizing behaviors across development (Beauchaine & Zalewski, 2016; Patterson, Capaldi, & Bank, 1991; Snyder et al., 1994, 1997). These family dynamics may be especially potent mediators of such progression among children who are physiologically reactive (e.g., Beauchaine et al., 2017; Crowell et al., 2017). Thus, evidence that a parenting intervention mediated improvements not only in children's behavior but also in their physiological responding may have important clinical implications—especially given the wide range of adverse outcomes associated with excessive autonomic reactivity (e.g., Beauchaine & Thayer, 2015; Shader et al., 2017).

Future research should continue to evaluate effects of psychosocial interventions on emotional lability and associated autonomic function among children, over longer follow-ups. Such research should continue to specify dose effects to ensure that mechanisms of emotional lability and emotion dysregulation are altered in the most cost-effective manner. Analyses with larger samples could evaluate incremental changes in physiology associated with additional hours of parent management training.

One limitation concerns the small number of female participants, which precluded analyses of sex effects. In addition, mothers accompanied their children to the lab in all but one case. Future research on sex differences in children's reactions to specific parenting behaviors may increase precision of models predicting coercive behaviors between mothers and sons versus fathers and daughters, for example. A second limitation concerns diagnosing based solely on parent-reports. Given the young age of child participants (mean age = 5.36 years, SD = 0.92 years) and the location of the study (Seattle, Washington), many children did not have teachers or daycare workers to report on symptoms in a second setting. Thus, we relied in part on nationally normed scores on parent-reports that placed children at or above the 95th percentile on attention problems, in addition to meeting parent-report criteria for the hyperactive/impulsive or combined subtypes of ADHD using the DISC.

A third limitation is that we did not include an untreated control group in our analyses. One could therefore argue that changes in RSA and RSA reactivity represent normative developmental shifts in autonomic responding. However, observed changes in resting RSA (0.38 Hz) were 20 or more times larger than expected across ages 4 to 5 (0.01 Hz) and ages 5 to 6 (0.02 Hz; see Shader et al., 2017). Thus, maturation is an unlikely alternative explanation for our findings.

Although sample-wide pre to post changes in PEP reactivity were not observed, individual-level changes in PEP responding were nevertheless mediated by reductions in negative parenting. It bears repeating that mediation does not require significant direct effects (Hayes, 2013), nor does it preclude potential effects of unmeasured third variables on outcomes. The IY series is a multifaceted intervention with numerous mechanisms of action, some of which may also account for changes in children's autonomic function. We chose, based on strong theoretical considerations, to test mediational effects of parenting. This choice follows from four decades of research linking negative parenting—including coercion, aggression, and invalidation—to children's behavior problems, emotional lability, emotion dysregulation, and autonomic reactivity (e.g., Beauchaine, 2015a; Beauchaine & Zalewski, 2016; Crowell et al., 2014, 2017; Snyder, 1977; Snyder et al., 1994, 1997). That being said, tests of other mediating effects should be evaluated in future research.

Conclusion

Considerable evidence links intervention-related changes in parenting to improvements in child behavior (Eyberg et al., 2008; Webster-Stratton et al., 2011). However, almost no studies have evaluated changes in psychophysiological function as treatment outcomes (for an exception, see Graziano et al., 2012). Our findings therefore make a unique contribution to the literature. Our study is also the first to use MEMORE to estimate indirect effects of behavioral management on changes in children's psychophysiological function. Understanding potential neurobiological mechanisms of interventions can aid in (a) identifying children who are resistant to treatment and (b) evaluating efficacy of treatments across multiple levels of analysis.

Changes in PNS- and SNS-linked cardiac function occurred during a relatively brief intervention for ADHD, and changes in parenting behaviors were observed. This study contributes to decades of research on the role of parenting in shaping children's behavior and emotion regulation and underscores the importance of reducing aversive interactions among family members. These interaction patterns appear to have implications for children's peripheral nervous system responding as well as their behavior.

Author Contributions

Z.B. drafted the paper and performed statistical analyses with T.S. Data collection was performed by C.W.-S., M.J.R., and T.P.B. T.P.B edited the paper. All authors approved the final version for submission.

Declaration of Conflicting Interests

C.W.-S. has disclosed a potential conflict of interest because she disseminates these treatments and stands to gain from favorable reports. She has voluntarily agreed to distance herself from certain critical research activities, including recruitment, consenting, primary data handling, and data analysis. The University of Washington has approved these arrangements. M.J.R. performs Incredible Years interventions as an independent contractor.

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Note

1. MEMORE yields unstandardized coefficients given that estimation of *a*-paths relies on the mean of the pre-post intervention difference. Standardizing variables in regression equations changes intercepts, which are required for proper interpretation of effects. We therefore report unstandardized coefficients.

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