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Electrodermal Responding Predicts Responses to, and May Be Altered by, Preschool Intervention for ADHD

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Objectives: To evaluate electrodermal activity (EDA) as a prospective biomarker of treatment response, to determine whether patterns of EDA are altered by treatment, and to assess oppositional defiant disorder (ODD) as a possible moderator of trajectories in EDA after an empirically supported behavioral intervention for attention-deficit hyperactivity disorder (ADHD) in preschool. ***Method:*** Nonspecific fluctuations (NSFs) in skin conductance, which index sympathetic nervous system activity, were assessed among 4–6 year old children with ADHD ($n = 99$) before they participated with their parents in 1 of 2 versions of the Incredible Years intervention. All were reassessed at posttreatment, and a subgroup ($n = 49$) were assessed again at 1-year follow-up. ***Results:*** No difference in pretreatment NSFs was observed between ADHD participants and a group of normal control children ($n = 41$). Nevertheless, among those with ADHD, fewer NSFs at pretest predicted poorer treatment response on 4 of 7 externalizing outcomes. Furthermore, treatment was associated with increasing NSFs across time, but not for those who scored high on ODD at pretest. ***Conclusions:*** Low EDA appears to mark resistance to treatment among preschoolers with ADHD. Furthermore, although our study was not experimental, treatment was associated with longitudinal increases in EDA, which were not observed in a normal control group. This may suggest increased sensitivity to discipline, with positive implications for long term outcome. In contrast to treated participants as a whole, however, those who scored high on ODD at pretest exhibited reduced EDA over time.

What is the public health significance of this article?
This study demonstrates that not all children benefit equally from behavioral treatments for ADHD, and that future work should develop more effective interventions for children who are not helped as much by current approaches.

Keywords: ADHD, intervention, electrodermal responding, skin conductance, treatment response

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Carolyn Webster-Stratton has disclosed a potential conflict of interest because she disseminates these treatments and stands to gain from favorable reports. Because of this, 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. Jamila Reid performs Incredible Years interventions as an independent contractor.

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In recent years, it has become increasingly apparent that interventions for externalizing behavior—although effective for many children—do not benefit all (see, e.g., Beauchaine, Webster-Stratton, & Reid, 2005; Brestan & Eyberg, 1998). Identifying those for whom existing interventions are not effective is exceedingly important, because doing so is a prerequisite of formulating more targeted treatment programs.

To date, most efforts aimed at identifying treatment nonresponders have examined either family level variables, such as marital adjustment, maternal depression, and parental substance abuse; or behavioral comorbidities, such as anxiety and depression (see Beauchaine et al., 2005). Although such studies are valuable, they overlook potential biomarkers of treatment response. Given that several neurobiological systems implicated in self-control can be assessed using genetic, autonomic, and other neurophysiological measures (see Zisner & Beauchaine, in press), this is an important oversight as we seek to understand why interventions work for some children but not others (see Beauchaine, Neuhaus, Brenner, & Gatzke-Kopp, 2008).

Genetic markers of treatment response to behavioral interventions for attention-deficit hyperactivity disorder (ADHD) are now being identified. For example, among 4–12 year olds with ADHD, van den Hoofdakker et al. (2012) found that those with 0 or 1 *DAT1* 10-repeat alleles responded favorably to a parent training intervention, whereas those with 2 *DAT1* 10-repeat alleles did not. Thus, genetic vulnerability appears to moderate treatment response. Similar findings have been reported for methylphenidate treatment (e.g., Winsberg & Comings, 1999). Thus, child-level vulnerabilities appear to influence the effectiveness of current interventions.

A potential peripheral biomarker of treatment response for externalizing interventions is electrodermal activity (EDA). Low EDA is observed across the life span among those with externalizing spectrum disorders, including ADHD (Beauchaine, Katkin, Strassberg, & Snarr, 2001; Iaboni, Douglas, & Ditto, 1997; Satterfield & Dawson, 1971), oppositional defiant disorder (ODD; Crowell et al., 2006), conduct disorder (CD; Beauchaine et al., 2001; Herpertz et al., 2001), antisocial personality disorder (ASPD; Raine, 1996; Raine, Lencz, Bihrle, LaCasse, & Colletti, 2000), and both psychopathy and psychopathic traits (Blair, 1999; Hare, Frazelle, & Cox, 1978). Although such findings have been replicated across various experimental conditions, associations between externalizing conduct and low EDA are most consistent when participants are assessed while at rest (see Lorber, 2004).

Electrodermal measures, including nonspecific fluctuations in skin conductance (NSFs) and skin conductance level, among others, all index activation of eccrine sweat glands, which are innervated cholinergically by the sympathetic nervous system (SNS; see Uno, 1977). Although full articulation of the neural bases and psychological correlates of EDA is beyond the scope of this article, deficiencies in electrodermal responding are associated with prefrontal cortex dysfunction (Tranel, & Damasio, 1994) and behavioral impulsivity (see Zisner & Beauchaine, in press)—hallmarks of externalizing psychopathology (Beauchaine & McNulty, 2013).

Traditionally, two theoretical perspectives have predominated attempts to explain EDA as a biomarker of externalizing liability. According to the sensation-seeking hypothesis, low resting EDA reflects autonomic underarousal (see, e.g., Hastings & Barkley, 1978), which is experienced aversively. This motivates affected individuals to engage in sensation-seeking behaviors to upregulate their basal arousal levels (see Gatzke-Kopp, Raine, Loeber, Stouthamer-Loeber, & Steinhauer, 2002). In contrast, others have focused on low EDA as a peripheral index of punishment insensitivity, which is associated with both fearlessness and failures to learn from aversive contingencies in the environment (see Beauchaine, 2001; Fowles, 1988; Matthys, Vanderschuren, & Schutter, 2013). These characteristics are common to externalizing spectrum disorders. Punishment insensitivity may render affected children less responsive to treatment, because most interventions effect behavior change at least in part by improving parental discipline practices.

Although no studies have examined EDA as a predictor of treatment response, several recent findings implicate skin conductance in moderating children's and adolescents' behavioral responses to the environment. For example, Gregson, Tu, and Erath (2013) demonstrated that victimization by peers is associated with externalizing conduct primarily among preadolescents who exhibit low electrodermal reactivity to laboratory stressors. In addition, associations between harsh parenting and children's externalizing behavior are stronger among children who score low versus high on electrodermal reactivity (Erath, El-Sheikh, & Cummings, 2009). Such findings suggest differential responses to high-risk environments for those who are low on EDA. More important, a differential response to treatment hypothesis follows directly from the punishment insensitivity model articulated above (Fowles, 1988; Matthys et al., 2013). Because improved parenting practices, including coaching strategies, consistent praise, and appropriate discipline, are mechanisms through which behavioral interventions operate, children with deficient punishment sensitivity—reflected in low EDA—are at a potential learning disadvantage.

Following from this brief discussion, our primary objective in writing this article was to evaluate EDA as prospective biomarker of treatment response among preschool children who were treated for ADHD. However, we also had three secondary aims. First, we sought to determine whether there are pretreatment group differences in EDA between preschoolers with ADHD and typically developing controls. Associations between low resting EDA and externalizing behavior are observed among children as young as ages 4–6 years (Crowell et al., 2006). To our knowledge, however, such findings apply only to preschoolers recruited for *both* ADHD and ODD (e.g., Crowell et al., 2006), and to those who are already aggressive (e.g., Posthumus, Böcker, Raaijmakers, Van Engeland, & Matthys, 2009). To date, no studies have evaluated whether low resting EDA is observed among preschoolers with "pure" ADHD, even though these children are at prospective risk for more severe externalizing conduct (see Beauchaine Hinshaw, & Pang, 2010; Beauchaine & McNulty, 2013). A primary advantage of using biomarkers is early detection of vulnerability to more serious forms of psychopathology (Beauchaine et al., 2008). Early detection may be especially important for externalizing spectrum disorders given that preschool ADHD portends high risk for later CD and delinquency in middle childhood and adolescence, through highly heritable mechanisms (see Beauchaine et al., 2010; Tuvblad, Zheng, Raine, & Baker, 2009). Thus, we compared resting EDA among typically developing preschoolers, and preschoolers with ADHD.

Second, we sought to determine whether participation in the intervention altered longitudinal trajectories in EDA. Although it is common to construe neurobiological vulnerabilities as stable, con-

stitutional characteristics that moderate individuals' reactions to external events, research conducted in the last decade reveals surprising plasticity in neurobiological systems implicated in self-control (see, e.g., Beauchaine et al., 2008; Beauchaine, Neuhaus, Zalewski, Crowell, & Potapova, 2011; Mead, Beauchaine, & Shannon, 2010). Because EDA is effected in part through prefrontal mechanisms (Tranel, & Damasio, 1994), which show extraordinary neural plasticity and maturation across development (see, e.g., Gogtay et al., 2004; Hanson et al., 2010), EDA may in fact be altered by treatment, with associated increases in compliance with discipline.

Finally, we examined whether longitudinal trajectories in EDA across pretreatment, posttreatment, and 1-year follow-up are moderated by symptoms of ODD. Although we recruited participants into the intervention based on stringent ADHD criteria, ODD symptoms were allowed to vary freely. Consistent with other clinical samples, almost half of participants with ADHD exhibited comorbid ODD. We expected that deficiencies in EDA would be correlated with symptoms of ODD, because (a) ADHD/ODD comorbidity reflects a more severe clinical course, and (b) EDA deficiencies are observed among more severe clinical groups (see above).

Method

In this article, we describe links between EDA and maternal reports of treatment outcome among 99 children, ages 4–6 years, who participated in a randomized controlled trial evaluating the effectiveness of the Incredible Years (IY) parent and child behavioral training programs for preschoolers with the *Diagnostic and Statistical Manual for Mental Disorders-Fourth Edition* (*DSM–IV*) hyperactive/impulsive and combined subtypes of ADHD. An untreated, typically developing control group of 4–6 year olds also participated ($n = 41$). Study procedures were approved by the University of Washington Institutional Review Board, and parental consent was obtained. Immediate posttreatment and 1-year follow-up outcomes have been reported elsewhere (Beauchaine et al., 2013; Webster-Stratton et al., 2011, 2013). In summary, significant intervention effects were observed at posttreatment on mother-, father-, and teacher-report measures of hyperactivity, inattention, oppositionality, and aggression. Almost all of these treatment effects were maintained at 1-year follow-up.

Participants

Children with ADHD were assigned randomly to either an immediate intervention condition ($n = 49$), or a delayed intervention condition ($n = 50$), described below. For purposes of this article, all immediate and delayed intervention participants were aggregated into a single group. This strategy was justified because between-groups comparisons of the immediate and delayed intervention groups at posttreatment yielded only 10 significant differences across 136 outcome measures (see Beauchaine et al., 2013)—about the number expected by chance. Perhaps more importantly, the average effect size for these differences was very small ($d = .04$).

A brief list of descriptive statistics appears in Table 1. More detailed tables can be found in Webster-Stratton et al. (2011, 2013). Participant children were 73% male, which is typical for ADHD samples. Ethnic minority participants comprised 22% of the sample, consistent with the demographic composition of Seattle.[1] Also consistent with Seattle demographics, parents tended to be older and more educated than most national samples. On average, typically developing controls were about 7 months younger than children with ADHD. Accordingly, age was modeled in all analyses that included contrasts between intervention and typically developing control participants. Children with ADHD also differed from controls on lifetime father imprisonment (24% vs. 8%). No other demographic differences were observed.

Intervention participants were recruited through pediatricians, mental health professionals, teachers, school counselors, and ads placed in family/parent-focused community publications. Parents were invited to call the lab if their child had (a) been diagnosed with ADHD previously, or (b) experienced excessive hyperactivity and/or impulsivity. In an initial phone screen, a trained research assistant explained study requirements (random assignment to immediate treatment or waitlist condition, no medication for the duration of the study, length of intervention, no autism diagnosis, etc.). In total, 204 parents inquired, 156 of whom thought their child might be eligible. These parents completed a structured telephone interview with a trained clinician, which included several subscales of the Child Behavior Checklist (CBCL; Achenbach & Edelbrock, 1991), and portions of the Child Symptom Inventory (CSI; Gadow & Sprafkin, 1997). Among the 156 families who completed the phone screen, 103 had a child who met the following inclusion criteria: (a) scored ≥95th percentile on the CBCL attention problems scale, (b) met full *DSM–IV* (American Psychiatric Association, 2000) criteria for the hyperactive/impulsive or combined subtype of ADHD on the CSI, and (c) were not taking medication to treat ADHD. These families were scheduled for a clinic appointment during which parents completed the Diagnostic Interview Schedule for Children ADHD and ODD modules (DISC; Shaffer, Fisher, Lucas, Dulcan, & Schwab-Stone, 2000). Of the 103 parents who were administered the DISC, 99 had a child who met criteria for ADHD and was enrolled. Among these children, 48 also met criteria for ODD.

Behavioral Interventions

Immediate intervention. Families who were randomized to the immediate intervention condition received the IY parent and child training programs directly after baseline assessment. The IY parent program is effective in reducing conduct problems among children in both the United States and Europe (e.g., Beauchaine et al., 2005; Drugli & Larsson, 2006; Reid, Webster-Stratton, & Beauchaine, 2001; Scott, Spender, Doolan, Jacobs, Aspland, & Webster-Stratton, 2001). The IY Dinosaur schoolchild program increases children's conflict management and cognitive problem solving, and reduces their aggression in the classroom (Webster-Stratton & Hammond, 1997; Webster-Stratton, Reid, & Ham-

[1] African American children sometimes exhibit lower EDA than White children (e.g., El-Sheikh, Keiley, & Hinnant, 2010). Accordingly, race differences should be accounted for if they provide a potential confound in analyses of EDA-behavior relations. In the present study, no group differences in EDA were observed at any time point between African American children ($n = 12$) and the remainder of the sample ($n = 128$), all Fs < 2.31, all ps $> .40$. Furthermore, effect sizes were negligible, all $\eta^2 < .02$. Thus, we did not covary race.

Table 1
Baseline Demographic Characteristics and Descriptive Statistics by Group

Variable	Group		Test-statistic[b]	Effect size (partial η^2)
	Intervention (n = 99)[a]	Control (n = 41)		
Child's sex (% male)	75 (76%)	28 (68%)	$\chi^2_{(1)} = 0.8$	.01
Child's age (months)	64.3 (10.9)	57.4 (7.7)	$F = 13.4^{**}$	.09
Child's ethnicity (% minority)	23 (24%)	8 (19%)	$\chi^2_{(1)} = 0.5$	.01
Family income (thousands)	83.4 (77.7)	96.7 (62.2)	$F = 0.9$	.01
Siblings in household	1.0 (0.9)	1.2 (0.7)	$F = 2.3$	.02
Mother's age (years)	38.0 (0.6)	37.3 (1.0)	$F = 0.4$	<.01
Father's age (years)	40.8 (0.8)	38.8 (1.3)	$F = 1.7$	.01
Mother's education (years)	15.7 (2.1)	16.3 (2.1)	$F = 2.0$	.02
Father's education (years)	15.2 (2.3)	15.9 (2.0)	$F = 3.2$	.02
Mother ever imprisoned?	10 (11%)	1 (2%)	$\chi^2_{(1)} = 2.6$	.02
Father ever imprisoned?	21 (24%)	3 (8%)	$\chi^2_{(1)} = 4.8^{*}$	.04

Note. Continuous variables are expressed as mean (*SD*).
[a] Includes both immediate intervention (n = 49) and delayed intervention (n = 50) participants. No significant differences were observed between the immediate intervention and the delayed intervention groups on any variables given random assignment. [b] Degrees of freedom for *F*-statistics varied slightly across tests because of missing data (missing data were negligible for all variables except fathers age, with 14 missing data points; no other variable had more than three missing data points).
* $p < .05$. ** $p < .01$.

mond, 2004). The IY parent intervention included 20 weekly 2-hr sessions conducted with six families per group. The newest versions of the IY preschool parent and child curricula (2008 revision) were offered. The program includes vignettes showing children with ADHD to enhance parents' understanding of how to respond effectively to impulsive children, and children's developmental levels and temperaments. Additional sessions from the IY advance parent curriculum included problem solving between adults and teachers and strategies to build family interpersonal support, reduce depression, and manage anger.

The IY Dinosaur training program was administered to children. Topics included following group rules, identifying/expressing feelings, problem solving, anger management, friendship skills, and teamwork. Each 2-hr session consisted of three short circle times and 3–4 planned activities to reinforce concepts. Therapists used coaching methods during unstructured play times to encourage appropriate peer interactions, and targeted social and emotional skills. More detailed information, including procedures for fidelity monitoring, can be found in Webster-Stratton (2007), Webster-Stratton and Reid (2008), and Webster-Stratton et al. (2011).

Delayed intervention. Delayed intervention families received the IY program after a posttreatment comparison with the immediate intervention group. Parents in the delayed intervention condition received 10 sessions of treatment (about half the dose received by parents in the immediate intervention). In contrast to parents, children in both conditions received an equivalent 40 hr of treatment (see Webster-Stratton et al., 2013). Baseline assessments were conducted for all participants before the immediate intervention. Posttreatment assessments were conducted immediately after each group received their intervention. Questions regarding Intervention Condition × EDA × Time interaction effects in predicting externalizing outcomes, although of potential interest, were not addressed because power to reliably detect three-way interactions typically requires sample sizes in the hundreds (see Beauchaine, 2009; Whisman & McClelland, 2005). This is often ignored in treatment-outcome research, resulting in high probabilities of Type II error, and in spurious findings that fail to replicate. For these reasons, and because we sought to limit the number of statistical tests run, we did not assess three-way interactions. Identical fidelity monitoring procedures were used for both intervention groups (see Webster-Stratton et al., 2011).

Measures of Psychopathology

We include a subset of psychopathology measures reported in our original analysis of behavioral outcomes (see Webster-Stratton et al., 2011). We chose these measures based on four considerations. First, we focused on externalizing outcomes given well-established links between low resting EDA and constructs including ADHD, ODD, CD, aggression, and delinquency (see above). Second, we restricted our analyses to seven outcomes to limit inflation of family wise Type I error. Third, we included only mother-reports because complete father data were available for only 58% of families. This small sample would have yielded limited power to detect two-way interactions, which were required to address one of our primary research hypotheses. Finally, teacher-reports were unavailable for many of the 1-year outcomes.

Child Symptom Inventory. The CSI (Gadow & Sprafkin, 1997) yields diagnostic cutoffs and symptom counts for most *DSM–IV* disorders. Both the hyperactive/impulsive and inattentive subscales were administered. Internal constancy (coefficient α) for the ADHD scale was .91 in the validation sample (Sprafkin, Gadow, Salibury, Schneider, & Loney, 2002). The CSI was used for screening purposes (see above).

Child Behavior Checklist. The CBCL (Achenbach & Edelbrock, 1991) assesses broadband internalizing and externalizing symptoms, and several more specific behavioral syndromes, all of which are age-normed for 4–16 year old children and adolescents. As outlined above, we used the attention problems subscale for screening purposes. In addition, we used the aggression subscale as an index of severe externalizing conduct. The CBCL demonstrates very good internal consistency, with coefficient αs of .84 and .91 for the attention problems and aggression scales, respectively.

Conners' Parent Rating Scale-Revised. The Conners' Parent Rating Scale-Revised (CPRS-R; Conners, Sitarenios, Parker, & Epstein, 1998) is a commonly used measure of ADHD and oppositionality. For this study, inattention, hyperactivity, oppositional subscale scores were used as externalizing outcomes. Coefficient αs for these scales all exceed .90.

Eyberg Child Behavior Inventory. The Eyberg Child Behavior Inventory (ECBI; Robinson, Eyberg, & Ross, 1980) is a reliable measure of conduct problems for children ages 2–16 years. We used the problem behavior subscale as a measure of severe externalizing conduct. Coefficient α for this scale is .94.

Electrodermal Assessments

Resting EDA was evaluated before children engaged in an assessment of cardiovascular responding to reward and emotion evocation, as reported elsewhere (Beauchaine et al., 2013). The EDA signal was recorded using a Grass 15LT Physiodata Amplifier System and a 15A12 DC amplifier (West Warwick, RI). The signal was sampled at 1 kHz through two 0.8 cm^2 Ag-AgCl electrodes adhered to the thenar eminence of the child's nondominant hand. Parker Labs Signa Gel (Fairfield, NJ) was used as a medium. Nonspecific fluctuations (NSFs) in skin conductance responses exceeding 0.05 μS were coded by a trained research assistant using Grass PolyVIEW software. Nonspecific fluctuations were counted during the final 2 min of a 5 min stimulus-free baseline condition, to maximize the likelihood that participants were in a true resting state (see Zisner & Beauchaine, in press). Data were collected while children sat in a sound-attenuated room facing a white wall. Sessions were monitored via microphone and closed-circuit video, so children could be asked to sit still when needed. Such instances were rare.

We chose to analyze NSFs over alternative measures of EDA for several reasons. First, NSFs (skin conductance responses in the absence of external stimulation) yield the most straightforward measure of EDA, and the most commonly used index by psychophysiologists (Boucsein et al., 2012). Although some authors report skin conductance level, NSFs should be removed from estimates of SCL to avoid artifactual distortion, a tedious process that can be difficult to standardize (see Boucsein et al., 2012). Second, SCL is especially sensitive to hydration artifacts (Bundy & Mangan, 1979). Third, unpublished data from our lab indicate larger effect sizes for NSFs than for SCL in contrasts between externalizing children and controls. Fourth, we chose a single measure of EDA to reduce the familywise Type I error rate. Finally, NSFs are well suited for assessment at rest—the stimulus condition most consistently linked with EDA deficiencies among those with externalizing spectrum disorders (Lorber, 2004).

Results

Pre- to postintervention improvements on externalizing measures used in this study are reported in the left side of Table 2. Large effects were observed on all measures except CBCL attention problems. Complete tables of participants' scores on all pretreatment, posttreatment, and 1-year follow-up measures can be found in Webster-Stratton et al. (2011, 2013).

Psychophysiological assessments took place during lab visits that were scheduled in addition to psychosocial assessments and treatment sessions. Given this extra burden on participant families, EDA data were missing for 5 intervention and 7 control participants at pretreatment, and for 19 intervention and 12 control participants at posttreatment. Missing values were imputed using SPSS 20, following recommendations set forth by Graham (2009). Multiple imputation is far more accurate than both listwise deletion and mean substitution of missing data (see, e.g., Acock, 2005).

Pretreatment Group Differences in EDA

Pretreatment group differences in EDA were assessed using one-way analysis of covariance (ANCOVA).[2] Group (aggregated treatment vs. typical control) was a fixed effect, and both age and number of ODD symptoms were included as covariates.[3] Age was covaried because ADHD participants were significantly older than typically developing controls (see above). Symptoms of ODD were covaried to evaluate the possibility that severity of externalizing behavior might predict differences in pretreatment EDA, over-and-above effects of ADHD.

No difference between ADHD ($M = 8.82$/min, $SD = 3.76$) and typically developing participants ($M = 8.96$/min, $SD = 3.60$) was found for pretreatment NSFs. Furthermore, neither age nor ODD symptoms were associated with pretreatment NSFs. In fact, negligible correlations were found at pretest between age and NSFs, $r = .07$, $p = .46$, and between ODD and NSFs, $r = .02$, $p = .83$.

Individual Differences in Pretreatment EDA and Prediction of Treatment Response

To assess prediction of treatment outcome from baseline EDA, we conducted ANCOVAs in which pre- and posttreatment psychopathology scores served as repeated measures, and NSFs were entered as a covariate. Normal control participants were omitted from these ANCOVAs because they did not receive treatment.

Differential prediction of treatment response by EDA is carried in the Psychopathology × NSFs interaction terms. Results are reported along with main effects in Table 2. Interactions between NSFs and treatment outcome were observed for three of the four mother-report measures of severe conduct (CBCL externalizing, CBCL aggression, and ECBI problem behavior), and one of the three measures of ADHD (CBCL attention problems). The Treatment Outcome × NSF interaction for ECBI problem behavior is depicted in Figure 1. For purposes of presenting the interaction, we divided the sample into those who scored above and below the sample mean on NSFs. Consistent with our a priori expectations, those who scored below the sample mean improved less over the course of treatment than participants who scored above the sample mean. All other interactions followed a similar form.

[2] We could have evaluated pretreatment group differences by testing intercepts in the multilevel models that are presented in later sections. Intercepts, however, represent estimates of baseline function—not observed scores.

[3] Some studies show correspondences between trait anxiety and EDA (see Beauchaine, 2001), which could introduce an interpretive confound. Therefore, we examined the correlation between CBCL anxious/depressed scale scores and NSFs. Because the correlation was nonsignificant, $r = .005$, $p = .952$, we did not use anxious/depressed scores as a covariate.

Table 2
Repeated Measures ANCOVAs With Electrodermal Responding Predicting Mother-Reports of Treatment Outcome

Outcome	Repeated measures effect[a]				NSFs			
	Pre-	Post-			Main effect		NSF × outcome interaction	
	Mean (*SD*)	Mean (*SD*)	*F*(1, 98)	η_p^2	*F*(1, 97)	η_p^2	*F*(1, 97)	η_p^2
Severe conduct problems								
CBCL externalizing (*T*)	64.6 (8.8)	58.3 (1.3)	42.6***	.30	0.0	<.01	3.0†	.03
CBCL aggression (*T*)	66.2 (11.0)	61.9 (10.2)	23.9***	.20	0.0	<.01	3.8*	.04
ECBI problem behavior	21.6 (6.6)	14.5 (7.9)	86.1***	.50	0.0	<.01	9.2**	.10
CPRS-R oppositional (*T*)	67.7 (12.0)	59.0 (14.7)	25.3***	.22	0.6	<.01	1.0	.01
Attention problems								
CBCL attention problems (*T*)	69.2 (10.5)	69.4 (11.5)	0.0	<.01	0.0	<.01	4.0*	.04
CPRS-R inattention (*T*)	69.4 (13.1)	64.9 (12.3)	15.2***	.15	0.8	.01	1.2	.01
CPRS-R hyperactivity (*T*)	74.5 (8.7)	63.8 (15.4)	44.0***	.31	0.0	<.01	0.0	<.01

Note. CBCL = Child Behavior Checklist (Achenbach & Edelbrock, 1991); ECBI = Eyberg Child Behavior Inventory (Robinson et al., 1980); CPRS-R = Conners' Parent Rating Scale-Revised (Conners et al., 1998).
[a] Without EDA variables in the model.
† $p < .10$. * $p < .05$. ** $p < .01$. *** $p < .001$.

Associations Between Treatment, ODD Symptoms, and Longitudinal Patterns of EDA

To evaluate trajectories in EDA across pretreatment, posttreatment, and 1-year follow-up, we constructed multilevel models (MLM) using Hierarchical Linear Modeling, version 6.08 (Raudenbush, Bryk, Cheong, & Congdon, 2004). We chose MLM for analyses of the three-wave data given numerous statistical advantages over traditional repeated measures ANOVA, including less restrictive assumptions, full maximum likelihood estimation of missing data, and increased power (see, e.g., Speer & Greenbaum, 1995).[4]

Psychophysiological assessments were not available for the delayed intervention group at 12 months. Thus, the HLM analyses reported below include 49 immediate intervention participants and 41 typically developing controls.[5] Electrodermal data were available for 92%, 80%, and 72% of these participants at pretreatment, posttreatment, and 1-year follow-up, respectively. Missing data were accommodated using full information maximum likelihood estimation, which is more accurate than dropping cases (see, e.g., Acock, 2005).

In the MLMs, trajectories in NSFs across pretreatment, posttreatment, and 1-year follow-up were nested within children at Level 1. Both treatment condition (intervention vs. typically developing control) and ODD symptoms were modeled as Level 2 predictors of Level 1 intercepts and slopes in NSFs. Including ODD was important because it indicates greater severity of externalizing symptoms, which has been linked with low EDA (see above; Crowell et al., 2006; Snoek, Van Goozen, Matthys, Buitelaar, & Van Engeland, 2004). The HLM model, which included mean-centered intercepts, was as follows:

$$\text{Level 1: NSFs} = \pi_0 + \pi_1(\text{age at each assessment}) + e$$

$$\text{Level 2: } \pi_0 = \beta_{00} + \beta_{01}(\text{ADHD vs. control}) + \beta_{02}(\text{ODD symptoms}) + r_0$$

$$\pi_1 = \beta_{10} + \beta_{11}(\text{ADHD vs. control}) + \beta_{12}(\text{ODD symptoms}) + r_1$$

Both treatment condition, $\beta_{01} = 1.12$, $t = 2.47$, $p = .016$, and ODD symptoms, $\beta_{02} = -0.21$, $t = -2.34$, $p = .022$, predicted mean-centered intercepts. The treatment effect indicates that those who participated in the intervention exhibited more NSFs, averaged across assessment waves, than typically developing controls. Thus, even though the ADHD and control groups did not differ on

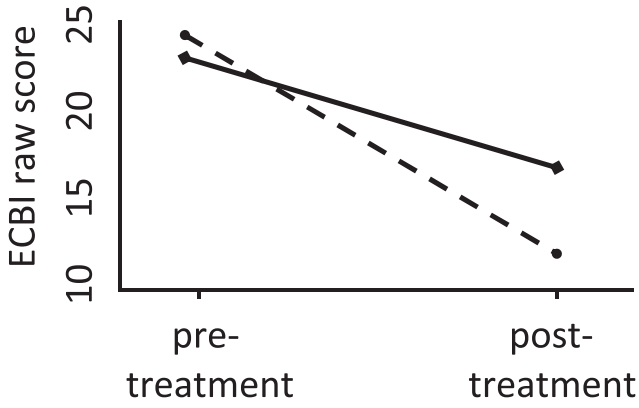

Figure 1. Eyberg Child Behavior Inventory (ECBI) problem behavior scores at pretreatment and posttreatment for children who scored below the sample mean on nonspecific fluctuations in skin conductance (solid line) and those who scored above the sample mean on nonspecific fluctuations in skin conductance (dashed line).

[4] We did not use HLM for the preceding prepost analyses because two-wave data yield no individual deviation scores at either pretreatment or posttreatment at Level 1. Because these deviation scores are necessary for estimating error, multilevel modeling is not as well suited for two-wave data as it is for $n > 2$ wave data.

[5] The delayed intervention group began treatment after the immediate intervention group finished (see above). This enabled us to compare posttreatment NSFs in the immediate intervention group with pretreatment NSFs in the delayed intervention group. No between-groups difference was found, $F(1, 97) = 0.82$, $p = .37$, $\eta^2 = .01$.

NSFs at baseline (see above), their electrodermal response patterns diverged over time. The negative effect of ODD symptoms indicates lower mean-centered NSFs for those who scored higher on ODD. Thus, although treatment was associated with higher mean-centered NSFs sample-wide, this was not the case for those who scored high on ODD.

Analysis of slopes yielded a significant treatment effect, $\beta_{11} = 0.06$, $t = 2.78$, $p = .007$, and a significant effect of ODD symptoms, $\beta_{12} = -0.01$, $t = -2.46$, $p = .016$. The treatment effect indicates increasing NSFs across pretreatment, posttreatment, and 1-year follow-up among those who participated in the intervention, compared with typically developing controls. The negative effect of ODD symptoms indicates reduced EDA over time for those who scored higher on ODD. In Figure 2 we present NSFs at pretreatment, posttreatment, and 1-year-follow-up for participants in the intervention group who experienced 2 or fewer ($n = 14$) versus 6 or more ($n = 12$) symptoms of ODD at the pretreatment psychophysiological assessment. Of note, neither ODD diagnostic grouping (yes, no), nor a simple median split illustrated the interaction effect well (i.e., there was little separation of longitudinal trajectories). Rather, the interaction was appears to be carried at more extreme ends of the ODD distribution.

Discussion

In this study, we (a) evaluated pretreatment group differences in EDA between preschool children with ADHD and typically developing controls, (b) examined EDA as a prospective biomarker of response to an empirically supported intervention, (c) assessed whether patterns of EDA appear to change as a function of treatment, and (d) determined whether symptoms of ODD moderate trajectories in EDA across pretreatment, posttreatment, and 1-year follow-up. In the remainder of this article, we consider each of these issues in turn, and discuss possible implications for future research and practice.

Contrary to an impressively consistent body of research (e.g., Beauchaine et al., 2001; Blair, 1999; Crowell et al., 2006; Herpertz et al., 2001; Iaboni et al., 1997; Posthumus et al., 2009; Raine et al., 2000), we found no association between resting EDA assessed at pretreatment and any measure of externalizing psychopathology. All group contrasts at pretreatment between ADHD participants and typically developing controls were nonsignificant, all effect sizes were small, and ODD was a nonsignificant covariate in all analyses. Thus, it appears that low resting EDA does not mark ADHD in this age range. As noted above, our sample of children with ADHD was not as severe on conduct problem measures as samples in previous studies in which associations between low EDA and externalizing behaviors were found (e.g., Posthumus et al., 2009). In our own previous work demonstrating group differences in EDA between preschoolers with ADHD and typical controls, all ADHD participants also met *DSM–IV* criteria for ODD, with a mean symptom count of 5.4 (Crowell et al., 2006). In contrast, although 48 of 99 intervention group children in the present study met criteria for ODD, the mean symptom count was 3.4.

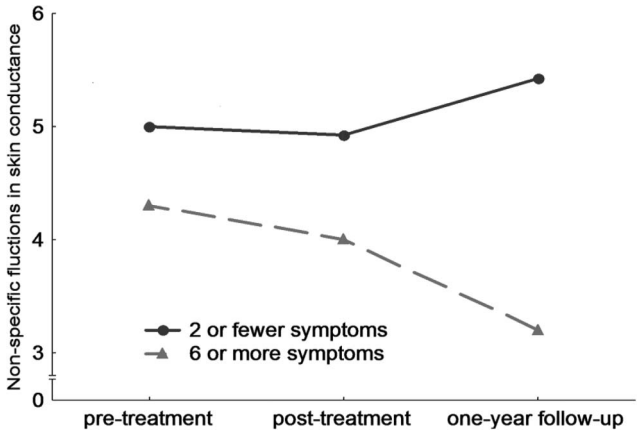

Figure 2. Nonspecific fluctuations in skin conductance (NSFs) across pretreatment, posttreatment, and 1-year follow-up for immediate intervention, ADHD participants who exhibited two or fewer symptoms of ODD ($n = 14$; solid line) versus six or more symptoms ($n = 12$; dotted line).

Our finding of no difference at pretest in resting EDA between preschoolers with ADHD and typically developing controls is especially interesting when compared with data from older samples of children with pure ADHD, who exhibit clear deficiencies in EDA. For example, in a sample of 12–17-year-olds with either uncomplicated ADHD or ADHD + CD, we reported fewer resting NSFs in skin conductance in *both* groups compared with controls, with a large effect size (Beauchaine et al., 2001). This may imply that deficiencies in EDA develop over time among those who are vulnerable to externalizing psychopathology. Such an interpretation is consistent with longitudinal data reported by El-Sheikh et al. (2010), who found—albeit during a lab task and not at rest—decreasing skin conductance across middle childhood among those who scored high on measures of anger and aggression. In contrast, stable trajectories in EDA were observed for those who scored low on anger and aggression.

It is also possible that electrodermal *reactivity*, measured in response to aversive stimuli rather than at rest, might have yielded a group difference. It is common in studies of adults with externalizing psychopathology to evaluate electrodermal responses to aversive tones. However, although psychopaths show reduced electrodermal reactivity in such studies, *positive* associations between electrodermal reactivity and aggression are often observed in nonpsychopathic samples (see Lorber, 2004). Future studies might disentangle this apparent discrepancy, perhaps by evaluating callous/unemotional (CU) traits as a moderator of EDA-behavior relationships (see, e.g., Muñoz, Frick, Kimonis, & Aucoin, 2008). Because we did not include a measure CU traits, we could not address this question.

Despite no group difference at pretest, EDA predicted treatment response on 4 of 7 externalizing measures. Among children with ADHD, those who scored low on resting EDA improved less than those who scored high on resting EDA. These findings follow directly from punishment insensitivity models (Beauchaine, 2001; Fowles, 1988), which predict more difficulty learning from experience—particularly operant reinforcement including appropriate discipline—among those with low resting EDA.

Although children with low resting EDA may be at a learning disadvantage compared with their peers, prediction of treatment response provides an opportunity for developing more targeted interventions (see Beauchaine et al., 2008). For example, had we known of this predictive relationship *before* conducting the inter-

ventions, we might have either implemented a longer intervention including more coaching learning experiences for children who scored low on resting EDA, or added other intervention components. One such possibility is psychostimulants. Stimulants increase central dopamine activity, which results in downstream elevations in SNS tone, and normalized EDA (e.g., Satterfield & Dawson, 1971). Thus, even though many parents are reluctant to begin stimulant treatment so early, preschoolers with ADHD *and* low resting EDA may be especially good candidates for adjunctive stimulant treatment. More important, stimulants enhance associative learning by elevating both tonic dopamine activity and phasic dopamine responses to external events, thereby improving punishment sensitivity pharmacologically (see, e.g., Gatzke-Kopp & Beauchaine, 2007; Sagvolden, Johansen, Aase, & Russell, 2005). As Brestan and Eyberg (1998) noted 15 years ago, now that we have effective treatments for externalizing behavior, we must ask the questions "For whom does this treatment work?" and "When is this treatment not enough?" Identifying biological vulnerabilities that predict treatment outcome address these questions directly.

Prediction of treatment response is indicated by interactions between existing vulnerabilities and intervention outcomes (Kraemer, Wilson, Fairburn, & Agras, 2002). Had any single interaction been significant, we might have attributed our findings to spuriousness or chance. These explanations are unlikely, however, given significant interactions across several measures. Furthermore, although response biases are a concern when relations are found among variables reported on by a single rater, mothers could not observe their child's EDA, so links between mother reports of child behavior and skin conductance cannot be attributable to such effects.

We also sought to determine whether trajectories in EDA appear to be altered by treatment. This is the most difficult of our questions to address, because doing so unambiguously requires a comparison of children with ADHD who are assigned randomly to treated and untreated groups. Early in the planning process of this study, we decided that such a design would be unethical, because we would have to deny at-risk children an empirically supported intervention. Nevertheless, by comparing intervention participants' EDA trajectories across pretreatment, posttreatment, and 1-year follow-up to those collected from both typically developing control participants, and untreated externalizing children in other samples, we can offer some speculation regarding possible alterations in EDA.

Results from our MLMs demonstrate that intervention participants, taken as a whole, exhibited increasing NSFs across pretreatment, posttreatment, and 1-year follow-up, compared with typically developing controls. This contrasts with findings reported elsewhere, which indicate, albeit with slightly older samples, declining skin conductance among untreated children who score high on externalizing measures (El-Sheikh et al., 2010). However, our results are consistent with findings of increased EDA across impressively long time intervals among at-risk children who receive multifaceted early interventions (Raine et al., 2001). Although we do not wish to overstate the implications of this finding, it may indicate increased sensitivity to operant reinforcement for most of the sample after intervention. This will be a difficult hypothesis to confirm because of the aforementioned ethical constraint. As noted above, however, it may not be as farfetched as once thought given impressive neural plasticity of the prefrontal cortex (Gogtay et al., 2004; Hanson et al., 2010), which mediates EDA (Tranel & Damasio, 1994).

Finally, even though treated participants as a whole exhibited increasing EDA from pretreatment to 1-year follow-up, those who scored high on ODD at pretreatment exhibited declining EDA. This is troubling given robust associations between low resting EDA and externalizing outcomes across the life span, as reviewed above (see Lorber, 2004; Raine, 1996). However, as we reported in exhaustive analyses of 1-year behavioral outcomes (Webster-Stratton et al., 2013), effect sizes for maintenance of improvement in oppositional behaviors were as large or larger than those observed on most other externalizing measures. Unfortunately, no additional follow-ups were conducted with this sample, so we cannot determine whether those who exhibit declining EDA are especially vulnerable to poorer outcomes as they mature.

We note that further research is needed to determine whether our findings generalize to other samples. Some studies link higher EDA to aggression and externalizing behavior among slightly older, primarily minority children recruited from high-risk urban regions with high rates of poverty and crime (Bubier, Drabick, & Breiner, 2009; Gatzke-Kopp, Greenberg, Fortunato, & Coccia, 2012). Although these were not treatment studies, seemingly divergent findings may reflect multiple etiological pathways to externalizing outcomes. In the present article, children were drawn from a high SES region, and although we did not assess trauma exposure, rates were almost certainly lower than among children in the studies cited above. Potential variability in mechanisms underlying externalizing behavior in different populations highlights the value of physiological assessment in understanding heterogeneities that are difficult to distinguish behaviorally. Psychophysiological research may, therefore, contribute to tailoring interventions across individuals and contexts, by providing insights into mechanisms through which vulnerabilities are potentiated (see Zisner & Beauchaine, in press).

Conclusions

To our knowledge, this is the first study to examine EDA as a predictor of treatment response among preschool children with ADHD. Furthermore, our sample is among the largest in which EDA-externalizing relations have been explored—especially in preschoolers. This enabled us to examine two-way interaction hypotheses, and to replicate them across several externalizing measures. As expected, resting EDA predicted treatment response, which suggests it may be of value in preintervention assessments where decisions are made regarding both intensity of treatment and adjunctive components of treatment, such as psychostimulants (see above). As a psychophysiological measure, resting EDA is noninvasive, tolerated well by young children, inexpensive to collect, and relatively easy to score. It may, therefore, provide practical advantages over other psychophysiological methods.

Two primary objectives of our program of research are to identify biological vulnerabilities that render children especially susceptible to psychopathology in contexts of risk, and to identify child-level variables that moderate treatment response, so future interventions might be tailored to address those individual differences (see, e.g., Beauchaine, 2003; Beauchaine & Gatzke-Kopp, 2012; Beauchaine et al., 2005, 2008, 2011, 2013; Brenner & Beauchaine, 2011; Mead et al., 2010). More important, our find-

ings may indicate that children with ADHD who exhibit normal EDR are more responsive to environmental influences in general than those who exhibit low EDR. Such children may present with ADHD behaviors not because they are "biologically loaded," but because their parents are dysregulated (see Beauchaine & Zalewski, in press). Although ADHD is among the most heritable of all psychiatric disorders, future research should continue to identify meaningful subtypes of children who respond to current interventions, and those who do not, so we can further develop treatments to help a broader range of affected families.

References

Achenbach, T. M., & Edelbrock, C. S. (1991). *Manual for the Child Behavior Checklist and Revised Child Behavior Profile*. Burlington, VT: University Associates in Psychiatry.

Acock, A. C. (2005). Working with missing values. *Journal of Marriage and Family, 67,* 1012–1028. http://dx.doi.org/10.1111/j.1741-3737.2005.00191.x

American Psychiatric Association. (2000). *Diagnostic and statistical manual of mental disorders* (4th ed., text revision). Washington, DC: Author.

Beauchaine, T. (2001). Vagal tone, development, and Gray's motivational theory: Toward an integrated model of autonomic nervous system functioning in psychopathology. *Development and Psychopathology, 13,* 183–214. http://dx.doi.org/10.1017/S0954579401002012

Beauchaine, T. P. (2003). Taxometrics and developmental psychopathology. *Development and Psychopathology, 15,* 501–527. http://dx.doi.org/10.1017/S0954579403000270

Beauchaine, T. P. (2009). Some difficulties in interpreting psychophysiological research with children. *Monographs of the Society for Research in Child Development, 74,* 80–88. http://dx.doi.org/10.1111/j.1540-5834.2009.00509.x

Beauchaine, T. P., & Gatzke-Kopp, L. M. (2012). Instantiating the multiple levels of analysis perspective in a program of study on externalizing behavior. *Development and Psychopathology, 24,* 1003–1018. http://dx.doi.org/10.1017/S0954579412000508

Beauchaine, T. P., Gatzke-Kopp, L., Neuhaus, E., Chipman, J., Reid, M. J., & Webster-Stratton, C. (2013). Sympathetic- and parasympathetic-linked cardiac function and prediction of externalizing behavior, emotion regulation, and prosocial behavior among preschoolers treated for ADHD. *Journal of Consulting and Clinical Psychology, 81,* 481–493. http://dx.doi.org/10.1037/a0032302

Beauchaine, T. P., Hinshaw, S. P., & Pang, K. L. (2010). Comorbidity of attention-deficit/hyperactivity disorder and early-onset conduct disorder: Biological, environmental, and developmental mechanisms. *Clinical Psychology: Science and Practice, 17,* 327–336. http://dx.doi.org/10.1111/j.1468-2850.2010.01224.x

Beauchaine, T. P., Katkin, E. S., Strassberg, Z., & Snarr, J. (2001). Disinhibitory psychopathology in male adolescents: Discriminating conduct disorder from ADHD through concurrent assessment of multiple autonomic states. *Journal of Abnormal Psychology, 110,* 610–624. http://dx.doi.org/10.1037/0021-843X.110.4.610

Beauchaine, T. P., & McNulty, T. (2013). Comorbidities and continuities as ontogenic processes: Toward a developmental spectrum model of externalizing psychopathology. *Development and Psychopathology, 25,* 1505–1528. http://dx.doi.org/10.1017/S0954579413000746

Beauchaine, T. P., Neuhaus, E., Brenner, S. L., & Gatzke-Kopp, L. (2008). Ten good reasons to consider biological processes in prevention and intervention research. *Development and Psychopathology, 20,* 745–774. http://dx.doi.org/10.1017/S0954579408000369

Beauchaine, T. P., Neuhaus, E., Zalewski, M., Crowell, S. E., & Potapova, N. (2011). The effects of allostatic load on neural systems subserving motivation, mood regulation, and social affiliation. *Development and Psychopathology, 23,* 975–999. http://dx.doi.org/10.1017/S0954579411000459

Beauchaine, T. P., Webster-Stratton, C., & Reid, M. J. (2005). Mediators, moderators, and predictors of 1-year outcomes among children treated for early-onset conduct problems: A latent growth curve analysis. *Journal of Consulting and Clinical Psychology, 73,* 371–388. http://dx.doi.org/10.1037/0022-006X.73.3.371

Beauchaine, T. P., & Zalewski, M. (in press). Physiological and developmental mechanisms of emotional lability in coercive relationships. In T. J. Dishion & J. J. Snyder (Eds.), *Oxford handbook of coercive relationship dynamics* (pp. in press). New York, NY: Oxford University Press.

Blair, R. J. R. (1999). Responsiveness to distress cues in the child with psychopathic tendencies. *Personality and Individual Differences, 27,* 135–145. http://dx.doi.org/10.1016/S0191-8869(98)00231-1

Boucsein, W., Fowles, D. C., Grimnes, S., Ben-Shakhar, G., Roth, W. T., Dawson, M. E., & Filion, D. L., & the Society for Psychophysiological Research Ad Hoc Committee on Electrodermal Measures. (2012). Publication recommendations for electrodermal measurements. *Psychophysiology, 49,* 1017–1034.

Brenner, S. L., & Beauchaine, T. P. (2011). Pre-ejection period reactivity and psychiatric comorbidity prospectively predict substance use initiation among middle-schoolers: A pilot study. *Psychophysiology, 48,* 1588–1596. http://dx.doi.org/10.1111/j.1469-8986.2011.01230.x

Brestan, E. V., & Eyberg, S. M. (1998). Effective psychosocial treatments of conduct-disordered children and adolescents: 29 years, 82 studies, and 5,272 kids. *Journal of Clinical Child Psychology, 27,* 180–189. http://dx.doi.org/10.1207/s15374424jccp2702_5

Bubier, J. L., Drabick, D. A., & Breiner, T. (2009). Autonomic functioning moderates the relations between contextual factors and externalizing behaviors among inner-city children. *Journal of Family Psychology, 23,* 500–510. http://dx.doi.org/10.1037/a0015555

Bundy, R. S., & Mangan, S. M. (1979). Electrodermal indices of stress and cognition: Possible hydration artifacts. *Psychophysiology, 16,* 30–33. http://dx.doi.org/10.1111/j.1469-8986.1979.tb01433.x

Conners, C. K., Sitarenios, G., Parker, J. D. A., & Epstein, J. N. (1998). The revised Conners' Parent Rating Scale (CPRS-R): Factor structure, reliability, and criterion validity. *Journal of Abnormal Child Psychology, 26,* 257–268. http://dx.doi.org/10.1023/A:1022602400621

Crowell, S. E., Beauchaine, T. P., Gatzke-Kopp, L., Sylvers, P., Mead, H., & Chipman-Chacon, J. (2006). Autonomic correlates of attention-deficit/hyperactivity disorder and oppositional defiant disorder in preschool children. *Journal of Abnormal Psychology, 115,* 174–178. http://dx.doi.org/10.1037/0021-843X.115.1.174

Drugli, M. B., & Larsson, B. (2006). Children aged 4–8 years treated with parent training and child therapy because of conduct problems: Generalisation effects to day-care and school settings. *European Child & Adolescent Psychiatry, 15,* 392–399. http://dx.doi.org/10.1007/s00787-006-0546-3

El-Sheikh, M., Keiley, M., & Hinnant, J. B. (2010). Developmental trajectories of skin conductance level in middle childhood: Sex, race, and externalizing behavior problems as predictors of growth. *Biological Psychology, 83,* 116–124. http://dx.doi.org/10.1016/j.biopsycho.2009.11.009

Erath, S. A., El-Sheikh, M., & Mark Cummings, E. (2009). Harsh parenting and child externalizing behavior: Skin conductance level reactivity as a moderator. *Child Development, 80,* 578–592. http://dx.doi.org/10.1111/j.1467-8624.2009.01280.x

Fowles, D. C. (1988). Psychophysiology and psychopathology: A motivational approach. *Psychophysiology, 25,* 373–391. http://dx.doi.org/10.1111/j.1469-8986.1988.tb01873.x

Gadow, K. D., & Sprafkin, J. (1997). *Child symptom inventories norms manual*. Stony Brook, NY: Checkmate Plus.

Gatzke-Kopp, L., & Beauchaine, T. P. (2007). Central nervous system substrates of impulsivity: Implications for the development of attention-deficit/hyperactivity disorder and conduct disorder. In D. Coch, G. Dawson, & K. Fischer (Eds.), *Human behavior, learning, and the developing brain: Atypical development* (pp. 239–263). New York, NY: Guilford Press.

Gatzke-Kopp, L. M., Greenberg, M. T., Fortunato, C. K., & Coccia, M. A. (2012). Aggression as an equifinal outcome of distinct neurocognitive and neuroaffective processes. *Development and Psychopathology, 24,* 985–1002. http://dx.doi.org/10.1017/S0954579412000491

Gatzke-Kopp, L. M., Raine, A., Loeber, R., Stouthamer-Loeber, M., & Steinhauer, S. R. (2002). Serious delinquent behavior, sensation-seeking, and electrodermal arousal. *Journal of Abnormal Child Psychology, 30,* 477–486.

Gogtay, N., Giedd, J. N., Lusk, L., Hayashi, K. M., Greenstein, D., & Vaituzis, A. C., . . . Thompson, P. M. (2004). Dynamic mapping of human cortical development during childhood through early adulthood. *Proceedings of the National Academy of Sciences of the United States of America, 101,* 8174–8179. http://dx.doi.org/10.1073/pnas.0402680101

Graham, J. W. (2009). Missing data analysis: Making it work in the real world. *Annual Review of Psychology, 60,* 549–576. http://dx.doi.org/10.1146/annurev.psych.58.110405.085530

Gregson, K. D., Tu, K. M., & Erath, S. A. (2013). Sweating under pressure: Skin conductance level reactivity moderates the association between peer victimization and externalizing behavior. *Journal of Child Psychology and Psychiatry*. Epublished ahead of print on June 4, 2013. http://dx.doi.org/10.1111/jcpp.12086

Hanson, J. L., Chung, M. K., Avants, B. B., Shirtcliff, E. A., Gee, J. C., Davidson, R. J., & Pollak, S. D. (2010). Early stress is associated with alterations in the orbitofrontal cortex: A tensor-based morphometry investigation of brain structure and behavioral risk. *The Journal of Neuroscience, 30,* 7466–7472. http://dx.doi.org/10.1523/JNEUROSCI.0859-10.2010

Hare, R. D., Frazelle, J., & Cox, D. N. (1978). Psychopathy and physiological responses to threat of an aversive stimulus. *Psychophysiology, 15,* 165–172. http://dx.doi.org/10.1111/j.1469-8986.1978.tb01356.x

Hastings, J. E., & Barkley, R. A. (1978). A review of psychophysiological research with hyperkinetic children. *Journal of Abnormal Child Psychology, 6,* 413–447. http://dx.doi.org/10.1007/BF00926054

Herpertz, S. C., Wenning, B., Mueller, B., Qunaibi, M., Sass, H., & Herpertz-Dahlmann, B. (2001). Psychophysiological responses in ADHD boys with and without conduct disorder: Implications for adult antisocial behavior. *Journal of the American Academy of Child & Adolescent Psychiatry, 40,* 1222–1230. http://dx.doi.org/10.1097/00004583-200110000-00017

Iaboni, F., Douglas, V. I., & Ditto, B. (1997). Psychophysiological response of ADHD children to reward and extinction. *Psychophysiology, 34,* 116–123. http://dx.doi.org/10.1111/j.1469-8986.1997.tb02422.x

Kraemer, H. C., Wilson, G. T., Fairburn, C. G., & Agras, W. S. (2002). Mediators and moderators of treatment effects in randomized clinical trials. *Archives of General Psychiatry, 59,* 877–883. http://dx.doi.org/10.1001/archpsyc.59.10.877

Lorber, M. F. (2004). Psychophysiology of aggression, psychopathy, and conduct problems: A meta-analysis. *Psychological Bulletin, 130,* 531–552. http://dx.doi.org/10.1037/0033-2909.130.4.531

Matthys, W., Vanderschuren, L. J. M. J., & Schutter, D. J. L. G. (2013). The neurobiology of oppositional defiant disorder and conduct disorder: Altered functioning in three mental domains. *Development and Psychopathology, 25,* 193–207. http://dx.doi.org/10.1017/S0954579412000272

Mead, H. K., Beauchaine, T. P., & Shannon, K. E. (2010). Neurobiological adaptations to violence across development. *Development and Psychopathology, 22,* 1–22. http://dx.doi.org/10.1017/S0954579409990228

Muñoz, L. C., Frick, P. J., Kimonis, E. R., & Aucoin, K. J. (2008). Types of aggression, responsiveness to provocation, and callous-unemotional traits in detained adolescents. *Journal of Abnormal Child Psychology, 36,* 15–28. http://dx.doi.org/10.1007/s10802-007-9137-0

Posthumus, J. A., Böcker, K. B. E., Raaijmakers, M. A. J., Van Engeland, H., & Matthys, W. (2009). Heart rate and skin conductance in four-year-old children with aggressive behavior. *Biological Psychology, 82,* 164–168. http://dx.doi.org/10.1016/j.biopsycho.2009.07.003

Raine, A. (1996). Autonomic nervous system factors underlying disinhibited, antisocial, and violent behavior. Biosocial perspectives and treatment implications. *Annals of the New York Academy of Sciences, 794,* 46–59. http://dx.doi.org/10.1111/j.1749-6632.1996.tb32508.x

Raine, A., Lencz, T., Bihrle, S., LaCasse, L., & Colletti, P. (2000). Reduced prefrontal gray matter volume and reduced autonomic activity in antisocial personality disorder. *Archives of General Psychiatry, 57,* 119–127. http://dx.doi.org/10.1001/archpsyc.57.2.119

Raine, A., Venables, P. H., Dalais, C., Mellingen, K., Reynolds, C., & Mednick, S. A. (2001). Early educational and health enrichment at age 3–5 years is associated with increased autonomic and central nervous system arousal and orienting at age 11 years: Evidence from the Mauritius Child Health Project. *Psychophysiology, 38,* 254–266. http://dx.doi.org/10.1111/1469-8986.3820254

Raudenbush, S., Bryk, A., Cheong, Y. F., & Congdon, R. (2004). *HLM 6: Hierarchical linear and nonlinear modeling*. Lincolnwood, IL: Scientific Software International.

Reid, M. J., Webster-Stratton, C., & Beauchaine, T. P. (2001). Parent training in head start: A comparison of program response among African American, Asian American, Caucasian, and Hispanic mothers. *Prevention Science, 2,* 209–227. http://dx.doi.org/10.1023/A:1013618309070

Robinson, E. A., Eyberg, S. M., & Ross, A. W. (1980). The standardization of an inventory of child conduct problem behaviors. *Journal of Clinical Child Psychology, 9,* 22–28. http://dx.doi.org/10.1080/15374418009532938

Sagvolden, T., Johansen, E. B., Aase, H., & Russell, V. A. (2005). A dynamic developmental theory of ADHD predominantly hyperactive/impulsive and combined subtypes. *Behavioral and Brain Sciences, 28,* 397–419. http://dx.doi.org/10.1017/S0140525X05000075

Satterfield, J. H., & Dawson, M. E. (1971). Electrodermal correlates of hyperactivity in children. *Psychophysiology, 8,* 191–197. http://dx.doi.org/10.1111/j.1469-8986.1971.tb00450.x

Scott, S., Spender, Q., Doolan, M., Jacobs, B., Aspland, H., & Webster-Stratton, C. (2001). Multicentre controlled trial of parenting groups for childhood antisocial behaviour in clinical practice. *British Medical Journal, 323,* 194–198. http://dx.doi.org/10.1136/bmj.323.7306.194

Shaffer, D., Fisher, P., Lucas, C. P., Dulcan, M. K., & Schwab-Stone, M. E. (2000). NIMH Diagnostic Interview Schedule for Children Version IV (NIMH DISC-IV): Description, differences from previous versions, and reliability of some common diagnoses. *Journal of the American Academy of Child & Adolescent Psychiatry, 39,* 28–38. http://dx.doi.org/10.1097/00004583-200001000-00014

Snoek, H., Van Goozen, S. H., Matthys, W., Buitelaar, J. K., & van Engeland, H. (2004). Stress responsivity in children with externalizing behavior disorders. *Development and Psychopathology, 16,* 389–406. http://dx.doi.org/10.1017/S0954579404044578

Speer, D. C., & Greenbaum, P. E. (1995). Five methods for computing individual client change and improvement rates: Support for an individual growth curve analysis. *Journal of Consulting and Clinical Psychology, 63,* 1044–1048. http://dx.doi.org/10.1037/0022-006X.63.6.1044

Sprafkin, J., Gadow, K. D., Salisbury, H., Schneider, J., & Loney, J. (2002). Further evidence of reliability and validity of the Child Symptom Inventory-4: Parent checklist in clinically referred boys. *Journal of Clinical Child & Adolescent Psychology, 31,* 513–524. http://dx.doi.org/10.1207/S15374424JCCP3104_10

Tranel, D., & Damasio, H. (1994). Neuroanatomical correlates of electrodermal skin conductance responses. *Psychophysiology, 31,* 427–438. http://dx.doi.org/10.1111/j.1469-8986.1994.tb01046.x

Tuvblad, C., Zheng, M., Raine, A., & Baker, L. A. (2009). A common genetic factor explains the covariation among ADHD ODD and CD symptoms in 9–10 year old boys and girls. *Journal of Abnormal Child Psychology, 37,* 153–167. http://dx.doi.org/10.1007/s10802-008-9278-9

Uno, H. (1977). Sympathetic innervation of the sweat glands and piloarrector muscles of macaques and human beings. *The Journal of Investigative Dermatology, 69,* 112–120. http://dx.doi.org/10.1111/1523-1747.ep12497915

van den Hoofdakker, B. J., Nauta, M. H., Dijck-Brouwer, D. A. J., van der Veen-Mulders, L., Sytema, S., Emmelkamp, P. M. G., . . . Hoekstra, P. J. (2012). Dopamine transporter gene moderates response to behavioral parent training in children with ADHD: A pilot study. *Developmental Psychology, 48,* 567–574. http://dx.doi.org/10.1037/a0026564

Webster-Stratton, C. (2007). Tailoring the Incredible Years parenting program according to children's developmental needs and family risk factors. In J. M. Briesmeister & C. E. Schaefer (Eds.), *Handbook of parent training* (pp. 305–344). Hoboken, NJ: Wiley.

Webster-Stratton, C., & Hammond, M. (1997). Treating children with early-onset conduct problems: A comparison of child and parent training interventions. *Journal of Consulting and Clinical Psychology, 65,* 93–109. http://dx.doi.org/10.1037/0022-006X.65.1.93

Webster-Stratton, C., & Reid, M. J. (2008). Adapting the incredible years child dinosaur social, emotional, and problem-solving intervention to address comorbid diagnoses. *Journal of Children's Services, 3,* 17–30.

Webster-Stratton, C., Reid, M. J., & Beauchaine, T. P. (2011). Combining parent and child training for young children with attention-deficit/hyperactivity disorder. *Journal of Clinical Child & Adolescent Psychology, 40,* 191–203. http://dx.doi.org/10.1080/15374416.2011.546044

Webster-Stratton, C., Reid, M. J., & Beauchaine, T. P. (2013). One-year follow-up of combined parent and child intervention for young children with ADHD. *Journal of Clinical Child & Adolescent Psychology, 42,* 251–261. http://dx.doi.org/10.1080/15374416.2012.723263

Webster-Stratton, C., Reid, M. J., & Hammond, M. (2004). Treating children with early-onset conduct problems: Intervention outcomes for parent, child, and teacher training. *Journal of Clinical Child & Adolescent Psychology, 33,* 105–124. http://dx.doi.org/10.1207/S15374424JCCP3301_11

Whisman, M. A., & McClelland, G. H. (2005). Designing, testing, and interpreting interactions and moderator effects in family research. *Journal of Family Psychology, 19,* 111–120. http://dx.doi.org/10.1037/0893-3200.19.1.111

Winsberg, B. G., & Comings, D. E. (1999). Association of the dopamine transporter gene (DAT1) with poor methylphenidate response. *Journal of the American Academy of Child & Adolescent Psychiatry, 38,* 1474–1477. http://dx.doi.org/10.1097/00004583-199912000-00006

Zisner, A., & Beauchaine, T. P. (in press). Psychophysiological methods and developmental psychopathology. In D. Cicchetti (Ed.), *Developmental psychopathology* (pp. in press, 3rd ed.). Hoboken, NJ: Wiley.

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