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EMPIRICAL RESEARCH

Physiological Self-Regulation Buffers the Relationship between Impulsivity and Externalizing Behaviors among Nonclinical Adolescents

Michelle A. Kuhn[1] · **Joshua J. Ahles**[1] · **Jaclyn T. Aldrich**[1] · **Madeline D. Wielgus**[1] · **Amy H. Mezulis**[1]

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Abstract Trait impulsivity is a risk factor for rule breaking and aggressive (externalizing) behaviors among nonclinical youth. Buffers of trait-based risk are of practical interest to preventing externalizing behaviors. One such buffer may be the capacity and efforts of a child to self-regulate their physiology. Youth who possess baseline physiological self-regulatory capacities are more likely to maintain adaptive engagement with their environment and may be less prone to impulsively rule break or be aggressive. Similarly, youth who are able to use self-regulatory skills to calm their physiology in times of stress may be less likely to externalize distress. This study examined self-regulatory capacity and efforts as a moderator of the relationship between trait impulsivity and externalizing behaviors, cross-sectionally and prospectively. We hypothesized that the effect of trait impulsivity on externalizing behaviors would depend on the presence of baseline self-regulatory capacity and/or self-regulatory efforts during stress. Participants were 134 nonclinical adolescents ($M_{age} = 12.59$, $SD = 1.20$ 51.9% female, 71% Caucasian). Trait impulsivity was measured using a parental report questionnaire. Physiological self-regulatory capacity and efforts were measured through collection of electrocardiogram data during a resting baseline and a stressful, unsolvable anagram task, respectively. Physiological self-regulation was quantified by calculating respiratory sinus arrhythmia scores across baseline and stress tasks. Respiratory sinus arrhythmia is the change in heart rate across the breathing cycle, and is hypothesized to index physiological self-regulation capacity and efforts under specific conditions. The results indicated that physiological self-regulation capacity, but not efforts, moderated the effect of trait impulsivity on externalizing behaviors prospectively. Stronger physiological self-regulatory capacity buffered the effect of greater trait impulsivity. Implications of these findings among typically developing youth are discussed.

Keywords Impulsivity · Externalizing symptoms · Self-regulation · Respiratory sinus arrhythmia · Parasympathetic nervous system · Adolescence

✉ Amy H. Mezulis
mezulis@spu.edu

Michelle A. Kuhn
mkuhn@spu.edu

Joshua J. Ahles
ahlesj@spu.edu

Jaclyn T. Aldrich
aldrichj@spu.edu

Madeline D. Wielgus
wielgusm@spu.edu

[1] Department of Clinical Psychology, Seattle Pacific University, Seattle, WA 98119, USA

Introduction

Externalizing behaviors, like aggression and rule-breaking, are frequently cited concerns within nonclinical adolescents. Although adolescence represents a time of normative developmental flux and behavioral maturation, externalizing behaviors can cause distress to youth and caregivers (Bornstein 2005). Externalizing behaviors are higher among adolescents who possess risk factors such as trait-level impulsivity; however, strong self-regulatory systems may buffer this risk.

Externalizing problems can only be understood within the context of developmentally normative externalizing levels. However, data regarding normative trajectories of externalizing behaviors over the transition to adolescence is mixed. Epidemiological studies indicate that most youth display highest levels of externalizing behaviors as children, and that externalizing declines across adolescence and into adulthood (Bongers et al. 2004; Leve et al. 2005). However, puberty is also described as a time of normative increases in risky externalizing behaviors (Ge et al. 2006). Discrepancies may be partially explained by the differential functions of externalizing behaviors over development.

In children, aggressive reactions or rule breaking often serve as a means of communicating discontent. In adolescence, externalizing is normally used to gain rewards or pleasurable physiological sensations. Thus, two simultaneous and opposite trends take place over the transition to adolescence: "acting out" decreases, while risk-taking and reward-seeking increase (Steinberg 2010). Youth may deviate from either normative trend. Children may exhibit typical reactive externalizing in childhood, but fail to show adaptive declines over time (Bongers et al. 2008; Moffitt et al. 2002). Alternately, youth may develop higher-than-typical rates of risk-taking-related externalizing behavior over adolescence. Both of these pathways may be influenced jointly by youth's tendency towards impulsivity and ability to engage in self-regulation.

Deviations from these normative trajectories are important. Research suggests that even nonclinical externalizing behaviors are related to negative outcomes. Children with more subclinical externalizing behaviors are at risk for mood, anxiety, and behavior problems, opposition, and academic underachievement throughout adolescence and adulthood (Broidy et al. 2003; Hinshaw 1992; Reef et al. 2011). In order to support positive development, it is important to understand factors that support risk and resilience among typically developing youth. Trait-level and physiological characteristics measured in childhood and early adolescence may be associated with risk for and protection from externalizing behaviors (Romer 2010; Romer et al. 2009).

Trait impulsivity may be related to increases in risk-taking and externalizing behavior in adolescence, when self-regulatory systems have yet to fully develop (Steinberg 2010). Youth may be able to compensate for impulsivity with the development of effective processes for self-regulating their physiology. That is, youth who are able to physiologically self-soothe may be better equipped to maintain a calm physiological baseline, and to remain calm during stress. In fact, physiological self-regulation may be associated with the development of better behavioral and emotional regulation (Calkins 2009).

The purpose of the current study was to examine whether physiological self-regulation capacity and efforts buffer against the effect of impulsivity on externalizing behaviors in nonclinical early adolescents. We examined short-term prospective changes in externalizing behaviors in a sample of early adolescents with nonclinical internalizing and externalizing behaviors. We hypothesized that self-regulation at two levels—trait and physiological—would be responsible differences in externalizing behaviors in our sample.

Impulsivity is Associated with Externalizing Behaviors

Trait impulsivity is a stable, genetically based, risk factor for externalizing from infancy into adulthood (Leve et al. 2005; Young et al. 2009). Trait impulsivity refers to individual differences in genetic and biological tendencies to demonstrate rapid behavioral and mood lability to stimuli without effective planning or consideration of potential consequences (Rothbart et al. 2001; Zuckerman and Kuhlman 2000), and is rooted in subcortical brain regions maturing early in life (Beauchaine 2015). Impulsivity is moderately heritable, with genetic studies indicating 33–56% heritability in early adolescence (Niv et al. 2012). This heritability decreases slightly over mid and late adolescence, with environmental influences increasing in importance. Increases in novelty-seeking and risk-taking also emerge over mid to late adolescence (Harden et al. 2012; Quinn and Harden 2013).

Trait impulsivity, in normative ranges and when accompanied by positive affect, can be adaptive and manifested as prosocial disinhibition and exuberance (Fox et al. 2001; Pfeifer et al. 2002; Stifter et al. 2008). However, some research suggests that even high average impulsivity may serve as a risk factor for externalizing and risky behaviors (Beauchaine and McNulty 2013; Beirness 1993; Colder and Chassin 1997; Romer 2010; Zuckerman and Kuhlman 2000). Children exhibiting elevated trait impulsivity are more likely to demonstrate externalizing behaviors such as drug and alcohol use, problem behaviors, and opposition as adolescents and adults (Beauchaine and Neuhaus 2008; Beauchaine 2012; Miller et al. 2003; Settles et al. 2010). Developmentally, impulsivity predicts externalizing problems emerging in late childhood and adolescence (Beauchaine and McNulty 2013; Beauchaine 2012; Olson et al. 1999; Romer 2010) and may also be a factor in the maintenance of externalizing problems (Beauchaine et al. 2017).

As children age, the relative impact of temperamental vulnerabilities such as trait impulsivity may be reduced by the development of capacities for self-regulation. The development of emotional and behavioral self-regulation systems throughout adolescence have been correlated with decreases in externalizing behaviors (Silk et al. 2003). However, research suggests that impulsive children have slower development of self-regulation systems (Shaw et al. 2011). For children with greater impulsivity, the lag of the emergence of regulatory skills may allow for a rise in externalizing behaviors (Dodge et al. 2007; Steinberg 2010).

Physiological Self-Regulation Capacity and Efforts are Associated with Externalizing Behaviors

Structural Bases of Physiological Self-regulation

Neural proliferation and pruning in the central and autonomic nervous systems create physiological structures that support emotional, cognitive, and behavioral self-regulation (Blakemore and Choudhury 2006; Calkins 2007; Fox 1994). Structures central to self-regulation in adolescence include the prefrontal cortex, which supports nuanced decision making and self-control, and accumbens, which drives reward seeking. Over adolescence, gradual development and functional connections occur within prefrontal cortices, while relatively faster development occurs within the accumbens (Blakemore and Choudhury 2006; Ernst et al. 2005; Galvan et al. 2006). This disparity between development of the accumbens and the prefrontal cortex results in adolescent risk-taking (Galvan et al. 2006). Measuring individual differences in the development of these structures within the central and autonomic nervous system is difficult because the procedures for imaging neural activity are often invasive and expensive. While most research on the accumbens has utilized brain scans, prefrontal development may be partially indexed by peripheral cardiac measures. Research has suggested that certain indexes of heart rate may be a helpful peripheral marker of these important neurologically-based self-regulation systems.

Peripheral Indices of Neurologically-based Regulation

Cardiac measures have been linked to brain function and physiological self-regulation through evolutionary-based theory. Mammals are able to control physiological responses during stress via the vagus nerve. The vagus nerve originates in the brain stem and terminates at the pacemaker of the heart. When activated, it acts as a *vagal brake*, decreasing heart rate, and consequently decreasing physiological arousal (Porges 1996, 2001).

Beauchaine and colleagues have extended on this theory, suggesting that deficiencies in physiological self-regulation exist at two levels: trait impulsivity, driven by early maturing subcortical regions (bottom-up), and higher-level deficiencies in the development of volitional, prefrontal control of reactivity (top-down). Beauchaine has suggested prefrontal activation and functional connectivity of the prefrontal cortex to the striatum and amygdala are more accurately responsible for parasympathetic regulation than brainstem activity (Beauchaine 2015; Beauchaine and Thayer 2015). Functionally, poor functional connectivity between the amygdala and striatum and the prefrontal cortex is related to deficits in executive control, emotion regulation, and externalizing behavior (Churchwell et al. 2009; Liston et al. 2011; Shannon et al. 2009).

Researchers have long used peripheral nervous system measures as markers of emotion regulation, and recent theoretical and empirical developments implicate respiratory sinus arrhythmia as a peripheral index of prefrontal cortical functioning (Beauchaine 2015; Berntson et al. 2007). Respiratory sinus arrhythmia refers to the quantification of parasympathetically controlled heart rate variability across respiratory cycle (Berntson et al. 2007). Neurovisceral integration theory (Thayer et al. 2009) describes the validity of indexing prefrontal activation using this parasympathetic marker as follows: (1) neural pathways link the prefrontal cortex to the parasympathetic nervous system and (2) positive correlations have been found linking respiratory sinus arrhythmia and executive function, and (3) neuroimaging links respiratory sinus arrhythmia and prefrontal activity.

Respiratory sinus arrhythmia can be measured at both a resting or trait level, and a reactive or state level. Resting respiratory sinus arrhythmia is computed as the average respiratory sinus arrhythmia value during a resting state, whereas respiratory sinus arrhythmia reactivity is computed as a difference between the resting respiratory sinus arrhythmia value and the respiratory sinus arrhythmia value in response to a stimulus (Alkon et al. 2003). Resting respiratory sinus arrhythmia reflects overall parasympathetic activity such that higher levels reflect greater parasympathetic nervous system activation and higher self-regulation at rest and in response to arousal (Beauchaine and Thayer 2015; Porges 1996). Resting respiratory sinus arrhythmia is stable measure of parasympathetic nervous system activation and physiological self-regulation capacity across childhood and into adolescence; whereas respiratory sinus arrhythmia reactivity may index stimulus-dependent regulation of reactivity (Beauchaine and McNulty 2013; El-Sheikh 2005).

It is important to note that the proportion of prefrontal activity detected through respiratory sinus arrhythmia has not been estimated, and is a subject of considerable debate within the field. It is likely that peripheral indexes capture only a part of the variance in self-regulation supported by prefrontal development. Therefore, we refer to respiratory sinus arrhythmia as an index of physiological self-regulation throughout this manuscript, as opposed to an index of prefrontal control.

Self-regulatory Capacity and Efforts are Associated with Externalizing Behaviors

Better physiological self-regulation has been linked to better emotional and behavioral regulation in stressful situations, lower risk for development of psychological disorders, and general expressions of emotionality and engagement with one's environment across adolescence and adulthood (for a review see Beauchaine 2001; Beauchaine and Thayer 2015). Conversely poor physiological self-regulation is associated with the emergence of externalizing behaviors in adolescents during middle and early high school (Beauchaine 2012).

A meta-analysis investigating vagal control within adolescents found that physiological self-regulation efforts in response to stressful situations were adaptive (Graziano and Derefinko 2013). However, a curvilinear relationship between adaptation and physiological self-regulation efforts may be more accurate. Specifically, moderate, but not especially high or low, levels of physiological self-regulatory reactivity are adaptive and indicative of psychological resilience (Beauchaine 2001; Marcovitch et al. 2010; Zisner and Beauchaine 2016). Adolescents who demonstrate moderate physiological self-regulatory efforts show less externalizing behaviors, and greater social skills (Marcovitch et al. 2010). Especially low physiological self-regulatory efforts are associated with behavior problems. Conversely, excessive physiological self-regulatory efforts are associated with anxiety and cognitive disengagement (Calkins et al. 2007). These findings support the hypothesis that adolescents with moderate physiological self-regulatory efforts to stress attempt to modulate their emotional response to changes in environmental conditions, and do so within an adaptive range (Marcovitch et al. 2010).

In contrast to biologically based bottom-up traits, top-down self-regulatory capacities and efforts emerge throughout late childhood and adolescence as cortical maturation and increased connectivity takes place. Externalizing behavior is most prevalent among children who possess trait vulnerability and who are slow to develop top-down regulatory mechanisms (Beauchaine 2015). Slow top-down development combines with rapid bottom-up accumbens development to create dual risk associated with reward-seeking and low self-regulation abilities.

Physiological Self-regulation may Moderate the Relationship between Trait Impulsivity and Externalizing Behaviors

Multiple risk factors converge to influence risk for externalizing behavior. Bottom-up trait impulsivity is influenced by genetic risk and developmental factors such as accumbens-based risk taking. Youth with bottom-up impulsivity and impulsive risk-taking might be able to compensate with the development of top-down prefrontal control and functional connectivity across childhood and adolescence (Beauchaine 2015; Beauchaine and Thayer 2015; Liston et al. 2011). Conversely, deficits in prefrontal cortex development and functional connectivity may exacerbate the effects of trait impulsivity and risk-taking (Beauchaine 2015). This model lends itself to moderation analyses. Specifically, the effect of trait impulsivity might be buffered or exacerbated under conditions of adaptive or maladaptive physiological self-regulatory capacity and efforts.

Current Study

The current study investigated the relationship between self-regulation and externalizing behaviors among a nonclinical adolescent sample. While many aspects of Beauchaine's model of externalizing behavior and pathology have been validated, surprisingly few studies have investigated the buffering or exacerbating effect of physiological self-regulation capacity and efforts—as indexed by respiratory sinus arrhythmia—on the relationship between trait impulsivity and externalizing behaviors. Additionally, these relationships are infrequently studied among subclinical samples.

We examined physiological self-regulation capacity and efforts as a moderator of the concurrent and prospective relationship between impulsivity and externalizing behaviors. Our sample was composed of young adolescents who were in a nonclinical range with respect to both externalizing and internalizing behaviors. Internalizing problems such as depression are associated with abnormalities in parasympathetic nervous system function, including physiological self-regulation. Thus, our broadly nonclinical sample provided a unique opportunity to test this model while potentially removing this often overlooked confound.

The current study examined the relationship between (1) the interaction of impulsivity and physiological self-regulation capacity and concurrent and prospective externalizing behaviors, and (2) the interaction of impulsivity and physiological self-regulation efforts and concurrent and prospective externalizing behaviors. We hypothesized that in the presence of low physiological self-regulation capacity, as impulsivity increases risk for externalizing behaviors would also increase. We also hypothesized that in the presence of very high or very low physiological self-regulation efforts, as impulsivity increases, risk for externalizing would also increase.

Methods

Participants

Participants were 134 adolescents (51.9% female, M_{age} = 12.59, SD_{age} = 1.20) enrolled in public schools in the Pacific Northwest. Approximately 71% were Caucasian; 5% were Asian-American; 1% were African-American; 1% were Native Hawaiian or Pacific Islander; 9% identified as biracial or other; the remaining participants elected not to respond. Out of 134 participants, 84 elected to share family income:

2.4% reported <30,000, 9.5% reported 30–75,000, 48.8% reported 75,000–150,000, 39.3% reported more than 150,000. Participants were enrolled in a broader prospective study investigating pathways to adolescent-onset depression.

Procedures

Youth were invited to participate in the school-based screening if they were (1) 10 to 14 years old; (2) in 5th to 8th grades; and (3) if they and one parent were sufficiently fluent in English to complete study questionnaires. Parents provided consent and youth provided assent for screening. Screening included administration of a set of self-report measures. Because the purpose of the broader study was to identify prospective pathways to adolescent-onset depression, youth were invited to the laboratory visit if youth's depressive symptoms at the screening visit were at or below the clinical cutoff (score of 14) on the Child Depression Inventory-2. At screening, 88% of youth were eligible to participate.

At the baseline visit, both parents and youth completed self-report measures on a desktop computer, the youth then experienced a stressful situation while physiological recording took place. The physiological recording included a 4-min baseline period in which they viewed relaxing nature scenes, followed by a 5-min anagram stressor task, which consisted of solvable and unsolvable anagrams designed so that the participant could not get more than 50% correct. Unsolvable anagrams have been used to reliably elicit affective and physiological stress responses (Schneider et al. 1996; Weidner et al. 1989). Youth were paid $30 and parents were paid $50. In total, 141 youth participated in the current study.

Measures

Trait impulsivity

Trait impulsivity was measured via the parental report UPPS (Miller et al. 2010; Zapolski and Smith 2013), a 16-item short-form of the UPPS scale (Whiteside and Lynam 2001). Studies suggest that the use of parental report impulsivity is a better predictor of long-term externalizing behavior than adolescent self-report (Bechtold et al. 2014). The UPPS measures four dimensions of impulsivity: negative urgency (acting impulsively under negative affect), lack of premeditation (difficulties planning and considering consequences), lack of perseverance (poor ability to remain focused), and sensation seeking (tendency to seek out dangerous or exhilarating activities). Items are rated on a Likert scale from 1 (*strongly agree*) to 4 (*strongly disagree*) and there are 4 items per dimension for a total of 16 items. For the current study, a total score was computed by averaging parental reports of all 16 items. Although often used as discrete scales, high correlations among subscales of the UPPS support the use of a unified scale (Billieux et al. 2008; Cyders et al. 2007). The overall UPPS has been used to index disposition toward impulsive behavior (Cirilli et al. 2011; Klonsky et al. 2013; Schmidt et al. 2008; Timpano et al. 2013). The short UPPS has shown good internal consistency with Cronbach alphas ranging from .74 to .85 (Cyders et al. 2014). Cronbach alpha for the current study was .78 for the total scale.

Physiological self-regulation capacity and efforts

Youth's cardiac activity was recorded throughout the 4-min seated resting baseline and 5-min unsolvable anagram stressor. All recordings occurred in the same sound-attenuated laboratory suite with standardized temperature and lighting. Participants were asked to refrain from use of caffeine and stimulant medication for 36 h prior to the laboratory session, and oral confirmation of their adherence to this protocol was obtained from both parent and youth upon arrival. In our sample, four youth were prescribed stimulant medications. Disposable pre-gelled Ag/AgCl electrodes were placed on the chest and abdomen using a Lead II placement. Electrocardiograph (ECG) data were acquired continuously using Biopac MP150 Data Acquisition Unit (Goleta, CA) and sampled at 1000 Hz. ECG data were processed offline using MindWare Technologies HRV 3.0.10 analysis program (Gahanna, OH). Data were visually inspected for movement artifacts or incorrect placement of markers by the automated scoring algorithm and corrected as needed by trained research assistants. The resulting inter-beat interval time series was subjected to a fast Fourier transformation by the MindWare software, and power in the respiratory frequency band (.15–.40 Hz) was derived from the spectral density function. Respiration rates were examined and all fell within the expected range, therefore we elected not to control for respiration. Respiratory sinus arrhythmia values were extracted in 30-s epochs. The average respiratory sinus arrhythmia value across the 4 min of resting baseline was used to create a single basal respiratory sinus arrhythmia score. Respiratory sinus arrhythmia reactivity to the laboratory stressor was determined by averaging participants' respiratory sinus arrhythmia across the 5 min of stressor task. This method was used in accordance with common practice in similar research (Morgan et al. 2013). Second, change scores were computed by subtracting basal respiratory sinus arrhythmia from respiratory sinus arrhythmia across the stressor. Thus, positive respiratory sinus arrhythmia change scores reflect vagal augmentation and negative change values reflect vagal withdrawal.

Externalizing behaviors

Externalizing behaviors were assessed with parental report Child Behavior Checklist (CBCL; Achenbach and Rescorla

2001). The CBCL is a 113-item inventory assessing behavioral and emotional problems. Parents rated whether each item was true of their youth's behavior over the previous 6 months using a three-point scale ranging from 0 (*not true*), 1 (*somewhat or sometimes true*), or 2 (*very or often true*). The externalizing scale is a sum of rule-breaking and aggressive behavior items. Parents completed the CBCL at the initial lab visit (T1) and at 6-month follow-up (T2). The internal consistency of the CBCL externalizing scale for this study was good (T1 = .83; T2 = .96).

Depressive symptoms

Youth depressive symptoms were assessed with the Children's Depression Inventory—2nd Edition (CDI-2; Kovacs 2004). The CDI-2 is a 28-item self-report inventory that inquires about the presence of depressive symptoms within the past 2 weeks; it is normed for use with youth aged 8 to 17. Each item contains three statements; participants were asked to select the statement that best described them in the previous 2 weeks. Total scores on the CDI-2 can range from 0 to 54, with higher scores indicating more severe depressive symptoms. The CDI-2 has repeatedly demonstrated adequate internal consistency (alpha reliability ranges from .80 to .87), test–retest reliability, and predictive and construct validity, especially in nonclinical samples (Blumberg and Izard 1986; Kovacs 2004). The CDI-2 was administered at screening and youth with scores greater than 14 were not eligible for the follow-up lab visit. The CDI-2 was re-administered throughout the study, though subsequent scores above 14 were not used as exclusion criteria, but controlled for in analyses.

Data Analytic Strategy

Missing data

Analyses included 134 adolescents who had completed both visits through the 6-month follow up, and who thus had data recorded for baseline and 6-month follow up variables. Seven of 141 original cases (5.0% of the sample) were identified as outliers using median absolute deviation scores on independent variables (Leys et al. 2013). Seven participants had outlier impulsivity values and excluded from analyses. Regarding missing data, four of seven variables (57.14%) used in these analyses had missing data. Of 141 original cases, 30 cases (21.28%) had missing data. Total missingness for the cells used in analyses was 3.5%. Little's MCAR test (X^2 [22] = 30.92, $p = .098$) indicated a completely random pattern of missing data. AMOS' structural equation modeling program was used to perform imputation with Maximum Likelihood Estimation. Analyses were run with imputed data from 134 participants.

Covariates

Gender and parental report youth depressive symptoms at screening were entered as covariates in all analyses. In analyses exploring changes in externalizing behaviors prospectively, externalizing behaviors at baseline was also entered as a covariate.

Regression analyses

Statistical analyses were conducted using SPSS version 23. Two hierarchical linear regression analyses were conducted to examine the relationship between baseline impulsivity and externalizing behaviors cross-sectionally and at 6-month follow up.

Moderation analyses

Moderation analyses were conducted with the PROCESS macro, using model 1 (Hayes 2012). Impulsivity measured by the UPPS at screening was entered as the independent variable. Resting respiratory sinus arrhythmia and respiratory sinus arrhythmia reactivity were examined separately as moderators. Each combination of predictors (impulsivity × resting respiratory sinus arrhythmia; impulsivity × respiratory sinus arrhythmia reactivity) was run with cross-sectional and prospective measures of externalizing behaviors, at baseline and at 6-month follow-up respectively. All together, a total of 4 moderation models were tested: impulsivity and resting respiratory sinus arrhythmia to concurrent externalizing, impulsivity and resting respiratory sinus arrhythmia predicting prospective externalizing, impulsivity and reactive respiratory sinus arrhythmia to concurrent externalizing, and impulsivity and reactive respiratory sinus arrhythmia predicting prospective externalizing. Furthermore, given the nonlinear associations between RSA reactivity and externalizing symptoms among developmental samples, we examined the nonlinear effects of RSA reactivity as a moderator. Variables were mean centered by the PROCESS software during analyses. For models in which a significant moderation was found, regions of significance for the moderator were identified using the Preacher's region of significance in MLR 2-way interactions technique (Preacher et al. 2006).

Results

Descriptive Statistics

Variable means, standard deviations, and bivariate correlations for study variables are provided in Table 1. As expected, all UPPS subscales were correlated with total

Table 1 Descriptive statistics and bivariate correlations among study variables

	1	2	3	4	5	6	7	M	SD	Observed range
1. Sex	–							–	–	51.9% female
2. Age	.01	–						12.59	1.20	10.80–14.61
3. Depression	−.23**	.21*	–					10.60	4.50	2–22
4. UPPS Impulsivity	−.13	.06	.32**	–				2.24	.39	1.38–3.00
5. T1 Resting respiratory sinus arrhythmia	.04	.03	−.08	−.03	–			7.06	.96	3.39–9.64
6. T1 Reactive respiratory sinus arrhythmia	.08	−.09	−.05	.07	−.30**	–		−.60	.61	−2.42–1.52
7. T1 Externalizing	−.11	.15	.51**	.42**	−.10	.06	–	49.19	9.12	37–68
8. T2 Externalizing[a]	−.09	.02	.40**	.37**	−.09	.09	.65**	47.58	9.06	37–69

Note: Sex was scored 0 = male; 1 = female

[a] All data presented came from baseline screening and questionnaires, except T2 externalizing, which was collected at the second lab visit

*$p < .05$; **$p < .01$

Table 2 Linear regression models predicting externalizing behaviors from trait impulsivity

	T1 Externalizing				T2 Externalizing			
Variable	B[a] (SE)	b[b]	*t*	*p*	B[a] (SE)	b[b]	*t*	*p*
Constant	−7.80 (2.19)		−3.56	.00	−2.25 (2.13)		−1.05	.30
Sex	.16 (.57)	.02	.28	.78	.06 (.56)	.01	.11	.91
Depression	.35 (.07)	.42	5.43	.00	.06 (.08)	.08	.99	.33
T1 Externalizing					.57 (.08)	.57	7.05	.00
Impulsivity total	3.41 (.89)	.29	3.81	.00	1.28 (.87)	.11	1.46	.15

[a] Unstandardized regression coefficients

[b] Standardized regression coefficients

impulsivity score, with correlations ranging from .36 to .76. Among the subscales, negative urgency was significantly correlated with lack of premeditation and lack of perseverance ($r = .44$, $r = .49$, $p < .001$, respectively) but was not significantly correlated with sensation seeking ($r = -.06$, $p = .49$). Lack of premedication was significantly correlated with lack of perseverance ($r = .59$, $p < .001$) but was not correlated with sensation seeking ($r = .04$, $p = .69$). Lastly, lack of perseverance and sensation seeking were not correlated ($r = -.15$, $p = .09$). Several alternative exploratory models were considered using the UPPS subscales, including lack of perseverance and premeditation, however no models were significant when taking all necessary controls (i.e. other UPPS subscales) into consideration.

Our sample represents a strictly subclinical sample of young adolescents. CBCL Externalizing subscale T-scores for all participants fell below the clinical cutoff of 70—with the highest score at a 69—both at screening ($M = 49.19$; $SD = 9.12$) and at 6-month follow up ($M = 47.58$; $SD = 9.06$). Impulsivity was significantly correlated with externalizing behaviors at baseline and 6-months later, such that as adolescents' impulsivity increased, externalizing behaviors also increased (see Table 1). No significant correlations were found between respiratory sinus arrhythmia and impulsivity or externalizing variables.

Paired sample *t*-tests were run to determine whether significant differences existed between resting and task respiratory sinus arrhythmia; a significant difference did exist between resting respiratory sinus arrhythmia and task respiratory sinus arrhythmia scores ($t[135] = 11.11$, $p < .000$). Further examining respiratory sinus arrhythmia reactivity a decrease in respiratory sinus arrhythmia from baseline, was observed in 88% ($n = 117$) of our sample, while 12% ($n = 16$) of our sample showed respiratory sinus arrhythmia augmentation, or an increase in respiratory sinus arrhythmia from baseline under stress.

Physiological Self-Regulation Capacity and the Relationship between Impulsivity and Externalizing Behavior

Linear regression models indicated that independent of physiological self-regulation, impulsivity was associated with externalizing behavior concurrently ($\beta = .29$ [.89], $t = 3.81$, $p < .000$), but was not associated with change in externalizing at the 6-month follow up ($\beta = .11$ [.87], $t = 1.46$, $p = .15$). See Table 2 for full regression results.

The interaction between impulsivity and resting respiratory sinus arrhythmia did not significantly predict externalizing behaviors cross-sectionally ($\beta = -.13$ [.93], $t =$

−1.68, $p = .09$). However, a significant interaction effect was found for impulsivity and resting respiratory sinus arrhythmia on change in externalizing behaviors prospectively ($\beta = -.15$ [.86], $t = -2.17$, $p = .03$; see Fig. 1). This interaction was examined using Preacher and colleagues (2006) procedure, which revealed a buffering effect such that at resting respiratory sinus arrhythmia values above 6.95, there were no differences in externalizing behaviors across the range of impulsivity. In contrast, for those with resting respiratory sinus arrhythmia below 6.95, those with higher levels of impulsivity exhibited significantly more externalizing behaviors than those with low impulsivity. Within our sample, 54.8% of adolescents demonstrated this buffering effect against this increase in externalizing behaviors over time (Tables 3 and 4).

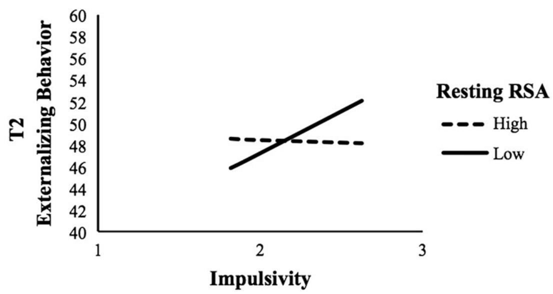

Fig. 1 Depiction of the interaction effect of impulsivity and physiological self-regulation capacity on change in externalizing behavior 6-months prospectively

Physiological Self-Regulation Efforts and the Relationship between Impulsivity and Externalizing Behavior

Physiological self-regulation efforts, as indexed by respiratory sinus arrhythmia reactivity did not significantly moderate the relationship between impulsivity and externalizing behaviors. No significant interaction was found cross-sectionally ($\beta = -.03$ [1.56], $t = .43$, $p = .67$), or prospectively ($\beta = .56$ [1.45], $t = .13$, $p = .90$). Curvilinear effects of respiratory sinus arrhythmia reactivity on externalizing behaviors were explored through nonlinear regressions examining quadratic and cubic relationships. No significant nonlinear effects were found for concurrent or prospective models. Respiratory sinus arrhythmia reactivity did not appear to affect the relationship between impulsivity and externalizing behaviors.

Alternative models were considered in terms of the UPPS subscales. Examining these facets of impulsivity,

Table 3 PROCESS moderation models predicting externalizing behaviors from the interaction of trait impulsivity and resting RSA

	T1 Externalizing				T2 Externalizing			
Variable	B[a] (SE)	*b*[b]	*t*	*p*	B[a] (SE)	*b*[b]	*t*	*p*
Constant	−.21 (1.24)		−.17	.87	.68 (1.14)		.59	.55
Sex	.04 (.56)	−.06	.07	.94	−.08 (.52)	−.01	−.16	.87
Depression	.36 (.06)	.42	5.50	.00	.08 (.07)	.10	1.25	.21
T1 Externalizing					.55 (.08)	.54	6.69	.00
Impulsivity total	3.08 (.91)	.26	3.38	.00	.98 (.88)	.08	1.12	.27
Resting RSA	−.26 (.28)	−.06	−.91	.37	−.13 (.26)	−.03	−.51	.61
RSA × Impulsivity	−1.56 (.93)	−.13	−1.68	.09	−1.87 (.86)	−.15	−2.17	.03

[a] Unstandardized regression coefficients

[b] Standardized regression coefficients

Table 4 PROCESS moderation models predicting externalizing behaviors from the interaction of trait impulsivity and reactive RSA

	T1 Externalizing				T2 Externalizing			
Variable	B[a] (SE)	*b*[b]	*t*	*p*	B[a] (SE)	*b*[b]	*t*	*p*
Constant	−.24 (1.25)		−.19	.85	.56 (1.18)		.48	.63
Sex	.10 (.57)	.01	.18	.86	.03 (.53)	.00	.06	.95
Depression	.35 (.07)	.42	5.36	.00	.07 (.06)	.08	1.05	.29
T1 Externalizing					.57 (.08)	.56	6.95	.00
Impulsivity total	3.38 (.91)	.29	3.73	.00	1.20 (.89)	.10	1.36	.18
Reactive RSA	.35 (.45)	.06	.77	.44	.35 (.42)	.06	.83	.41
RSA × Impulsivity	−.67 (1.56)	−.03	.43	.67	.19 (1.45)	.56	.13	.90

[a] Unstandardized regression coefficients

[b] Standardized regression coefficients

especially sensation seeking in light of accumbens differences in adolescence, could have provided more detailed insight into the moderating mechanism of resting and reactive RSA, however no alternative models were found to be significant.

Discussion

Adolescent risk for externalizing behavior is influenced by youth's developing neurology. Youth enter adolescence with a certain degree of genetically-influenced risk or protection from externalizing behaviors in the form of trait-impulsivity. The bottom-up processes responsible for trait-impulsivity are related to early-developing neurological structures responsible for drive motivation and reward-seeking (Beauchaine and Thayer 2015). During adolescence, bottom-up risk is enhanced by the relatively rapid development of the accumbens and related increases in reward-seeking, and risk-taking (Galvan et al. 2006). Despite these developmental risk factors, top-down processes may buffer risks presented by deficient bottom-up regulation. Top-down regulation is driven by increases in prefrontal development and functional connectivity between the prefrontal cortices, striatum, and amygdala. Structures and networks responsible for top-down processes are largely underdeveloped in early adolescence, and develop slowly throughout adolescence and into early adulthood (Beauchaine 2012).

This study sought to explore the hypothesis that externalizing behaviors in adolescence are jointly influenced by bottom-up and top-down processes unique to the adolescent developmental period. As is common in the field of physiological self-regulation research, we utilized peripheral measurements to estimate development in the aforementioned brain regions critical to adolescent self-regulatory development (Thayer et al. 2009). While accumbens activity and functional connectivity is measured using brain scans, prefrontal development may be peripherally indexed by respiratory sinus arrhythmia.

This study addresses a key component of the model articulated by Beauchaine in the literature supporting the aforementioned neurovisceral integration model of externalizing behavior. Previous studies have provided support for key components of Beauchaine's model. The core pathway of impulsivity as a broad risk factor for externalizing behaviors has been supported (Beauchaine and Neuhaus 2008). Furthermore, moderators such regulatory skill development and capacity are supported in the literature (Beauchaine and McNulty 2013). However, though physiological self-regulation has been linked to respiratory sinus arrhythmia (Beauchaine and McNulty 2013), there have been no studies that directly assess the interaction between impulsivity and respiratory sinus arrhythmia in adolescence.

The results supported the hypothesized model. Independent of physiological self-regulation, trait-impulsivity was positively associated with externalizing behavior concurrently. At 6-month follow up, presence of stronger physiological self-regulation capacity buffered the relationship between impulsivity and externalizing behaviors. In contrast, among youth without the protective factor of physiological self-regulation capacity, the relationship between internalizing behaviors and externalizing behaviors remained. These results suggest support for the model of proposed bottom-up risk, and top-down self-regulatory protection among adolescents.

We did not find a significant effect of physiological self-regulation efforts as a moderator. While physiological self-regulation efforts have been consistently linked with externalizing behaviors, most studies describe respiratory sinus arrhythmia reactivity in the context of emotion eliciting situations when attempting to explain variations in externalizing behavior across individuals (see Zisner and Beauchaine 2016). A recent study by Fortunato et al. (2013) found varied respiratory sinus arrhythmia reactivity profiles across fear, sadness, happiness, and anger induction tasks, with externalizing behaviors best predicted by blunted reaction to a task intended to induce happiness. As a non-social, failure-related stress induction, our stimulus may have elicited reactions of frustration and learned helplessness from our participants, partially accounting for the lack of effect on respiratory sinus arrhythmia reactivity in impacting externalizing behaviors.

These findings suggest that there may be benefits to exploring the emergence of self-regulation within samples of nonclinical youth. While many studies have focused on clinical samples, our sample provided the unique opportunity to observe correlates of a sensitive period of neurological development, within a nonclinical sample. Such research is important to understanding normative development, and may also be helpful in supporting healthy development of executive control in at risk youth. Youth with trait-impulsivity may benefit from increased focus on the development of physiological self-regulation skills.

Limitations

Our study had several limitations. The short, 6-month time span between baseline and follow up limited our ability track externalizing trajectories across adolescence to provide additional support that the observed impact of respiratory sinus arrhythmia reactivity was indeed a developmentally significant moderator throughout adolescence.

Another limitation stems from our measurement techniques. We used parental report data for all measures except for physiological variables. We chose to utilize parental reports of adolescent behaviors as adolescents have difficulty remembering mood incongruent states, reporting frequency of externalizing behaviors with accuracy, and recalling across longer time periods (Henry et al. 1994). Furthermore, research suggests that parental report of child impulsivity is a more accurate predictor of related externalizing problems (Bechtold et al. 2014). Still, other studies indicate that children may be the more accurate raters of externalizing problems, as parents may not be aware of rule-breaking behaviors (Laird and LaFleur 2016). Both methods likely introduce rater and recall bias. We also used only one measure of self-regulation. While the use of physiological data to measure self-regulation reduces bias from self-report, it was the only measure of self-regulation used in this study. Results could be bolstered by the use of an additional measurement.

Finally, our sample introduced several limitations. Our participants were largely Caucasian and high income, with family incomes higher than $75,000 for 88.1% of our sample. This population should be taken into consideration when attempting to generalize results. Additionally, utilizing a nonclinical sample was helpful in examining the relationship between impulsivity and respiratory sinus arrhythmia in predicting externalizing behaviors in a group of adolescents with a wide range of externalizing behavior rates. However, we were unable to make statements about variables that reliably predict clinical levels of externalizing behaviors.

Future Directions

Our study presented a short-term prospective design. Elongating this window of time or replicating this study among middle and late adolescents should be a priority in further research. Longer prospective designs would allow for observation of maturation within the domain of self-regulation, driven by the development of critical brain regions. As indicated in the introduction to this study, prefrontal connectivity and development are in early phases during the transition from childhood to adolescence. Consistent contact with youth over adolescence would allow for stronger inferences to be made about the magnitude of long-term risk represented by early self-regulatory lag. Methodologically, studies should also consider the use of multiple methods of self-regulatory measurement, and children's reports of externalizing behavior.

Conclusion

This study examined self-regulation on two levels: bottom-up and top-down. We hypothesized that youth who possess trait-impulsivity may at higher risk for externalizing behaviors; and, that the development of top-down physiological self-regulation may buffer risk associated with trait impulsivity. Our study examined this relationship in a nonclincal sample of early adolescents using respiratory sinus arrhythmia as an index of top-down regulation. Results supported trait impulsivity as a bottom-up risk factor for externalizing problems in adolescence. Furthermore, strength of adolescent physiological self-regulation capacity served as a top-down protective factor, buffering the relationship between impulsivity and externalizing problems. Adolescence presents a time of developmental risk for externalizing problems. Neurological risk for impulsive risk taking behaviors combines with risk associated with the difficult developmental task of acquiring complex emotion-regulation skills. This research emphasizes the importance of regulation of physiology in the successful navigation of the transition from childhood to adolescence.

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Compliance with Ethical Standards This research was conducted in accordance to ethical standards for the protection of the health, safety, and confidentiality of subjects enrolled.

Conflict of Interest The authors declare that they have no competing interests.

Ethical Approval This study was approved as human subjects research, through full board institutional review. All procedures were in accordance with national and institutional ethical standards.

Informed Consent Informed consent was obtained from all participants included in the study.

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Michelle A. Kuhn MS, is a doctoral student in Clinical Psychology in the School of Psychology, Family, and Community, at Seattle Pacific University. Her research interests focus on the development of internalizing and externalizing disorders in youth, including temperamental, environmental, and physiological risk and protective factors.

Joshua Ahles MS, is a Ph.D. candidate in Clinical Psychology in the School of Psychology, Family, and Community, at Seattle Pacific University. His research interests center on the interaction between cognitive processes and physiological stress reactivity and recovery.

Jaclyn T. Aldrich MA, MS, is a doctoral student in Clinical Psychology in the School of Psychology, Family, and Community, at Seattle Pacific University. Her research interests include the development of cognitive and biological vulnerabilities to depression during adolescence.

Madeline Wielgus MS, is a doctoral student in Clinical Psychology in the School of Psychology, Family, and Community, at Seattle Pacific University. Her research interests include developmental psychopathology, psychophysiology, and maladaptive emotion regulation behaviors, with a focus on understanding factors that contribute to the onset and maintenance of self-injurious thoughts and behaviors.

Amy H. Mezulis is an associate professor of Clinical Psychology in the School of Psychology, Family, and Community, at Seattle Pacific University. Her research interests lie in developmental psychopathology and factors contributing to adolescent onset disorders.