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School-aged children with higher anxiety symptoms show greater correspondence between subjective negative emotions and autonomic arousal

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ABSTRACT

Individuals exhibit variability in the degree of correspondence between autonomic and subjective indicators of emotional experience. The current study examined whether convergence between autonomic arousal and negative emotions during emotion-inducing story vignettes is associated with internalizing symptoms in school-aged children. A diverse sample of 97 children aged 8 to 12 years participated in this study in which they reported on their anxiety and depression. Children's electrodermal activity was assessed while they read vignettes depicting children experiencing sadness and fear. Participants also reported on their emotional reaction to the vignettes. Children's anxiety and electrodermal activity to fear vignettes were associated only at high levels, but not mean or low levels, of self-reported negative emotions to fear vignettes. These findings suggest that hyperawareness, in which self-reported negative emotionality is high when physiological reactivity is also high, is associated with greater risk for anxiety, but not depression, during middle childhood.

Abbreviations: EDA, Electrodermal activity; NE, Negative emotions.

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Introduction

Emotion is traditionally described as involving coordinated changes in subjective experience, autonomic nervous system activation, and expressive behavior (Ekman, 1992; Lazarus, 1991; Levenson, 1994; Scherer, 2005; Sze, Gyurak, Yuan, & Levenson, 2010). For example, feeling threatened, sweating, and displaying fearful facial expressions are typically regarded as signs of fear. This assumption that greater correspondence, or *psychobiological convergence,* between these different indicators of emotional experience also pervades the clinical world, where the general belief undergirding many forms of psychological interventions (e.g., mindfulness, cognitive behavioral therapy; Davis, Kendall, & Suveg, 2019) is that greater alignment between visceral changes in one's body and subjective experience ostensibly facilitates adaptive behavior and improves emotional health.

But are these different aspects of emotion actually coordinated? More often than not, there is great variability in the degree of correspondence, or convergence, between these different indicators of emotional experience (Mauss, Levenson, McCarter, Wilhelm, & Gross, 2005). In contrast to these theories of emotion and therapy (e.g., Sze et al., 2010), we contend that high psychobiological convergence may in some contexts actually be detrimental to children's emotional functioning and potentially increase internalizing problems, including anxiety and depression. In this study, we examined associations between subjective–autonomic (electrodermal activity [EDA]) indices of emotion and internalizing symptoms (anxiety and depression) in preadolescent youths. We tested whether children's subjective negative emotions (NE) to emotional story vignettes is a moderator of the associations between autonomic arousal to story vignettes and psychopathology. That is, we asked the following: Are internalizing symptoms elevated when children report high levels of subjective NE relative to their physiological reactions to emotion-eliciting scenarios, and do patterns of convergence vary depending on emotional context?

Theories of embodied cognition posit that there is a reciprocal relationship between bodily activity and the way emotional information is processed (Niedenthal, 2007; Winkielman, Coulson, & Niedenthal, 2018). These notions are similarly reflected in neuroscience (Damasio, 1996). Yet, the joint role of subjective experience and physiology with respect to anxiety is rarely considered, particularly among children. There are hints in the scarce relevant literature involving comparisons across physiological and self-report indices that psychobiological convergence measures might prove to be fruitful in understanding anxiety symptoms broadly. In general, this work has been unable to consistently link individual differences in autonomic arousal with subjectively experienced somatic symptoms (Anderson & Hope, 2009; McLeod, Hoehn-Saric, & Stefan, 1986; Wilhelm, Kochar, Roth, & Gross, 2001). However, recent accounts assert that the subjective experience of arousal-related somatic sensations may be more pertinent to anxiety than the accurate detection of physiological phenomena (Grossman, Wilhelm, Kawachi, & Sparrow, 2001; Mauss, Wilhelm, & Gross, 2004; Rosebrock, Hoxha, Norris, Cacioppo, & Gollan, 2017; Taschereau-Dumouchel, Michel, Lau, Hofmann, & LeDoux, 2022; Wilhelm et al., 2001). For instance, one disorder in which individuals exhibit elevation in subjective distress relative to physiological states is panic disorder, characterized by recurrent unexpected panic attacks and hypervigilance to autonomic changes coupled with a negatively biased appraisal of these changes (American Psychiatric Association, 2013). Amplified subjective experience of bodily sensations has also been implicated in generalized anxiety disorder (Hoehn-Saric, McLeod, Funderburk, & Kowalski, 2004), social anxiety (Anderson & Hope, 2009; Edelmann & Baker, 2002; Mauss et al., 2004), and social phobia (Mersch, Hildebrand, Lavy, Wessel, & van Hout, 1992). These observations challenge a simple global hyperreactivity account of anxiety and propose a more nuanced account, whereby subjective experience may moderate the influence of physiological arousal on anxiety symptoms depending on the emotive situation. Thus, the subjective experience of distress in the context of heightened physiological arousal can sometimes be maladaptive, particularly when combined with concern regarding what the physiological states signify.

Additional insights into the possible relationship between heightened psychobiological convergence and anxiety can be gleaned from the literature on attachment. Attachment theorists posit that chronically attachment anxious children tend to upregulate (hyperactivate) the presence of threats in the service of the children's aim of maintaining proximity and care from an inconsistently available attachment figure, resulting in a heightening of the expression of NE and a fixation on emotional states (Cassidy, 1994). This pattern contrasts with attachment avoidant children who may likewise fixate on emotional states but suppress (deactivate) potential threats in order to preserve the availability of a caregiver who is likely to reduce their responsiveness in the presence of expressions of need (Borelli, David, Crowley, Snavely, & Mayes, 2013; Borelli, Hilt, West, Weekes, & Gonzalez, 2014a; White, Wu, Borelli, Mayes, & Crowley, 2013; White et al., 2012). Securely attached children, on the other hand, may be able to adaptively regulate in response to threats by physically seeking proximity to a caregiver or self-soothing by using internal modes of regulation (Borelli et al., 2021; Brumariu, 2015). Relevant to the current study, insecure anxious attachment involves exaggeration of subjective NE accompanied by heightened physiological arousal along with correspondence between the two. Amplified psychobiological convergence is thus thought to be sustained by exaggerating appraisal processes and/or perceptually heightening the threatening aspects of relatively mild stressors (Manassis, 2001; Mikulincer & Shaver, 2008). Although the current study does not assess attachment security directly, these observations of heightened sensitivity to mildly negative situations in anxiously attached individuals nonetheless support our working hypothesis that escalating subjective distress that accompanies heightened physiological arousal may be relevant to the development of anxiety symptoms in children.

Unlike clinical observations, lab-based work on psychobiological convergence in anxiety often relies on acute stressors (e.g., social stressors, phobia objects) to elicit emotional responses. Importantly, such "strong situations" (Lissek, Pine, & Grillon, 2006) generally evoke a similar response across individuals, obscuring more subtle individual differences potentially relevant to risk profiles. In contrast, milder situations are events that attenuate the influence of the situation and expose the vulnerability of individuals prone to anxiety, increasing the contribution of individual differences on subsequent responses. Such mild situations may better approximate what happens during daily life, and through their cumulative impact they may have a larger impact on daily functioning. To better probe individual differences in psychobiological convergence, our experimental paradigm leveraged emotive stories that are mildly evocative but not too intense so as to capture more nuanced dynamics across response systems. Employing such mildly evocative stressors, we contend that when children's autonomic arousal is coupled with high self-reported NE, this can sometimes exacerbate anxiety via either sustained focus on distress or greater sensitivity to the evocative event. In other words, psychobiological convergence—convergence between autonomic and self-reported indicators of emotion (e.g., Borelli, Ho, & Epps, 2018)—may heighten anxiety or depressive symptoms in the context of negative emotionality.

Currently, it is unknown whether co-occurrence of physiological arousal and subjective experience of distress is related to anxiety symptoms in typically developing children versus those with psychiatric disorders. However, consistent with a developmental psychopathology perspective, understanding whether such associations are present among community (i.e., nonclinical) samples is important in building models of pathology that span the full continuum of symptoms (from complete absence to complete presence). Behavioral, emotional, and autonomic response patterns change with age, and the associations between these systems and adaptive versus maladaptive functioning may also change (Cicchetti, Ackerman, & Izard, Ackerman, & Izard, 1995). No studies to our knowledge have investigated the relationship between psychobiological convergence and internalizing problems in children. We focused on middle childhood (8–12 years of age) because it is a transitional period marked by developmental changes in psychosocial functioning, cognition, and brain development that can amplify anxiety symptoms (Michalska et al., 2016). Studies show a peak in the prevalence of anxiety during this developmental period (Costello, Mustillo, Erkanli, Keeler, & Angold, 2003). New challenges occur during middle childhood that can contribute to the development of anxiety (Beesdo-Baum & Knappe, 2012). In addition, alterations in the normative development of brain structure, function, and connectivity likely underlie the emergence of anxiety during middle childhood (Giedd, 2004; Giedd et al., 2004; Paus et al., 2001).

Despite renewed interest in characterizing psychobiological convergence to gain traction on models of emotion and adaptive functioning, questions remaining include (a) whether psychobiological convergence is meaningfully correlated with anxiety symptoms in youths, (b) whether psychobiological convergence is specific to anxiety or whether it also extends to other internalizing symptoms such as depression, and (c) whether any associations between psychobiological convergence and internalizing symptoms vary across different negative emotional contexts (e.g., fear vs. sad). Most studies on self-report biases in anxiety typically consider performance on only a single task or emotional valence (e.g., fear). However, our emotional experiences are contextually situated and engage physiological resources in a dynamic flexible way. Not accounting for emotional context might interfere with efforts to understand psychobiological convergence in emotion-eliciting situations. To better characterize the underlying structure of internalizing symptoms in children, it is important that biases in subjective experience of NEs be assessed on a variety of emotion-eliciting tasks.

Psychobiological convergence across emotional response modalities may look different in youths who manifest emotional adjustment problems compared with those who do not (Hastings, Zahn-Waxler, & Usher, 2007). For instance, compared with typically developing youths, children with *externalizing* problems exhibit weakened correspondence between heart rate and subjective negative feelings (Hastings et al., 2009) and between cardiac measures and facial sadness (Marsh, Beauchaine, & Williams, 2008). Findings in children with internalizing problems are less consistent, but the available data likewise point to the centrality of psychobiological convergence such as convergence between autonomic reactions (heart rate) and NE in contextually inappropriate contexts as well as atypical convergence between autonomic reactions and positive feelings (Hastings et al., 2009). However, the degree to which non-normative psychobiological convergence effects are specific to anxiety versus also characteristic of other internalizing pathology such as depression is unknown. On the one hand, anxiety and depression show high rates of diagnostic comorbidity (Kessler, Chiu, Demler, & Walters, 2005), suggesting that patterns of psychobiological convergence might be similarly associated with both types of symptoms in children. On the other hand, evidence also supports the isolation of these symptoms in youths, indicating that anxiety and depression are related yet distinct sets of symptoms that may have distinct patterns of convergence as well (Achenbach, Dumenci, & Rescorla, 2003; Boots & Wareham, 2010). Work on psychobiological convergence in depression is scarce, although research on a related construct, self-focused attention, supports the existence of a relationship between ruminative self-focus and depression in adults (see Mor & Winquist, 2002, for a meta-analysis), particularly in the context of negative affect. Whether this relationship holds in pediatric populations is to our knowledge, unknown.

The current study addressed whether patterns of psychobiological convergence to emotional story vignettes relate to symptoms of anxiety and depression in typically developing preadolescent children. We examined children's psychobiological convergence via their subjective and autonomic responses to emotionally evocative story vignettes using children's EDA as an index of physiological function. Story vignettes were used because they provide a more controlled and standardized, yet vivid, way of eliciting emotions than other mood induction procedures such as imagination.

We tested three sets of hypotheses. First, we tested whether anxiety and depression symptoms will be associated with greater overall self-reported NE in response to our experimental conditions (fear and sad vignettes) relative to baseline (neutral vignettes). We hypothesized, based on prior investigations using this dataset (Borelli, Hilt, West, Weekes, & Gonzalez, 2014a), that depression would not be associated with overall NE to either fear or sad vignettes. Because anxiety is frequently associated with high levels of nonspecific negative reactivity in adults (e.g., Brown, Chorpita, & Barlow, 1998; Mennin, Heimberg, Turk, & Fresco, 2005; Turk, Heimberg, Luterek, Mennin, & Fresco, 2005), we hypothesized that anxiety will be positively associated with overall NE to both fear and sad vignettes. Second, we tested whether anxiety and depression will be associated with deviations in overall EDA in response to fear and sad vignettes. Because both anxiety and depression have previously been associated with both elevated and diminished EDA to negatively valenced stimuli (Abend et al., 2020; Brown et al., 1998; Eckman & Shean, 1997; Erath, Su, & Tu, 2018), with other studies failing to differentiate anxious individuals from non-anxious individuals with regard to psychophysiological arousal (Anderson & Hope, 2009; Mauss et al, 2004; Michalska et al., 2016), we made no directional hypotheses for this set of analyses. Third, and most critical, we tested whether children's self-reported NE to emotional story vignettes is a moderator of the associations between EDA to story vignettes and psychopathology. That is, we asked the following: Are psychopathology symptoms elevated when both children's physiological reactions and subjective distress to emotion-eliciting scenarios are convergent? Because some forms of anxiety (e.g., social anxiety) specifically incorporate a fear aspect, we examined children's NE to fear vignettes for its association with anxiety moderated by physiology. This enabled us to test whether the subjective component of emotional responses to fear may interact with physiological reactivity to predict anxiety levels. Based on prior work in adults documenting attunement to physiological states in anxious individuals in response to fear-relevant contexts (Anderson & Hope, 2009; Edelmann & Baker, 2002; Mauss et al., 2004; Wilhelm et al., 2001), we hypothesized that children who report greater NE to fear vignettes at high levels of physiological responses will report higher anxiety levels. Because anxiety and depression share common features (Kessler, Chiu, Demler, & Walters, 2005), we evaluated whether similar patterns are observed for associations with depression. Specifically, we tested whether children's NE to fear interacts with physiological responses to predict depressive symptoms. The literature on depression and ruminative self-focus in adults (Mor & Winquist, 2002) suggests that children high in depression may likewise exhibit heightened awareness of physiological states in fear contexts. However, such hypotheses remain speculative given the lack of empirical work on psychobiological convergence in depression. Finally, in an exploratory analysis, to examine whether psychopathology is associated with greater psychobiological convergence in negatively valenced emotional contexts in general, we tested whether NE to sad vignettes is a moderator of the associations between EDA to sad vignettes and psychopathology (e.g., depression, anxiety).

Method

Participants

A total of 111 children aged 8 to 12 years participated in this study consisting of two sessions 2 weeks or less apart. The protocol for the study was approved by the researcher's institution; primary caregivers provided informed consent, and children provided informed assent, prior to completing the study. Participants were recruited from the community via flyers, internet postings, and word of mouth. The resultant sample included 37.3% girls with a mean age of 9.71 years (*SD* = 1.50) and their primary caregivers (90% female) with a mean age of 37.32 years (*SD* = 6.28). Reflective of the larger region, the sample was diverse in terms of race/ethnicity (39% Hispanic, 35% Caucasian, 18% African American, 32% Asian, 2% Native American, and 4% other) and household income (46% reported an annual income of less than $40,000). Experimenters informed children that they could refuse to participate in any part of the study if they wished. Previously reported data on subjective NE for 94 participants (Borelli, Hilt, West, Weekes, & Gonzalez, 2014a) were combined with unpublished data on EDA and anxiety for 97 participants. The current article reports on novel analyses of all data.

Procedure

Children completed measures assessing depression and anxiety symptoms during the first visit. At their second visit 2 weeks later, they completed the Vulnerability Vignettes Paradigm (VVP; Sichko et al., 2018), which included subjective response assessment and recording of EDA.

Measures

Psychopathology

Multidimensional Anxiety Scale for Children.. The Multidimensional Anxiety Scale for Children (MASC; March, Parker, Sullivan, Stallings, & Conners, 1997) is a 39-item self-report measure assessing children's anxiety symptoms. The questionnaire assesses four subscales: physical symptoms, social anxiety, harm avoidance, and separation anxiety. Children report how often statements (e.g., "The idea of going away to camp scares me") are true for them on a 4-point scale (1 = *never true about me* to 4 = *often true about me*). The scale has demonstrated high test–retest reliability and validity in past research with both clinical and nonclinical populations (March et al., 1997; March & Sullivan, 1999). Cronbach's alpha in this sample was .88.

Children's Depression Inventory.. The Children's Depression Inventory (CDI; Kovacs, 1992) consists of 27 items designed to measure various dimensions of depression (i.e., behavioral, cognitive, emotional, and physiological) in youths. Children are prompted to choose one of three statements that most accurately captures their symptoms over the past 2 weeks (e.g., "I am sad once in a while," "I am sad many times," "I am sad all the time"). Responses are coded on a scale of 0 to 2, with higher scores indicating greater severity of depressive symptoms. Strong support has been shown for the validity and reliability of the CDI through past studies (Kovacs, 1992; Smucker, Craighead, Craighead, & Green, 1986). In this sample, Cronbach's alpha was .86.

Vulnerability Vignettes Paradigm.. The VVP has been used in prior studies of school-aged children (Borelli, Hilt, West, Weekes, & Gonzalez, 2014a; Borelli, Hilt, West, Weekes, & Gonzalez, 2014b) wherein children's subjective verbal responses to the VVP are associated with their physiological responding (Borelli, Hilt, West, Weekes, & Gonzalez, 2014a), their depressive and anxiety symptoms (Borelli, Hilt, West, Weekes, & Gonzalez, 2014b), and their attachment representations (Borelli, Smiley, Gaskin, Pham, Kussman, & Shahar, 2019). Children were presented with text vignettes depicting hypothetical gender-matched children experiencing mildly emotionally distressing situations (sadness and fear); they also were presented with a series of neutral vignettes as a manipulation check. Of note, vignettes depicting children experiencing physical hurt and physical illness were also presented but were not the focus of this investigation and are not discussed further. Children were seated approximately 20 inches in front of a 20.5-inch stimulus presentation computer monitor, which was connected to a stimulus presentation computer located in the control room and controlled by the experimenter. Stimuli were presented using E-Prime Version 2.0 (Psychology Software Tools, Sharpsburg, PA, USA) (Schneider, Eschman, & Zuccolotto, 2007), which triggered recording signals to a physiological data collection program, BioLab (Mindware Technologies, Gahanna, OH, USA). Responses to study questions were collected via computer keyboard.

First, children were presented with a 5-min nature video to stabilize the physiological signal and acclimate children to the laboratory setting. Next, they were shown an example neutral vignette and were asked to respond to sample questions to practice the protocol. Following the practice session, children completed the VVP. During this paradigm, text vignettes and their accompanying questions were broken down into three blocks (neutral, sad, and fear), with each block comprising three scenarios. All three vignettes within a block had identical structures; one vignette described the hypothetical child's experience (e.g., "Taylor didn't get picked to be on a sports team at school and he felt sad."), one described the experience and mentioned that the hypothetical child opted out of an activity (e.g., "Bill got a bad grade on a test. He felt really sad, started crying, and went to the bathroom."), and the third described the experience and the hypothetical child asking the parent for assistance with it (e.g., "While at a party, someone said something mean to Brandon and he felt really sad. He called his parent and asked to get picked up early."). Children read each vignette for 30 s, after which they answered questions about the hypothetical child for another 30 s.

EDA recording began immediately upon the presentation of each of the vignettes and continued for 1 min (during which time the children read the vignette and answered questions about it). After each block, the participants were given a 30 s recovery period before beginning the next block.

Self-reported subjective distress.. Children's subjective distress was assessed with the Self-Assessment Manikin (SAM; Bradley & Lang, 1994), a pictorial rating system featuring human-like figures that assess affective valence (unpleasant–pleasant). Figures were augmented with the words "very happy, pleased, good" next to the figure with the biggest smile and the words "very unhappy, scared, sad" next to the figure with the biggest frown. Possible scores ranged from 1 to 5, with higher scores indicating more self-reported NE. The reliability and validity of the measure have been documented in adults and children (Bradley & Lang, 1994; McManis, Bradley, Berg, Cuthbert, & Lang, 2001).

Electrodermal activity.. Children's EDA was evaluated in response to the VVP as well as during the 5-min baseline period, which we used as a control variable. EDA was recorded using disposable Mindware 1.5 × 1.0-inch foam GSC electrodes with 0% chloride wet gel. These electrodes had touchproof snap leads that were connected to a BioNex 8 slot chassis equipped with an impedance cardiograph

(Mindware Technologies). Two electrodes were placed on the palm of the nondominant hand for EDA measurement.

Prior to conducting data analysis, we computed mean EDA across each vignette type (e.g., sad). A total of 14 participants' data were excluded from statistical analyses due to computing equipment error (e.g., E-Prime malfunction during paradigm; $n = 10$) or unusable signals ($n = 4$); thus, we had a sample of 97 participants for study analyses. EDA data were opened and written in Mindware EDA Analysis Software. No edits were made unless the data contained artifacts or the video-feed revealed behaviors that required adjustments (e.g., sneezes). The mean EDA measurements computed by the software were used.

Data analysis

The aims of this research were to determine whether convergence between autonomic arousal and emotional awareness during emotion-inducing story vignettes is associated with internalizing symptoms in school-aged children. To address the first aim, we performed two separate hierarchical regression analyses to test whether anxiety and depression predicted (a) self-reported NE to fear vignettes, controlling for neutral vignettes, and (b) self-reported NE to sad vignettes, controlling for neutral vignettes. To address the second aim, we performed two separate hierarchical regression analyses to test whether anxiety and depression predicted (a) EDA to fear vignettes, controlling for baseline EDA, and (b) EDA to sad vignettes, controlling for baseline EDA. To address the third aim, we conducted regression analyses to test the interactive effects of children's self-reported NE and EDA on children's internalizing symptoms (anxiety or depression). First, we tested the interactive effect of children's EDA and children's self-reported NE in response to fear vignettes on child anxiety. Given the substantial overlap between anxiety and depression (Kessler et al., 2005), to improve specificity of inferences we controlled for depression and baseline EDA. To probe significant interactions, simple slopes were examined to assess predictions of anxiety from EDA to fear vignettes across three levels of self-reported NE to fear vignettes (-1 *SD,* 0 *SD,* and + 1 *SD*). Next, we tested the interactive effect of children's EDA and children's self-reported NE in response to fear vignettes on child depression, controlling for anxiety and baseline EDA. Simple slopes assessed predictions of depression from EDA to fear vignettes across three levels of self-reported NE to fear vignettes. Finally, we conducted exploratory analyses to examine the interactive effects of EDA and self-reported NE to sad vignettes on predictions of internalizing symptoms. First, we conducted a regression analysis testing self-reported NE $\times$ EDA to sad vignettes as predictors of anxiety, controlling for depression. Next, we performed a second parallel regression analysis consisting of self-reported NE $\times$ EDA to sad vignettes as predictors of depression, controlling for anxiety symptoms. All analyses were conducted in SPSS Version 27 (IBM, Armonk, NY, USA).

Results

Means and standard deviations for all study variables are presented in Table 1. The results of independent-samples *t* tests revealed that girls were slightly older in this sample and scored higher on self-reported NE to both fear and sad vignettes. Conversely, boys had higher baseline EDA and higher EDA to fear and sad vignettes than girls. Paired-samples *t* tests revealed that children showed elevated NE for the sadness context relative to the neutral context as well as elevated NE to the fear context relative to the neutral context, thereby supporting the validity of our experimental manipulation of context. Zero-order correlations revealed that trait anxiety was significantly associated with trait depression. Furthermore, self-reported NE to fear vignettes was significantly associated with self-reported NE to sad vignettes. Baseline EDA was associated with both EDA to fear vignettes and EDA to sad vignettes. Lastly, EDA to fear vignettes was significantly associated with EDA to sad vignettes (see Table S1 in online supplementary material). We include correlated variables as covariates in all subsequent analyses.

Table 1
Descriptive statistics for key study variables for total sample and by child sex.

	Male (n = 51)		Female (n = 46)		Sex differences	Total (N = 97)	
Variable	*M*	*SD*	*M*	*SD*	*t*	*M*	*SD*
Child age	9.29	1.43	10.17	1.36	−3.10**	9.71	1.46
MASC	49.98	17.03	49.65	17.05	0.10	49.82	16.94
CDI	8.50	5.73	7.42	6.21	0.89	7.98	5.96
NE fear	2.75	1.05	3.20	0.83	−2.30*	2.96	0.97
NE sad	2.93	1.15	3.41	0.83	−2.30*	3.16	1.03
Baseline EDA	6.84	8.91	3.54	5.81	2.14*	5.27	7.74
EDA fear	8.43	9.00	4.40	5.48	2.63*	6.52	7.77
EDA sad	7.84	8.99	4.27	5.58	2.32*	6.15	7.74

Note. Statistical comparisons are from independent-samples *t* tests. MASC, Multidimensional Anxiety Scale for Children; CDI, Children's Depression Inventory; NE, negative emotions; EDA. electrodermal activity.
* p <.05.
** p <.01.

Hypothesis 1. *Associations between internalizing symptoms and self-reported negative emotions to fear and sad vignettes.*

Hierarchical linear regressions were used to examine anxiety and depression as predictors of self-reported NE during the task. Using NE to fear vignettes (NE–fear) and NE to sad vignettes (NE–sad) as dependent variables in two separate regressions, we entered NE–neutral on an initial step (as a control variable), followed by anxiety and depression entered on a second step (independent variables). NE–neutral significantly predicted NE–fear (ΔR^2 =.054, p =.02) but not NE–sad (ΔR^2 =.026, p =.12). The step containing our trait measures (anxiety and depression) did not significantly add to the prediction of either NE–fear (ΔR^2 =.016, p =.46) or NE–sad (ΔR^2 =.004, p =.81) (Table S2).

Hypothesis 2. *Association between internalizing symptoms and EDA to fear and sad vignettes.*

Hierarchical linear regressions examined anxiety and depression as predictors of EDA during the task. Using EDA to fear vignettes (EDA–fear) and EDA to sad vignettes (EDA–sad) as dependent variables in two separate regressions, we entered baseline EDA on an initial step, followed by anxiety and depression entered on a second step. Baseline EDA significantly predicted both EDA–fear (ΔR^2 =.899, p < .001) and EDA–sad (ΔR^2 =.895, p <.001). Step 2, containing our trait measures, significantly added to the prediction of EDA–fear (ΔR^2 =.009, p <.01) but did so only marginally to EDA–sad (ΔR^2 =.006, p =.051). Anxiety (b =.075, p =.03), but not depression (b =.038, p =.27), was associated with higher EDA–fear (Table S3).

Hypothesis 3. *Psychobiological convergence.*

Next, we conducted regression analyses in which children's self-reported NE to the vignettes was examined as a moderator of the associations between EDA and internalizing symptoms (anxiety or depression, tested separately). We first examined children's responses to fear vignettes. Controlling for depression and baseline EDA, the interaction between children's EDA–fear and children's NE–fear was a significant predictor of children's anxiety (ΔR^2 =.06, p =.006) (Table 2). Simple slopes revealed that children's anxiety and EDA–fear were significantly associated only at high levels of NE–fear (b = 0.05, p =.006) but not at mean levels (b = 0.03, p =.053) or low levels (b = 0.02, p =.22) of NE–fear (Fig. 1). To rule out the possibility that the significant interaction is driven by both ends of the distribution, we applied the Johnson–Neyman technique to our data. Results show that the relationship between children's EDA–fear vignettes and anxiety symptoms was significant when NE–fear is higher than 3.0288, which was the case for 36.08% of the sample. Thus, only children with high levels of NE and high EDA to fear vignettes, not children with low levels of NE and low EDA to fear vignettes, are driving the observed interaction.

Next, controlling for anxiety and baseline EDA, the interaction between children's EDA–fear and children's NE–fear was not a significant predictor of child depression (ΔR^2 =.003, p =.58) (Table 3; see also Fig. S1 in supplementary material).

Table 2
Regressions examining children's NE to a fear stimulus as a moderator of the association between children's trait anxiety and their physiological response to fear vignettes.

Dependent variable:	Children's anxiety (MASC)		
Predictor variable	*B*	*SE*	CI
Step 1 R^2	0.27***		
Constant	2.17	0.17	[1.85, 2.50]
NE	−0.05	0.05	[−0.15, 0.05]
EDA fear	−0.01	0.02	[−0.06, 0.04]
EDA baseline	−0.03	0.02	[−0.06, 0.003]
Depression (CDI)	0.65	0.18	[0.28, 1.02]
Step 2 ΔR^2	0.06**		
EDA Fear × NE	0.01	0.01	[0.004, 0.02]

Note. NE, negative emotions; MASC, Multidimensional Anxiety Scale for Children; CI, confidence interval; EDA, electrodermal activity; CDI, Children's Depression Inventory.
** p <.01,
*** p <.001.

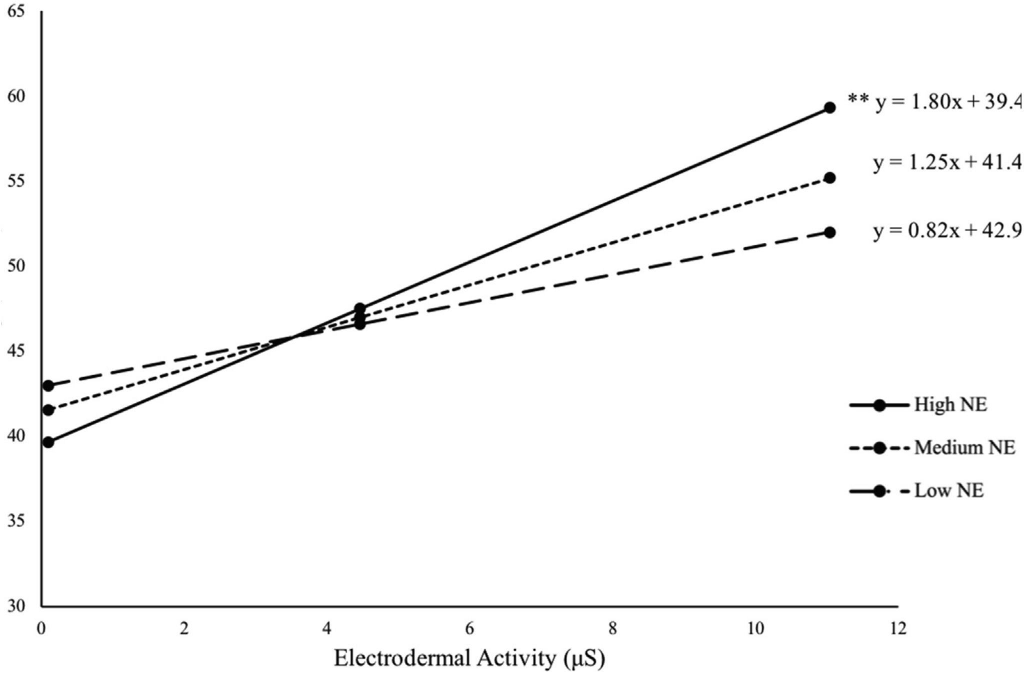

Fig. 1. Associations between negative emotions (NE) and electrodermal activity (EDA) to fear vignettes predicting anxiety. Children's total anxiety score (Multidimensional Anxiety Scale for Children [MASC]) and EDA (measured in microsiemens [μS]) to fear vignettes were significantly associated only at high levels of self-reported NE to fear vignettes (b = 0.05, p =.006).

We then examined children's responses to sad vignettes. Controlling for depression and baseline EDA, the interaction between children's EDA–sad and children's NE–sad vignettes was a significant predictor of children's anxiety (ΔR^2 =.06, p <.008). Children's anxiety and EDA–sad were significantly associated only at high levels of NE–sad (b = 0.04, p =.02) but not at mean levels (b = 0.02, p =.22) or low levels (b = 0.006, p =.73) of NE–sad (Fig. S2). Next, controlling for anxiety and baseline EDA, we

Table 3
Regressions examining children's NE to a fear stimulus as a moderator of the association between children's trait depression and their physiological response to fear vignettes.

Dependent variable:	Children's depression (CDI)		
Predictor variable	*b*	*SE*	CI
Step 1 R^2	0.19**		
Constant	−0.21	0.15	[−0.50, 0.09]
NE	0.03	0.03	[−0.02, 0.08]
EDA fear	0.02	0.01	[−0.01, 0.04]
EDA baseline	−0.01	0.01	[−0.03, 0.004]
Anxiety (MASC)	0.19	0.05	[0.08, 0.29]
Step 2 ΔR^2	0.003		
EDA Fear × NE	−0.002	0.003	[−0.007, 0.004]

Note. NE, negative emotions; CDI, Children's Depression Inventory; CI, confidence interval; EDA, electrodermal activity, MASC, Multidimensional Anxiety Scale for Children.
** p <.01.

found that the interaction between children's EDA–sad and children's NE–sad was not a significant predictor of children's depression (ΔR^2 =.0001, p =.91) (Fig. S3).

Discussion

Variability exists in the degree of correspondence between individuals' autonomic and subjective indicators of emotional experience. Although it is generally held that correspondence between these multiple indicators is associated with well-being, high convergence can sometimes also confer risk for forms of psychopathology in adults. The aim of this study was to examine what we considered to be one of the fundamental questions raised by these data: Does convergence between autonomic arousal and subjective NE have consequences for children's mental health? Three main findings emerged. First, anxiety, but not depression, was associated with higher overall EDA to fear but not sad vignettes, whereas neither anxiety nor depression was associated with overall self-reported NE to either fear or sad vignettes. Second, we found evidence of greater psychobiological convergence for fear vignettes linked with anxiety but not depression. Children's anxiety and EDA to fear vignettes were associated only at high levels, but not mean or low levels, of self-reported NE to fear vignettes. Third, as with fear vignettes, children's anxiety and EDA to sad vignettes were associated only at high levels, but not mean or low levels, of self-reported NE to sad vignettes. Our results suggest that psychobiological convergence, in which self-reported NE is high when physiological reactivity is also high, is uniquely associated with greater risk for anxiety during middle childhood.

Psychophysiological theories attribute pathological anxiety to increased psychophysiological arousal driven by the sympathetic nervous system (e.g., Clark & Watson, 1991). Our findings provide some support for these theories in that we observed associations between anxiety and higher EDA when children read fear-evoking story vignettes. Notably, whereas prior studies relate anxiety to elevated autonomic responding in response to stressors, these relationships are not always consistent (Britton et al., 2013; Michalska et al., 2016, 2017, 2019; Monk et al., 2001). Our results extend this research by employing emotional story vignettes to quantify affective responses to fear versus sad contexts in children (Borelli, Hilt, West, Weekes, & Gonzalez, 2014a). This approach might explain the discrepancy with prior work that relies on acutely distressing stimuli (e.g., Britton et al., 2013). Whereas this research frequently finds that anxiety and EDA are not related for discrete stimuli, this work also notes such effects to be partly dependent on threat levels (Lissek et al., 2005). In general, in many fear-learning studies, anxious adults do not evidence greater autonomic reactions compared with non-anxious adults in response to cues signaling explicit threat (e.g., of electric shock). Rather, they evidence less specific conditioning indexed by general elevations to both threat and safety cues (Abend et al., 2020; Lissek et al., 2005), and elevated responding in contexts associated with threat

(Grillon, 2002; Grillon, Dierker, & Merikangas, 1998). This determination reflects what has been referred to as the ‘‘strong situation” (Lissek et al., 2006), wherein anxious and non-anxious individuals respond similarly to high-intensity aversive stimuli, but only anxious individuals also respond strongly to low-intensity aversive stimuli. Accordingly, our results could reflect individual differences in response to low-intensity aversive stimuli and may provide an advantage over traditional fear-learning paradigms, which might not elicit individual differences because all participants are at ‘‘ceiling”.

With regard to context specificity, EDA and anxiety were uniquely associated in response to fear but not sad vignettes (although patterns were similar), which argues against the hypothesis that anxiety reflects uniformly heightened physiological reactivity to any low-intensity hedonically negative feelings. Rather, high-anxious children may be responsive to some attribute of affective stories such as degree of arousal displayed in certain words. Given that sadness tends to be lower in the degree of expressed arousal than fear (Watson & Tellegen, 1985), the differences in EDA to fear stories between high-anxious and low-anxious children may reflect a responsiveness to the arousal dimension of affect.

Somewhat inconsistent with our hypotheses, we identified a discrepant pattern with respect to the subjective report data in that self-reported negative emotions were not associated with overall anxiety or depression. Indeed, it is not uncommon for studies investigating the physiological bases of affective processes to find dissociations between physiological responses and reported affect (Mauss et al., 2005; Michalska, Kinzler, & Decety, 2013). What is somewhat discrepant with our predictions and with prior literature is the fact that in this study we found links between heightened physiological reactivity and anxiety rather than between subjective distress and anxiety. Although identifying discrepant findings across different indices of emotional response systems is par for the course, the pattern of associations we identified differs from prior literature.

Here, children’s anxiety and EDA to fear vignettes were associated only at high levels, but not mean or low levels, of self-reported NE. For children who manifested higher levels of EDA to fear vignettes, only those who also reported the highest NE ratings endorsed greater anxiety. In contrast, children who also manifested higher levels of EDA but reported average or lower levels of NE did not rate themselves as having anxiety symptoms that were as high despite the fact that their EDA was just as high. In other words, children who showed the highest level of correspondence between their NE and their physiology also reported the highest levels of anxiety, whereas children whose NE was somewhat lower relative to their physiology reported lower anxiety. Importantly, we cannot disambiguate with the current data whether children reporting less anxiety were unaware of their arousal, were suppressing their NE, or were consciously working to regulate (perhaps through reappraisal) their internal states, but the end result was lower NE. Of note, mean levels of anxiety were below clinical threshold (our sample’s mean anxiety = 49.82; clinical threshold > 65), and only 18% of the sample scored above this clinical threshold (March et al., 1997). These findings should be contextualized in light of this fact; further testing within a clinical sample would help to refine our understanding of the boundary conditions of these findings.

These data are in line with models of anxiety that highlight the role of cognitive processes including threat evaluation biases, heightened self-focused attention, and dysfunctional appraisal of social situations (Leary & Kowalski, 1995; Mogg & Bradley, 2018). Specifically, appraisal of autonomic activation might play an important role within the cognitive processes implicated in children’s anxiety. Some emotion researchers argue that individuals experience a specific emotion only after they interpret an emotional situation and the perceived autonomic activation evoked by it (e.g., Lindquist & Barrett, 2008). Under this view, what begins as an arousal signal from the body is transformed into a specific feeling of emotional experience by assigning an appropriate cognitive label. Thus, children’s anxiety may entail a combination of perceptible visceral activation and an NE label inferred from situational cues or cognitive expectations associated with that activation (Michalska et al., 2018; Paulus, Feinstein, & Khalsa, 2019).

The embodied predictive interoception coding model (EPIC; Barrett & Simmons, 2015) may provide an additional account of convergence. According to this model, the brain continually forms neural representations of the environment that are constructed from previous experience. These so-called *interoceptive predictions*—efferent autonomic modulatory commands—enable predictions of incoming sensory inputs (including interoceptive sensations) even prior to direct perception of the body's internal state. Interoceptive predictions are matched with actual incoming sensory information, and this information is modulated to match the predicted states. Such an interpretation is aligned with attachment theory perspectives, whereby the interpretation of sensory states might be motivated by what individuals perceive may be needed in order to get a response from the caregiving environment (Cassidy, 1994). Thus, expectations may plausibly drive children's interoceptive predictions such that children's experience of anxiety may be a reflection of what their brain predicts is going on inside their body based on prior experience. Under this account, psychobiological convergence between children's subjective reports of their affective states and autonomic recordings could result from alterations of body sensations via psychological factors, such as cognitive expectations (Michalska et al., 2018) and interoceptive predictions, which may lead to heightened anxiety. It will be worth considering in future work whether psychobiological convergence in anxiety could be due to increased or exaggerated anticipatory predictions (see also Paulus & Stein, 2006). For example, perhaps anxiety arises because of a failure to appropriately adjust expectancies when predicted negative events are milder than anticipated. This supports prior work showing that what differentiates anxious individuals from non-anxious individuals is their response in low-threat contexts (Lissek et al., 2006). Follow-up studies might test whether anxious children over-endorse interoceptive symptoms in anticipation of upcoming evocative situations subsequently escalating subjective NEs.

Even though we did not directly ask children to report their interoceptive accuracy, our results could support the notion that higher anxiety individuals are overly attuned to, or hyperaware of, their physiological responding in stressful situations. This perspective holds that higher anxiety children are higher in their arousal and keyed into this arousal state. This awareness could result in cognitive distortions regarding what their physiological states signify (e.g., "My fast heartbeat means I'm dying"; Reed, Harver, & Katkin, 1990), which over time could further amplify anxiety symptoms if not adequately regulated/reappraised. In this way, hyperawareness or accuracy of arousal may ironically be associated with negative psychological outcomes. One interpretation of this pattern of findings is that this represents a case of "anxious realism," wherein greater anxiety is associated with greater accuracy regarding physiological reactivity, not unlike what is observed with respect to self-appraisals in the case of depression (e.g., Alloy, Albright, Abramson, & Dykman, 1990). To be convincing, this suspicion would need to be followed up longitudinally, through the use of clinical samples, and employ multiple paradigms and psychophysiological assessments that explicitly probe attunement to physiological responses at various levels of arousal and control for other potential sources of coupling. Yet, prior research tells us that under-estimation of physiological arousal by subjective reports is associated with a different set of negative outcomes such as dismissing attachment, non-suicidal self-injury, and substance use (e.g., Borelli et al., 2013, 2014b, 2018). Might there be an optimal level of self-deception or lack of awareness regarding arousal that can be facilitated by emotion regulation techniques such as reappraisal and distraction?

Together, our data suggest that autonomic activation might be necessary for the experience of anxiety, but such activation is insufficient to account for between-participant variation in anxiety experience (McTeague & Lang, 2012) and a better understanding of the role of physiological awareness is needed. To elucidate the potential causal role of hyperawareness in children's anxiety, future research might build on promising work examining the role that self-distancing plays (i.e., focusing on negative experiences from the perspective of an observer; Kross, Duckworth, Ayduk, Tsukayama, & Mischel, 2011) in distinguishing adaptive emotional functioning from maladaptive emotional functioning. For example, studies might probe whether cueing children to examine their fear-related feelings from a self-distanced perspective leads them to experience less emotional reactivity than children who analyze their feelings from a self-immersed perspective. Complementing such studies, incorporating attachment security priming might likewise attenuate emotional reactivity. Reminding children of times when they were safe and protected or via security priming can reduce attachment-related anxiety and perhaps awareness of NE.

In contrast to context specificity for overall levels of EDA, we observed diminished specificity when considering psychobiological convergence. High-anxious children showed similar levels of hyperreactivity to both fear and sad vignettes. Importantly, we believe that this is the first study of psychobiological divergence to differentiate as a function of emotional valence; this leaves us in the position of being unable to rely on prior research to develop hypotheses regarding the meaning of similarity of patterns across fear and sadness vignettes. Our post hoc speculation regarding these findings, which we did not anticipate, is that once an anxiety cycle has begun, generalization of these processes to different emotional contexts may occur. In other words, perhaps children with more anxiety symptoms are initially more subjectively sensitive to internal cues related to fear; over time, this may generalize to heightened sensitivity to other negative emotions. In offering this interpretation of the findings, it is important to acknowledge the cross-sectional nature of this study design. We hope that future studies can investigate these ideas using methods that are appropriately rigorous.

Several limitations of the current study should be acknowledged. First, this was a cross-sectional study; a longitudinal design would allow stronger inferences about causal processes. Second, following previous work by our group that establishes psychobiological convergence by the position of a child within the group (Borelli, Hilt, West, Weekes, & Gonzalez, 2014a, Borelli, Hilt, West, Weekes, & Gonzalez, 2014b, AUTHOR 3, AUTHOR 4), this study was not designed to link changes in the correlation of experience and physiology over time within an individual (see, e.g., Gatzke-Kopp & Ram, 2018), thereby limiting the scope of evidence with respect to convergence. Third, psychobiological convergence was examined across only two components (EDA and self-report). Coherence is in fact a "three-component process" (e.g., physiology, self-report, behavior) (Bulteel et al., 2014; Hollenstein & Lanteigne, 2014), and future work should test associations between all three components. Fourth, this study focused on anxiety and depression as continuous variables; replication in children with clinical diagnoses is an important next step.

Conclusions

Hyperawareness, in which self-reported negative emotionality is high during high levels of physiological reactivity, is associated with greater risk for anxiety during middle childhood. Moreover, we relate internalizing symptoms to emotional context. These findings extend understanding of psychobiological convergence in anxiety.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jecp.2022.105451.

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