Development and Psychopathology (2023), 1–18
doi:10.1017/S095457942200150X

Regular Article

Autonomic nervous system reactivity to emotion and childhood trajectories of relational and physical aggression

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Abstract

This study investigated the role of autonomic nervous system (ANS) coordination in response to emotion in girls' and boys' development of relational (e.g., ignoring, excluding) and physical (e.g., hitting, kicking) aggression. Caregivers reported on children's relational and physical aggression at ages 6, 7, 8, and 10 years ($N = 232$, 50.4% girls, 46.6% Latinx). Sympathetic nervous system (assessed via pre-ejection period) and parasympathetic nervous system (assessed via respiratory sinus arrhythmia) reactivity were measured in response to video clips depicting fear, happiness, and sadness at age 7. Growth curve models indicated that ANS reactivity to sadness, but not to fear or happiness, was related to trajectories of relational aggression. In contrast, ANS reactivity to all three emotions was associated with trajectories of physical aggression. Effects differed across genders, indicating that distinct patterns of ANS reactivity to emotion may be involved in girls' and boys' development of aggression. Overall, these findings contribute to a growing literature documenting the role of ANS reactivity to emotion in aggressive behavior. Moreover, this study considers ANS reactivity to specific emotions, as related to both relational and physical aggression, and as differentially expressed among girls versus boys.

Keywords: autonomic nervous system reactivity; emotion induction; growth curve modeling; physical aggression; relational aggression

(Received 31 May 2022; revised 21 December 2022; accepted 23 December 2022)

A large body of research suggests that dysregulated autonomic nervous system (ANS) functioning is associated with aggression and antisocial behavior in children and adolescents (e.g., Graziano & Derefinko, 2013; Lorber, 2004; van Goozen et al., 2007), perhaps in part because it reflects atypical emotional responses to stimuli (Kalvin et al., 2016). In addition, emerging research indicates that coordination of the two branches of the ANS, the sympathetic nervous system (SNS), which coordinates "fight or flight" responses, and the parasympathetic nervous system (PNS), which coordinates "rest and digest" responses, plays a unique role in the development of aggression and externalizing behaviors (Colasante et al., 2021; El-Sheikh et al., 2009; McKernan & Lucas-Thompson, 2018). Further, ANS risk factors may differ for relational (e.g., ignoring, social exclusion; Crick & Grotpeter, 1995) versus physical (e.g., hitting, kicking) forms of aggression (Murray-Close et al., 2014), as well as for girls versus boys (e.g., Crozier et al., 2008). Thus, the goal of the present study was to investigate the individual and interactive contributions of SNS and PNS reactivity in response to stimuli inducing fear, happiness, and sadness to trajectories of relational and physical aggression in children assessed across four data waves from age 6 to 10 years. We also examined whether these associations differed for girls and boys.

Autonomic coordination and aggressive behavior

Several studies have documented that individual indices of ANS reactivity serve as risk factors for aggression and antisocial behavior (El-Sheikh & Erath, 2011; van Goozen et al., 2007). Further, theoretical explanations of these associations often focus on the role of emotional responding (e.g., Fanti et al., 2019). Although a large body of research examines the implications of resting ANS measures, which are thought to reflect capacity for response (e.g., Graziano & Derefinko, 2013), the current study focused on ANS reactivity to specific emotion induction events, which are hypothesized to play an important role in social behavior and adjustment. Specifically, the SNS branch of the ANS is activated in response to threat and facilitates "fight or flight" reactions. SNS activation (i.e., heightened SNS activity in response to stimuli) functions to increase peripheral measures of physiological arousal (e.g., heart rate; Murray-Close, 2013), and heightened SNS activation to threat is hypothesized to reflect anxiety, fear, or inhibition (El-Sheikh & Erath, 2011). Conversely, SNS inhibition (i.e., lower SNS activity in response to stimuli) functions to decrease physiological arousal and is hypothesized to reflect behavioral disinhibition or impaired emotional reactions, ultimately increasing risk for aggression (El-Sheikh & Erath, 2011). Two commonly used indices of SNS activity are skin conductance level (SCL) and pre-ejection period (PEP). SCL is an index of sweat production, with higher SCL reflecting greater SNS activation. PEP is an index of cardiac contractility reflecting the length of time between heartbeat onset and the ejection of blood from the left ventricle, with longer PEP reflecting lower SNS activation (El-Sheikh & Erath, 2011).

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Cite this article: Murray-Close, D., *et al.* (2023). Autonomic nervous system reactivity to emotion and childhood trajectories of relational and physical aggression. *Development and Psychopathology*, 1–18, https://doi.org/10.1017/S095457942200150X

Findings using both SCL and PEP reactivity indicate that SNS inhibition in response to stimuli may serve as a risk factor for aggression or antisocial behavior. Indeed, SNS inhibition, as reflected in low SCL reactivity to stress, is related to greater externalizing and conduct problems in children and adolescents (El-Sheikh & Erath, 2011; Fanti et al., 2019; Jimenez-Camargo et al., 2017; Lorber, 2004). Likewise, SNS inhibition, as reflected in lengthening of PEP in response to stress or reward, predicts heightened externalizing behaviors and conduct problems in youth (El-Sheikh & Erath, 2011; Fanti et al., 2019).

Researchers have also documented associations between PNS functioning and aggressive and antisocial behavior. One commonly measured index of PNS activity is respiratory sinus arrhythmia (RSA), which indexes heart rate variability tied to respiration and reflects vagally mediated influences on the heart. Porges (2007) describes this regulation as the vagal brake, because increases in vagal tone provide an inhibitory function on the heart. That is, RSA activation (i.e., higher RSA in response to stimuli) functions to decrease heart rate and promotes calm physiological states as well as attention and social engagement. In contrast, RSA inhibition (i.e., lower RSA in response to stimuli) enables the mobilization of resources (e.g., increases in heart rate) to cope with environmental demands (Porges, 2007). According to polyvagal theory (Porges, 2007), the implications of RSA depend on the social context, such that RSA activation is adaptive in safe contexts. In contrast, in response to challenge, RSA inhibition is considered adaptive because it connotes better emotion regulation capabilities and facilitates the mobilization of metabolic resources to enact well-regulated, adaptive coping responses (Graziano & Derefinki, 2013; Porges, 2007).

Consistent with this hypothesis, meta-analytic findings from studies with children and adolescents indicate that RSA inhibition in response to a stressor or challenge is associated with lower levels of externalizing problems (Graziano & Derefinko, 2013). That said, other theorists have argued that RSA inhibition, especially during negative events and emotion evocation tasks, reflects emotional lability and increases risk for externalizing problems (Beauchaine & Thayer, 2015). For instance, in the context of negative emotion induction, the mobilization of metabolic resources that accompanies RSA inhibition may reflect dysregulated negative emotional reactions and support "fight or flight" responses that ultimately engender aggressive responding (Beauchaine et al., 2019). In support of this assertion, a recent meta-analysis of studies with adults found that greater RSA inhibition to negative emotion, but not other types of emotion induction (e.g., attention demanding tasks, positive emotion induction, neutral tasks), was associated with heightened externalizing behaviors (Beauchaine et al., 2019). These findings suggest that the implications of RSA inhibition may depend on the valence of the emotional context that elicits reactivity.

The implications of PNS inhibition, as reflected in RSA, may also depend on patterns of sympathetic responding. In fact, over the past decade, growing research interest and evidence have highlighted the need to consider both individual and interactive contributions of SNS and PNS regulation to understand a variety of adjustment outcomes, including aggression (e.g., Murray-Close et al., 2018). In their foundational monograph, El-Sheikh et al. (2009) argued that, because the SNS and PNS eventuate in opposing physiological outcomes, adaptive functioning is supported when both branches work together in a reciprocal, push-pull fashion to facilitate a coherent directional response. As detailed in Table 1, coordinated ANS patterns include *reciprocal SNS activation* (i.e., SNS activation accompanied by PNS inhibition, which supports mobilization of metabolic resources for action) and *reciprocal PNS activation* (i.e., PNS activation accompanied by SNS inhibition, which supports homeostasis and promotes calm states; El-Sheikh & Erath, 2011). Nonreciprocal patterns that may undermine positive adaptation include coinhibition (i.e., inhibition in both branches) and coactivation (i.e., activation in both branches; El-Sheikh et al., 2009). Accumulating research indicates that nonreciprocal ANS activation patterns exacerbate risk for aggressive and antisocial behavior among children and adolescents experiencing adversity (El-Sheikhh et al., 2009; McKernan & Lucas-Thompson, 2018; Philbrook et al., 2018; Suurland et al., 2018). In their meta-analysis examining associations between ANS reactivity and conduct problems in children and adolescents, Fanti et al. (2019) reported that inhibition in both the SNS (assessed via PEP lengthening) and PNS (assessed via decreases in RSA) were associated with heightened conduct problems. Importantly, mirroring the differential meaning of PNS inhibition as a function of the emotion that elicits reactivity (Beauchaine et al., 2019), the implications of ANS coordination for children's adjustment depend on the nature of the stimuli used to elicit reactivity. For instance, meta-analyses support distinct associations between ANS activity to negatively versus neutrally valenced stimuli and aggression and externalizing behavior (Beauchaine et al., 2019; Lorber, 2004). Thus, patterns of ANS reactivity and coordination in response to fear, happiness, and sadness may play important, yet distinct, roles in the development of children's aggression.

Table 1. Autonomic nervous system profiles

Profile	SNS activity	PNS activity	Net effect on ANS arousal
Reciprocal sympathetic	Activation (short PEP-R)	Inhibition (low RSA-R)	Increase
Reciprocal parasympathetic	Inhibition (long PEP-R)	Activation (high RSA-R)	Decrease
Coactivation	Activation (short PEP-R)	Activation (high RSA-R)	Ambiguous
Coinhibition	Inhibition (long PEP-R)	Inhibition (low RSA-R)	Ambiguous

Note. Shortened PEP reflects heightened SNS activation, whereas elongated PEP reflects SNS inhibition. Adapted from "Salivary alpha-amylase as a longitudinal predictor of children's externalizing symptoms: Respiratory sinus arrhythmia as a moderator of effects" (Keller & M. El-Sheikh, 2009, Psychoneuroendocrinology, 34, p. 635). Copyright 2009 by Elsevier. Adapted with permission.

ANS reactivity to emotional stimuli

Fear

One prominent theory regarding associations between ANS reactivity and aggression is *fearlessness theory,* which holds that physiological underarousal (e.g., lower heart rate reactivity) reflects temperamental fearlessness, which interferes with socialization against aggression (Murray-Close, 2013; Ortiz & Raine, 2004; Scarpa & Raine, 1997). This underarousal may occur as a result of SNS inhibition and/or PNS activation, which both yield a directional response that results in decreased peripheral arousal (e.g., lower heart rate reactivity). However, other theorists have highlighted the potential role of SNS activation and/or PNS inhibition in response to negative emotions, both of which facilitate increases in peripheral arousal (e.g., higher heart rate reactivity) as risk factors for aggressive behaviors enacted in response to stress or threat (e.g., Beauchaine et al., 2019; Hubbard et al., 2002; Scarpa et al., 2010). For instance, overarousal in response to fear induction may facilitate aggressive responses.

Empirically, although preliminary research suggests that ANS reactivity to fear may play an important role in aggression and antisocial behavior, both the magnitude and direction of effects have varied across studies. For instance, Kalvin et al. (2016) found that heightened heart rate reactivity to a fear-inducing film clip was positively associated with teacher-reported externalizing problems in kindergarteners, yet SNS reactivity to fear, which was assessed via PEP in this same sample, was not significantly related to externalizing problems. Recently, a study with adults showed that heightened SNS activation to a virtual reality fear induction, as assessed via SCL, was related to more aggression enacted in response to threat in women and men, whereas PNS activation, as assessed via RSA, to the same fear induction was related to more goal-directed aggression in women only (Thomson et al., 2021). In contrast, Gatzke-Kopp et al. (2015) found that PNS inhibition, as assessed via RSA, in response to viewing a fear-inducing film clip was associated with heightened externalizing problems over time (i.e., slower declines) among a subset of highly aggressive kindergarteners undergoing a targeted intervention. Further, other researchers have failed to find significant associations between PNS inhibition (assessed via RSA) to fear-inducing film clips and externalizing behavior (e.g., Fortunato et al., 2013; Kalvin et al., 2016).

These mixed findings may in part reflect a failure to assess interactions across the SNS and PNS branches (i.e., ANS coordination). In fact, preliminary research has highlighted the role of nonreciprocal ANS reactivity patterns in response to fear for understanding aggressive and antisocial behavior. These nonreciprocal patterns reflect poor coordination and have ambiguous net effects on arousal. For instance, in a young adult sample, the interpersonal facet of psychopathy (e.g., manipulative behaviors) was related to ANS coinhibition in response to a virtual reality fear induction (Thomson, 2022). In two adolescent samples, Thomson et al. (2020) found that coactivation in response to fear induction (via a roller coaster ride depicted on a 3D television in study 1 and via virtual reality in study 2) was related to callous-unemotional traits, which tend to be associated with particularly severe levels of aggression (Frick & White, 2008). However, to our knowledge, the interactive role of SNS and PNS reactivity to fear as related to aggression among younger children has not been investigated. This is a major limitation because the transition to adolescence is associated with significant changes in fear processing (Spielberg et al., 2014) that may alter ANS reactivity to negative emotional stimuli and modify relations between ANS coordination and aggression. In addition, extant studies of ANS coordination in response to fear have been cross-sectional, raising important questions about how these processes relate to the development of aggression over time.

Happiness

Dysregulated ANS reactivity in response to positive emotions, such as happiness, may also serve as a risk factor for aggression. *Stimulation-seeking theory* holds that chronically underaroused individuals are motivated to engage in exciting behaviors, including antisocial and aggressive actions, to raise their arousal to more comfortable levels (Murray-Close, 2013; Scarpa et al., 2010). Although this theory has frequently been applied to studies of resting ANS arousal (e.g., Ortiz & Raine, 2004), researchers have also highlighted its relevance to studies of ANS reactivity. In fact, ANS underarousal in response to reward contexts may be closely tied to stimulation-seeking tendencies because it reflects deficits in approach motivation and insensitivity to reward (e.g., a failure to experience happiness in the presence of positive experiences; Fortunato et al., 2013). Thus, underaroused individuals may seek high intensity experiences, including antisocial conduct, to achieve desired reward states (e.g., positive mood; Beauchaine et al., 2001). Further, although much of this research has focused on ANS reactivity to tangible rewards or incentives (e.g., Beauchaine et al., 2013), researchers have also applied this perspective to reactivity to happiness (Fortunato et al., 2013).

Low levels of peripheral arousal (e.g., low heart rate reactivity) in response to happiness may reflect underlying ANS processes of SNS inhibition and/or PNS activation. Consistent with stimulation-seeking theory, preliminary research shows that relatively high levels of PNS activity, as assessed via RSA, in response to happiness predicted both higher concurrent externalizing problems in 5–6 year old children (Fortunato et al. 2013) and higher peer-nominated aggression 1 year later in a high-aggression subsample from the same study (Gatzke-Kopp et al., 2015). Similarly, prior research indicates that youth with attention-deficit/hyperactivity disorder (ADHD), who tend to exhibit deficits in reward sensitivity, display PNS activation (i.e., higher RSA) in response to a positive emotion induction, whereas control children exhibit PNS inhibition (i.e., lower RSA; Musser et al., 2011). This observed failure to exhibit PNS inhibition, or even to exhibit PNS activation, in response to happiness may help explain the tendency for youth with ADHD to seek out higher intensity experiences, including aggression or risk-taking, to achieve positive states (Fortunato et al., 2013). That said, other findings in this area have been mixed. For instance, Kalvin et al. (2016) failed to find associations between either SNS reactivity (assessed via PEP) or PNS reactivity (assessed via RSA) to happiness and externalizing problems in a sample of kindergarteners. Thus, although a majority of early findings suggest that dysregulated ANS responses to positive, approach-oriented emotions (e.g., happiness) may increase risk for antisocial behaviors, additional research is needed. In fact, to our knowledge, no research to date has investigated interactions between SNS and PNS reactivity to happiness in the development of aggression. Further, given that reward processing changes across development (Spielberg et al., 2014), it is important for researchers to investigate associations of ANS reactivity and coordination in response to happiness with aggression during childhood.

Sadness

To date, few studies have examined the role of ANS reactivity to sadness in aggressive or antisocial behavior. However, Oldenhof et al. (2022) argue that ANS responses to sadness offer particularly strong indicators of emotion processing deficits, and thus may be especially well-suited to test associations between ANS hypo- and hyper-responsivity and antisocial behavior. In fact, these authors found larger decreases in heart rate and increases in PNS activation, as indicated by higher RSA, among children and adolescents with conduct disorder, as compared to typically developing controls, following exposure to sad film clips. In addition, PNS activation to sadness was dimensionally correlated with higher externalizing problems in this study (Oldenhof et al., 2022). These authors suggest that PNS activation in response to sadness may reflect poor emotion regulation, which increases risk for aggressive behavior. However, other researchers have failed to find significant associations between either SNS or PNS reactivity to sadness and externalizing behavior problems in children (e.g., RSA, Fortunato et al., 2013; RSA and PEP, Kalvin et al., 2016), underscoring the need for additional research in this area. In fact, to our knowledge, no research to date has investigated interactions between SNS and PNS reactivity to sadness in the development of aggression.

Summary

Taken together, extant research on the role of ANS reactivity to specific emotions and aggressive and antisocial behavior is mixed, with stronger support emerging in studies of reactivity to fear relative to studies of ANS reactivity to happiness and sadness. In addition, there appears to be more evidence documenting associations between PNS reactivity to fear, happiness, or sadness and aggression than SNS reactivity. However, despite theoretical arguments suggesting that ANS reactivity reflects emotion processing deficits, many studies do not adopt stimuli that target specific emotions (see Beauchaine et al., 2019; Gatzke-Kopp et al., 2015), and researchers have rarely investigated the role of ANS coordination across SNS and PNS branches in the development of aggressive behavior.

Forms of aggression and gender

Studies of the physiological correlates of antisocial behavior have varied widely in the specific behaviors of interest (e.g., ADHD, conduct disorder, externalizing problems, aggressive behavior; for review, see Fanti et al., 2019), and there may be important differences in patterns of effects across facets of antisocial behavior (e.g., Gatzke-Kopp et al., 2015). One potentially important distinction is between physical and relational forms of aggression. Whereas physical aggression is defined as behaviors that harm others via damage to physical well-being, such as hitting, kicking, and punching (Crick & Grotpeter, 1995), relational aggression is defined as behaviors that harm others via damage to relationships, such as giving a peer the “silent treatment” and social exclusion (see related forms of aggression such as indirect and social aggression; Björkqvist et al., 1992; Crick & Grotpeter, 1995; Galen & Underwood, 1997).

Although extant research has focused on physical forms of aggression (Gatzke-Kopp et al., 2015; Thomson et al., 2021), recent studies have documented associations between ANS functioning and relational aggression (e.g., McQuade et al., 2019; see Murray-Close et al., 2018 for review). Of note, however, researchers have rarely investigated interactions across ANS branches in studies of either relational or physical aggression. In a preliminary study examining interactions across the SNS and PNS in the prediction of relational aggression, Murray-Close et al. (2017) found that reciprocal PNS activation, which has a net negative effect on arousal, was related to heightened relational aggression in adults. Interestingly, in several studies investigating ANS predictors of both relational and physical aggression, patterns of effects have varied across the different forms of aggression (Murray-Close et al., 2014; Sijtsema et al., 2011), highlighting the importance of examining both relational and physical forms of aggression.

Further, although boys and girls engage in similar levels of relational aggression, boys tend to be more physically aggressive than girls (Card et al., 2008). Thus, an exclusive focus on physical forms of aggression may fail to capture the ANS correlates of aggression in girls. Indeed, some researchers have suggested that ANS reactivity may be more strongly associated with relational aggression in girls and physical aggression in boys (e.g., Murray-Close et al., 2018). Most studies do not investigate differential relations between physiology and aggression subtypes across gender (see Fanti et al., 2019 for review), even though researchers have reported gender differences in associations between ANS activity and both conduct problems (Beauchaine et al., 2008) and antisocial behavior (Crozier et al., 2008), with some evidence that predicted effects in these outcomes were stronger for boys than girls. Preliminary work has also documented gender differences in associations between ANS reactivity and relational forms of aggression. For instance, Murray-Close et al. (2014) found that blunted diastolic blood pressure reactivity to relational stress (e.g., being left out) was positively associated with relational aggression for girls but not for boys. Moreover, recent data point to heightened goal-directed aggression in adult men who showed ANS coinhibition in response to a virtual reality fear induction (Thomson et al., 2021), which reflects a lack of coordination across the branches of the ANS and has an ambiguous net effect on arousal. This pattern was not found in women (Thomson et al., 2021), highlighting the need to consider potential gender effects on relations between ANS functioning and aggression. Thus, in the present study, we investigated potential gender moderation of ANS reactivity effects to different emotion stimuli on separate trajectories of physical and relational aggression.

The current study

The purpose of the present study was to investigate individual and interactive influences of SNS and PNS reactivity to three specific emotion inductions (i.e., fear, happiness, and sadness) at age 7 on trajectories of relational and physical forms of aggression from ages 6 to 10. We focus on middle childhood because the achievement of social competence, including the inhibition of aggressive behavior, is a key developmental task that children face when they enter formal schooling (Masten & Coatsworth, 1998). We used growth curve modeling to investigate trajectories of aggression over time because ANS reactivity is hypothesized to serve as a risk factor for the *development* of aggression. Growth curves provide a powerful and flexible method for assessing between-person variability in within-person change over time, as well predictors of individual differences in developmental trajectories (Curran et al., 2010). Thus, this approach is well-suited to address questions of continuity and change that are foundational in developmental psychopathology research (Curran & Willoughby, 2003). This longitudinal approach provides an important extension of prior research on the physiology of aggression, which has predominantly used cross-sectional designs (see Portnoy & Farrington, 2015, for a review related to heart rate). Additionally, our focus on ANS activity provides a multi-level perspective regarding risk for aggressive behavior that is consistent with the tenets of developmental psychopathology (Burnette & Cicchetti, 2012; Cicchetti, 2008).

Given accumulating research indicating that uncoordinated or nonreciprocal patterns of autonomic reactivity increase risk for aggressive and antisocial behavior (El-Sheikh et al., 2009; Thomson et al., 2021), we hypothesized that patterns of ANS coactivation and coinhibition would be associated with elevated levels of both forms of aggression both concurrently and over time, whereas reciprocal or coordinated patterns would be associated with lower levels of both forms of aggression both concurrently and over time. We further expected that associations would be most evident in ANS reactivity to fear and happiness, given the prominence of fearlessness and stimulation-seeking theories in research on ANS correlates of aggression (Scarpa & Raine, 1997). Finally, the inclusion of both relational and physical forms of aggression assessed in a sizable sample of girls and boys provided unique opportunities to explore whether patterns of effects differed by the form of aggression and/or by gender.

Method

Participants

Participants were drawn from an ongoing study of child development among 250 caregiver–child dyads followed from ages 6 to 10 years. Youth ($N = 232$; 50.4% girls) who completed study assessments at ages 6 ($N = 214$, $M_{\text{age\_wave1}} = 6.11$ years, $SD = .21$), 7 ($N = 197$, $M_{\text{age\_wave2}} = 7.13$, $SD = .23$), 8 ($N = 214$, $M_{\text{age\_wave3}} = 8.13$, $SD = .27$), and/or 10 ($N = 213$, $M_{\text{age\_wave4}} = 9.64$, $SD = .31$) were included in these analyses. The current sample was ethnically and racially diverse (46.6% Latinx, 23.3% multiracial, 18.1% Black, 11.6% White, 0.4% Asian), and representative of the surrounding community from which it was drawn (U.S. Census Bureau, 2011). Youth ($N = 232$) were included in these analyses if the family completed any of the aggression assessments across the four waves of data; 215 (93%) of the dyads completed two or more data waves. Participating caregivers were predominantly biological mothers (91.6% biological mothers) with the remaining being foster/adoptive mothers (2.8%) and grandmothers or other female kin caregivers (5.6%). Most caregivers were married (60.8%) or in a committed relationship (19.6%), and over half were employed (65.6%). Education levels were variable (e.g., 14.6% of caregivers had not finished high school, 11.8% had a high school diploma or GED, 57.1% had a 2-year or technical degree, and 16.5% had completed a bachelor's degree or higher). The average family socioeconomic status (SES) score using the Hollingshead (1975) Four-Factor Index of Social Status was 33.07 ($SD = 12.31$), which corresponds to semi-skilled employment (e.g., salesclerk).

Procedures

At the start of the ongoing study, primary caregivers and their preschool-aged child were recruited to participate in "a study of children's learning and development" via flyers posted in community-based childcare centers in Southern California. Exclusionary criteria included children with diagnosed developmental disabilities or delays ($N = 3$), children who were unable to understand English ($N = 4$), and children outside the recruitment age range of 45–54 months at study entry (not tracked). At each data wave, caregiver–child dyads completed an extensive laboratory assessment that included both observational and survey-based measures of regulation and behavior. Caregivers were compensated with $25/hour for their participation, and each child received a small gift. Written informed consent was obtained from the legal guardian at the beginning of each laboratory visit, and informed assent was obtained from the participating child beginning at age 7. All procedures were approved by the University's Human Research Review Board.

Measures

Relational aggression

At ages 6, 7, 8, and 10, caregivers reported on children's relational aggression perpetration using the Preschool Proactive and Reactive Aggression measure (PPRA; Ostrov & Crick, 2007). Although this reliable measure is often used for teacher reports (Ostrov & Crick, 2007; O'Toole et al., 2017), it has been successfully adapted for use with caregivers (Baker, 2022). Adaptations for the present study included changing "this child" (from teacher reports) to "your child" for caregiver reports. Some items were reworded slightly to improve clarity (e.g., moving "to get what s/he wants" from the beginning to the end of the item). This measure was selected for the present study because it is developmentally appropriate for children at the first assessment period (age 6; e.g., Hart & Ostrov, 2013). Further, although developed for early childhood samples, the PPRA contains content and wording that mirrors measures used in older samples (e.g., 3rd–6th grade overall relational aggression, Crick, 1996; 5th–8th grade functions of relational aggression, McQuade et al., 2016), with the exception that the PPRA does not include an item assessing gossip and rumor-spreading. Caregivers rated their children's engagement in goal-directed, proactive relational aggression across three items (e.g., "Your child will often ignore or stop talking to others to get what s/he wants") and emotional, reactive relational aggression across three items ("When your child is angry at others, your child will often tell them that s/he won't be their friend anymore") on a scale from 0 (*never true*) to 4 (*always true*). This response scale reflected a slight adaptation from the original scale (1 = *never or almost never true*; 5 = *always or almost always true* in Ostrov & Crick, 2007) to match the response scale of the physical aggression items. Scores were averaged across all six items to yield an overall relational aggression score in this study for two reasons. First, correlations between proactive and reactive functions of relational aggression across data waves were high in the present sample (rs ranged from .62–.71, all $ps < .001$). Second, initial attempts to simultaneously model growth curves of proactive and reactive functions of relational aggression indicated that the intercept and slope latent variables had standardized correlations greater than 1.0. Averages across functions of relational aggression using the PPRA have been used in prior work to capture overall rates of relational aggression (O'Toole et al., 2017), including when assessed via caregiver reports (see Baker, 2022). In fact, Baker (2022) argues that this approach provides greater ecological validity than measures that do not explicitly assess multiple causes of relational aggression. The relational aggression subscale was reliable at each assessment point ($\alpha_{\text{age }6} = .82$, $\alpha_{\text{age }7} = .84.$, $\alpha_{\text{age }8} = .88$, $\alpha_{\text{age }10} = .87$).

Physical aggression

At ages 6, 7, 8, and 10, caregivers reported on children's physical aggression perpetration using a questionnaire developed by Dodge and Coie (1987). Caregivers rated their children's engagement in proactive physical aggression across three items (e.g., "Your child uses or threatens physical force in order to dominate other kids") and reactive physical aggression across three items (e.g., "When your child has been teased or threatened, s/he gets angry easily and strikes back") on a scale from 0 *(never true)* to 4 *(always true).* Although originally developed for use with teachers, this measure has been successfully used for caregiver reports (e.g., Fite & Colder, 2007; Miller-Johnson et al., 2002; Poulin & Boivin, 2000), and has been used with similarly diverse samples in prior work (e.g., Baker et al., 2008). Consistent with Dodge et al. (2003, study 1), scores were averaged across all six items to yield an overall physical aggression score for several reasons. First, correlations between proactive and reactive functions of physical aggression were moderate to large at each data wave in the present study (rs ranged from .39 to .52, all $ps < .001$). Second, initial attempts to simultaneously model growth curves of proactive and reactive functions of physical aggression indicated that the slope latent variables were strongly associated (standardized correlation of .90). Third, this approach allows parallel models across relational and physical forms of aggression. The physical aggression subscale was reliable at each assessment point ($\alpha_{\text{age 6}} = .72$, $\alpha_{\text{age 7}} = .74$, $\alpha_{\text{age 8}} = .78$, $\alpha_{\text{age 10}} = .75$).

ANS reactivity

At the age 7 assessment (wave 2), caregivers were informed that they would be viewing a series of emotion videos with their child that "show kids in various situations, such as in a fun food fight, running away from a train, and receiving bad news about a sick parent." They were told that the clips were "designed to elicit various emotions, but no one gets hurt in any of the clips." Children were informed that they would be viewing a series of video clips with their caregiver about the outdoors (baseline), about a family (sad), about a dinner (happy), and about a train (fear). They were also told that they would see a clip about the outdoors after each movie during which time they should try to clear their mind and get ready for the next movie clip. Caregiver–child dyads viewed a series of film clips beginning with a peaceful nature film, followed by: (a) a sad scene from *Crooklyn* depicting three young children sobbing after they learn that their mother has died; (b) a happy scene from *Hook* depicting a children's food fight; and (c) a scary/fear scene from *Stand by Me* depicting a train barreling down on two children. These clips were piloted and confirmed to elicit the intended emotion by Bennett and Lewis (2011). Although these clips were meant to induce emotions, dyads were monitored by the examiner through a video-feed to assess whether termination of the task was necessary. No participant expressed sufficient distress (e.g., crying, asking to stop) to warrant task termination. At no point during any of the assessments did a caregiver or child request to stop the video clips. Although *Stand by Me* was rated R at the time of release based on foul language (PG-13 was not yet a designation), the clip used in this study was edited to ensure there were no swear words, which rendered the clip below the PG-13 threshold and suitable for the age range of this study. Of note, the same clip from *Stand by Me* has been used in prior studies with younger children (e.g., 5–6 year olds, Quas & Lench, 2007; 4–5 year olds, Wolff et al., 2012). Clips were administered in a standardized order – sad, happy, fear – with 1-min neutral nature film clips separating each emotion elicitation. This standardized order was adopted to ensure that negative emotions were separated by a positive emotion induction to avoid emotional fatigue (see Rottenberg et al., 2007).

ANS regulation was assessed during each film clip using four spot electrodes placed on the neck and torso to collect impedance and respiratory measures, and three spot electrodes placed on the right clavicle, left lower rib, and right abdomen for electrocardiogram (ECG) measures. ANS data were collected using Mindware MW1000A ambulatory cardiography (www.mindwaretech.com) via Kendall Medi-Trace #133 spot electrodes. PEP data were extracted and scored using the IMP 3.0.3 analysis program and the dZ/dt waveforms were used to obtain impedance-derived PEP measures quantified as the time interval in milliseconds from the onset of the ECG Q-wave to the B point of the dZ/dt wave (Berntson et al., 2004). RSA data were filtered, extracted, and scored using Mindware's HRV 3.0.10 analysis program. This technique utilizes the Mindware software algorithms to calculate the variance in R-R wave intervals. RSA scores were calculated using the interbeat intervals on the ECG reading, respiratory rates derived from the impedance (i.e., dZ/dt) signal, and a specified RSA bandwidth range for 7-year-olds of 0.15 to 0.80 Hz (Bar-Haim et al., 2000). The respiratory frequency band adhered to the gold standard recommendations at the time of original data collection and cleaning, however, given recent concerns about potential mis-specification of RSA values based on respiratory frequency bands (Shader et al., 2018), we assessed whether this band accurately captured respiratory rates in the current sample. Of the children with ANS data at age 7, 12 evidenced one epoch outside the specified frequency band, 2 evidenced two epochs outside this range, and no cases had more than two epochs with mis-specified RSA bands. Thus, respiratory frequency bands were mis-specified in 1.1% of the epoch-level data and appeared as anomalous epochs randomly distributed across cases, rather than systematic variation within a child. Moreover, the appearance of these mis-specified epochs varied across the broader task, suggesting that sudden changes in respiratory rate likely reflected random alterations in body-posture or vocalization across the task (Grossman & Taylor, 2007; Houtveen et al., 2005).

Data cleaning procedures for PEP and RSA included visual inspection of each epoch for errors or abnormalities in the B-points and R-peaks, respectively. For RSA, extensively trained research assistants manually edited R-peaks, which were then checked and finalized by an expert doctoral scorer. PEP was cleaned using the finalized RSA epochs, which were also visually inspected by trained research assistants. If B points were not accurate, the assistant flagged the case for inspection by the expert scorer who then manually edited as necessary. Further procedures included screening each epoch for outliers (i.e., values greater than 3 *SD* above or below the mean; Alkon et al., 2011) and deleting a child's data if more than 25% of their epochs were missing due to computer malfunction, electrode conduction problems, or outliers. Of the 197 participants who completed aggression measures at wave 2, 137 (70%) had usable PEP data and 169 (86%) had useable RSA data. Missing ANS data was the result of physiology task noncompletion due to a partial visit ($N = 4$), video errors ($N = 13$), computer/electrode/connection issues ($N = 33$ for PEP, $N = 7$ for RSA), and segment deletion due to artifacts ($N = 9$ for PEP, $N = 4$ for RSA). Finally, ANS for happiness and fear segments only were missing due to early task termination ($N = 4$), and PEP for sadness only was missing due to artifact segment deletion ($N = 1$).

Following a 5-min calibration period, baseline ANS activity was indicated by the average of six 30-s epochs across a 3-min film baseline during which children viewed a neutral nature scene. This initial baseline was used to calculate all reactivity scores given the greater reliability afforded by its longer duration of 3 min (yielding six, 30-s epochs) as compared to the 1-min intervening neutral nature clips (yielding just two, 30-s epochs). In addition, the intervening nature clips also encompassed recovery processes and thus were not true baselines. ANS reactivity was indicated by standardized residual values obtained from a regression of the average across four 30-s epochs during each 2-min emotion-eliciting film on baseline ANS values to yield an index of each child's relative change in ANS activity from baseline to each emotion condition as compared to other children in the sample (El-Sheikh et al., 2001; Manuck et al., 1990; Rudd & Yates, 2018). This approach was adopted given evidence that using standardized residuals maximizes reliability in cases where the ratio of baseline variance to challenge variance is greater than the correlation between baseline and challenge values (Burt & Obradović, 2013), which was the case in the current study for all challenge tasks. In addition, this approach for assessing reactivity has been employed in prior work with the present sample (see Coloumbe et al., 2019) as well as foundational research focused on the role of ANS coordination in externalizing behavior (El-Sheikh et al., 2009). For PEP, positive standardized residual scores indicated that, relative to the rest of the sample, the individual exhibited greater PEP elongation (i.e., sympathetic inhibition), whereas negative standardized residual scores indicated that the individual exhibited greater PEP shortening (i.e., sympathetic activation) than expected. For RSA, positive standardized residual scores indicated that, relative to the rest of the sample, the individual exhibited greater RSA activation (i.e., increased parasympathetic activity) than expected, whereas negative standardized residual scores indicated that the individual exhibited greater RSA inhibition (i.e., decreased parasympathetic activity) than expected.

Data analytic plan

First, analyses were conducted to investigate patterns of missing data and attrition. We also examined descriptive statistics for key study variables, including an assessment of the presence of outliers in PEP reactivity (PEP-R) and RSA reactivity (RSA-R), which reflected values greater than 3 *SD*s above or below the mean. Outliers in PEP-R and RSA-R were winsorized to +/- 3 *SD* from the mean (Kline, 2015). We then investigated correlations between study variables for girls and boys. Next, we conducted unconditional growth models of aggression from age 6 to age 10 years using Mplus version 8.6 (Muthén & Muthén, 1998–2017). Unconditional growth models were run separately for each form of aggression. In the unconditional models, a latent intercept (i.e., level of aggression at the time point defined as the intercept) and latent linear slope (i.e., rate of change over time) were estimated. A model including quadratic change was also examined for each form of aggression. In the unconditional growth models, the intercept was set at age 7, as this is when the ANS assessment occurred, which allowed us to investigate concurrent associations between ANS activity and aggression in our more complex models. Maximum likelihood estimation accommodated missing data, and robust standard errors (MLR) addressed data skew. The standardized root mean square residual (SRMR), the comparative fit index (CFI), and the root mean squared error of approximation (RMSEA) were used to evaluate model fit (Hu & Bentler, 1999). Good fit was defined as CFI >.95, SRMR < .08, and RMSEA < .06 (Hu & Bentler, 1999), with lower thresholds for acceptable fit (e.g., CFI > .90, RMSEA < .08; Little, 2013).

We conducted models to test for gender differences in model parameters. When gender differences were significant or marginal, associations were allowed to vary across groups; otherwise, these paths were constrained across gender. In the first model, fully unconstrained multigroup analyses were conducted with gender as the grouping variable. An omnibus Wald chi-square test of parameter equalities (see Muthén & Muthén, 1998–2017) evaluated whether the aggression residuals differed by gender. Next, Wald chi-square tests were run for each parameter to test gender differences in mean intercept, mean slope, intercept variance, and slope variance.

Imposing the gender constraints identified in this initial model, we next investigated associations between ANS reactivity and trajectories of aggression. Specifically, mean-centered observed PEP-R and RSA-R, as well as their interaction, served as predictors of intercept and change in aggression (i.e., slope). Ethnicity (1 = Latinx, 0 = not Latinx) was included as a covariate. These parameters were freely estimated across gender. We then conducted tests of parameter equalities to assess gender differences in the variances of model parameters, associations between ethnicity and study variables, and associations between ANS reactivity and trajectories of aggression. Since the PEP-R*RSA-R interaction effects qualify the component main effects, we conducted an omnibus Wald chi-square test of gender differences in the main effects and their interaction predicting latent intercept and latent slope, respectively. When omnibus tests indicated that effects significantly or marginally differed by gender, the entire block (i.e., both main effects and the interaction) was allowed to vary freely across groups in the final model and follow-up parameter equality tests were run separately by parameter to identify which components significantly differed across gender. Significant interactions in the prediction of intercept and slope were probed at +/- 1 *SD* from the mean using simple slope analyses. Parameter comparisons were also used to investigate differences in intercept and slope parameters at high and low values of moderators. Given model complexity and the sample size, separate models were run for each form of aggression, as well as for ANS reactivity to each of the emotions (i.e., fear, happiness, and sadness).

Results

Descriptives, correlations, and missing data

Descriptive data regarding key study variables, including the number of participants contributing data to each variable, are shown in Table 2. Correlations indicated that girls were less physically aggressive at age 10 and exhibited greater shortening of PEP (i.e., greater SNS activation) in response to sadness. Latinx participants exhibited lower physical aggression at ages 8 and 10, and greater lengthening of PEP (i.e., SNS inhibition) in response to sadness. Ethnicity was included in analyses as a covariate, and models were run with gender as a grouping variable. SES was unrelated to study variables, with the exception that higher SES was associated with greater shortening of PEP (i.e., SNS activation) in response to sadness. However, as study findings were unchanged in sadness models when SES was included as a covariate, more parsimonious final models are presented that do not include SES.

Relational and physical aggression were both stable across the course of the study, with the exception that relational aggression at age 6 was not significantly correlated with relational aggression at age 10. Within-time correlations between relational and physical aggression were significant and similar across data waves, yet slightly lower in size (*r*s = .48–.52, all *p*s < .001) than in prior research (see Card et al., 2008), which supports the distinct nature of relational and physical aggression subtypes. ANS reactivity scores across the three emotion conditions were positively correlated for both PEP-R and RSA-R, with correlations ranging from moderate to large in size. PEP-R and RSA-R to fear were moderately, positively correlated.

Missing data analyses yielded no significant differences in child gender, ethnicity, or SES between participants with complete data and those missing data on key study variables. Additionally, there were no significant differences between participants with versus without ANS data in terms of demographics (i.e., gender, ethnicity, SES), relational aggression, or physical aggression. Little's missing completely at random (MCAR) test including both forms of aggression at all time points, physiological reactivity to each of the emotion tasks, ethnicity, and gender was not significant, suggesting data might be MCAR [χ^2 (230) = 213.69 $p = 0.77$]. However, given this study was not designed to have data be MCAR, missing data were more likely missing at random (Little et al., 2014). Levels of missing relational aggression data at age 6 were relatively high due to the late addition of the measure to

Table 2. Descriptive statistics and correlations of study variables

	N	M (*SD*)	Min–Max	Skew	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
1. Gender	232	.50 (.50)	–	−.02	–															
2. Ethnicity	232	.46 (.50)	–	.16	−.07	–														
3. SES	212	33.08 (12.31)	11–66	.64	.13	−.10	–													
4. RelAgg Age 6	94	1.01 (.72)	.00–3.33	.51	.06	.06	.05	–												
5. RelAgg Age 7	197	.91 (.73)	.00–3.17	.61	.13	−.11	.10	**.50**	–											
6. RelAgg Age 8	214	.81 (.75)	.00–3.83	1.08	.12	−.08	−.03	**.42**	**.59**	–										
7. RelAgg Age 10	213	.60 (.67)	.00–3.83	1.44	−.01	−.11	.01	.15	**.53**	**.52**	–									
8. PhyAgg Age 6	214	.83 (.56)	.00–2.83	.77	−.07	−.16	.00	**.48**	**.38**	**.31**	**.27**	–								
9. PhyAgg Age 7	197	.75 (.58)	.00–2.50	.82	.02	−.11	−.02	**.49**	**.52**	**.45**	**.38**	**.57**	–							
10. PhyAgg Age 8	214	.68 (.58)	.00–3.17	1.13	−.11	**-.21**	−.08	**.22**	**.31**	**.48**	**.42**	**.47**	**.62**	–						
11. PhyAgg Age10	213	.61 (.56)	.00–2.50	1.05	**-.15**	**-.17**	−.04	.17	**.29**	**.30**	**.51**	**.46**	**.51**	**.67**	–					
12. PEP-R Fear	134	.02 (.80)	−3.00–3.00	−.36	−.03	−.01	−.07	.00	−.05	.06	−.09	−.02	−.10	−.05	−.11	–				
13. RSA-R Fear	165	.00 (.98)	−2.76–3.00	.19	−.11	−.14	−.07	.08	−.05	−.02	.01	−.04	−.07	−.08	−.08	**.22**	–			
14. PEP-R Happy	134	.00 (.72)	−3.00–3.00	−1.21	−.07	−.07	.06	.16	.06	.15	.02	.15	−.01	.12	.05	**.66**	.10	–		
15. RSA-R Happy	165	.01 (.97)	−3.00–2.38	−.31	−.05	−.11	.08	.10	−.02	−.06	.06	.01	.03	.04	−.02	.00	**.54**	−.01	–	
16. PEP-R Sad	137	.00 (.80)	−3.00–3.00	−.16	**-.21**	**.21**	**-.20**	.08	.00	−.03	−.05	.08	.15	−.01	.01	**.30**	.05	.06	.01	–
17. RSA-R Sad	169	−.01 (.97)	−2.78–3.00	.23	−.08	−.05	.05	−.07	−.06	−.05	.00	.03	−.04	−.01	−.03	.05	**.51**	.13	**.49**	−.14

Note. Bolded estimates are significant correlations at $p < .05$. Gender is coded: 1 = girls, 0 = boys; Ethnicity is coded: 1 = Latinx, 0 = non-Latinx; SES = socioeconomic status; RelAgg = relational aggression; PhyAgg = physical aggression; PEP-R = pre-ejection period reactivity; RSA-R = respiratory sinus arrhythmia reactivity; physiological values represent post-winsorized data.

the study midway through this assessment period. Levels of missing data for the ANS measurements conducted at age 7 were also elevated primarily due to technical errors. Thus, following recommendations of Little et al. (2014) to adopt modern approaches that can accommodate missing data when levels of missingness are high, we used maximum likelihood estimation procedures in these analyses.

Relational aggression

Latent growth curve analysis

The first unconditional growth curve was conducted with the overall sample and included a latent intercept (at age 7) and linear and quadratic change in relational aggression. There was not significant quadratic change in relational aggression ($M = .000$, $p = .999$), nor was there significant variance in quadratic change, and the estimate was negative ($Var = -.005$, $p = .43$). Thus, quadratic change was not included in the final model. Fit indices for the final model indicated that model fit was good to acceptable (see Table 3). On average, participants exhibited relatively low levels of relational aggression at age 7 and declined in relationally aggressive behaviors across the course of the study. There was significant variance in the intercept and linear slope, indicating that participants differed in their levels of relational aggression at age 7 as well as in their rate of change in relational aggression over time.

Next, we conducted a multigroup unconditional growth curve with gender as the grouping variable. The final multigroup model with nonsignificant parameter differences constrained across gender exhibited acceptable fit to the data (see Table 4). Girls exhibited higher levels of relational aggression at age 7 than boys, as well as steeper declines in relational aggression over time. Both girls and boys exhibited significant variance in relational aggression at age 7, as well as in their trajectories of relational aggression over time.

Table 3. Unstandardized growth curve parameters and fit statistics for relational and physical aggression for overall sample

	Relational aggression			Physical aggression		
	Estimate	*SE*	*p*	Estimate	*SE*	*p*
Fixed effects						
Intercept	.91	.04	.001	.75	.03	.001
Linear slope	−.10	.02	.001	−.05	.01	.001
Random effects						
Variance, intercept	.31	.05	.001	.18	.02	.001
Variance, linear slope	.03	.01	.002	.01	.004	.006
Fit statistics						
	CFI = .97			CFI = .95		
	RMSEA = .07			RMSEA = .09		
	SRMR = .09			SRMR = .05		

ANS predictors

We conducted multigroup conditional models by gender in which mean-centered PEP-R and RSA-R to each emotion (i.e., fear, happiness, and sadness), as well as their interaction, served as predictors of relational aggression growth curves. Table 5 depicts the associations between ANS reactivity to each emotion and relational aggression trajectories. The fear model indicated that ANS reactivity to fear was not associated with relational aggression intercept or linear change for girls or boys. For the happiness model, the omnibus test indicated that the association between ANS reactivity and the relational aggression slope marginally differed by gender. However, as individual follow-up tests of the association between PEP-R, RSA-R, and their interaction and the relational aggression slope were all not significant, these associations were constrained across gender in the final model. The happiness model indicated that ANS reactivity to happiness was not associated with relational aggression intercept or linear change for girls or boys.

The sadness model revealed a significant main effect of PEP-R and a significant interaction between PEP-R and RSA-R in the prediction of the relational aggression intercept for girls only. In the prediction of the relational aggression slope, the interaction between PEP-R and RSA-R was significant for both girls and boys. For girls, coactivation to sadness was related to lower relational aggression at age 7 as compared to other patterns of reactivity (reciprocal PNS activation, Wald χ^2 [1] = 9.31, p = .002; reciprocal SNS activation, Wald χ^2 [1] = 4.76, p = .03; coinhibition, Wald χ^2 [1] = 4.27, p = .04). Further, girls with coactivation showed weaker declines in relational aggression relative to girls with reciprocal PNS activation (Wald χ^2 [1] = 7.85, p = .01), and marginally differed from declines among girls with reciprocal SNS activation (Wald χ^2 [1] = 2.85, p = .09; see Figure 1). For boys, coactivation to sadness was associated with stable levels of relational aggression over time, in contrast to significant linear declines associated with other ANS patterns (see Figure 2). Further, boys with reciprocal PNS activation to sadness exhibited steeper declines in relational aggression than boys with coactivation (Wald χ^2 [1] = 7.95, p = .005), and marginally steeper declines than boys with coinhibition (Wald χ^2 [1] = 3.22, p = .07).

Physical aggression

Latent growth curve analysis

An unconditional growth curve for physical aggression was conducted with the overall sample and included a latent intercept (at age 7) and linear and quadratic change. In this initial model, there was not significant quadratic change in physical aggression (M = .01, p = .15). Although there was significant variance in quadratic change (Var = .006, p = .012), subsequent models indicated that this variance was not explained by study predictors[1]. Thus, the final model included only linear change, and provided good to adequate fit to the data (see Table 3). On average, participants exhibited relatively low levels of physical aggression at age 7, and a linear decline in physically aggressive behaviors across the course of the study. There was significant variance in the intercept and linear slope, indicating that participants differed in their levels of physical aggression at age 7, as well as in their trajectories of physical aggression over time.

Next, we conducted a multigroup unconditional growth curve with gender as the grouping variable (Table 4). Tests of gender moderation indicated marginally significant gender differences in linear change, as well as significant gender differences in the omnibus test of the aggression residuals. Follow-up tests run individually by each aggression residual indicated a significant difference across gender in the physical aggression residual at age 7; thus, this parameter was freely estimated across gender in the final model and the remaining residuals were constrained across gender. The final multigroup model with nonsignificant parameter differences constrained across gender provided adequate to good fit to the data. Both girls and boys exhibited relatively low levels of physical aggression at age 7 and a linear decline in these behaviors over time. Both girls and boys exhibited significant variance in physical aggression at age 7, as well as in their trajectories of physical aggression over time.

ANS predictors

We conducted multigroup conditional models by gender in which mean-centered PEP-R and RSA-R to each emotion (i.e., fear, happiness, and sadness), as well as their interaction, served as predictors of physical aggression growth curves. Table 6 depicts the associations between ANS reactivity to each emotion and physical aggression trajectories. In all three emotion models, non-Latinx participants exhibited heightened physical aggression at age 7 relative to their Latinx peers. In the fear model, for boys only, RSA-R was related to change in physical aggression, such that boys exhibiting RSA activation (simple slope = -.07, p = .002), but not boys exhibiting RSA inhibition (simple slope = .001, p = .98), to fear exhibited declines in physical aggression over time. For girls only, the interaction between PEP-R and RSA-R to fear was related to change in physical aggression. Although girls with all ANS patterns exhibited significant or marginally significant declines in physical aggression over time, the decline was marginally steeper among girls with coinhibition than among girls with reciprocal PNS activation (Wald χ^2 [1] = 3.56, p = .06; see Figure 3).

Results for the happiness model indicated that the interaction between PEP-R and RSA-R was related to the physical aggression intercept for boys only. Boys with reciprocal SNS activation to happiness exhibited lower levels of physical aggression at age 7 than boys with nonreciprocal patterns (i.e., coinhibition, Wald χ^2 [1] = 9.13, p = .003; coactivation, Wald χ^2 [1] = 7.05, p = .008). Boys with reciprocal PNS activation also exhibited lower levels of physical aggression at age 7 than boys with coinhibition, Wald χ^2 [1] = 6.42, p = .01. ANS reactivity to happiness was not associated with change in physical aggression over time for girls or boys.

Results of the sadness model indicated that the interaction between PEP-R and RSA-R was significantly related to physical aggression at age 7 for girls but not boys. Follow-up tests indicated that girls with reciprocal PNS activation exhibited marginally higher physical aggression at age 7 than did girls with coactivation (Wald χ^2 [1] = 2.94, p = .09). In addition, PEP-R was related to slope for boys only, such that boys with greater PEP lengthening (i.e., sympathetic inhibition; simple slope = -.05, p = .007), but not boys with PEP shortening (i.e., sympathetic activation; simple slope = -.02, p = .46), to sadness exhibited declines in physical aggression over time.

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[1] In initial models unconstrained across gender, quadratic change in physical aggression was positively related to PEP-R to sadness for boys only. However, the omnibus test of gender moderation of associations between ANS reactivity and quadratic change in physical aggression was not significant; thus, following the data analytic plan, these paths were constrained across gender. With these associations constrained across gender, there were no significant associations between ANS reactivity and quadratic change in physical aggression.

Table 4. Unstandardized growth curve parameters and fit statistics for relational and physical aggression by gender

	Relational aggression			Physical aggression		
	Estimate	*SE*	*p*	Estimate	*SE*	*p*
			Fixed effects			
Intercept	1.01/.82	.07/.05	.001/.001	.75/.75	.03/.03	.001/.001
Linear slope	−.14/-.08	.02/.02	.001/.001	−.07/-.03	.01/.01	.001/.02
			Random effects			
Variance, intercept	.41/.19	.07/.04	.001/.001	.19/.19	.03/.03	.001/.001
Variance, linear slope	.02/.02	.01/.01	.006/.006	.01/.01	.004/.004	.005/.005
			Fit statistics			
		CFI = .96			CFI = .97	
		RMSEA = .07			RMSEA = .07	
		SRMR = .10			SRMR = .09	
			Parameter comparisons by gender			
Mean intercept		Wald χ^2 (1) = 4.68, p = .03			Wald χ^2 (1) = 1.12, p = .29	
Mean linear slope		Wald χ^2 (1) = 4.47, p = .03			Wald χ^2 (1) = 3.43, p = .06	
Variance, intercept		Wald χ^2 (1) = 11.89, p < .001			Wald χ^2 (1) = .98, p = .32	
Variance, linear slope		Wald χ^2 (1) = .81, p = .37			Wald χ^2 (1) = 1.66, p = .20	
Aggression residuals		Wald χ^2 (4) = 7.35, p = .12			Wald χ^2 (4) = 13.55, p = .01	

Note. Estimates for girls are on the left of the / and those for boys are on the right.

Table 5. Standardized parameter estimates, standard errors (*SE*), and statistical significance of the conditional relational aggression latent growth curve models

	Fear			Happiness			Sadness		
	Estimate	*SE*	*p*	Estimate	*SE*	*p*	Estimate	*SE*	*p*
Intercept									
Ethnicity	−10/-.14	.07/.10	.15/.15	−.08/-.11	.07/.09	.24/.24	−.10/-.14	.07/.10	.16/.16
PEP-R	04/.05	.09/.13	.69/.69	.14/.20	.10/.14	.14/.14	**.24/-.06**	**.11/.12**	**.04/.64**
RSA-R	−.04/-.05	.07/.10	.61/.61	−.01/-.02	.07/.09	.84/.84	−.02/-.06	.10/.13	.84/.64
PEP-R X RSA-R	−.05/-.07	.07/.10	.48/.48	−.01/-.02	.07/.10	.88/.88	**.24/-.03**	**.12/.08**	**.03/.73**
Linear slope									
Ethnicity	−.04/-.04	.10/.10	.69/.69	−.04/-.04	.10/.10	.69/.69	.00/.00	.10/.10	.98/.98
PEP-R	−.13/-.13	.11/.10	.22/.22	−.12/-.12	.10/.10	.24/.24	−.15/-.17	.09/.10	.10/.10
RSA-R	.06/.06	.11/.11	.61/.61	.11/.11	.11/.11	.34/.34	.01/.01	.11/11	.91/.91
PEP-R X RSA-R	−.12/-.12	.07/.07	.14/.14	−.11/-.11	.10/.10	.28/.28	−.24/-.23	.11/.10	.03/.03
					Fit statistics				
		CFI = 1.0			CFI = .97			CFI = 1.0	
		RMSEA = .01			RMSEA = .04			RMSEA = .00	
		SRMR = .10			SRMR = .11			SRMR = .08	
					Physiology omnibus comparisons by gender				
Intercept		Wald χ^2 (3) = .88, p = .83			Wald χ^2 (3) = 1.67, p = .64			Wald χ^2 (3) = 6.70, p = .08	
Linear slope		Wald χ^2 (3) = 4.00, p = .26			Wald χ^2 (3) = 6.49, p = .09			Wald χ^2 (3) = .36, p = .95	

Note. Estimates for girls are on the left of the / and those for boys are on the right. Bolded estimates were different for girls and boys at p < .05. PEP-R = pre-ejection period reactivity; RSA-R = respiratory sinus arrhythmia reactivity. Ethnicity was coded 1 = Latinx, 0 = non-Latinx. Physiology omnibus comparisons by gender were conducted in a multigroup model with parameters freely estimated across groups; parameters that did not differ across groups were constrained to be equal in the final model.

Discussion

The purpose of the present study was to investigate interactions between SNS and PNS reactivity to emotion induction (i.e., fear, happiness, and sadness) and trajectories of relational and physical aggression from age 6 to 10 years. In several instances, findings supported study hypotheses that uncoordinated, nonreciprocal patterns of ANS reactivity would increase risk for aggressive behavior, whereas reciprocal patterns would be protective. Further, patterns

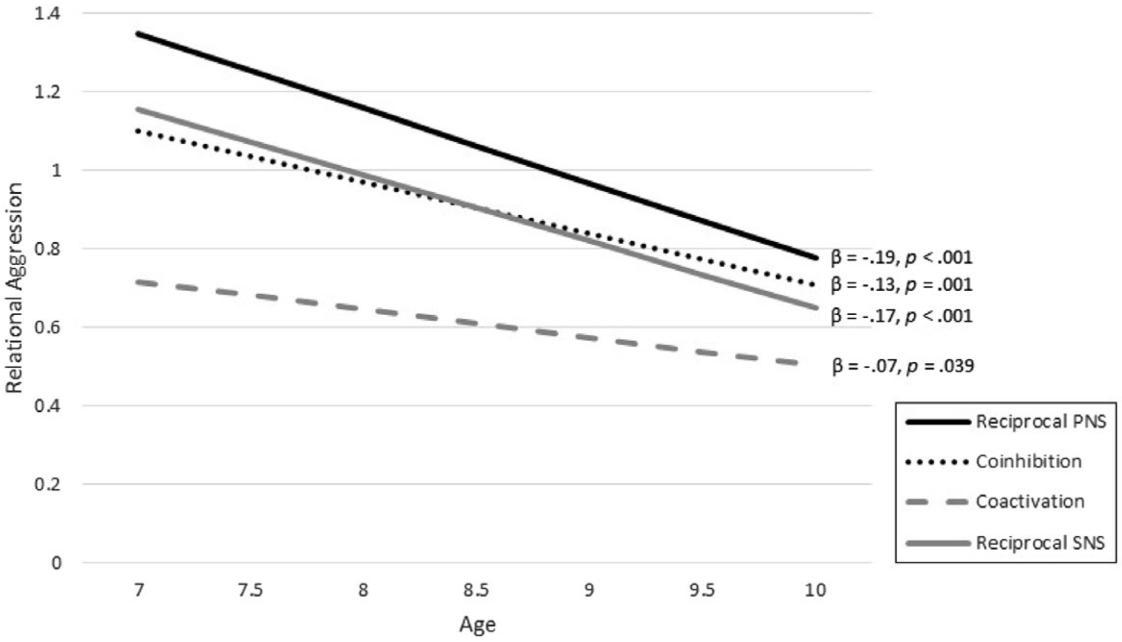

Figure 1. Girls' trajectories of relational aggression based on physiological reactivity to sadness. *Note*. *Reciprocal PNS* refers to RSA augmentation (i.e., PNS activation) accompanied by PEP lengthening (i.e., SNS inhibition). *Coinhibition* refers to RSA inhibition (i.e., PNS inhibition) accompanied by PEP lengthening (i.e., SNS inhibition). *Coactivation* refers to RSA augmentation (i.e., PNS activation) accompanied by PEP shortening (i.e., SNS activation). *Reciprocal SNS* refers to RSA inhibition (i.e., PNS inhibition) accompanied by PEP shortening (i.e., SNS activation).

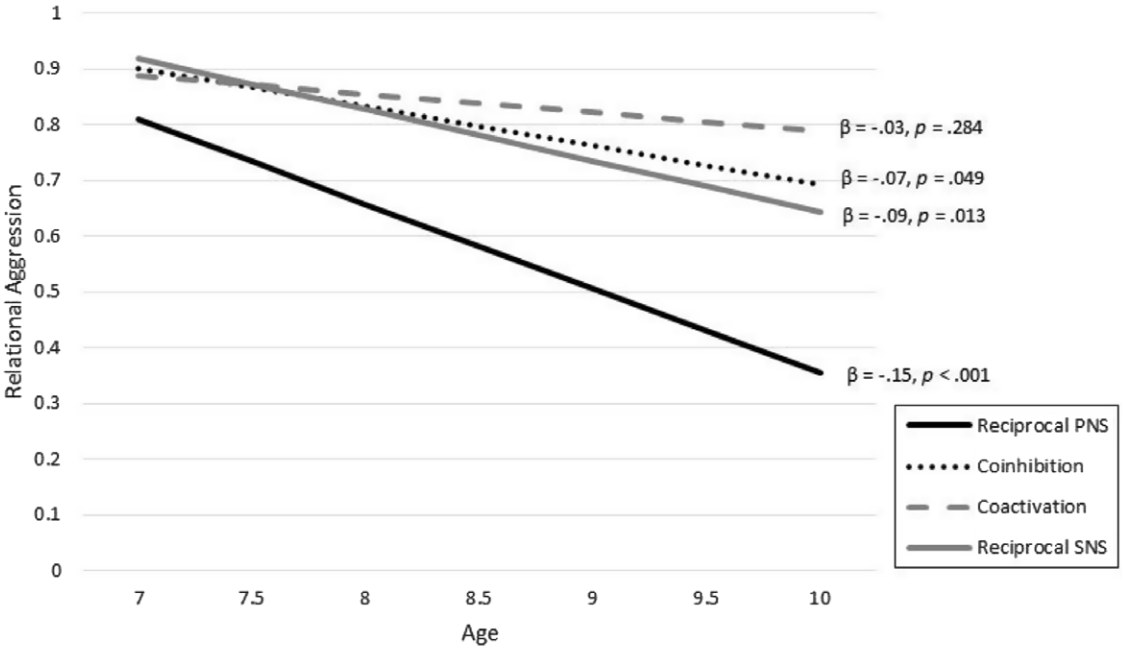

Figure 2. Boys' trajectories of relational aggression based on physiological reactivity to sadness. *Note*. *Reciprocal PNS* refers to RSA augmentation (i.e., PNS activation) accompanied by PEP lengthening (i.e., SNS inhibition). *Coinhibition* refers to RSA inhibition (i.e., PNS inhibition) accompanied by PEP lengthening (i.e., SNS inhibition). *Coactivation* refers to RSA augmentation (i.e., PNS activation) accompanied by PEP shortening (i.e., SNS activation). *Reciprocal SNS* refers to RSA inhibition (i.e., PNS inhibition) accompanied by PEP shortening (i.e., SNS activation).

of effects differed across emotional stimuli, highlighting the importance of ANS reactivity to distinct emotions, as well as across gender.

Relational aggression

Results of the latent growth curve analyses indicated that, on average, girls and boys exhibited relatively low levels of relational aggression at age 7, which is consistent with prior studies with community samples of children (e.g., Ostrov & Crick, 2007; O'Toole et al., 2017). In addition, children exhibited linear declines in relational aggression over time. These findings are consistent with Fite and Pederson's (2018) recent review indicating that, overall, rates of relational aggression tend to decrease from early to

Table 6. Standardized parameter estimates, standard errors (*SE*), and statistical significance of the conditional physical aggression latent growth curve models

	Fear			Happiness			Sadness		
	Estimate	*SE*	*p*	Estimate	*SE*	*p*	Estimate	*SE*	*p*
Intercept									
Ethnicity	−.23/-.23	.07/.07	.002/.002	−.20/-.20	.07/.07	.01/.01	−.27/-.26	.07/.07	.001/.001
PEP-R	−.04/-.04	.10/.10	.68/.68	.07/.25	.13/.14	.61/.10	.14/.20	.13/.12	.29/.09
RSA-R	−.09/-.09	.07/.07	.22/.22	.04/.07	.09/.09	.67/.48	.06/-.06	.10/.15	.50/.71
PEP-R X RSA-R	−.07/-.07	.07/.07	.36/.36	**.08/-.37**	**.11/.13**	**.50/.001**	**.22/-.14**	**.11/.08**	**.047/.08**
Linear slope									
Ethnicity	−.03/-.03	.10/.10	.78/.78	−.04/-.04	.10/.10	.66/.66	.004/.003	.11/.10	.97/.97
PEP-R	−.10/-.26	.13/.16	.44/.11	−.03/-.03	.12/.12	.79/.79	**.06/−.49**	**.10/.23**	**.52/.03**
RSA-R	**.13/-.32**	**.17/.15**	**.44/.02**	−.06/-.06	.11/.11	.57/.57	.07/−.25	.13/.16	.58/.11
PEP-R X RSA-R	**.23/-.14**	**.11/.12**	**.03/.23**	−.07/-.07	.14/.14	.62/.62	−.02/.03	.13/.14	.91/.85
Fit statistics									
	CFI = .99			CFI = .96			CFI = .99		
	RMSEA = .03			RMSEA = .05			RMSEA = .03		
	SRMR = .09			SRMR = .09			SRMR = .08		
Physiology omnibus comparisons by gender									
Intercept	Wald χ^2 (3) = 2.46, *p* = .48			Wald χ^2 (3) = 6.91, *p* = .07			Wald χ^2 (3) = 7.72, *p* = .05		
Linear slope	Wald χ^2 (3) = 8.78, *p* = .03			Wald χ^2 (3) = 2.51, *p* = .47			Wald χ^2 (3) = 8.62, *p* = .04		

Note. Estimates for girls are on the left of the / and those for boys are on the right. Bolded estimates were different for girls and boys at $p < .05$. PEP-R = pre-ejection period reactivity; RSA-R = respiratory sinus arrhythmia reactivity. Ethnicity was coded 1 = Latinx, 0 = non-Latinx. Physiology omnibus comparisons by gender were conducted in a multigroup model with parameters freely estimated across groups; parameters that did not differ across groups were constrained to be equal in the final model.

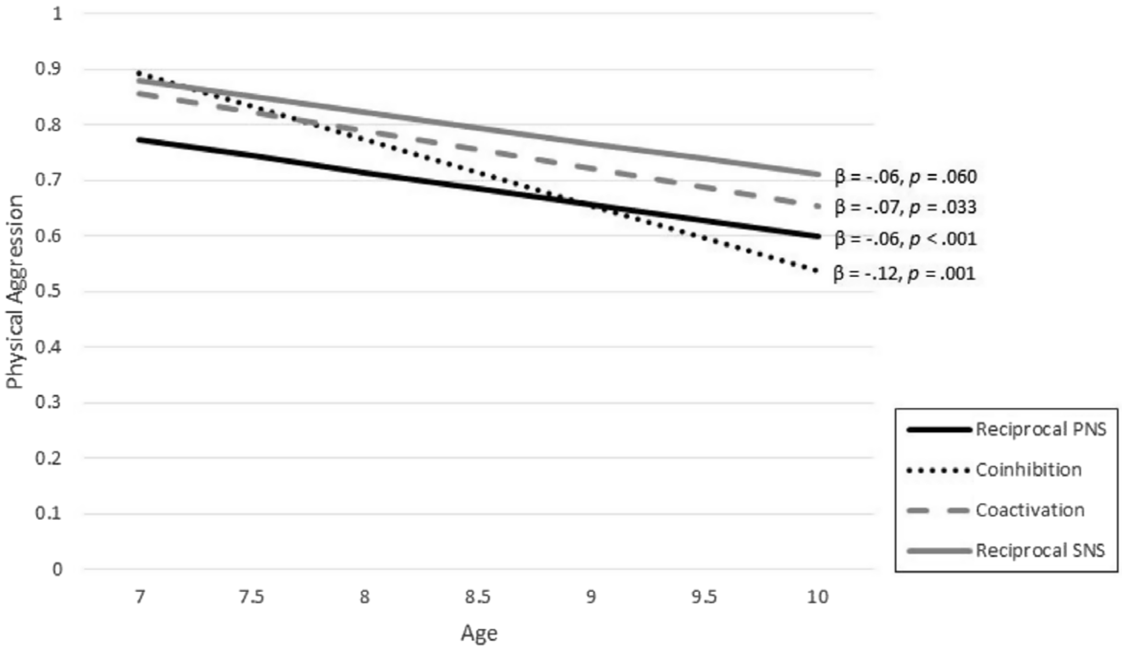

Figure 3. Girls' trajectories of physical aggression based on physiological reactivity to fear. *Note*. *Reciprocal PNS* refers to RSA augmentation (i.e., PNS activation) accompanied by PEP lengthening (i.e., SNS inhibition). *Coinhibition* refers to RSA inhibition (i.e., PNS inhibition) accompanied by PEP lengthening (i.e., SNS inhibition). *Coactivation* refers to RSA augmentation (i.e., PNS activation) accompanied by PEP shortening (i.e., SNS activation). *Reciprocal SNS* refers to RSA inhibition (i.e., PNS inhibition) accompanied by PEP shortening (i.e., SNS activation).

middle childhood. Further, compared to boys, girls exhibited higher levels of relational aggression at age 7 years. These findings are consistent with prior meta-analytic research indicating that girls tend to exhibit higher levels of relational aggression than boys when behaviors are assessed via caregiver reports (Card et al., 2008). Interestingly, girls exhibited steeper declines in relational aggression over time. These declines may reflect gender differences in factors such as rule internalization, which emerge during early childhood and are related to decreases in relational aggression, especially in girls (Ostrov et al., 2022).

Importantly, there was significant variance in the intercept and slope of relational aggression, and ANS reactivity to sadness was a salient correlate of relational aggression for girls and boys, although the pattern of effects differed by gender. Among boys, reciprocal PNS activation to sadness was associated with faster declines in relational aggression over time, as compared to patterns of coactivation (and, at a trend level, compared to coinhibition). Further, boys with coactivation to sadness exhibited relatively stable levels of relational aggression, rather than the decreases in these behaviors shown by their peers. These findings are consistent with the suggestion that nonreciprocal patterns of ANS activity are maladaptive and thus increase risk for externalizing behaviors (El-Sheikh et al., 2009). They also underscore the relevance of ANS reactivity and coordination processes following sadness, rather than following fear or happiness, in the development of boys' relational aggression. Some prior work has highlighted the importance of sadness in relational aggression. For instance, Sullivan et al. (2010) found that 5th and 8th graders with higher sadness regulation coping (e.g., remaining calm when dealing with sad feelings) engaged in lower levels of relational, but not physical, aggression. Boys exhibiting reciprocal PNS activation, which has been hypothesized to reflect effective self-soothing (El-Sheikh & Erath, 2011), may be less likely to lash out with relationally aggressive behaviors. In contrast, as coactivation is hypothesized to reflect dysregulated emotional reactivity (El-Sheikh & Erath, 2011), findings indicate that dysregulated reactions to sadness place boys at risk for relational aggression over time. These findings are consistent with the suggestion by Sullivan et al. (2010) that difficulties coping with sadness may lead to relational aggression as a maladaptive effort to establish social connections with others (e.g., using gossip about a peer to feel close to a friend).

Interestingly, a different pattern of effects emerged in the prediction of trajectories of relational aggression among girls. Specifically, girls with coactivation to sadness exhibited lower rates of relational aggression concurrently, as well as slower declines in these behaviors over time. The finding that girls with coactivation to sadness engaged in relatively low levels of relational aggression across the course of the study was unexpected. One possibility is that girls are less likely than boys to use relational aggression to cope with dysregulated ANS responses to sadness. For instance, girls exhibiting coactivation to sadness may engage in alternative coping behaviors, such as support-seeking and emotional expression, which have been documented in prior research as behaviors that are more common among girls than among boys (Rose & Rudolph, 2006). It is also possible that coactivation to sadness is more strongly associated with internalizing problems among girls. Indeed, some work indicates that nonreciprocal ANS activation exacerbates risk for depressive symptoms in women exposed to relational victimization (Holterman et al., 2016). Interestingly, ANS reactivity to fear and happiness was not associated with relational aggression for girls or boys. Together, these findings underscore the importance of ANS reactivity to sadness in the development of relational aggression and suggest that the implications of dysregulated responses to sadness differ by gender.

Physical aggression

Results of the latent growth curve analyses for physical aggression indicated that, on average, girls and boys exhibited relatively low levels of physical aggression at age 7, consistent with prior studies with community samples of young children using caregiver reports (e.g., Miller-Johnson et al., 2002). In addition, children exhibited a linear decline in physical aggression, consistent with a recent review by Fite and Pederson (2018) indicating that physical aggression tends to decrease from early to middle childhood. Unexpectedly, there were no significant gender differences in trajectories of physical aggression; however, prior meta-analytic work indicates that gender differences in physical aggression and related behaviors tend to be smaller when assessed via caregiver reports, rather than peer reports or observations (Card et al., 2008). Finally, Latinx participants exhibited lower levels of physical aggression than their peers at age 7. This finding was unexpected, and may reflect the methods used in the present study (e.g., caregiver-reported aggression). Future research should integrate other methods and informants to clarify the role of sociodemographic factors, such as ethnicity, in the development of aggression.

ANS reactivity to all three emotion conditions predicted significant variance in the intercept and slope of children's trajectories of physically aggressive behavior, though in different ways for girls and boys. Specifically, boys exhibiting PNS inhibition to fear (assessed via RSA) demonstrated stable, rather than declining, levels of physical aggression over time. Although prior work is mixed (e.g., Fortunato et al., 2013; Kalvin et al., 2016), these findings are consistent with research by Gatzke-Kopp et al. (2015) indicating that PNS inhibition to viewing a fear-inducing film clip was associated with slower declines in externalizing problems among highly aggressive kindergarteners in a targeted intervention. These findings are also consistent with the suggestion that PNS inhibition, as indicated by lower RSA, in response to negative events reflects emotional lability and thus increases risk for externalizing problems (Beauchaine & Thayer, 2015). Additionally, boys with higher SNS activation to sadness exhibited stable, rather than declining, levels of physical aggression over time. Gresham et al. (2016) suggest that unpleasant emotions, including sadness, generate fight-flight reactions that elicit feelings of anger, ultimately facilitating aggressive responding. Further, there is some indication that boys may be more likely than girls to engage in aggression (e.g., hitting, stomping around) in response to sadness (Zeman & Shipman, 1996). Taken together, exaggerated physiological arousal resulting from SNS activation or PNS inhibition to negative emotions may energize physically aggressive responses in boys.

With regard to happiness, boys with reciprocal SNS activation to happiness engaged in lower levels of concurrent physical aggression than boys with coinhibition or coactivation. Further, boys with reciprocal PNS activation to happiness engaged in lower levels of concurrent physical aggression than boys with coinhibition. These patterns are consistent with hypotheses suggesting that coordinated, reciprocal patterns of ANS reactivity are protective against aggressive behavior (El-Sheikh et al., 2009). The results also support prior suggestions that adaptive regulation of positive emotions is critical in children's social functioning (Moore et al., 2019), and highlight the role of well-regulated responses to happiness in boys' inhibition of physical aggression.

For girls only, reciprocal PNS activation to negative emotions appeared to increase risk for physical aggression, whereas nonreciprocal patterns were protective. Specifically, a significant interaction emerged between SNS and PNS reactivity to fear in the prediction of linear change in physical aggression. Follow-up analyses indicated that reciprocal PNS activation to fear was associated with marginally slower declines in physical aggression relative to coinhibition. Similarly, a significant interaction emerged between SNS and PNS reactivity to sadness and physical aggression at age 7. Follow-up tests indicated that girls with reciprocal PNS activation to sadness exhibited marginally higher physical aggression at age 7 than did girls with coactivation. Although unexpected, these findings are consistent with a recent study by Thomson et al. (2021), which found that PNS activation to fear (i.e., higher RSA) was associated with heightened physical and verbal proactive aggression in women, but not in men. Although several theorists have posited that coinhibition to fear reflects fearlessness and thus increases risk for aggression and antisocial behavior (Fanti et al., 2019; Thomson et al., 2021), there may be sex-specific manifestations of fearlessness involving ANS activity (Thomson et al., 2021). For example, in a recent study with a late adolescent/early adult sample, Thomson (2022) found that affective (e.g., lack of guilt, callousness) and antisocial (e.g., behavior problems) facets of psychopathy were associated with SNS inhibition to fear, whereas, lifestyle facets (e.g., boredom proneness) were related to PNS activation. It is also notable that reciprocal PNS activation reflects a coordinated response that functions to reduce arousal (e.g., heart rate), and a large body of work has documented low heart rate reactivity in aggressive and antisocial youth (Ortiz & Raine, 2004). Taken together, then, reciprocal PNS activation may reflect an overall pattern of underarousal to negative emotions, perhaps indicating a combination of affective deficits and a tendency toward boredom, thus increasing the risk for girls' engagement in physical aggression.

Strengths, limitations, and future directions

Strengths of the present study include our focus on interactions across branches of the ANS, which researchers have argued play an important role in the development of externalizing problems (e.g., El-Sheikh et al., 2009). We also evaluated ANS reactivity to multiple prominent emotions (i.e., fear, happiness, sadness) to extend current theoretical perspectives that underscore the importance of underlying emotional processes (e.g., dysregulated fear; Fanti et al., 2019) in aggressive and antisocial behavior. Our focus on middle childhood extends prior research on ANS coordination and aggression in adults (e.g., Thomson et al., 2021). Further, the longitudinal design supported our investigation of associations between ANS reactivity and changes in aggression over a period of 4 years, which builds on prior studies using cross-sectional or shorter-term longitudinal designs. Further, whereas most research in this area has focused on physical forms of aggression (e.g., Gatzke-Kopp et al., 2015; Thomson et al., 2021), we considered both relational and physical expressions of aggression. Finally, the current study adds to the limited research investigating gender differences in ANS correlates of aggression (Fanti et al., 2019) by documenting distinct ANS risk factors for relational and physical aggression in girls and boys.

Despite these strengths, several important limitations in the present study should be addressed in future research. First, the current sample of children experienced diverse caregiving arrangements. Although most (91.6%) caregivers in the present study were biological mothers, other caregiving arrangements (e.g., female kin, foster mothers) were represented as well. On the one hand, as these caregiver arrangements are becoming increasingly common (e.g., Rubin et al., 2008), this diversity likely increased the generalizability of study findings. On the other hand, different caregiving arrangements may have distinct implications for children's ANS regulation, behavior, and/or adjustment (e.g., Rubin et al., 2008). It will be important for future research to include samples with greater representations of diverse caregiving arrangements to investigate this possibility. Second, although our measure of physical aggression emphasized physical forms, some items were ambiguous in nature (e.g., "threatens or bullies others to get their way"; Cooley et al., 2018; Mathieson & Crick, 2010). Thus, future studies should endeavor to replicate these findings using measures that exclusively tap physically aggressive behaviors in all items (e.g., Mathieson & Crick, 2010).

Third, both physical and relational aggression were assessed via caregiver reports, which have been shown to have strong psychometric properties for both relational (Brandes et al., 2021) and physical (White et al., 2013) aggression. However, it is important to note that caregivers are more likely to observe their children's aggression in relatively intimate relationships, such as with close friends or siblings, whereas teachers are more likely to observe aggression in youth across more diverse relational settings (Kuppens et al., 2009). Further, some researchers have raised questions about the validity of caregiver reports of relational aggression, in particular, noting that caregivers may not be aware of some of their children's more indirect or covert aggressive actions (e.g., spreading gossip; see Brandes et al., 2021). To address these concerns, Brandes et al. (2021) recently conducted a multistage validation study of caregiver-reported relational aggression across 6 community samples with over 3,000 children/adolescents (spanning approximately 6–18 years). Based on this comprehensive analysis, the authors conclude that caregivers can provide reliable assessments of relational aggression that are both structurally and externally valid. Further, they note significant agreement across caregiver and youth reports of relational aggression, which suggests that caregivers are able to report on these seemingly covert behaviors. In further support of the validity of caregiver-reported relational aggression, multiple informants of relational aggression among 8–10 year olds in the same context (e.g., mothers and fathers at home) tend to converge, as do measures of relational aggression across home and school contexts in middle childhood (Kuppens et al., 2009). Nevertheless, inclusion of additional informants on aggression, such as peer reports, teacher reports, and self reports, as well as multiple measures, such as computerized aggression tasks (e.g., competitive reaction time task; Warburton & Bushman, 2019), will strengthen future research in this area.

Fourth, in addition to relational and physical aggression types, some researchers have found that ANS risk for aggression varies depending on whether the aggression is proactive (i.e., goal-directed) or reactive (i.e., enacted in response to threat or provocation) in function (Murray-Close et al., 2017; Thomson et al., 2021). For instance, ANS indicators of fearlessness may be especially relevant to proactive functions of aggression, whereas heightened SNS reactivity to negative emotions may be especially relevant to reactive functions of aggression (Thomson et al., 2021). These physiological patterns may have significant implications for peer relations, particularly as children approach adolescence and relational and physical aggression are increasingly used to gain popularity (Rose et al., 2004). Indeed, popularity appears to be more closely tied to proactive than reactive functions of aggression during adolescence (van den Berg et al., 2019). It is possible, for instance, that patterns of ANS coordination indicative of fearlessness may be related to proactive functions of aggression, ultimately facilitating high social status and power with peers. It will be important for future research to investigate this possibility. Fifth, despite our use of maximum likelihood estimation to address missing data, levels of missing relational aggression data at age 6 were relatively high due to the late addition of the measure to the study midway through this assessment period and levels of missing data for the ANS measures at age 7 were also elevated due primarily to technical errors.

Sixth, the three emotion film clips were presented in a standardized rather than counterbalanced order. Consistent with prior work in this area (Gatzke-Kopp et al., 2015), neutral videos were shown between each emotion clip to allow participants to recover from the preceding emotion induction, but it remains possible that physiological "spill-over" effects may have influenced study findings in ways that could not be examined here. Seventh, the current investigation focused on ANS reactivity, but a growing body of research supports the incremental value of considering recovery processes in ANS regulation (El-Sheikh & Erath, 2011; Suurland et al., 2018). Thus, future research will benefit from considering the role of ANS coordination during recovery from emotion induction in trajectories of aggression. Eighth, future studies should consider integrating additional mood-induction procedures that may have greater ecological validity. That said, meta-analytic findings indicate that film clips can elicit large changes in both negative and positive subjective mood states (e.g., Fernández-Aguilar et al., 2019), and these methods offer significant advantages over some mood induction procedures, such as recalling autobiographical memories or manipulations to elicit social success or failure, because they reduce ethical concerns related to first-hand emotion induction (e.g., recalling or experiencing emotionally upsetting events) and support the standardization of experiences across participants (Fernández-Aguilar et al., 2019).

Ninth, although the inclusion of reactivity to multiple emotions (i.e., fear, happiness, sadness) was an important strength of the study, future studies should asses ANS reactivity to anger, which has also been found to increase risk for externalizing behavior (Gatzke-Kopp et al., 2015). Likewise, although this study supported our investigation of individual and interactive contributions of RSA and PEP reactivity to aggression trajectories, future studies should incorporate additional measures of stress system dysregulation, including alternative indices of SNS activity (e.g., SCL) as well as hypothalamic-pituitary-adrenal axis (HPA) activity (e.g., cortisol). Indeed, prior research has documented interactions between HPA and ANS regulation in the prediction of children's problem behavior (Allwood et al., 2011).

Finally, there are several analytic limitations in the present study. For instance, ANS reactivity was conceptualized as a predictor of the development of aggressive behavior. Although the longitudinal design provided initial support for the hypothesized direction of effects, bidirectional associations between ANS reactivity and aggression are possible and were not tested in the present study. Indeed, children who engage in high levels of aggressive behavior may become desensitized to emotional experiences (e.g., fear) over time. Future longitudinal research assessing ANS reactivity and aggression at multiple time points would allow for a test of these potential bidirectional effects. In addition, given the complexity of models, we conducted these analyses separately by form of aggression (i.e., relational, physical) and emotion induction (i.e., fear, happiness, and sadness). Although the correlations between forms of aggression were somewhat lower in the present study than in prior work (see Card et al., 2008), these behaviors did co-occur. Further, patterns of ANS activation were correlated across emotional events. Thus, we encourage future research with larger samples to consider the benefit of models including physiological reactivity to multiple emotions and multiple forms of aggression.

Conclusions

The current findings offer unique insights regarding the association between ANS reactivity and the development of aggression across middle childhood. First, findings contribute to a growing body of research documenting how the two branches of the ANS work together in the development of aggression (Thomson et al., 2021). Second, although much of the theory regarding ANS correlates of aggression has focused on atypical responses to fear (Scarpa & Raine, 1997), the current results suggest that dysregulated ANS reactions to happiness and sadness also play an important role in aggression. Indeed, in the present study, relational aggression was associated with ANS reactivity to sadness, but not to fear or happiness, which underscores the importance of assessing ANS reactivity to varied emotions. Moreover, the current findings point to distinct ANS correlates of relational versus physical forms of aggression, as well as gender differences in patterns of effects. For instance, ANS reactivity to fear was associated with physical, but not relational, aggression, which raises the possibility that fearlessness theory may be most relevant to the development of physical forms of aggression. Regarding gender, ANS reactivity to happiness was related to physical aggression for boys, but not for girls, which may suggest that dysregulated reactions to happiness are particularly problematic among boys.

The current findings also have implications for improving prevention and intervention efforts aimed at reducing children's aggressive behavior. For instance, some intervention and prevention programs targeting relational and physical aggression involve emotion identification skill development, including recognizing physiological changes in the body and developing strategies for self-soothing (Waasdorp et al., 2022). Findings from the present study suggest that the impact of these strategies may be increased by tailoring them to specific emotions (e.g., fear versus sadness), children's subtypes of aggression, and child gender. For instance, prevention and intervention programs may benefit from extending their focus to address dysregulated responses to happiness, particularly among boys. Finally, given mounting research highlighting the potential benefits of biofeedback for altering ANS activity (e.g., Lehrer, 2021), future prevention and intervention work should adapt these techniques to promote coordinated ANS responses that buffered against the development of aggression in the present study.

Acknowledgments. We express our gratitude to the caregivers and children who participated in this research.

Funding statement. Funding for this project was provided by the National Science Foundation Developmental and Learning Sciences (0951775) awarded to TMY.

Conflicts of interest. None.

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