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RESEARCH ARTICLE

WILEY AGGRESSIVE BEHAVIOR

The simultaneous assessment of and relations between children's sympathetic and parasympathetic psychophysiology and their reactive and proactive aggression

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The goal of the current study was to examine the link between children's psychophysiology and aggression when both constructs were assessed simultaneously in scenarios designed to provide the opportunity to aggress for either a reactive reason or a proactive reason. Both sympathetic nervous system (SNS) activity (skin conductance) and parasympathetic nervous system (PNS) activity (respiratory sinus arrhythmia or RSA), as well as their interaction, were included as physiological measures. Participants were 35 5th-grade children who were placed in two virtual-peer scenarios; one scenario provided the opportunity to aggress in response to peer provocation (i.e., reactive aggression) and the other scenario provided the opportunity to aggress for instrumental gain (i.e., proactive aggression). Both skin conductance and RSA were assessed at the time that children were given the opportunity to aggress; this simultaneous assessment of psychophysiology and aggression allowed for an examination of in-the-moment relations between the two constructs. For the reactive scenario, RSA moderated the in-the-moment relation between skin conductance and aggression such that the association was positive at low RSA but negative at high RSA. For the proactive scenario, skin conductance negatively predicted aggression in-the-moment, and RSA positively predicted aggression in-the-moment, but their interaction was not a significant predictor of aggression. Theoretical implications for reactive and proactive aggression and underlying physiological processes are discussed.

KEYWORDS
aggression, peer, physiology, proactive aggression, reactive aggression

1 | INTRODUCTION

Although psychophysiology of the autonomic nervous system (ANS) has been important for understanding childhood aggression, a major gap in the literature remains. Specifically, studies have not addressed the role of psychophysiology at the moment that aggression occurs, and this is particularly true of investigations of reactive and proactive aggression, for which differing physiological mechanisms are theorized. To address this gap, we assessed psychophysiology and aggression simultaneously as children were given the opportunity to aggress in two different scenarios—in response to provocation (reactive scenario) or for instrumental gain (proactive scenario). Moreover, we included both sympathetic nervous system (SNS) activity (skin conductance) and parasympathetic nervous system (PNS) activity (respiratory sinus arrhythmia; RSA), as well as their interaction, a comprehensive assessment of autonomic functioning uncommon in physiological studies of reactive and proactive aggression.

2 | PHYSIOLOGICAL INDICATORS OF CHILDHOOD AGGRESSION

2.1 | SNS and aggression

Research on the physiology of childhood aggression has emphasized the SNS (Murray-Close, 2013). Physiological measures used in these studies include heart rate, skin conductance, salivary alpha amylase and pre-ejection period (PEP; see Murray-Close, 2013 for review). The following section integrates findings across these different indices.

Low baseline SNS has been linked concurrently with aggression (e.g., Baker, Shelton, Baibazarova, Hay, & van Goozen, 2013; Fung et al., 2005; Lorber, 2004; Murray-Close et al., 2014; Ortiz & Raine, 2004; Sijtsema, Shoulberg, & Murray-Close, 2011; Snoek, Van Goozen, Matthys, Buitelaar, & Van Engeland, 2004; van Goozen et al., 1998) using SNS measures of heart rate and skin conductance and aggression measures including diagnostic categories, self and parent report, and behavioral paradigms. Longitudinally, low resting SNS activity in infancy predicts aggression in toddlerhood (Baker et al., 2013) and middle childhood (Raine, Venables, & Mednick, 1997). These findings have led to the idea that low baseline SNS functioning may serve as an indicator of childhood aggression (Baker et al., 2013).

The association between low baseline SNS activity and aggression has been explained by theories of fearlessness and sensation seeking. Fearlessness theory posits that aggression results from an inability to experience appropriate levels of fear, putting youth at risk for aggression due to lack of proper socialization via punishment processes (e.g., Raine, 2002). Alternatively, sensation-seeking theory proposes that physiological under-arousal is an aversive condition that perpetuates engagement in risky behavior (including aggression) in order to raise arousal (e.g., Raine, 2002).

Beyond baseline physiology, theoretical and empirical work also documents the importance of assessing arousal to stress. In contrast to under-arousal theories, the frustration-aggression hypothesis posits that aggression is marked by over-arousal reflecting negative emotion following aversive events (Berkowitz, 1993). In support of this theory, meta-analytic findings suggest that heart rate reactivity (HRR) may be a stronger predictor of youth antisocial conduct than low resting heart rate (Ortiz & Raine, 2004).

Findings on SNS reactivity to stress and childhood aggression have been mixed. Some studies have linked blunted skin conductance reactivity (SCR) and HRR to aggression (Ortiz & Raine, 2004), while others have found associations to heightened SCR (Hubbard et al., 2002) and HRR (Lorber, 2004). In fact, Keller and El-Sheikh (2009) found elevated externalizing problems among children at both the low and high extremes of SNS (i.e., salivary alpha amylase). Thus, the SNS correlates of aggression support both over- and under-arousal theories of aggression.

2.2 | PNS and aggression

The PNS has also emerged as important to understanding youth aggression. Vagal tone, a fundamental element of the PNS (Porges, 1995), has been proposed as a psychophysiological marker of regulation (Graziano & Derefinko, 2013) and a mechanism for appropriate social behavior (Porges, 2003). Vagal tone is most often assessed through RSA, an element of heart rate variability which is a sensitive measure of vagal influence on the heart.

This literature has been informed by polyvagal theory. Polyvagal theory posits that vagal tone is a dynamic neurophysiological mechanism that (i) maintains homeostasis and promotes states of calm (i.e., baseline RSA) and (ii) responds adaptively to cope with stress (i.e., vagal regulation; Porges, 2007). At rest, RSA inhibits arousal and reflects the capacity for regulation. In response to stress, vagal influences on the heart withdraw, which increases heart rate.

Indeed, children with higher baseline RSA are more resilient to parental conflict (El-Sheikh, Hinnant, & Erath, 2011), have better social functioning (Eisenberg et al., 1995), and exhibit fewer externalizing problems (El-Sheikh & Hinnant, 2011; Graziano & Derefinko, 2013). In contrast, lower baseline RSA is replicated in externalizing samples (e.g., Beauchaine, Gatzke-Kopp, & Mead, 2007; Xu, Raine, Yu, & Krieg, 2014). Furthermore, children who exhibit blunted RSA suppression are more likely to aggress (Graziano & Derefinko, 2013; Miller et al., 2013).

However, some findings contradict polyvagal theory and its empirical support, with respect to the negative relations between both baseline RSA and aggression (Zhang & Gao, 2015) and RSA suppression to stress and aggression (e.g., Gatzke-Kopp, Greenberg, & Bierman, 2015; Hastings et al., 2008). In fact, some have argued that higher RSA during social interaction may protect against aggression by inhibiting fight-flight arousal (Hastings et al., 2008). Thus, similar to the SNS literature, research on PNS functioning in aggression is inconsistent.

2.3 | Joint patterns of SNS and PNS in relation to aggression

Although much work focuses on either the SNS or PNS, assessing both systems jointly may better specify relations between aggression and physiology. In community samples, the combined effects of the SNS and PNS largely support under-arousal theories of aggression. Specifically, children are more likely to exhibit delinquency (El-Sheikh et al., 2011), externalizing problems (Keller & El-Sheikh, 2009; Nederhof, Marceau, Shirtcliff, Hastings, & Oldehinkel, 2015), and aggression (Xu et al., 2014) if they exhibit higher RSA in conjunction with lower SNS activity. These findings emerge for physiology both at rest (Keller & El-Sheikh, 2009) and in response to stress (El-Sheikh et al., 2011; Nederhof et al., 2015). This pattern (i.e., reciprocal parasympathetic activation) relates to aggression by decreasing arousal (Murray-Close, Holterman, Bresland, & Sullivan, 2017), consistent with sensation-seeking and fearlessness theories of aggression.

However, reciprocal sympathetic activation may also increase risk for aggression because it increases arousal (Murray-Close et al., 2017) through reductions in PNS and increases in SNS activity. In other words, prolonged suppression of RSA concomitant with heightened SNS activity may accompany anger and aggression, an idea in keeping with frustration-aggression theory. In fact, externalizing problems are most likely for youth displaying this pattern in response to stress (Nederhof et al., 2015).

In addition to these reciprocal patterns, non-reciprocal patterns also predict risk for aggression (Boyce et al., 2001; El-Sheikh et al., 2009; Gordis, Feres, Olezeski, Rabkin, & Trickett, 2009), particularly among high-risk samples. Coinhibition occurs when RSA suppresses along with blunted SNS reactivity, whereas coactivation occurs when RSA increases in conjunction with heightened SNS activity. Some theorists contend that these patterns confer risk for aggression because they reflect disorganized stress responses (El-Sheikh et al., 2009). Thus, multiple patterns of SNS and PNS activation may be linked to childhood aggression.

3 | PSYCHOPHYSIOLOGY OF REACTIVE AND PROACTIVE AGGRESSION

An important theoretical distinction has been made between two functions of aggression. Reactive aggression is described as defensive, retaliatory behavior following provocation, and proactive aggression is defined as purposeful behavior to achieve an instrumental or social goal. Reactive aggression stems from the frustration-aggression model and is linked with hostile attributional biases (e.g., Hubbard, Dodge, Cillessen, Coie, & Schwartz, 2001), emotion dysregulation (e.g., Hubbard et al., 2002), and adult dating violence (Brendgen, Vitaro, Tremblay, & Lavoie, 2001). In contrast, proactive aggression is conceptualized as a learned behavior motivated by the expectation that aggression will be rewarded (Vitaro, Brendgen, & Barker, 2006). Proactive aggression is associated with the prioritization of instrumental over social goals (e.g., Salmivalli, Ojanen, Haanpää, & Peets, 2005) and more positive expectations for aggression (e.g., Smithmyer, Hubbard, & Simons, 2000). Some have argued that reactive aggression may be characterized as "hot," or driven by dysregulated anger, whereas proactive aggression is considered "cold," or resulting from the calculation that aggression will yield a goal. Accordingly, physiological over-arousal may better characterize reactive aggression while under-arousal may mark proactive aggression (e.g., Hubbard et al., 2002).

In support of this theory, heightened SCR to peer stress positively predicts reactive but not proactive aggression among children (Hubbard et al., 2002) and young adults (Murray-Close et al., 2017; Wagner & Abaied, 2016). In terms of PNS functioning, low resting RSA positively predicts reactive but not proactive aggression in children (Xu et al., 2014). In contrast, low resting heart rate in Chinese youth (Raine, Fung, Portnoy, Choy, & Spring, 2014), as well as blunted SCR to peer stress in young adults (Murray-Close et al., 2017; Wagner & Abaied, 2016), have been linked with proactive but not reactive aggression. Furthermore, young adults who exhibit RSA withdrawal concordant with low SCR are at highest risk for self-reported proactive aggression (Murray-Close et al., 2017). Taken together, these studies suggest reactive aggression may be best characterized by heightened arousal along with weakened regulatory ability (i.e., elevated SNS, blunted RSA) whereas proactive aggression may be best characterized by patterns promoting low autonomic arousal (i.e., blunted SNS, heightened RSA).

4 | SIMULTANEOUS ASSESSMENT OF PSYCHOPHYSIOLOGY AND AGGRESSION

In the work reviewed thus far, physiology and aggression are assessed in separate contexts. Aggression is rated by parents or teachers, assessed via diagnoses, or measured in behavioral paradigms unrelated to the assessment of physiology, while ANS activity is captured at baseline or in response to stressors unrelated to aggression. Often, these stressors are non-social in nature (e.g., cognitively difficult tasks, white noise bursts; Boyce et al., 2001; Fung et al., 2005), making it challenging to draw connections between physiology and aggression.

Of course, some investigators do use social stressors such as interviews (e.g., Murray-Close et al., 2014; Sijtsema et al., 2011), audio/video-tapes of adult conflicts (e.g., Keller & El-Sheikh, 2009), or peer interaction (e.g., Hastings et al., 2008) when relating physiological reactivity to aggression. Differences in stressors across studies are important, because relations between physiology and aggression depend on the type of stressor (Lorber, 2004). In fact, more recent work suggests that social situations may be particularly sensitive contexts in which to assess the link between ANS functioning and aggression (Murray-Close et al., 2017).

However, even when researchers assess physiology in the context of social stress, this assessment remains separate from the measurement of aggression. This separation may in part explain the inconsistencies throughout the literature reviewed above. Furthermore, when investigators study physiology and aggression, they are ultimately interested in the physiological mechanisms driving aggression as it occurs. The separate assessment of physiology and aggression represents a significant weakness in this body of literature, in that it does not elucidate ANS functioning during acts of aggression. Moreover, given that reactive and proactive aggression may be characterized by distinct physiological patterns, it seems important to assess ANS functioning during acts of both reactive and proactive aggression.

5 | THE CURRENT STUDY

The goal of the current study was to examine the link between children's physiology and aggression when both constructs were assessed as children were given the opportunity to aggress for reactive and proactive reasons. Both SNS activity (skin conductance) and PNS activity (RSA), as well as their interaction, were measured. A normative sample of children were given the opportunity to aggress in two virtual-peer scenarios, one involving peer provocation (i.e., reactive aggression) and the other involving instrumental gain (i.e., proactive aggression), while their skin conductance and RSA were assessed. This simultaneous assessment of physiology and aggression allowed for an examination of in-the-moment relations between the two constructs and is a significant strength of the study. To our knowledge, this investigation marks the first time that measures of psychophysiology have been collected at the same moment in time as measures of aggression in the study of childhood reactive and proactive aggression.

This advance required one important departure from previous studies. That is, we did not create change scores by subtracting children's baseline physiological scores from their scores in the aggression scenarios. Rather, we examined relations between aggression and physiology at the moment that children were given the opportunity to aggress. Thus our measures of physiology may best be considered measures of physiological activity in that moment, rather than physiological reactivity in contrast to a previous baseline state. Instead of calculating change scores, we controlled for baseline measures of psychophysiology in all analyses to account for between-person differences in resting physiological states.

For the reactive scenario, we predicted an over-arousal pattern such that (i) skin conductance and reactive aggression would be positively related in-the-moment; (ii) RSA and reactive aggression would be negatively related in-the-moment; and (iii) RSA would moderate the link between skin conductance and reactive aggression such that the positive association would be stronger for children with lower RSA. For the proactive scenario, we predicted an under-arousal pattern such that (i) skin conductance and proactive aggression would be negatively related in-the-moment; (ii) RSA and proactive aggression would be positively related in-the-moment; and (iii) RSA would moderate the link between skin conductance and proactive aggression such that the negative relation would be stronger for children with higher RSA. Of note, the sample size of the current study was quite small, and so the examination of interaction effects should best be characterized as exploratory.

6 | METHOD

6.1 | Participants

Participants were 16 girls and 19 boys randomly selected from 20 5th-grade classrooms in four elementary schools in a mid-Atlantic state (*M* age = 11.32 years; SD = 1.07). These children had participated in a previous school-based study unrelated to the current study, and their parents had agreed to be contacted about future studies. Participants were randomly contacted until 35 children had been scheduled and participated. Parents reported children's race/ethnicity as 66% European American, 28% African American, 3% Latino American, and 3% mixed. In the school district from which participants were recruited, 39% of children qualify for free or reduced-price lunch. Parents were compensated $50 and children were compensated $20 for participation.

6.2 | Procedures

6.2.1 | Physiological equipment

After parental consent and child assent, the experimenter fitted the participant with a Biolog Model 3992/4 device worn in a small backpack. This device recorded disturbances resulting from movement and verbalization using an embedded actometer, and the accompanying software factored these disturbances into the skin conductance and RSA data produced for each child. The participant and experimenter then spent 5 min playing a game to allow the participant to habituate to the equipment.

6.2.2 | Baseline

Next, the participant watched a video of a creek for 3.5 min. Before leaving, the experimenter said, “Now, you are going to watch a video of a creek. I'm going to go in the other room, and the video will start. Just sit as still and quiet as you can and watch the video.” The second half of this period was used to calculate baseline psychophysiological scores.

6.2.3 | Task providing the opportunity to display reactive aggression

Next, in the Reactive Task, the experimenter introduced the participant to a same-age, same-sex virtual peer “in another room,” and with whom he/she could talk via computer speaker. The participant then prepared a computer art picture while he or she believed that the virtual peer was doing the same.

Next, the experimenter told the participant that he/she and the virtual peer would “exchange” pictures and be able to fade the other's picture: “First, your picture will go to Alex/Alicia. He/she will change it if he/she wants to using the fade and color buttons, and then he/she will send it back to you. Then, Alex/Alicia's picture will come to you. You will change it if you want to using the fade and color buttons. I'll be back when you are done.” The experimenter then left the room, and the picture exchange was videotaped for later observational coding.

The participant's picture was first sent to the virtual peer, who criticized it harshly, faded the picture until it was entirely blank, and sent it back to the participant. Then, the virtual peer's picture was sent to the participant, who had the opportunity to comment on it and fade it if he or she chose to do so, providing measures of both verbal and behavioral aggression.

Throughout the task, both the experimenter and parent monitored the participant for distress behind a mirror. Experimenters were trained to terminate the task if a participant became distressed, and they reminded parents that they could do so as well. Ultimately, neither the experimenter nor the parent terminated the task for any participant. Afterward, the experimenter allowed the participant to talk about the experience, expressed empathy, restored the picture, printed it out, gave the participant a copy to take home, and hung a copy prominently in the lab.

6.2.4 | Task providing the opportunity to display proactive aggression

Next, in the Proactive Task, the experimenter introduced the participant to a different same-age, same-sex virtual peer, and both the participant and virtual peer again prepared pictures. The experimenter stated: "We will have a competition to see whose picture is best. First, you will have a chance to exchange pictures and change each other's picture if you want with the fade and color buttons. But, then, the computer will compare your two final pictures. The computer will determine which picture is the winner based on design and color. If your picture is judged to be the best, you will be able to take home any one of these prizes that you choose. First, your picture will go to Josh/Jasmine. He/she will change it if he/she wants to using the fade and color buttons, and then he/she will send it back to you. Then, Josh/Jasmine's picture will come to you. You will change it if you want to using the fade and color buttons. After you have finished exchanging pictures, the computer will have a message that says 'Please wait while the computer judges the competition.' Wait for a few seconds, and then the computer will put up another message telling you who won."

The participant and second virtual peer then exchanged pictures. However, the second virtual peer praised and did not fade the participant's picture. When the virtual peer's picture was sent to the participant, he or she had the opportunity to comment on it and fade it if he or she chose to do so, again providing measures of both behavioral and verbal aggression. Finally, the computer "announced" that the participant had won the competition.

Of note, the first picture exchange involved peer provocation but no instrumental gain from aggression, whereas the second picture exchange involved no peer provocation but clear instrumental gain from aggression. Thus, the two tasks were designed such that, if participants aggressed, their aggression could be clearly labeled as reactive or proactive in function.

The reactive task always preceded the proactive task. We worried that counterbalancing would lead children who first participated in the proactive task to expect a prize following the subsequent reactive task as well, which would confound the functions of the two tasks.

Anecdotal evidence suggested that children found the virtual peer methodology realistic. For example, they asked to meet the virtual peers. They also made comments during the tasks suggesting they were believable (e.g., "I think you're going to win honestly," "If you think it's terrible, that's your opinion," "Thanks for not ruining my picture like that last kid did").

6.2.5 | Informed consent and debriefing

Families were recruited through phone calls in which procedures were explained. Families who agreed scheduled a lab visit, and parents signed a consent form at the start of the visit. Children also signed an assent form explaining the voluntary nature of participation, the ability to stop participation at any time, and confidentiality. However, participants were not told about the virtual peers or provocation beforehand.

At the end of the visit, parents were given the choice of whether to have their child debriefed about the virtual peer interaction. We offered this choice after consulting with virtual peer researchers who reported that parents are sometimes upset by debriefing (e.g., Atkins, Osborne, Bennett, Hess, & Halperin, 2001). In fact, no parents chose to have their child debriefed.

6.3 | Measures

6.3.1 | Aggression

The Reactive (Proactive) Behavioral Aggression and Reactive (Proactive) Verbal Aggression measures described below were summed to form an overall measure of Reactive Aggression in the Reactive Task and Proactive Aggression in the Proactive Task.

Behavioral aggression

For both tasks, a Behavioral Aggression score was created by counting the number of times the participant pushed the "fade button" (maximum = 25).

Verbal aggression

For both tasks, all comments the participant made when viewing the virtual peer's picture were transcribed verbatim and coded. Observers were four blind undergraduate research assistants trained to criterion (overall kappa of 0.80 on three consecutive practice trials); 25% of participants were coded by two observers.

For the present study, the number of comments the participant made that were coded as Verbal Aggression were counted. This category included insults (e.g., "Loser"), threats (e.g., "You are gonna wish you were never born"), criticisms of the virtual peer's artwork (e.g., "You didn't like my picture, yours is uglier"), and statements that the participant intended to fade the virtual peer's picture (e.g., "I'm gonna fade it all out"). The kappa for Verbal Aggression was 0.79.

6.3.2 | Skin conductance

Skin conductance was recorded with two UFI 1081FD Ag-AgCl electrodes with an isotonic NaCl electrolyte gel attached with velcro bands to the volar surfaces of the first and third medial phalanges on the non-dominant hand. The Biolog recorded skin conductance level 10 times per second at a resolution of 0.012 µSiemens. Skin conductance artifacts were defined as exceeding either the upper (50 µSiemens) or lower (0.12 µSiemens) limit of the Biolog detected during an automated scan, or as large, abrupt discontinuities identified by an experimenter blind to the participant's aggression scores. Points containing artifact were excluded from subsequent data reduction. The participant's Baseline Skin Conductance score was computed as the number of peaks recorded during the second half of the 3.5-min period during which the participant watched the creek video. For both aggression tasks, the participant's Skin Conductance score was computed as the number of peaks recorded during the time that he or she was given the opportunity to view, comment on, and fade the virtual peer's picture.

6.3.3 | Respiratory sinus arrhythmia (RSA)

The electrocardiogram (EKG) was recorded with Ag-AgCl disposable stress foam electrodes attached to the participant's left ribcage at the V-6 level and placed on the right ribcage. Interbeat intervals (IBI) were computed in milliseconds as the time between consecutive R-waves in the EKG. IBI artifacts were defined as excessively long or short intervals relative to a moving 30-s average. Short IBIs were combined and long IBIs were segmented as appropriate. The average was recomputed and the IBIs were rescanned until the 30-s epoch was artifact free.

We assessed RSA using an autonomic analysis program (Map 1060; Nihon Santeku, Osaka, Japan). Power spectral analysis was performed using a fast Fourier transform applied to each segment with a Hanning window and determined following a high-frequency oscillation (0.25–1.50 Hz) representing parasympathetic activity modulated by respiratory cycles. The bandwidth was extended from the adult standard of 0.15–0.40 Hz due to the higher speed of respiration in children. RSA was calculated by summing power spectral density values over the bandwidth. The participant's Baseline RSA score was calculated across the second half of the 3.5-min period during which the participant watched the creek video. For both aggression tasks, RSA was calculated across the time that the participant was given the opportunity to view, comment on, and fade the virtual peer's picture using a moving 3-min average.

7 | RESULTS

7.1 | Descriptive statistics and gender differences

Means, standard deviations, and correlations for variables are provided in Table 1. Gender differences were examined for all variables using one-way ANOVAs. Boys were higher than girls on Baseline Skin Conductance, $F(1,34) = 5.79$, $p < 0.05$, Reactive Task Skin Conductance, $F(1,34) = 8.01$, $p < 0.01$, and Proactive Task Skin Conductance, $F(1,34) = 4.33$, $p < 0.05$. Thus, gender was entered as a covariate in the regressions described below.

7.2 | Regressions

We opted to use negative binomial regression due to the count nature of our Reactive and Proactive Aggression outcome variables (some participants receive a score of 0, and remaining participants receive whole-number count scores; Atkins & Gallop, 2007; Coxe, West, & Aiken, 2009). Negative binomial regression is an extension of Poisson regression used when count outcomes are over-dispersed (i.e., mean significantly greater than variance), as was the case for our Reactive and Proactive Aggression scores. Over-dispersion is particularly likely when many participants receive a score of 0 on the outcome, and this was especially true of Proactive Aggression (*Ns* for Proactive Aggression scores as follows: 27 scored 0; 2 each scored 1, 2, and 3; 1 each scored 6 and 9).

Two negative binomial regression analyses were conducted, with Reactive Aggression and Proactive Aggression serving as the dependent variable in a separate analysis. Predictor variables were Gender (0 = female, 1 = male), Baseline Skin Conductance, Baseline RSA, (Reactive or Proactive) Task Skin Conductance, (Reactive or Proactive) Task RSA, and (Reactive or Proactive) Task Skin Conductance × (Reactive or Proactive) Task RSA.

7.2.1 | Reactive task

Two significant predictors of Reactive Aggression emerged–Reactive Task RSA (negative) and the interaction between Reactive Task Skin Conductance and Reactive Task RSA (see Table 2). In negative binomial regression, coefficients must be exponentiated before they can be interpreted, using an exponent that is the product of the coefficient and the standard deviation of the coefficient (Atkins & Gallop, 2007). When we performed this exponentiation, results suggested that a participant one standard deviation below the mean in Reactive Task RSA was 1.22 times more likely to engage in Reactive Aggression.

TABLE 1 Descriptive statistics and zero-order correlations among all variables ($N = 35$)

Variable	Mean	SD	Skewness	Kurtosis	1	2	3	4	5	6	7	8
1. Baseline skin conductance	9.18	8.03	.46	−.88	–	−.02	.30	.18	.02	−.37*	.33	.05
2. Baseline RSA	2.91	.67	−.62	.08		–	−.03	.02	−.45**	−.06	−.20	.26
3. Reactive task aggression	14.40	9.55	−.29	−1.50			–	−.10	−.20	.04	−.03	−.07
4. Reactive task skin conductance	3.80	1.26	−.17	−.44				–	−.10	−.18	.33*	.02
5. Reactive task RSA	3.88	.57	.19	−.46					–	−.07	−.06	−.71****
6. Proactive task aggression	.77	1.91	3.19	10.91						–	−.43**	.15
7. Proactive task skin conductance	3.75	1.59	.35	.94							–	.05
8. Proactive task RSA	3.81	.46	−.37	−.33								–

*$p < .05$.
**$p < .01$.
****$p < .0001$.

TABLE 2 Negative binomial regressions predicting aggression in the reactive task and the proactive task

	Aggression in the reactive task		Aggression in the proactive task	
Predictor variables	**Estimate**	**SE**	**Estimate**	**SE B**
Gender	−.19	.22	.43	1.51
Baseline SC	.02	.01	−.16	.12
Baseline RSA	.00	.00	−.02	.01
Task skin conductance	.01	.14	−1.26***	.38
Task RSA	−.01*	.00	.11*	.06
Task skin conductance × task RSA	.01**	.00	−.01	.03

*$p < .05$.
**$p < .01$.
***$p < .001$.

Significant interaction effects were plotted using a spreadsheet available online (www.jeremydawson.co.uk/slopes.htm), and the resulting graph is shown in Figure 1. The relation between Reactive Task Skin Conductance and Reactive Aggression appears positive at low levels of RSA (1 SD below mean) but negative at high levels of RSA (1 SD above mean). The slopes are also slightly curvilinear, as is typical of over-dispersed count data. Furthermore, two physiological patterns appear predictive of high levels of reactive aggression: (i) high skin conductance in the context of low RSA (as predicted) and (ii) low skin conductance in the context of high RSA (contrary to predictions).

7.2.2 | Proactive task

Two significant predictors of Proactive Aggression emerged–Proactive Task Skin Conductance (negative) and Proactive Task RSA (positive; see Table 2). Participants one standard deviation below the mean in Proactive Task Skin Conductance were 1.85 times more likely to engage in Proactive Aggression, and participants one standard deviation above the mean in Proactive Task RSA were 6.24 times more likely to engage in Proactive Aggression.

8 | DISCUSSION

The goal of the current study was to give children the chance to aggress in response to provocation or for instrumental gain, assess their SNS and PNS, and relate their physiology to the reactive and proactive aggression that they displayed in that same moment. An advance of this study is the simultaneous assessment of physiology and aggression at the same moment. Other strengths include the use scenarios indexing both reactive and proactive aggression, and the assessment of both sympathetic and parasympathetic physiology and their interaction.

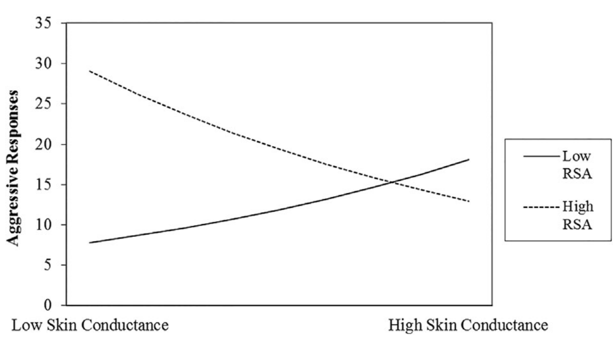

FIGURE 1 Interaction of skin conductance and RSA predicting reactive aggression. Low and high RSA are plotted at ±1 SD

8.1 | Reactive aggression in conjunction with high SNS and low PNS

In the reactive scenario, we predicted that children's skin conductance response and aggression would be positively related in-the-moment, that their RSA and aggression would be negatively related, and that RSA would moderate the relation between skin conductance and reactive aggression such that the positive relation would be stronger for children with lower RSA. The findings supported hypotheses regarding the main effect for RSA and the interaction between skin conductance and RSA. Given the small sample size, this interaction effect should be considered exploratory and requires replication.

Reactive aggression has been described as “hot headed” (e.g., Scarpa, Haden, & Tanaka, 2010), a description in keeping with links between reactive aggression and emotion dysregulation and anger (e.g., Hubbard et al., 2001), as well as the frustration–aggression hypothesis (Berkowitz, 1993). Our findings extend this work by suggesting that physiological dysregulation occurs at the moment that children display reactive aggression. Although the reciprocal suppression of RSA and activation of SNS may be adaptive in the face of serious threat, if this physiological response is prolonged, it may lead children to “fight” or engage in reactive aggression when doing so is not socially acceptable (Hastings et al., 2008).

8.2 | Proactive aggression in conjunction with low SNS and high PNS

We predicted that children's in-the-moment proactive aggression would be underpinned by a pattern of under-arousal; as follows, their skin conductance would be negatively linked, RSA be positively linked, and RSA would moderate the link between skin conductance and aggression such that the negative link would be stronger for children with higher RSA. The findings supported hypotheses for the main effects for both skin conductance and RSA.

Theorists have described proactive aggression as "cold-blooded" (e.g., Scarpa et al., 2010). Although previous studies have revealed a negative link between baseline SNS and proactive aggression, this is the first investigation to document this relation at the moment that aggression occurs. Additionally, the positive link between RSA and proactive aggression supports the characterization of proactive aggression as calm, well-regulated, and purposeful.

In the current study, RSA did not moderate the association between skin conductance and proactive aggression. Given the small *N*, we may be underpowered to detect a true effect. Future research with considerably large sample sizes will be needed to answer this question.

8.3 | Reactive aggression in conjunction with low SNS and high PNS

Unexpectedly, children displayed reactive aggression in conjunction not only with a pattern of high skin conductance and low RSA, but also in conjunction with a pattern of low skin conductance and high RSA. Previous research documents both heightened (Lorber, 2004; van Goozen et al., 1998) and blunted (e.g., Fung et al., 2005; Ortiz & Raine, 2004; Snoek et al., 2004) SNS reactivity in relation to aggression. This discrepancy may be driven not only by the distinction between reactive and proactive aggression, but also by differing physiological patterns linked to reactive aggression, with one pattern characterized by high arousal and low regulation and the other pattern marked by low arousal and strong regulation.

When children are grouped by the function of their aggression, a reactive-only group and a reactive-and-proactive group emerges (Smeets et al., 2017; Vitiello, Behar, Hunt, Stoff, & Ricciuti, 1990). This literature parallels two pathways toward conduct disorder outlined by Frick (2012), one marked by dysregulation and the other by callous-unemotional traits (e.g., fearlessness, blunted empathy). Our results may support this framework, indicating that some children display reactive aggression while in a dysregulated state while others display low arousal (i.e., low SNS and high PNS) during both reactive and proactive aggression.

9 | LIMITATIONS AND FUTURE DIRECTIONS

This study is marked by a number of limitations which suggest directions for future research. First, the procedures used to provide children with an opportunity to aggress were more extreme and contrived than children would typically face. In particular, the unexpected finding in which some children's reactive aggression was characterized by a well-regulated physiological profile may be an artifact of the extreme nature of the provocation. It may be that children who can remain physiologically well-regulated in the face of peer provocation may not typically aggress in response, but that some of these children decided that the severity of the provocation in this instance warranted aggression. Accordingly, future research should strive to develop more ecologically valid procedures for assessing children's physiological patterns as they are given the chance to engage in reactive and proactive aggression.

Of note, these contrived procedures may also explain the fact that children's reactive and proactive aggression were uncorrelated, when most investigations reveal strong correlations between the functions of aggression. In fact, the association between reactive and proactive aggression may be much lower when observational rather than questionnaire assessment approaches are used (e.g., Lorber, 2004). In this respect, the findings of the current study may contribute to a growing body of research suggesting that the correlation between reactive and proactive aggression may be weaker than suggested by typical questionnaire measures.

A second major limitation is that slope scores were not used to assess changes in children's physiology over the course of the tasks. The short duration of our tasks prohibited the assessment of slope scores, particularly for RSA. A substantial literature has investigated reciprocal and non-reciprocal patterns of the SNS and PNS in relation to aggression (e.g., Boyce et al., 2001; El-Sheikh et al., 2009). However, while these studies have assessed physiological reactivity or slope, they have not employed in-the-moment measures of aggressive behavior. Combining the assessment of physiological reactivity or slope with the simultaneous measurement of children's aggression and physiology at the same moment is likely to lead to important advances in our understanding of the physiological profiles of childhood aggression.

Third, contrary to prior studies, we did not use change scores calculated by subtracting baseline from task physiology. In one sense, we do not consider this decision a limitation but rather a choice that reflects our question of interest. However, this decision does make it more difficult to compare our findings to previous studies which took a change-score approach. Even so, our findings are largely consistent with prior theory and empirical work, particularly for physiology and reactive/proactive aggression, suggesting these findings may be quite robust.

Fourth, results of the current study should not be generalized beyond the normative sample used. Adaptive levels of SNS and PNS activity may differ between clinical and normative samples. In fact, greater initial RSA suppression may be protective against social problems among community samples but harmful among clinical samples (Graziano & Derefinko, 2013). Future research should address this gap by comparing clinical and typically developing samples to better understand adaptive and maladaptive physiological patterns in both groups.

Finally, due to the small sample size, we were not able to evaluate the moderating role of gender. Previous investigations suggest that girls and boys may differ in their physiological activity at baseline and in response to emotionally evoking stimuli including peer provocation (see Murray-Close, 2013). Future researchers should strive for adequate sample sizes to assess gender differences in the physiological profiles of reactive and proactive aggression.

In spite of these limitations, the present study advances our understanding of the psychophysiology of childhood aggression through the measurement of physiology and aggression at the same moment, the use of procedures indexing both reactive and proactive aggression, and the assessment of the interaction of sympathetic and parasympathetic physiological systems. We look forward to future advances building on these findings and furthering our understanding of the physiological underpinnings of childhood aggression.

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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