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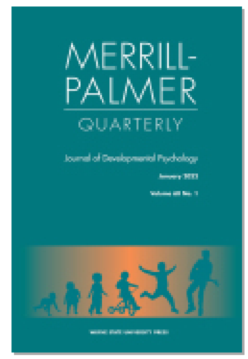

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Associations Between Adolescents' Subjectively Experienced Emotions and Psychophysiological Reactions in Achievement Situations

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This study investigated associations of early adolescents' (N = 190, median age = 12) subjectively experienced emotions and psychophysiological reactions in achievement situations. Self-reported questions assessed adolescents' experienced emotions. Additionally, adolescents' autonomic nervous system (ANS) reactions were recorded; skin-conductance response (SCR) and heart rate (HR) were used to measure sympathetic nervous system activity, and heart rate variability (HRV) was used to measure parasympathetic nervous system activity. The between-person-level results of multilevel modeling showed that increased HR was associated with higher levels of hope and fear and that decreased SCR was associated with a higher level of hopelessness. In turn, increased HRV was moderately associated with lower surprise at the within-person level. The results also showed that gender, hyperactivity, depressive symptoms, and cognitive ability moderated some of the associations between experienced emotions and physiological reactions. For example, high hyperactivity was related to stronger associations between SCR and hope and high depressive symptoms were related to a stronger association between HR and surprise. These findings enhance current understandings of connections between experienced emotions and psychophysiological reactions in achievement situations.

Emotions can be seen as multicomponent, coordinated psychological processes in which affective processes, physiologically constructed in the

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interaction of several interconnected domain-general brain networks (i.e., salience/ventral attention, mentalizing, executive control, dorsal attention, limbic networks), are central (Barrett & Satpute, 2013; Damasio, 2004; Fellous & LeDoux, 2005; Pekrun, 2006; Scherer, 1984). Inherently, emotions are responses to personally meaningful events or situations, changing the quality of feelings, expressive behaviors, and physiological activation (Eteläpelto et al., 2018; Kreibig, 2010; Levenson, 2014; Mauss & Robinson, 2009). For example, anxiety may involve uneasiness and nervous feelings, anxious facial expression, and peripheral physiological activation shown, for example, as an increased heart rate and sweating in distressing situations. It has also been suggested that affective, physiological, and expressive processes mutually amplify one another to form emotional states (Hollenstein, & Lanteigne, 2014). Hence, complementary emotional information can be gathered by asking the person about his or her emotional experiences and measuring physiological reactions during emotion-evoking situations (Wolf, 2015)

Although self-reports are limited to conscious aspects of emotions and affected by memory bias and sometimes by social desirability, they provide important information on subjectively experienced emotions that are not accessible through other methods (Pekrun, 2016). Self-reports of emotions are suggested to be more accurate when they relate to currently experienced emotions (Kreibig, 2010). Even in this case, not all individuals are aware of and/or capable of reporting their momentary emotional states accurately (Mauss & Robinson, 2009). Despite the degree of their accuracy, subjective emotional experiences, emotional interpretations, and emotional memories have been shown to have substantial effects on individuals' beliefs, choices of action, psychological well-being, and even in broader life paths (Pekrun, 2017).

Psychophysiological measures during emotion-evoking situations can provide valuable information about activation of the autonomic nervous system (ANS; Dawson et al., 2007; Levenson, 2014) that is not under direct voluntary control (Jänig, 1989). The purpose of the ANS is to maintain homeostasis and adjust the body to changing circumstances. The ANS is divided into excitatory sympathetic nervous system (SNS) and inhibitory parasympathetic nervous system (PNS) that interact to produce physiological reactions in emotional situations (Berntson et al., 1991). During physical or psychological stress, the SNS's activity dominates as evidenced by increased heart rate (HR) and increased skin-conductance response (SCR; changes in the skin's electrical properties depending on the quantity of sweat; Boucsein, 2012) to aid in adapting to a challenge. During periods of safety and stability, the PNS dominates as evidenced by decreased heart rate and increased heart rate variability (HRV; Beauchaine, 2001; Crowell et al., 2014; Porges, 2007). Heart rate variability describes variation in the time interval between heartbeats and reflects how much cardiac activity is modulated to meet changing situational demands (Berntson et al., 1997).

An important question is how much the subjectively experienced emotions and related physiological activation/deactivation converge vs. diverge when aiming to understand a person's emotional state. Previous research suggests that emotional responses are structured along two dimensions: valence (pleasure vs. displeasure) and arousal (activation vs. deactivation) (Barrett, 2006; Levenson, 2014). Research conducted on adult samples has shown that HR tends to increase for negative (e.g., anger, anxiety, or fear) and positive (e.g., pleasure, happiness, or joy) experienced emotions, as well as for surprise (Kreibig, 2010). In turn, HR tends to decrease in experienced emotions involving passivity (deactivation), such as noncrying sadness and contentment (Porges, 2001). Similarly, SCR decreases tend to co-occur with deactivating experienced emotions, like noncrying sadness, contentment, and relief (Kreibig, 2010), whereas other emotions are accompanied by increased SCR (Benedek & Kaernbach, 2010).

Adolescence is an interesting age to assess associations between subjectively experienced emotions and related physiological activation/deactivation because neural networks regulating one's emotions, cognitions, and behavior continue to develop and mature during adolescence (Best & Miller, 2010). Influenced by pubertal hormonal changes and social stressors, adolescents are increasingly prone to mood swings and diminished impulse control (Dahl & Gunnar, 2009). Mauss et al. (2005) took a within-subject approach to studying associations between subjectively experienced emotions, emotion expression, and SNS activation while watching film. The results revealed that during amusement emotion experience and expression were moderately related to HR and SCR, whereas for sadness emotion experience and expression were unrelated to HR and negatively related to SCR. Using a relatively ecologically valid situation, Hubbard et al. (2004), in turn, found that within-individual concordance among experience, expression, and SNS activation in an anger context (playing a game for a prize where the opponent cheats) predicted second graders' tendencies to reactively aggress. Zalewski et al. (2011), in turn, found that distinct typologies of preadolescent frustration regulation differentially predicted both internalizing and externalizing problems. Lanteigne and colleagues (2014) showed that between-subjects concordance in emotional experience, related SNS activation, and expression of emotions was weak or nonexistent among adolescent girls under social stress when giving a spontaneous speech. By contrast, within-subjects associations revealed that stronger experienced self-conscious affect during the spontaneous speech was related to girls' greater shame and that girls with stronger self-reported emotions together with low arousal had more difficulty in regulating their emotions and more internalizing problems.

The degree of congruence between emotional systems likely depends on many situational, contextual, and individual factors. First of all, it has been generally predicted that concordance should increase with emotion intensity (Davidson, 1992; Mauss et al., 2005; Mulligan & Sherer, 2012). Full concordance may be possible only in extreme circumstances, such as when experiencing fear in violent and life-threatening situations. Modern challenges are typically less direct than the extreme environmental pressures and thus strong concordance between emotional systems may be relatively rare (Hollenstein & Lanteigne, 2014). Second, a person's regulatory efforts to disrupt emotional processes (e.g., suppression of expression, reappraisal, or relaxation to modulate physiological arousal) contribute to congruence between emotional systems (Butler et al., 2014; Dan-Glauser & Gross, 2013). Finally, in previous research, there has been the relative neglect of different moderators of emotion processes (Hollenstein & Lanteigne, 2014).

As far as we know, only little is known about the congruence of adolescents' emotional systems in achievement situations and about possible moderators of this congruence. Increased understanding of the congruence of adolescents' emotional systems might help in designing interventions to promote positive and adaptive emotional patterns and emotion-regulation strategies in order to maximize adolescents' learning and achievement potential. Adolescents frequently experience a variety of emotions, such as enjoyment, hope, pride, anger, anxiety, shame, hopelessness, and boredom, when taking tests, attending classes, and doing homework (Pekrun et al., 2011). Essentially, achievement emotions have been shown to influence students' motivation, learning strategies, and even learning outcomes (Pekrun, 2006, 2017). In this study, adolescents' emotions and related psychophysiological reactions were investigated in simulated achievement situations aiming to evoke achievement emotions. The participants were given challenging and nonchallenging tasks that presented cognitive load and required similar reasoning that is typical for school tasks. Students were instructed to do their best and to try to be as quick as possible. Throughout the tasks, they were able to see how much time remained for task completion. We expected task challenge to play a role in the intensity of experienced emotions prompted by experimental tasks such that, compared to the nonchallenging task, the challenging task would evoke more negative emotions and fewer positive emotions among adolescents (Lehikoinen et al., 2019).

Furthermore, four potential moderators of associations between subjectively experienced emotions and psychophysiological reactions were considered—that is, gender, depressive symptoms, hyperactivity, and cognitive ability. These factors might be connected to the degree of congruence between emotional systems, for example, through their contribution to the intensity of experienced emotions in achievement situations and emotion-regulation abilities in the face of a task challenge (see also Hollenstein & Lanteigne, 2014). Previous research has shown that adolescent girls have higher rates of psychological symptoms related to challenges in emotion regulation (Aldao et al., 2010) and that there may be gender differences in activation/deactivation of PNS and SNS (Koenig & Thayer, 2016). Previous research has also shown that depressed individuals are more prone to experience enhanced negative emotions and diminished positive emotions (Polanczyk et al., 2015). These individuals have also been shown to have a maladaptive selective attention mechanism, associated with bias toward negative stimuli (Lichtenstein-Vidnea et al., 2017), as well as to have challenges in physiological regulation of emotions (Crowell et al., 2014). Similarly, adolescents with hyperactivity and low abilities may be more vulnerable to experiencing negative emotions and have difficulties in their regulation when challenged (see also Beauchaine & Cicchetti, 2019; Jensen & Rosén, 2014). For example, evidence suggests hyperactivity is linked to the low activation of the ANS in cognitively challenging tasks (Beauchaine et al., 2013; Ward et al., 2015), possibly indicating failure in emotion regulation in demanding situations.

The Research Questions and Hypotheses

This study examined associations of adolescents' subjectively experienced emotions (i.e., enjoyment, hope, surprise, anger, anxiety, fear, and hopelessness) and physiological reactions (SCR, HR, and HRV) during simulated achievement situations of challenging and nonchallenging tasks aiming to evoke achievement emotions. Additionally, we investigated whether the associations between adolescents' experienced emotions and psychophysiological reactions differ depending on adolescent gender, hyperactivity, depressive symptoms, and cognitive ability. Task performance was controlled for in the analyses as it was expected to be related to adolescents' achievement emotions (Pekrun, 2017).

Based on previous research among adults (Kreibig, 2010), we expected that adolescents' activating self-experienced emotions would be related to increased SNS (HR and SCR) activation and decreased PNS (HRV) activation, whereas deactivating self-experienced emotions were expected to relate to decreased SNS (HR and SCR) activation and increased PNS (HRV) activation. As we expected, gender, hyperactivity, depressive symptoms, and cognitive ability to play a role in the intensity of experienced emotions in achievement situations (Beauchaine & Cicchetti, 2019; Fujita et al., 1991; Polanczyk et al., 2015) and as congruence of emotional systems should increase with emotion intensity (Davidson, 1992; Mauss et al., 2005; Mulligan & Sherer, 2012), we also tentatively expected stronger associations between emotional systems for adolescents with more depressive symptoms and hyperactivity and less cognitive ability compared to other adolescents (see also Hollenstein & Lanteigne, 2014).

Methods and Materials

Participants and Procedure

The study comprised 190 Finnish sixth-graders (mean age = 12.31 years; age *SD* = 0.38 years; 47% girls) from 52 different school classes drawn from the larger community sample of about 850 students. Those in this study participated in an experiment with challenging and nonchallenging achievement tasks in Grade 6's spring semester. Parents' written consent and students' assent was required for participation. Experimental procedures involving human subjects were performed according to European Union guidelines and approved by the local university's ethical committee.

In an experiment, the participants were assigned tasks that presented cognitive load and required similar reasoning that is typical to school tasks, the Raven's progressive matrices measuring nonverbal reasoning (Lehikoinen et al., 2019; Raven et al., 1998). In order to eliminate the effect of the task order on the findings, one-half of adolescents (n = 97) were randomized to complete, first, a nonchallenging task and, second, a challenging task; whereas other half of students (n = 93) were randomized to complete, first, a challenging task and, second, a nonchallenging task. Between the actual tasks, the participants completed intervening tasks intended to focus their attention away from the experimental situation (i.e., they were shown two student jokes and asked to rate which joke was better) so as to eliminate possible carryover effects. The time limit for each achievement task was 4 min, and 28–30 Raven matrix items were shown both in the challenging task and in the nonchallenging tasks, depending on the difficulty level. The tasks were completed by using a touch-screen computer. Students were instructed to do their best as quickly as possible.

Throughout the task, they were able to see how much time remained for task completion. The students did not receive any external feedback regarding their performance. Altogether the individual assessments took approximately 1½ hr, of which the simulated achievement situation with questionnaires and challenging and nonchallenging Raven tasks took about 15 min.

In order to guarantee equal cognitive demand for all the students within both conditions (challenging and nonchallenging), the students were exposed to these conditions according to their personal skill level. The Raven items' difficulty level in challenging and nonchallenging tasks was individually adapted according to skill levels based on previous scores in the standard Raven matrices task (Raven et al., 1998) performed approximately 6 months earlier. Individual differences in nonverbal reasoning have been shown to be highly stable across time (Rönnlund et al., 2015), and notable changes in rank-order stability of nonverbal reasoning were not expected within 6 months among sixth graders. Individual adaptation of task challenge was accomplished as follows. First, based on the previous data from Grade 6 fall, the Raven items were divided into six separate difficulty levels (1 = *easiest*; 6 = *most difficult*). Second, based on their previous (Grade 6 fall) performance on the Raven, the adolescents were divided into three skill groups: (1) low performance = lowest quartile, (2) medium performance = between lowest quartile and highest quartile, and (3) high performance = highest quartile. Third, the adolescents in each skill group were further randomized to first either a nonchallenging task or a challenging task. Based on their skill level and randomized task condition, the Raven items were administered to the adolescents in the following way: Adolescents in the low-performance group were given tasks from difficulty levels 1–2 in the nonchallenging task condition and from difficulty levels 3–4 in the challenging task condition, adolescents in the medium-performance group received tasks from difficulty levels 2–3 in the nonchallenging task condition and from difficulty levels 4–5 in the challenging task condition, and adolescents in the high-performance group were given tasks from difficulty levels 3–4 in the nonchallenging task condition and from difficulty levels 5–6 in the challenging task condition. Items on difficulty levels 1–4 were obtained from Raven Standard Matrices (Raven et al., 1998), and items on difficulty levels 5–6 were obtained from Raven Advanced Matrices (Raven et al., 1998).

The experiment was performed during normal school hours in the schoolyard, using a campervan with a built-in ambulatory laboratory. Each testing session included two trained testers: a principal and an assistant tester. During test sessions, adolescents' SCR and finger pulse volume (FPV) were registered by using a BrainVision QuickAmp amplifier and BrainVision Recorder 2.0 software (both from Brain Products GmbH, Gilching, Germany). Their facial expressions were videorecorded. Adolescents' HR was registered by using the BodyGuard (Firstbeat Technologies, Jyväskylä, Finland) system. The Bodyguard and BrainAmp recording systems' data were synchronized by using an algorithm to precisely calculate the same time points, using HR and FPV, both of which measured heartbeat (Lampinen et al., 2018). During the test sessions, the students also filled in short computerized questionnaires on their emotional experiences.

Measures During Achievement Tasks

Self-reports

Adolescent reports of emotions

Students' self-reported emotions were measured separately for the challenging achievement task and the nonchallenging achievement task, immediately after students had completed each task by asking *"How did you feel during the task?"* The items used from the Emotions in Achievement Situations (EAS) scale (see Lehikoinen et al., 2019) with a 5-point Likert scale ranging from 1 (*disagree*) to 5 (*agree*) measured separately during the challenging task and the nonchallenging task were the following: (1) *I was enthusiastic (enjoyment);* (2) *I was optimistic that I could do the task (hope);* (3) *I was surprised (surprise);* (4) *I was angry/irritated (anger);* (5) *I was nervous/restless (anxiety);* (6) *I feared failing (fear);* and (7) *I felt hopeless (hopelessness)*. Items' test–retest reliabilities were good (above .70).

ANS Measurements

SCR

Adolescents' skin conductance was recorded by using two disposable electrodes (Ag/AgCI and AmbuNeurolone 710) on the palm of each adolescent's nondominant hand, below the first and fourth digits. The electrodes were connected to a QuickAmp skin-conductance module (Brain Products GmbH), which determines skin conductance with a DC instrumentation amplifier by using 0.5 V constant voltage. The signal was amplified in DC mode and low-pass filtered at 250 Hz. The baseline was the relaxed and calm everyday discussion about daily activities prior to the actual test situation, lasting approximately 5 min (see also Lehikoinen et al., 2019). Skin-conductance data were divided into phasic and tonic SC components by using the LEDALAB (V.3.4.6) toolbox for MATLAB (Benedek & Kaernbach 2010). Values were down sampled to 1 Hz, corresponding to the sampling rate of calculated heart rate variables (see also Lampinen et al., 2018). Because of tasks' short duration, analyses targeted phasic SCRs. First, SCR values for each participant were normalized according to the mean and standard deviation of each student's baseline by subtracting the mean of the baseline and dividing by the standard deviation of the baseline. Subsequently, the sum of peaks (above +2 standard deviations) in the normalized SCRs were calculated and divided by the length of the task period separately for challenging and nonchallenging tasks.

HR and HRV

Heartbeat data were measured by using a Firstbeat Bodyguard recording device (Firstbeat Technologies; www.firstbeat.com) recording continuously at a 1,000-Hz sampling rate. The device's two recording electrodes were positioned under the collarbone on the body's right side and the ribcage on the left. Heartbeat data were automatically artifact-corrected with the web-based Lifestyle assessment software using a proprietary algorithm (Firstbeat Technologies, 2014). The software calculated several heartbeat variables and stored results at 1-Hz resolution. HR and HRV were the variables used in this study. HRV was determined by calculating the root mean square of successive heartbeat differences by using a 5-min window centered on each time point (for a more detailed description, see also Goedhart et al., 2007; Penttilä et al., 2001). All raw values for HR and HRV were normalized like the SCRs according to the mean and standard deviation of each student's baseline by subtracting the mean of the baseline and dividing by the standard deviation of the baseline. Each adolescent's means were calculated across normalized HR and HRV separately for challenging and nonchallenging tasks.

Moderators

Gender. Gender was coded as follows: 0 = girl and 1 = boy

Hyperactivity

Classroom teachers, who have an opportunity to observe adolescents in many kinds of learning and achievement situations in the school context (see also Burgess et al., 2006; Klenberg et al., 2017), provided ratings about adolescents' hyperactivity by using a five-item hyperactivity/inattention scale (e.g., restless, overactive, cannot stay still; 0 = *not true*, 2 = *certainly true*) from the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997). A mean score was calculated across the five items ($\alpha = .88$).

Depressive symptoms
Adolescents reported depressive symptoms by using the 10-item (e.g., I felt sad, 0 = *not at all*, 3 = *very much*) Depression Scale (DEPS; Salokangas et al., 1995). DEPS has proven useful for depression, with diagnostic and predictive validity (Poutanen et al., 2007). A mean score was calculated across the 10 items (α = .92).

Cognitive ability
The Raven Standard Progressive Matrices (Raven et al., 1998) assessed adolescents' cognitive ability in the fall of Grade 6. Raven's test consists of diagrams with one part missing. In this study, only half the items were used and alternating items were picked for presentation (see also McMullen et al., 2019). Responses were scored correct or incorrect; the maximum score was 30 (α = .81).

Control Variables

Task performance
This was assessed as the number of correct answers. Task-performance score was calculated separately for the challenging and nonchallenging Raven tasks.

Statistical Analyses

Descriptive statistics for challenging and nonchallenging task conditions were explored first. The actual statistical analyses were performed by using a multilevel modeling technique (Heck & Thomas, 2015; Muthén & Muthén, 1998–2020), where repeated measurements (i.e., challenging and nonchallenging task conditions; level 1; within—person level) were nested within individuals (level 2; between-person level). Together with the two-level analyses, the Type = Complex approach (Muthén & Muthén, 1998–2020) was applied to account for the third possible level—that is, classroom level. This method corrects possible distortions of standard errors in the estimation that are caused by the clustering of observations (classroom differences). Multilevel modeling enabled us to investigate associations between self-reported emotions and ANS variables simultaneously at within-person and between-person levels when accounting for classroom differences, as well as to include within- and between-level predictors in the models.

Two-level complex models were conducted along the following steps. First, intraclass correlations and within-and between-variance estimates were calculated for emotion variables and task performance to determine what proportion of the variance in observed variables is attributed to differences between individuals (between-person variation) and what proportion of the variance is attributed to differences between task conditions (i.e., challenging vs. nonchallenging) within individuals (i.e., within-person variation). Second, within-person and between-person-level correlations between emotional variables were investigated. Correlations of task performance with emotional variables were also examined at the within-person level, whereas correlations of between-level variables—that is, gender, hyperactivity, depressive symptoms, and cognitive ability with emotional variables—were examined at the between-person level. Finally, separate multilevel models to predict each of the seven self-reported emotions (i.e., enjoyment, hope, surprise, anger, anxiety, fear, and hopelessness) were constructed. At the within-person level, self-reported emotions were predicted by ANS variables (i.e., SCR, HR, and HRV) and task performance, whereas, at the between-person level, self-reported emotions were predicted by ANS variables (i.e., SCR, HRV, and HRV), moderator variables (i.e., gender, hyperactivity, depressive symptoms, and cognitive ability) and interaction terms between ANS variables and moderators (i.e., SCR × gender, SCR × hyperactivity, SCR × depressive symptoms, SCR × cognitive ability, HR × gender, HR × hyperactivity, HR × depressive symptoms, HR × cognitive ability, HRV × gender, HRV × hyperactivity, HRV × depressive symptoms, and HRV × cognitive ability).

The analyses were performed by using the Mplus statistical package (Version 8.4; Muthén & Muthén, 1998–2020). The data set had no missing data (0%) in youth-rated emotions. In turn, the SCR information was missing for 18% and HR and HRV information for 23% of adolescents. For moderator variables, the proportion of missingness varied 0%–2%. The parameters of the models were estimated by using full-information maximum likelihood that allowed us to use all the information in the data with nonnormality robust standard errors (Muthén & Muthén, 1998–2020).

Results

Descriptive Statistics (Table 1)

Descriptive statistics are listed in Table 1. Adolescents' self-reported positive emotions were relatively high, and negative emotions low. Adolescents reported less enjoyment (d = 0.25), less hope (d = 0.24), more anger (d = 0.13), more anxiety (d = 0.29), and more hopelessness (d = 0.18) in the challenging task than in the nonchallenging task. Adolescents' task performance was substantially higher in the nonchallenging than in the

Table 1. Means and standard deviations of observed variables during achievement tasks (N = 146–190)

	Challenging task		Nonchallenging task	
Variable	*M*	*SD*	*M*	*SD*
Self-reported emotions				
Enjoyment	3.22	1.08	3.48	1.09
Hope	3.52	0.94	3.75	0.88
Surprise	3.18	0.93	3.09	0.97
Anger	1.25	0.61	1.18	0.47
Anxiety	1.63	0.94	1.39	0.70
Fear	2.19	1.15	2.08	1.03
Hopelessness	1.63	0.96	1.47	0.77
ANS variables				
SCR	2.15	3.98	2.39	4.36
HR	–1.00	1.42	–1.07	1.44
HRV	0.33	1.28	0.32	1.32
Control variable				
Task performance	8.70	2.83	19.64	5.40

Note. ANS = autonomic nervous system; HR = heart rate; HRV = heart rate variability; SCR = skin-conductance response.

challenging task (d = 2.54). In turn, no marked mean differences between task conditions were found in psychophysiological reactions.

Intraclass Correlations and Within- and Between-Person Variance Estimates (Table 2)

Intraclass correlations (ICCs) were calculated for emotion variables and task performance to determine what proportion of the variance in observed variables is attributed to differences between individuals (between-person variation) and what proportion of the variance is attributed to differences between task conditions (i.e., challenging vs. nonchallenging) within individuals (i.e., within-person variation). ICCs and within- and between-variance estimates of observed variables are listed in Table 2. The results for subjectively experienced emotions revealed that variance

Table 2. Intraclass correlations and between-person and within-person-level variance estimates of observed variables ($n_{between}$ = 292–380, n_{within} = 146–190)

Variable	ICC	Between-level		Within-level	
		Variance	*SE*	Variance	*SE*
Self-reported emotions					
Enjoyment	.68***	0.81***	0.09	0.38***	0.05
Hope	.55***	0.46***	0.08	0.38***	0.06
Surprise	.27***	0.24***	0.08	0.65***	0.08
Anger	.64***	0.19***	0.04	0.11***	0.02
Anxiety	.39***	0.27***	0.07	0.43***	0.07
Fear	.57***	0.67***	0.09	0.51***	0.05
Hopelessness	.50***	0.37***	0.09	0.38***	0.07
ANS variables					
SCR	.98***	16.99***	4.32	0.34**	0.11
HR	.89***	1.81***	0.28	0.23***	0.03
HRV	.62***	1.04***	0.17	0.63**	0.19
Control variable					
Task performance	.002	0.12	0.38	48.49***	1.89

Note. ANS = autonomic nervous system; HR = heart rate; HRV = heart rate variability; ICC = intraclass correlation; SCR = skin-conductance response; *SE* = standard error.

*** $p < .001$.

was significant at both between and within levels. A total of 27%-68% of the total variation was explained by differences between individuals, whereas the rest of the variation was explained by differences within individuals between task conditions. Between-person differences were most stable for enjoyment and anger, whereas variation within individuals between task conditions was largest in surprise.

For ANS variables 62%–98% of the total variance was explained by differences between individuals. Differences within individuals and between task conditions were small but still statistically significant. Finally, all of the variance in task performance was explained by the task condition, leaving no significant variance to predict at the between-person level.

Within- and Between-Person-Level Correlations Between Self-Reported Emotions and ANS Variables During Achievement Situations (Table 3)

Table 3 presents correlations between self-reported emotions and ANS variables. Within-person correlations are listed below the diagonal, and between-person correlations are listed above the diagonal. Table 3 also shows how task performance is correlated with emotional variables at the within level and how gender, hyperactivity, depressive symptoms, and cognitive ability are correlated with emotional variables at the between level.

Within-measurement modality results showed that self-reported emotions correlated weakly to moderately strongly other (e.g., enjoyment was positively associated with hope but negatively associated with anger) both at within- and between-person levels. SCR also correlated moderately positively with HR, which correlated moderately negatively with HRV. Between-person correlations were somewhat larger than within-person correlations.

Between-measurement modality results showed at the between-person level that increased HRV was moderately and negatively associated with lower self-reported hope, whereas decreased SCR was related to higher self-rated hopelessness (deactivating emotion). At the within-person level, in turn, increased HRV was moderately and negatively associated with lower self-reported surprise. Other between- and within-level correlations between self-reported emotions and ANS variables were not statistically significant.

The within-person-level results showed further that high task performance was associated with a higher level of enjoyment and hope and lower levels of anger, anxiety and hopelessness. In addition, high task performance was related to increased SCR. Finally, between-person-level results showed that in comparison to boys being a girl was related to higher levels of enjoyment, fear, and SCR and but lower HRV. High hyperactivity was related to lower levels of hope and SCR and higher levels of anger, anxiety and hopelessness. High depressive symptoms, in turn, were related to a lower level of hope and a higher level of surprise, anger, anxiety, fear, and hopelessness. Finally, low cognitive ability was related to a higher level of surprise in achievement situations.

Table 3. Correlations of observed variables (between-person level above the diagonal and within-person level below the diagonal), ($n_{between}$ = 292–380, n_{within} = 146–190)

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. SR Enjoyment	–	.52[a]	.48[a]	–.31[b]	–.30[b]	–.03	–.21	–.13	–.08	–.05	–	–.14[c]	–.01	–.06	.01
2. SR Hope	.38[a]	–	.15	–.34[b]	–.46[b]	–.34[b]	–.36[b]	.06	.14	–.27[b]	–	.07	–.17[c]	–.20[c]	.13
3. SR Surprise	–.06	–.02	–	.01	.17	.42[b]	.16	.03	.08	–.18	–	.04	.12	.22[b]	–.21[c]
4. SR Anger	–.20[c]	–.14[c]	.03	–	.82[a]	.40[a]	.59[a]	–.08	.01	.05	–	.13	.27[b]	.28[b]	–.06
5. SR Anxiety	–.21[c]	–.11	.01	.14	–	.64[a]	.66[a]	–.09	.07	–.08	–	.03	.21[c]	.45[a]	.05
6. SR Fear	–.08	–.17[c]	.04	.13	.16	–	.65[a]	–.09	.09	.07	–	–.21[c]	.04	.36[a]	–.05
7. SR Hopelessness	–.23[c]	–.26[c]	.04	.28[a]	.26[c]	.38[a]	–	–.22[b]	.01	.02	–	.04	.20[c]	.34[b]	–.11
8. SCR	.02	.06	–.06	–.10	–.04	.04	–.04	–	.30[a]	–.06	–	–.17[c]	–.18[b]	–.10	–.07
9. HR	–.01	–.01	.01	.11	–.01	–.05	.02	.11[c]	–	–.42[a]	–	–.12	.01	.02	–.01
10. HRV	.07	–.05	–.28[a]	.03	.04	–.04	.00	–.15[c]	–.38[a]	–	–	–.21[c]	.07	–.03	–.11
11. Task performance	.20[a]	.21[b]	–.04	–.21[a]	–.22[a]	–.13	–.21[a]	.26[a]	.05	.02	–	–	–	–	–
12. Gender[d]	–	–	–	–	–	–	–	–	–	–	–	–	.40[a]	.04	.08

Continued

Table 3. Correlations of observed variables (between-person level above the diagonal and within-person level below the diagonal), ($n_{between}$ = 292–380, n_{within} = 146–190) (*Continued*)

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
13. Hyperactivity	–	–	–	–	–	–	–	–	–	–	–	–	–	.31[a]	–.18[c]
14. Depr. symptoms	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–.16[c]
15. Cognitive ability	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

Note. Task performance = within-person-level variable; hyperactivity, depressive symptoms, and cognitive ability = between-person variables; other variables are analyzed both at within- and between-person levels. HR = heart rate; HRV = heart rate variability; SCR = skin-conductance response; SR = self–rating.

[a] $p < .001$. [b] $p < .01$. [c] $p < .05$. [d] 0 = girl, 1 = boy.

Multilevel Models to Predict Self-Reported Emotions With ANS Variables and Exploring Moderators of These Associations

Finally, separate multilevel path models to predict each of the seven self-reported emotions (i.e., enjoyment, hope, surprise, anger, anxiety, fear, and hopelessness) were constructed. At the within-person level, self-reported emotions were simultaneously predicted by ANS variables (i.e., SCR, HR, and HRV) and task performance, whereas, at the between-person level, self-reported emotions were simultaneously predicted by ANS variables (i.e., SCR, HRV, and HRV), moderator variables (i.e., gender, hyperactivity, depressive symptoms, and cognitive ability), and interaction terms between ANS variables and moderators. The results of these multilevel models are shown in Table 4.

The within-person-level results showed, first, that, after accounting for the effects of the other variables in the model, high task performance significantly predicted higher levels of enjoyment and hope and lower levels of anger, anxiety, fear, and hopelessness. Furthermore, decreased HRV (PNS activation) predicted a higher level of self-reported surprise.

The results at the between-person level showed that increased HR was related to higher levels of self-reported hope and fear. In turn, decreased HRV predicted a higher level of self-reported surprise. Furthermore, being a girl predicted a higher level of self-reported enjoyment, whereas a high level of depressive symptoms predicted higher levels of surprise, anger, anxiety, fear, and hopelessness. No significant main effects of hyperactivity and cognitive ability were detected.

Finally, eight interaction terms between moderators (i.e., gender, hyperactivity, depressive symptoms, and cognitive ability) and ANS variables (i.e., SCR, HR, and HRV) were significant when predicting self-reported emotions at the between-person level. First, the results showed that gender moderated the associations of HRV with enjoyment, hope, and hopelessness (see Figure 1) such that for boys increased HRV was related to lower enjoyment, lower hope, and higher hopelessness, whereas for girls increased HRV was related to higher enjoyment, higher hope, and lower hopelessness.

Second, hyperactivity moderated the associations of SCR with enjoyment and hope (see Figure 2) such that, for adolescents with high hyperactivity, decreased SCR was related to higher levels of enjoyment and hope. For adolescents with low hyperactivity, SCR was unrelated to enjoyment and hope.

Third, depressive symptoms moderated the association between HR and surprise (see Figure 3) such that increased HR was related to higher

Table 4. Multilevel models: Predicting self-reported emotions with autonomous nervous system (ANS) variables and moderators

	Dependent variable													
	SR enjoyment		SR hope		SR surprise		SR angry		SR anxiety		SR fear		SR hopelessness	
	Within-level		Within-level		Within-level		Within-level		Within-level		Within-level		Within-level	
Independent variable	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*
SCR	.02	.15	.40	.31	–.11	.18	–.45	.46	–.32	.28	.10	.23	.10	.29
HR	.06	.22	–.11	.14	–.21	.24	.27	.28	–.03	.10	.27	.15	–.00	.19
HRV	.13	.16	–.07	.09	–.46***	.08	.10	.10	–.01	.07	–.13	.11	–.01	.11
Task performance	.20**	.06	.19**	.07	–.05	.05	–.17*	.07	–.22***	.05	-.13*	.06	–.20***	.04
R^2 (within)	R^2 = .05		R^2 = .18		R^2 = .20		R^2 = .23		R^2 = .15		R^2 = .07		R^2 = .05	
	Between-level		Between-level		Between-level		Between-level		Between-level		Between-level		Between-level	
Independent variable	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*
SCR	–.28	.18	–.34	.25	.21	.33	.38	.41	.39	.33	–.12	.22	–.26	.32
HR	–.17	.27	.30*	.15	.31	.33	–.18	.22	–.01	.14	.42*	.21	–.10	.23
HRV	–.07	.16	.03	.16	–.62**	.22	–.08	.13	–.03	.14	.23	.20	–.07	.19
Gender[a]	–.36***	.08	.05	.10	.12	.10	.14	.08	.05	.09	–.19	.10	–.04	.11
Hyperactivity	.14	.10	–.13	.08	.03	.09	.19	.12	.14	.10	.00	.10	.10	.11
Depressive symptoms	–.15	.09	–.16*	.08	.22**	.07	.29**	.11	.48***	.13	.40***	.10	.30**	.10

Independent variable	Dependent variable													
	SR enjoyment		SR hope		SR surprise		SR angry		SR anxiety		SR fear		SR hopelessness	
	Within-level		Within-level		Within-level		Within-level		Within-level		Within-level		Within-level	
	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*
Cognitive ability	.03	.07	.07	.08	–.13	.09	–.01	.08	.10	.10	.02	.09	–.08	.09
SCR × Gender	.00	.11	–.11	.09	.07	.10	.10	.09	. 05	.10	.14	.08	.03	.10
SCR × Hyperactivity	–.30**	.11	–.18*	.09	.10	.13	.23	.15	.21*	.11	–.12	.07	.15	.09
SCR × Depr. symptoms	.18	.10	.14	.11	.12	.07	–.03	.09	–.02	.09	.08	.08	–.01	.10
SCR × Cognitive ability	.03	.11	.03	.09	–.07	.15	.10	.09	–.11	.10	–.15	.08	–.05	.09
HR × Gender	–.06	.22	–.18	.16	.14	.28	.11	.15	.16	.14	–.11	.16	.24	.18
HR × Hyperactivity	.08	.15	.03	.12	–.03	.18	.05	.13	–.03	.10	.16	.14	–.11	.12
HR × Depr. symptoms	–.05	.11	.04	.10	.22*	.11	.04	.10	.05	.10	–.01	.12	–.05	.12

Continued

Table 4. Multilevel models: Predicting self-reported emotions with autonomous nervous system (ANS) variables and moderators (*Continued*)

	Dependent variable													
	SR enjoyment		SR hope		SR surprise		SR angry		SR anxiety		SR fear		SR hopelessness	
	Within-level		Within-level		Within-level		Within-level		Within-level		Within-level		Within-level	
Independent variable	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*	Stand β	*SE*
HR × Cognitive ability	–.24	.15	–.13	.10	.08	.14	.12	.11	.15	.11	.14	.12	.14	.15
HRV × Gender	–.32*	.13	–.27*	.12	–.21	.16	.20	.15	.14	.16	–.06	.16	.29*	.16
HRV × Hyperactivity	.07	.11	.07	.10	.10	.13	–.06	.11	.04	.11	.22	.14	–.19	.12
HRV × Dep. symptoms	–.06	.07	.03	.07	.04	.09	.07	.10	.09	.12	.06	.11	.10	.11
HRV × Cognitive ability	–.15	.13	–.06	.11	–.13	.11	.17	.13	.25*	.12	.13	.13	.20	.16
R^2 (between)	R^2 =.25		R^2 = .29		R^2 = .55		R^2 = .25		R^2 = .35		R^2 = .34		R^2 = .35	

Note. Paths are presented as standardized estimates. HR = heart rate; HRV = heart rate variability; SCR = skin-conductance response.
*** $p < .001$. ** $p < .01$. * $p < .05$. [a] 0 = girl, 1 = boy. Correlations between predictors were allowed.

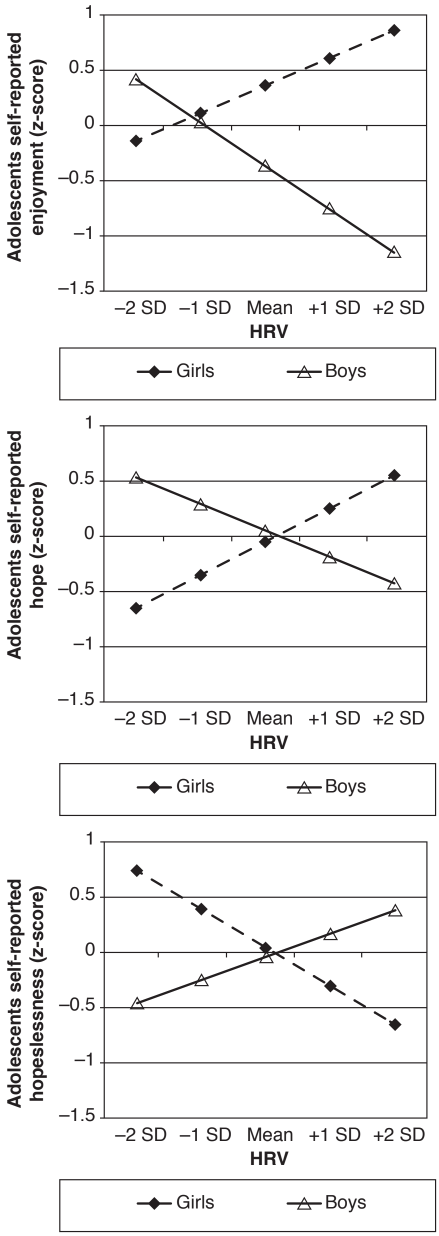

Figure 1. Adolescent gender as a moderator of the associations between heart rate variability (HRV) and self-reported emotions: (top) between HRV and enjoyment, (middle) between HRV and hope, and (bottom) between HRV and hopelessness.

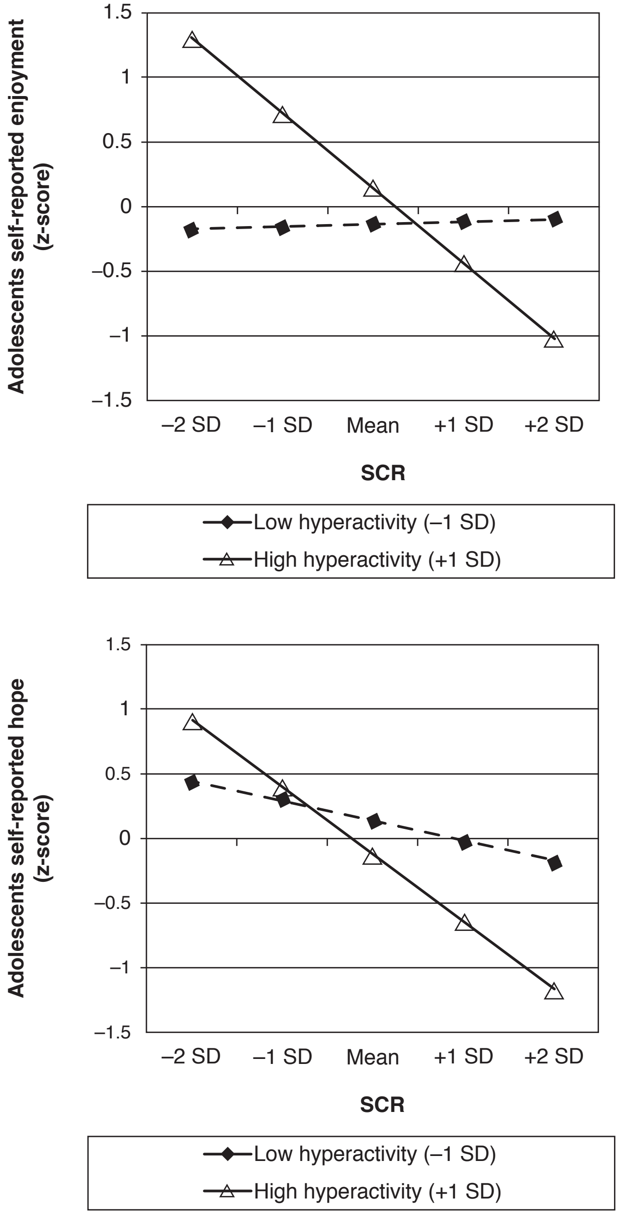

Figure 2. Adolescent hyperactivity as a moderator of the associations between skin-conductance response (SCR) and self-reported emotions: (top) between SCR and enjoyment, and (bottom) between SCR and hope.

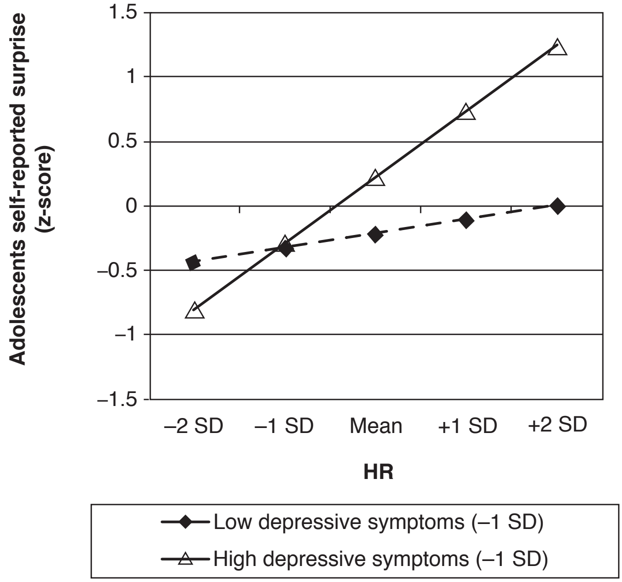

Figure 3. Adolescent depressive symptoms as a moderator of the associations between heart rate (HR) and self-experienced surprise.

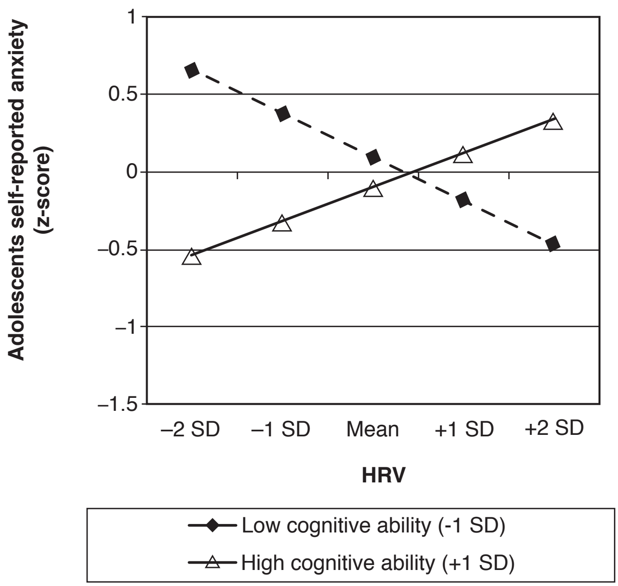

Figure 4. Adolescent cognitive ability as a moderator of the associations between heart rate variability (HRV) and anxiety.

level of surprise especially for adolescents with high depressive symptoms. For adolescents with low depressive symptoms, HR was unrelated to surprise.

Finally, cognitive ability moderated the association between SCR and fear and the association between HRV and anxiety (see Figure 4) such that, especially for adolescents with low cognitive ability, decreased HRV (PNS activation) was related to a higher level of anxiety, whereas, for adolescents with high cognitive ability, decreased HRV was weakly related to a lower level of anxiety.

Discussion

This study provided a novel understanding of the associations between adolescents' subjectively experienced emotions (i.e., enjoyment, hope, surprise, anger, anxiety, fear, and hopelessness) and psychophysiological reactions during simulated achievement situations with a varying task challenge aiming to evoke achievement emotions. As expected, task challenge played a role in the intensity of experienced emotions prompted by experimental tasks, such as that compared to the nonchallenging task adolescents reported less enjoyment, less hope, more anger, more anxiety and more hopelessness during the challenging task. Adolescents' task performance was also substantially higher in the nonchallenging task than in the challenging task, suggesting that the manipulation of the level task challenge was successful. High task performance was associated with a higher level of enjoyment and hope and lower levels of anger, anxiety, and hopelessness. No marked mean differences between task conditions were found in psychophysiological reactions. However, high task performance was related to increased SCR (SNS activation).

Our main aim was to investigate congruence of adolescents' emotional systems (i.e., subjectively experienced emotions and psychophysiological reactions) during achievement tasks intended to evoke achievement emotions. Research questions were analyzed by using a multilevel modeling technique (Heck & Thomas, 2015; Muthén & Muthén, 1998–2020), where repeated measurements (i.e., challenging and nonchallenging task conditions; level 1; within-person level) were nested within individuals (level 2; between-person level). First, *within-measurement-modality results* showed that adolescents' self-reported emotions were moderately and meaningfully associated with one another (e.g., enjoyment was positively associated with hope but negatively associated with anger) both at within- and between-person levels. For psychophysiological responses, the results showed that SCR was moderately positively associated with HR, which was moderately negatively associated with HRV, meaning that increases in SNS activity were visible in SCR and HR. In turn, increases in PNS activity (HRV) decreased HR. The moderate convergence within measurement modalities supports validity of the measures used.

Between-measurement-modality results showed only weak coherence between adolescents self-reported emotions and ANS measures (Mauss & Robinson, 2009). At the within-person level, decreased HRV (PNS deactivation) was found to be moderately associated with higher self-reported surprise in achievement tasks. At the between-person level, increased HR (SNS activation) was related to higher levels of self-reported hope and fear during achievement tasks. This might reflect adolescents' greater enthusiasm, alertness, and task focus shown also at physiological level when completing achievement tasks. In addition, increased HRV measuring the relative activity of PNS activation was moderately and negatively associated with lower self-reported hope (i.e., activating emotion), whereas decreased SCR (deactivation of SNS) was related to higher self-rated hopelessness (de-activating emotion) related to passivity and perhaps also task avoidance. The results suggest that activating emotions were related to SNS activation and PNS deactivation, whereas deactivating emotions (e.g., hopelessness) were related to SNS deactivation.

Our next research question was to examine whether gender, hyperactivity, depressive symptoms, and cognitive ability might moderate the magnitude of the foregoing described associations. Because we expected that gender, hyperactivity, depressive symptoms, and cognitive ability play a role in the intensity of experienced emotions in achievement situations (Beauchaine & Cicchetti, 2019; Polanczyk et al., 2015) and that congruence of emotional systems should increase with emotion intensity (Davidson, 1992; Mauss et al., 2005; Mulligan & Sherer, 2012), we also tentatively expected stronger associations between emotional systems for adolescents with more depressive symptoms and hyperactivity and less cognitive ability compared to other adolescents (see also Hollenstein & Lanteigne, 2014).

First, the results supported our expectations about the role of moderators in the intensity of experienced emotions during achievement tasks (see also Eteläpelto et al., 2018; Mulligan & Sherer, 2012). The between-person-level results showed that, in comparison to boys, girls reported higher levels of enjoyment and fear during achievement tasks (see also Fujita et al., 1991). In addition, being a girl was related to both increased SCR (SNS activation) and increased HRV (PNS activation) during achievement tasks, possibly reflecting girls' more intense experienced emotions and attempts to regulate these emotions during achievement tasks (Beauchaine

& Cicchetti, 2019; Koenig & Thayer, 2016). High hyperactivity was also related to lower levels of hope and decreased SCR (SNS deactivation) and with higher levels of self-experienced anger, anxiety, and hopelessness during achievement tasks. One possible explanation for these findings may relate to challenges in recognizing and regulating emotions for adolescents with high hyperactivity (e.g., Jensen & Rosén, 2004; Martel, 2009). Some previous evidence also points toward atypical functioning of the autonomic nervous system among individuals with high hyperactivity shown particularly as underactivation of ANS (Bellatoa et al., 2020; Marsh et al., 2008; Musser et al., 2011). High depressive symptoms, in turn, were related to a lower level of hope and a higher level of surprise, anger, anxiety, fear, and hopelessness during achievement tasks (see also Lichtenstein-Vidnea et al., 2017; Polanczyk et al., 2015). Finally, low cognitive ability was related to higher level of experienced surprise in achievement situations.

Second, the results revealed that eight interaction terms between moderators (i.e., gender, hyperactivity, depressive symptoms, and cognitive ability) and ANS variables (i.e., SCR, HR, and HRV) were significant when predicting self-reported emotions at the between-person level, partly supporting our tentative hypothesis that associations between self-reported measures and ANS measures would be particularly strong for adolescents with high levels of hyperactivity and depressive symptoms, and low levels of cognitive ability (see also Beauchaine et al., 2013; Ward et al., 2015).

First, the results showed that gender moderated the associations of HRV with enjoyment, hope, and hopelessness (see Figure 1) such that for boys increased HRV (PNS activation) was related to lower enjoyment, lower hope, and higher hopelessness, whereas for girls increased HRV (PNS activation, possibly reflecting an increased level of emotion regulation) was related to higher enjoyment, higher hope, and lower hopelessness. Previous research has suggested that high HRV may be related to proper emotion regulation, decision-making, and attention, whereas low HRV reflects the opposite (Koenig & Thayer, 2016). Boys, who experienced less-intense emotions than girls in achievement emotions, might have been more relaxed in achievement situations, evidenced as increased PNS activation that was related with less-intense experienced emotions.

Second, hyperactivity moderated the associations of SCR with enjoyment and hope (see Figure 2) such that, for adolescents with high hyperactivity, decreased SCR (SNS activation) was related to higher levels of enjoyment and hope. For adolescents with low hyperactivity, SCR was unrelated to enjoyment and hope. These results suggest greater emotional reactivity (Jensen & Rosén, 2004) and/or problems in regulating negative emotions (Martel, 2009) among hyperactive adolescents in cognitively demanding situations.

Third, depressive symptoms moderated the association between HR and surprise (see Figure 3) such that increased HR (SNS activation) was related to higher level of surprise especially for adolescents with high depressive symptoms. For adolescents with low depressive symptoms, HR was unrelated to surprise. These results tentatively suggest stronger physiological activation related to some of the activating emotions for adolescents with depressive symptoms (see also Crowell et al., 2014).

Finally, cognitive ability moderated the association between HRV and anxiety (see Figure 4) such that, especially for adolescents with low cognitive ability, decreased HRV (PNS deactivation) was related to a higher level of anxiety, perhaps reflective of higher alertness and task focus in the situations. In turn, for adolescents with high cognitive ability, increased HRV (PNS activation) was related to a higher level of anxiety. Cognitive systems employ control over emotional regulation (Bell & Wolfe, 2004), so adolescents with lower abilities perhaps experience difficulty with down-regulating negative emotions when facing academic challenges that possibly remind them of previous school failures. Previous research has shown that children have typically more HRV activation for negative than positive emotions (Musser et al., 2011). In this study, adolescents with average/high cognitive ability actually had higher HRV when they experienced anxiety. This finding seems to align with other research that finds high rates of tonic HRV reflect general psychophysiological flexibility or preparedness for adaptation (e.g., Beauchaine, 2001; Butler et al., 2006), whereas low tonic HRV is thought to reflect less capacity for flexible responsiveness (e.g., Ode et al., 2010) and has been associated with problems in emotion regulation.

This study is not without limitations. First, whereas ANS measures during the tasks were averaged separately for each task condition, self-reported emotions were requested immediately after tasks lasting 4 min (to avoid interfering with task performance). Although immediately requested self-reports may relatively accurately describe emotional experiences during tasks, memory bias might still partly influence self-reports. Emotional responses and regulation also change dynamically, and responses' timing at experiential, physiological and behavioral levels can vary (Butler et al., 2014; Kreibig, 2010; Levenson, 2014). Future studies are needed to examine real-time dynamics and predictive associations between emotional systems in more depth both between and within individuals. One possible explanation for low coherence between self-reported emotions and physiological measures is the relatively small amount of within-person variance (i.e., between the two tasks). In future studies, distinctly different achievement tasks should be used in order to generate more within-person situational variability.

Second, our sample also was not clinical, but included normally developing adolescents. Future studies should examine associations between emotional systems among adolescents with different numbers and types of comorbid problems. Third, the sample consisted of Finnish 12-year-old early adolescents, and the associations of emotional systems were assessed only during achievement tasks intended to evoke achievement emotions. Results might vary for other cultures, ages, and types of tasks/stimuli, like those regarding interpersonal relationships.

Despite the limitations, the results of this study provide a novel understanding of how adolescents' subjectively experienced emotions are related to psychophysiological measures during achievement situations. Results indicating only low convergence among multiple measures imply the complexity with which autonomic processes contribute to the encoding and recall of emotional information (Cacioppo et al., 2000; Hollenstein & Lanteigne, 2014). It has been noted that the experience of emotion involves many aspects, like intensity, duration, communication success, and the degree in which the emotion is overtly expressed (Levenson, 2014). Emotional responses also change dynamically, and responses' timing can vary at experiential, physiological, and behavioral levels. The awareness of emotional responses and the extent of emotion regulation, as well as related individual differences, may also influence subsystem associations (e.g., Hollenstein & Lanteigne, 2014; Koole, 2009). Hence, different types of measures are needed to tap emotions' complementary aspects like conscious emotional experiences and less conscious physiological reactions and nonverbal cues related to emotions and emotion regulation. Our results also suggest that it is worthwhile to assess both positive and negative emotions and both activating and nonactivating emotions. Finally, our study provided a novel understanding of potential moderators of emotional coherence among adolescents. The results revealed that congruence between emotional systems may be especially high among special subgroups of adolescents—that is, those with hyperactivity, depressive symptoms, and low cognitive ability. Adolescents with lower abilities and difficulties with emotion regulation seem especially emotionally reactive when faced with cognitive challenges. A better consideration of individual differences so as to emotionally react to challenges in the educational context might help provide tailored learning support for various types of adolescents.

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