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ARTICLE

Biophysiological stress markers relate differently to grit and school engagement among lower- and higher-track secondary school students

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Abstract

Background: This study examines the relationship between adolescents' biophysiological stress (i.e. cortisol, alpha-amylase and oxidative stress) and the development of grit and school engagement over one school year.

Aims: The study aims to identify how objective stress affects grit and three dimensions of school engagement. Based on the conservation of resources (COR) theory, the study considers lower- and higher-track school students and their genders.

Sample: The sample consists of secondary school students ($N = 82$; $M_{Age} = 13.71$; SD = 0.67; 48% girls) from Germany.

Methods: Students participated in a questionnaire and a biophysiological study in the first semester (t1) of the school year and completed the same questionnaire at the end of the school year (t2). After conducting whole-sample analysis, a multigroup cross-lagged panel model was calculated to identify differences among students at lower- and higher-track schools.

Results: Whole-sample analysis reveals that students who exhibit high levels of cortisol report lower cognitive school engagement at t2, whereas students who exhibit high levels of alpha-amylase exhibit less grit at t2. Additionally, lower-track students who exhibited high cortisol levels reported lower cognitive and emotional school engagement throughout the school year. Furthermore, higher-track students with high oxidative stress levels reported lower grit and behavioural school engagement at t2.

Conclusions: Examining the relationship between biophysiological stress markers and grit and school engagement of students at lower- and higher-track schools indicates that the educational context and its specific subculture shapes physiological stress reactions, which are related differently to grit and engagement dimensions.

KEYWORDS

amylase, cortisol, grit, oxidative stress, school engagement

BACKGROUND

Students' school engagement and grit—in other words, perseverance and passion for long-term goals—contribute significantly to learning and achievement (Tang et al., 2019; Wang & Eccles, 2012). Over the course of secondary school, most students' engagement is at risk of declining (Bakadorova et al., 2020; Van de Gaer et al., 2009; Lam et al., 2016) as is their grit (Postigo et al., 2021). This decline may be reinforced even further if students perceive high levels of stress, as stress has been negatively associated with engagement (Raufelder et al., 2014) and grit (Kim et al., 2012). However, existing studies on how adolescents' stress relates to grit and school engagement are based mainly on self-report data. While students' self-reports capture how they feel and think, self-reports are also prone to systematic error due to desired response behaviour (Masood et al., 2012). Accordingly, objective stress markers could provide additional information about students' biophysiological responses to stressors, reflecting energy-consuming mechanisms within the body and playing an essential role in the prognosis of stress-related disorders and diseases. Nevertheless, the interpretation of biophysiological measures may be challenging, as physiological measures often present momentary or accumulated states of the bodily functions. However, by bringing together self-report data and biophysiological stress markers, new insights into the research topic can be acquired. Therefore, the present study is designed to understand how biophysiological stress markers relate to grit and school engagement over one school year.

As students' stress levels are likely to depend on their school set-up, culture and the emphasis placed on learning and academic achievement, two public school types are considered in the current study: lower- and higher-track schools. Whereas higher-track schools certify their students with a school-leaving exam after 12 years, which allows them to enter university, lower-track schools offer various school-leaving exams and tend to prepare students for a vocational track or applied studies.

Grit, school engagement and objective stress markers

Duckworth et al. (2007) define grit as 'perseverance and passion for long-term goals' (p. 1087) even when a person encounters obstacles or failures. It comprises two facets: the consistency of interests and the perseverance of effort. Although some research distinguishes the two facets (see Tang et al., 2019), most extant studies use an overall score for grit by aggregating two facet-level scores (see Credé et al., 2017; Guo et al., 2019). Because recent studies have proposed a unidimensional structure (Areepattamannil & Khine, 2017; Gonzalez et al., 2020; see Postigo et al., 2021), the present study also uses the aggregated grit score. Research indicates that grit functions as a predictor of high achievement (Duckworth et al., 2007, 2011; Duckworth & Quinn, 2009; Muenks et al., 2017, 2018) and school engagement (Muenks et al., 2017; Steinmayr et al., 2018).

School engagement is a multifaceted construct comprising three components, according to Fredericks et al. (2005): behavioural, emotional and cognitive school engagement. Behavioural school engagement includes active participation in class—for example, a student's persistence in completing tasks, attentiveness during class or effort expended—and adherence to rules (Finn, 1993; Skinner & Belmont, 1993). Emotional school engagement encompasses a student's feelings towards the school, the classroom and the social context, supporting a sense of belonging at school (Harris, 2008; Skinner & Belmont, 1993). Cognitive school engagement is also referred to as the psychological investment a student makes in learning, manifested through the use of deep learning strategies (Walker et al., 2006). Studies indicate that, like grit, school engagement is an essential determinant of students' achievement (Archambault et al., 2009; Wang & Eccles, 2012).

To date, only few studies have examined the association between adolescents' stress, grit (Kim et al., 2021; Lee, 2017) and school engagement (Raufelder et al., 2014). The studies have in common a detection of negative relationships between stress and both grit and school engagement. However, these studies are cross-sectional and are based on students' self-reported stress perceptions only. To complement self-reported data and to follow a more holistic approach to the topic, objective stress markers such as alpha-amylase, cortisol and oxidative stress may contribute to our understanding of the unique effects of biophysiological stress markers on grit and school engagement.

Empirical studies investigating the relationship of cortisol, alpha-amylase and oxidative stress with grit and engagement in academic contexts are scarce and have mainly been investigated with adult samples. For example, a study of 39 residency trainees enrolled at an urban academic medical centre revealed no significant relationship between trainees' salivatory cortisol and their status as part of the high- or low-grit group (Wong et al., 2019). However, another study investigating 122 military personnel found lower cortisol levels measured in the hair of gritty individuals (Gucciardi et al., 2021). In a study of 89 early childhood professionals, Nislin et al. (2016) found no significant relationship between professionals' work engagement and salivary cortisol or alpha-amylase.

In general, objective markers can provide information about biophysiological mechanisms in the body in response to stressors. Cortisol, alpha-amylase and oxidative stress are involved in stress-related arousal in the body and are considered to be essential, sensitive biomarkers for metabolic homeostasis (Granger et al., 2007). Cortisol is commonly known as the stress hormone and has been investigated in the academic context in relation to behavioural school engagement, social support and stress experience (Adams et al., 2013; Groeneveld et al., 2020; Simons et al., 2016). The enzyme alpha-amylase has been investigated mainly within the fields of health and psychopathology; research in academic fields relating alpha-amylase to students' behavioural outcomes and perceived stress have begun only recently (Inagaki et al., 2017; Khalid et al., 2019).

Although both biological stress markers are valid markers for detecting physiological changes in response to stress, cortisol reflects the activity of the hypothalamic-pituitary-adrenal axis (HPA axis), whereas alpha-amylase indicates the activity of the sympathetic-adrenal-medullary axis (SAM axis; Nater et al., 2005; Vineetha et al., 2014). This is why some studies have failed to demonstrate a significant correlation between the two biomarkers (Chatterton et al., 1996; Nater et al., 2005). Nater et al. (2005) stated that salivary alpha-amylase presents a useful additional parameter to detect psychosocial stress, as it is not related to other biological stress markers such as cortisol.

Another parameter to detect biophysiological stress reactions is oxidative stress, which indicates an imbalance between the production of reactive oxygen species (free radicals) and the counteracting antioxidant mechanisms (Betteridge, 2000). Various human and animal studies indicate that psychosocial stress is associated with higher levels of oxidative stress, which, in turn, promotes cell and tissue damage in the body (Felippe et al., 2021; Kim et al., 2021; Møller et al., 1996). However, studies investigating the relationship between oxidative stress, grit and engagement among healthy adolescent students in academic contexts have not yet been undertaken.

While cortisol, alpha-amylase and oxidative stress are implicated in the physical stress response, they trigger different biophysiological reactions and may induce several chronic and degenerative diseases by damaging, for example, the DNA, cells and tissue, leading to negative cognitive, emotional and physical consequences (Lupien et al., 2007; Pizzino et al., 2017). By including different biophysiological stress markers, it is possible to make nuanced statements of how cortisol, alpha-amylase and oxidative stress relate to grit and school engagement. Thus far, the most common biophysiological measure in educational research has been cortisol. By including additional objective stress markers that are not yet as common within the research field, such as alpha-amylase and oxidative stress, alternative or substitute biophysiological stress markers may be tested and can represent the basis for future studies using biophysiological markers. Given that the physiological stress system is a complex, multifaceted system, involving dynamic interactions between the autonomic nervous system (ANS), the HPA axis and the immune system, Ali and Nater (2020) suggest including various biophysiological stress markers from these different systems to capture the complex bodily stress response system.

With respect to their relationships with grit and school engagement, each biophysiological marker provides information on whether the activation of the HPA axis (cortisol), the activation of the SAM axis (alpha-amylase) and/or the production of reactive oxygen (oxidative stress) is related significantly to grit and school engagement. Taking an epidemiological perspective, various biophysiological stress markers may be linked to the prognosis of stress-related disorders and diseases, which, in turn, may impair students' grit and engagement. By considering students at lower- and higher-track schools, possible differences with respect to the link between biophysiological markers and grit and school engagement are considered.

School track as developmental context

Various theoretical frameworks suggest that the context in which individuals grow up and spend most of their time plays an important role in their cognition, behaviour, attitudes and perceptions (Bronfenbrenner, 1979; Hobfoll & Ford, 2007; Lerner, 1991). Consequently, whether students decide to engage in school, apply gritty behaviour or experience stress may depend, to a large extent, on their school environment. In particular, the conservation of resources theory (COR) states that whether stressors are perceived as stressful is determined by environmental, social and cultural aspects that place demands on individuals and, consequently, cause them to acquire and protect conditions that help maintain their well-being (Hobfoll & Ford, 2007).

To consider the school context in which students are embedded, the current study investigates two public school forms that exist in the federal state of Mecklenburg-Western Pomerania, Germany, where this study was conducted, namely, academic higher-track schools (*Gymnasien*) and non-academic lower-track schools (*Regionalschulen*). The school systems differ in their didactic concepts, achievement orientation and school culture (Maaz et al., 2008). As the German school system is based on early ability tracking (in grades four or six), children are placed at a relatively young age into the academic or non-academic track. The choice of whether students attend lower- versus higher-track schools depends both on their academic record and parental choice. As such, parents from academic backgrounds tend to encourage their children to also follow an academic career and attend higher-track schools (Crede et al., 2015). In fact, there has been evidence that students at lower-track schools tend to come from families with lower socio-economic status compared to students at higher-track schools (Batruch et al., 2019; Schnabel et al., 2002). In stress research, lower socio-economic status has been associated with higher stress levels measured by cortisol (Roubinov et al., 2018; Tarullo et al., 2020).

Empirical studies on the variation of stress levels among higher- and lower-track school students have yielded mixed results, providing different rationales. Some researchers argue that higher-track school students experience greater stress levels, as they attend schools that place more pressure on students to perform, and academic expectations are higher compared to lower-track schools (Seiffge-Krenke, 2006). This rationale is supported by empirical research put forward by Seiffge-Krenke (2006) and Valtin and Wagner (2004). A study of Finnish students revealed that higher levels of stress and exhaustion were prevalent among students at higher-track schools compared to those enrolled in lower-track schools (Salmela-Aro et al., 2008, 2009).

Still others argue that higher- and lower-track students are exposed to different stressors, such as the disadvantaged socio-economic family conditions common among low-track students, where they may be exposed to stressors including financial stress and compromised living conditions (Batruch et al., 2019; DeCarlo Santiago et al., 2011).

The current study

By combining self-report data and objective biophysiological measures, the current study aims to understand the unique effects of biomarkers on students' grit and school engagement throughout the school year, controlling for previous levels of the two factors. To consider school contextual differences, this study further investigates the variables of interest and their relationships for students at lower- and higher-track schools. In detail, the following research questions are investigated: (1) How are cortisol, alpha-amylase and oxidative stress related to grit and school engagement at the end of the school year, controlling for grit and school engagement at the beginning of the school year? (2) How are these relationships further differentiated among lower- and higher-track school students? (3) How do the mean levels of the variables school engagement, grit and biophysiological stress markers differ among students at lower- and higher-track schools?

As gender differences have been found in both self-reported grit and school engagement (in favour of girls, Furrer & Skinner, 2003; Pagani et al., 2012) as well as in biophysiological stress markers with mixed findings (Carr et al., 2016; Kirschbaum et al., 1992; Maruyama et al., 2012), gender is considered to be a control variable. Additionally, sleep duration, body mass index, age, medication intake and self-reported stress were tested as predictors of all three biomarkers to determine whether they should also be included as control variables.

METHODS

Sample and procedure

The present study is part of a larger project investigating students' well-being, which involved the participation of 733 seventh- and eighth-grade students at 11 randomly selected secondary schools (six lower-track schools and five higher-track schools) and 60 classrooms in the federal state of Mecklenburg-Western Pomerania, Germany. There are approximately 41 public higher-track schools and 144 public lower-track schools in the state (Mecklenburg-Vorpommern & Ministerium für Bildung und Kindertagesförderung, 2022).[1] In 2019, the disposable income of private households per inhabitant in Mecklenburg-Western Pomerania amounted to €20,671, indicating one of the lowest incomes among German states (Statista, 2022b). However, official data on the income of neighbourhoods or families who send their children to higher- or lower-tracking schools are not available. With respect to the questionnaire used in this study, all children had sufficient German language skills to complete the questionnaire and no children were excluded from participation. In preparation for the study, we obtained approval from the Ministry of Education, Science and Culture of Mecklenburg-Western Pomerania as well as the data protection officer and the ethics committee of the university medical centre. Subsequently, we obtained consent forms from the pupils and their parents. The assent rate of both parents and children to participate in the questionnaire study was 83%. The confidentiality of the answers and the voluntary nature of participation in both the questionnaire study and the stress marker test were emphasized. The survey was conducted in the classrooms of the schools during regular class hours, and the biomarker testing was conducted at home after the students awakened as well as in the rooms of the university.

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[1] The state of Mecklenburg-Western Pomerania has the lowest proportion of foreign population with 4.8% in 2020 (Statista, 2022a, 2022b) compared to other German federal states. The most common ethnic background is Polish.

The first measurement point (t1; questionnaire study and biomarker testing) took place in the first semester of the school year 2018–19, and the second measurement point (t2; questionnaire study) in the second semester of the same school year.

For biomarker testing, we randomly selected 83 students from the total sample. Due to extreme values, one student was excluded so that the final sample was composed of 82 students ($M_{Age} = 13.71$; SD = 0.67; 48% girls; 40 lower-track students and 42 higher-track students). Students reported that they had 8.38 hr of sleep (SD = 1.32) the night before the biomarker testing and awoke at approximately 7:53 a.m. (SD = 1.29). On average, students had a height of 169 cm (SD = 7.77), a weight of 62.15 kg (SD = 15.09) and an abdominal girth of 72.34 cm (SD = 11.19). Of the total sample, 74.7% reported that they did not take medication regularly, and 6% reported taking painkillers weekly. Daily, 4.8% took medication for allergies (e.g. pollen), 1.2% took Ritalin and 2.4% used asthma inhalers.

For the analysis of cortisol, students independently provided saliva samples in the morning immediately after waking, and they provided another saliva sample at approximately noon that was collected by trained staff. Alpha-amylase was extracted from the saliva sample collected at noon. Saliva samples were kept refrigerated in polypropylene Salivettes and then frozen at −20°C before being analysed in a laboratory. Oxidative stress was measured using urine samples that students also provided at approximately noon. The samples were immediately stored on ice and then frozen at −80°C before they were analysed. In preparation for the biomarker testing, students were given detailed information on the procedure for providing their saliva and were instructed, for example, not to eat, drink (except for water), smoke, chew gum or engage in sporting activities for one hour before providing it.

An a priori power analysis for multiple regression was performed using G*Power by Faul et al. (2009) to estimate the sample size needed for a regression model containing seven predictors. The a priori power analysis for linear multiple regression with seven predictors using G*Power (Faul et al., 2009) revealed a total sample size of $N = 70$ for an actual statistical power level of 0.95 for a large effect size ($f^2 = 0.35$) and a probability level of .05. Medium ($f^2 = 0.15$; $N = 153$) and small ($f^2 = 0.02$; $N = 1099$) effect sizes would require a larger sample (Cohen, 1969). Accordingly, only large effects can be identified with the present sample.

Measures

Questionnaire instruments

School engagement

The school engagement instrument developed by Fredericks et al. (2005) was used, which consists of three subscales: The behavioural school engagement (BSE) subscale ($\alpha_{T1} = .63$, $\alpha_{T2} = .75$; $\alpha_{T1low\text{-}track} = .64$, $\alpha_{T1high\text{-}track} = .62$; $\alpha_{T2low\text{-}track} = .77$, $\alpha_{T2high\text{-}track} = .72$) comprises four items (e.g. 'During lessons, I pay attention'). The emotional school engagement (ESE) subscale ($\alpha_{T1} = .88$, $\alpha_{T2} = .88$; $\alpha_{T1low\text{-}track} = .89$, $\alpha_{T2high\text{-}track} = .88$; $\alpha_{T2low\text{-}track} = .90$, $\alpha_{T2high\text{-}track} = .86$) comprises six items (e.g. 'I feel good at school'). The cognitive school engagement (CSE) subscale ($\alpha_{T1} =.65$, $\alpha_{T2} =.67$; $\alpha_{T1low\text{-}track} =.66$, $\alpha_{T1high\text{-}track} =.63$; $\alpha_{T2low\text{-}track} =.69$, $\alpha_{T2high\text{-}track} =.65$) comprises five items (e.g. 'I check my schoolwork for mistakes'). The students rated the items on a 5-point Likert scale (1 = 'never'; 5 = 'always'). Other studies conducted with German school students, using the school engagement instrument provided by Fredericks et al. or adopted versions, yield similar Cronbach's alphas, ranging from .67 to .76 (Bakadorova et al., 2020; Hoferichter et al., 2022).

Grit

The BISS-8 scale by Schmidt et al. (2017) was used to measure the construct of grit. The scale consists of eight items (e.g. 'New ideas and plans sometimes prevent me from achieving my school goals' (recoded), 'I work hard for school'; $\alpha_{T1} = .77$, $\alpha_{T2} = .76$; $\alpha_{T1low\text{-}}$ $\alpha_{T1low\text{-}track} = .78$, $\alpha_{T1high\text{-}track} = .76$; $\alpha_{T2low\text{-}track} = .77$,

$\alpha_{\text{T2high-track}} = .75$). The students rated the items on a 5-point Likert scale (1 = 'not at all true'; 5 = 'completely true'). For the current analysis, grit was aggregated as two facet-level scores, representing a unidimensional structure. In the German context, the grit scale was validated with 525 university students, and the Cronbach's alpha of the scale was α = .80 (Schmidt et al., 2017). In another study, Fleckenstein et al. (2014) validated the domain-specific grit scale with a sample of 271 secondary school students at higher-track schools. Thereby, the Cronbach's alpha for grit in the subject of mathematics was α =.75 and for the subject of German was α = .79; therefore, they were similar to the current study's reliabilities of the scale.

Gender

Gender was included as a dichotomous control variable (1 = girls; 2 = boys) because research indicates that girls tend to report higher stress levels than boys (Mezulis et al., 2010; Pettit et al., 2010; Shih et al., 2006). Furthermore, girls tend to report more school engagement (Frawley et al., 2014; Lam et al., 2016) compared to boys, particularly during adolescence. With respect to grit, a study based on self-reports and teacher and parent ratings revealed that girls tend to be more self-disciplined than boys when gratification is delayed (Duckworth & Seligman, 2006). However, Fleckenstein et al. (2014) did not find gender differences with respect to grit, which was confirmed by Sigmundsson et al. (2020). However, Sigmundsson and colleagues found that boys tend to be more passionate than girls; in other words, boys reported that they have an area, theme or skill about which they feel passionate and with which they spend a significant amount of time, while girls tend to work harder and remain more focused over longer periods of time (Sigmundsson et al., 2017, 2018, 2020).

Biophysiological stress markers

Alpha-amylase

Salivary alpha-amylase from the late-morning saliva sample was analysed in duplicate using the AMY method (an in vitro diagnostic method for the quantitative determination of amylase in human serum) on the Dimension Vista® system (Siemens Healthcare Diagnostics Inc.), and the data are reported in μkatal/s. For the present analysis, we calculated an average of both values from the duplicate determination. Alpha-amylase is a proxy measure of sympathetic arousal and a valid marker of the stress-related activity of the ANS. Among healthy individuals, who do not exhibit a dysfunction of the ANS, high scores of alpha-amylase indicate high activation of the SAM axis that is triggered by stressors.

Cortisol

Salivary cortisol was analysed using the IDS-iSYS Multi-Discipline Automated System (Immunodiagnostic Systems Limited), and the data are reported in μg/dl. For the present study, we averaged the cortisol from morning and noon samples. Cortisol measures the systemic fluctuations of the HPA axis, whereas high levels of cortisol indicate significant levels of activation of the HPA axis triggered by stressors in individuals with regular, non-clinical functioning.

Oxidative stress

Fifty-five μl of urine were analysed using the immunoassay kit OxiSelect™ 8-iso-Prostaglandin F2a ELISA Kit from Cell Biolabs, Inc. The immunoassay and measurement were performed according to the manufacturer's protocol. Photometric measurement was performed on a Tecan Infinite 200 PRO using a 450 nm filter. From these absorbance measurements, we calculated the concentration of 8-iso-prostaglandin F2a in the samples. A high score of oxidative stress results from toxic effects of reactive oxygen species, indicating an imbalance between production and accumulation of reactive oxygen species. This imbalance can be induced by various stressors.

Statistical analysis

In preliminary analyses, we computed descriptive statistics and conducted bivariate correlations and t-tests. In preparation for the final model, we first designed a structural equation model in which students' gender, sleep duration, body mass index, age, medication intake and self-reported stress were tested as predictors of all three biomarkers. None of these control variables were identified as significant regressors, so we did not integrate them in the final model (see Table A2 in the Appendix S1). In fact, no prior literature had identified these variables as potential covariates, except for gender differences, which is why gender was included as a control variable.

Cross-lagged panel design

Using Mplus Version 8.5 (Muthén & Muthén, 1998–2013), we performed cross-lagged panel design with a robust maximum likelihood estimator (see Figure 1), which is robust against violations of normality assumptions (Yuan & Bentler, 2000). The cross-lagged panel analysis makes it possible to examine the stability and relationships between students' experience of stress, school engagement and grit within and overtime to elicit the mutual influence of the variables (Geiser, 2011; Kearney, 2017). The model includes both autoregressive effects of each variable overtime and regression effects of one variable on other variables (cross-lagged effect). This method makes it possible to estimate the effect of a variable on another variable while taking into account previous states of this variable.

As a first step, we ran a model with the entire sample to make general statements about the relationships between biomarkers and school engagement as well as grit. In a second step, we designed a multi-group model that differentiated between lower-track and higher-track students. Following Chen's (2007) recommendations, the comparison of the models was evaluated by means of a Satorra–Bentler-scaled χ^2 difference test, which adjusts raw χ^2 difference values to the model's sample size, complexity and potential deviations from normality assumptions (Satorra & Bentler, 2001). These guidelines state that a more restricted model better replicates the data if $\Delta\chi^2$ is insignificant (Satorra & Bentler, 2001) and favours models in which ΔRMSEA $\leq$ .015, ΔCFI $\leq$ .010

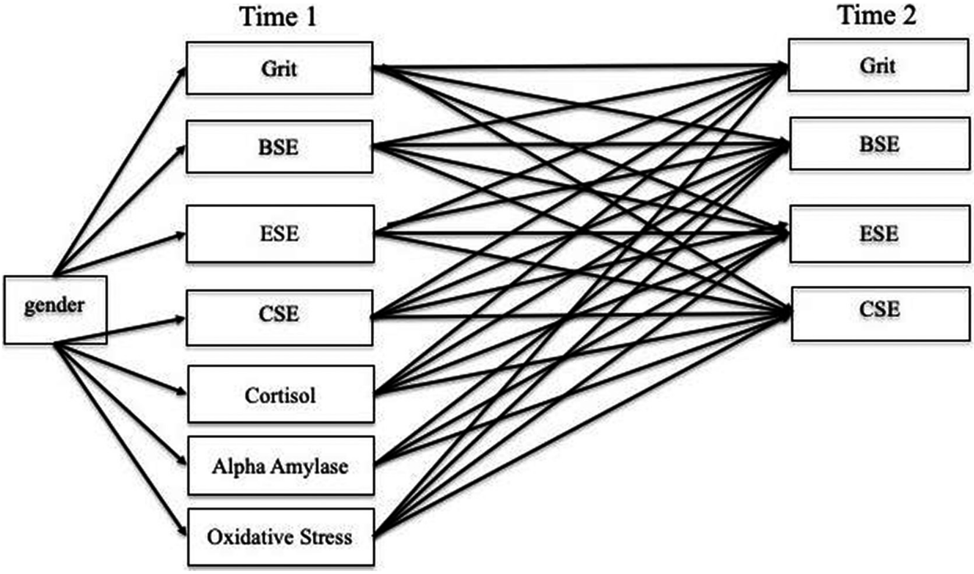

FIGURE 1 Basic model. BSE, behavioural school engagement; CSE, cognitive school engagement; ESE, emotional school engagement. For clarity, the within-time associations between variables are not plotted in the model

and ΔSRMR ≤ .010 (Chen, 2007). The multi-group design represents a moderation approach with a categorical (group) indicator. The multi-group command outputs the results separately for each group within one model.

As several authors have suggested (West et al., 2012), we considered the following fit indices: chi-square test of model fit (χ^2), root mean square error of approximation (RMSEA), comparative fit index (CFI) and standardized root mean square residuals (SRMR). CFI values greater than .90 and RMSEA and SRMR values lower than .08 usually indicate an acceptable fit to the data.

Missing data

The present study is based on data from students who participated in both measurement time points. Therefore, there is no drop-out rate, but there are cases with missing values. In total, the study has 16 incomplete cases. At t1, only 3 cases are incomplete, and at t2, 16 cases on the school engagement and grit variables are incomplete. Little's missing completely at random test was performed and suggested that data were missing completely at random: $\chi^2(df) = 22.38$ (29), $p > .05$. As the missing completely at random test confirmed the use of full information maximum likelihood to account for missing data, all analyses were run with a robust maximum likelihood estimator with full information maximum likelihood. The analytical procedure is unbiased under the missing at random assumption and, as such, retains statistical power because no observations are deleted (Enders, 2010).

RESULTS

Descriptive statistics and bivariate correlations

Additional t-tests were run to compare mean values of lower-track and higher-track students. There were statistically significant differences between the two groups, with mean oxidative stress lower in the higher-track group, $t(80) = 2.16$, $p < .05$, BSE at t1 higher in the higher-track group, $t(80) = -3.69$, $p < .001$, CSE at t1 higher in the higher-track group, $t(80) = -2.47$, $p < .05$), grit at t1 higher in the higher-track group, $t(80) = -2.19$, $p < .05$) and BSE at t2 higher in the higher-track group, $t(66) = -2.30$, $p < .05$. The mean value differences of all other variables were statistically not significant.

Table A1 in the Appendix S1 presents the descriptive statistics and bivariate correlations for all variables (whole sample, higher- and lower- track students) separately.

Whole-sample cross-lagged panel design

The model indicated an acceptable fit: $\chi^2(4) = 4.07$, $p > .05$, CFI = 1.00, RMSEA = .02 (90% CI 0.00 to 0.17), SRMR = .01. The within-time associations are presented in Table 1, and the overtime associations are reported in Table 2. These reveal that cortisol predicted cognitive school engagement $B = -0.35$, $\beta = -0.20$, SE = 0.09, $p < .05$ whereas alpha-amylase predicted grit $B = -0.19$, $\beta = -0.15$, SE = 0.07, $p < .05$.

Multi-group cross-lagged panel design

The model indicated a good fit: $\chi^2(8) = 7.67$, $p > .05$, CFI = 1.00, RMSEA = .00 (90% CI 0.00 to 0.18), SRMR = .01. The results of the $\Delta\chi^2$, ΔRMSEA ≤ .015, ΔCFI ≤ .010 and ΔSRMR ≤ .010 (Chen, 2007) reveal that the multi-group model does not represent the data worse than the whole-sample model: $\Delta\chi^2(4) = 3.59$, $p = .46$; ΔRMSEA = .015, ΔCFI = 0 and ΔSRMR = .002.

TABLE 1 Within-time results of the final whole-sample and multi-group model

Whole-sample model (N = 82)	**BSE t1, r (SE)**	**ESE t1, r (SE)**	**CSE t1, r (SE)**	**Grit t1, r (SE)**	**Cortisol**	**Alpha-amylase**	**Oxidative stress**
BSE t1	–	.42*** (.08)	.28** (.10)	.57*** (.06)	.04 (.09)	−.11 (.15)	.03 (.15)
ESE t1		–	.37*** (.10)	.59*** (.07)	−.04 (.11)	.03 (.10)	.06 (.10)
CSE t1			–	.29** (.11)	.14 (.12)	.00 (.12)	.06 (.12)
Grit t1				–	.18 (.10)	−.03 (.11)	.02 (.12)
Cortisol					–	−.14 (.09)	.17 (.09)
Alpha-amylase						–	−.05 (.07)
Oxidative stress							–
	BSE t2, r (SE)	**ESE t2, r (SE)**	**CSE t2, r (SE)**	**Grit t2, r (SE)**			
BSE t2	–	.26*** (.10)	.10 (.12)	−.01 (.08)			
ESE t2		–	.14 (.12)	.32*** (.09)			
CSE t2			–	.12 (.07)			
Grit t2				–			
Students from lower-track schools MG Model (n = 40)	**BSE t1, r (SE)**	**ESE t1, r (SE)**	**CSE t1, r (SE)**	**Grit t1, r (SE)**	**Cortisol**	**Alpha-amylase**	**Oxidative stress**
BSE t1	–	.61*** (.08)	.32* (.13)	−.15 (.08)	.06 (.15)	−.03 (.20)	.08 (.24)
ESE t1		–	.52*** (.12)	.72*** (.07)	.04 (.17)	.07 (.16)	.20 (.15)
CSE t1			–	.13 (.09)	.11 (.21)	−.12 (.15)	−.09 (.13)
Grit t1				–	.26 (.16)		
Cortisol					–	−.12 (.14)	.08 (.13)
Alpha-Amylase						–	−.06 (.11)
Oxidative stress							–
	BSE t2, r (SE)	**ESE t2, r (SE)**	**CSE t2, r (SE)**	**Grit t2, r (SE)**			
BSE t2	–	.17 (.14)	.05 (.20)	−.15 (.08)			
ESE t2		–	.04 (.17)	.29* (.13)			
CSE t2			–	.13 (.09)			
Grit t2				–			

(Continues)

TABLE 1 (Continued)

Students from higher-track schools MG model (n = 42)	**BSE t1, r (SE)**	**ESE t1, r (SE)**	**CSE t1, r (SE)**	**Grit t1, r (SE)**	**Cortisol**	**Alpha-amylase**	**Oxidative stress**
BSE t1	–	.16 (.13)	.14 (.17)	.46*** (.10)	.21 (.13)	−.16 (.14)	.17 (.14)
ESE t1		–	.22 (.15)	.46*** (.11)	−.12 (.13)	−.01 (.10)	−.08 (.12)
CSE t1			–	.14 (.18)	.23 (.15)	.20 (.14)	.29 (.15)
Grit t1				–	.23 (.13)	−.02 (.15)	.03 (.18)
Cortisol					–	−.29** (.10)	.23 (.25)
Alpha-amylase						–	−.06 (.15)
Oxidative stress							–
	BSE t2, r (SE)	**ESE t2, r (SE)**	**CSE t2, r (SE)**	**Grit t2, r (SE)**			
BSE t2	–	.33* (.15)	.24 (.15)	.30* (.15)			
ESE t2		–	.25 (.21)	.43* (.17)			
CSE t2			–	.25 (.15)			
Grit t2				–			

Note: N = 82. ***$p < .001$; **$p < .01$; *$p < .05$.

Abbreviations: Alpha, alpha-amylase; BSE, behavioural school engagement; CSE, cognitive school engagement; ESE, emotional school engagement; gender 1 = girls, 2 = boys; OxStr, oxidative stress; r, STDYX-standardized; SE, standard error; T1, time 1 (winter term); T2, time 2 (summer term).

TABLE 2 Overtime results of the final whole-sample and multi-group model

Whole sample (*N* = 82)	**BSE t1, β (SE)**	**ESE t1, β (SE)**	**CSE t1, β (SE)**	**Grit t1, β (SE)**	**Cortisol t1, β (SE)**	**Alpha-Amylase t1, β (SE)**	**Oxidative Stress t1, β (SE)**
Gender	−.20 (.11)	−.20 (.11)	−.43*** (.04)	−.21 (.11)	−.17 (.10)	.03 (.11)	.15 (.10)
	BSE t2, β (SE)	**ESE t2, β (SE)**	**CSE t2, β (SE)**	**Grit t2, β (SE)**			
BSE t1	.59*** (.08)	.02 (.03)	.12 (.12)	−.19 (.16)			
ESE t1	.24* (.11)	.97*** (.02)	.07 (.11)	−.04 (.11)			
CSE t1	−.05 (.08)	.03 (.03)	.59*** (.08)	−.05 (.07)			
Grit t1	.05 (.10)	−.01 (.03)	−.12 (.12)	.36*** (.08)			
Cortisol t1	−.00 (.09)	−.02 (.02)	−.20* (.09)	−.08 (.10)			
Alpha-Amylase t1	−.05 (.07)	−.02 (.03)	.16 (.10)	−.15* (.07)			
Oxidative stress t1	−.22 (.12)	.01 (.02)	.03 (.08)	−.04 (.05)			
Students from lower-track schools (*n* = 40)	**BSE t1, β (SE)**	**ESE t1, β (SE)**	**CSE t1, β (SE)**	**Grit t1, β (SE)**	**Cortisol t1, β (SE)**	**Alpha-Amylase t1, β (SE)**	**Oxidative Stress t1, β (SE)**
Gender	.07 (.17)	−.13 (.16)	−.35* (.14)	.03 (.16)	−.32* (.14)	−.19 (.16)	.08 (.14)
	BSE t2, β (SE)	**ESE t2, β (SE)**	**CSE t2, β (SE)**	**Grit t2, β (SE)**			
BSE t1	.57*** (.09)	.06 (.03)	.06 (.14)	−.17 (.17)			
ESE t1	.24* (.12)	.90*** (.03)	.17 (.19)	−.21 (.13)			
CSE t1	−.02 (.12)	.05 (.04)	.49*** (.12)	−.06 (.12)			
Grit t1	.16 (.11)	.04 (.04)	.04 (.16)	.45*** (.12)			
Cortisol t1	.07 (.09)	−.05 (.03)	−.32*** (.09)	−.16 (.11)			
Alpha-Amylase t1	−.07 (.10)	−.02 (.03)	.24 (.14)	−.12 (.07)			
Oxidative stress t1	−.03 (.09)	.03 (.03)	−.11 (.11)	.02 (.07)			
Students from higher-track schools (*n* = 42)	**BSE t1, β (SE)**	**ESE t1, β (SE)**	**CSE t1, β (SE)**	**Grit t1, β (SE)**	**Cortisol t1, β (SE)**	**Alpha-amylase t1, β (SE)**	**Oxidative stress t1, β (SE)**
Gender	−.35** (.12)	−.24 (.15)	−.41** (.12)	−.32* (.13)	−.06 (.17)	.30* (.14)	.10 (.16)
	BSE t2, β (SE)	**ESE t2, β (SE)**	**CSE t2, β (SE)**	**Grit t2, β (SE)**			
BSE t1	.60*** (.15)	.00 (.04)	.07 (.16)	−.01 (.11)			
ESE t1	.11 (.16)	.98*** (.03)	.04 (.15)	.19 (.12)			

(Continues)

TABLE 2 (Continued)

	BSE t2, β (SE)	ESE t2, β (SE)	CSE t2, β (SE)	Grit t2, β (SE)
CSE t1	.01 (.13)	.05 (.04)	.61*** (.11)	.23 (.15)
Grit t1	−.04 (.16)	−.04 (.04)	−.20 (.17)	.35* (.15)
Cortisol t1	−.09 (.12)	.02 (.03)	−.15 (.17)	.19 (.12)
Alpha-Amylase t1	−.04 (.12)	−.02 (.03)	−.06 (.11)	−.16 (.13)
Oxidative stress t1	−.49** (.17)	−.02(.03)	.10 (.11)	−.40* (.17)

Note: $N = 82$. $^{***}p < .001$; $^{**}p < .01$; $^{*}p < .05$.

Abbreviations: Alpha, alpha-amylase; BSE, behavioural school engagement; CSE, cognitive school engagement; ESE, emotional school engagement; gender 1 = girls, 2 = boys; OxStr, oxidative stress; SE, standard error; T1, time 1 (winter term); T2, time 2 (summer term); β, STDYX-standardized.

The within-time associations for both lower-track and higher-track students are presented in Table 1, and the overtime associations are reported in Table 2. These reveal that for lower-track school students, cortisol predicted cognitive school engagement $B = -0.49$, $\beta = -0.32$, $SE = 0.09$, $p < .001$, whereas for higher-track school students, oxidative stress predicted behavioural school engagement $B = -0.82$, $\beta = -0.49$, $SE = 0.17$, $p < .01$ and grit $B = -0.75$, $\beta = -0.40$, $SE = 0.17$, $p < .05$.

DISCUSSION

The present study aimed to investigate the unique effects of biophysiological stress markers—namely, cortisol, alpha-amylase and oxidative stress—on secondary school students' grit and school engagement (behavioural, cognitive, emotional), controlling for prior grit and school engagement as well as for gender. As the school context and culture determines the extent to which students engage in school, apply grit and experience stress (cf. COR, Hobfoll, 1989, 2001; Hobfoll & Lilly, 1993), we also investigated how the biophysiological stress markers would relate to lower- and higher-track school students' grit and school engagement.

Following an exploratory approach, whole-sample analysis revealed that students who exhibited high levels of cortisol reported less cognitive school engagement, whereas students who had high levels of alpha-amylase applied less grit at school. Gender differences emerged with respect to cognitive school engagement, as girls indicated more cognitive engagement in school compared to boys, which is in line with previous studies (Lam et al., 2016; Frawley et al., 2014).

The result of the whole-sample analysis indicate that high levels of stress expressed through cortisol are associated with a lower cognitive engagement in school tasks. Considering the negative effects of alpha-amylase on students' grit, the results indicate that the bodily stress response affecting the ANS, expressed by high levels of alpha-amylase, is negatively associated with perseverance and passion for long-term goals. It may be that resources to apply gritty behaviour are bound by the activation of the ANS and the attempt to return to a state of homeostasis.

Drawing on the COR theory (Hobfoll & Ford, 2007), which suggests that school context and culture influence the extent to which students experience stress or engage in school work and gritty behaviour, this study was also interested in potential differences between students at higher- and lower-track schools. Mean-level differences occurred with respect to behavioural and cognitive school engagement in favour of students at higher-track schools but not emotional school engagement or grit. This is partially in line with previous studies conducted with German secondary school students, which reported that higher-track school students generally engage more in the classroom (Grützmacher & Raufelder, 2015). An examination of previous research into students' grit indicates that students who pursue an academic career display higher levels of grit (Duckworth, 2016; Duckworth et al., 2007; Eskreis-Winkler et al., 2014), which was confirmed in the current study. However, in a German study, Kulakow and Hoferichter (2021) did not find differences in grit among students at lower- and higher-track schools.

The current study further indicates that students at higher-track schools exhibit greater levels of oxidative stress compared to their peers in lower-track schools. This finding implies that stressors experienced by students at higher-track schools compared to those at lower-track schools are more likely to result in an imbalance between the production of reactive oxygen species and the counteracting antioxidant mechanisms.

Investigation into how cortisol, alpha-amylase and oxidative stress relate to grit and school engagement among students at higher-track and lower-track schools indicates that lower-track school students who exhibited greater levels of cortisol at the beginning of the school year were more likely to report lower cognitive engagement in school at the end of the academic year. This finding indicates that objective stress, measured by the hormone cortisol, impairs the engagement of lower-track school students on a cognitive level. A longitudinal study conducted with infants reveals that high levels of cortisol are related to cognitive impairment (Andiarena et al., 2017). These findings indicate that students who attend lower-track schools are particularly prone to exhibit physiological stress expressed by cortisol levels, which inhibits them from engaging cognitively in school. In fact, neurobiological studies have linked stress to impaired cognitive functioning and regulation of emotions (Arnsten, 2009; Goldman-Rakic, 1996).

Furthermore, higher-track school students who exhibited oxidative stress at the beginning of the school year were more likely to report lower levels of grit and behavioural school engagement at the end of the academic year. Therefore, the stress experienced by student at higher-track schools, reflected through oxidative stress, inhibits them on a behavioural level from pursuing their interests, maintaining constant effort and engaging in schoolwork.

In summary, by considering school type differences with respect to the link between biophysiological stress markers and students' grit and school engagement, we followed the theoretical framework of the COR theory (Hobfoll, 1989, 2001). Since we found mean-level differences among students from different school types with respect to their oxidative stress; behavioural, cognitive and gritty behaviour; and the interaction of the biophysiological stress markers of grit and engagement, we extend the theoretical framework by Hobfoll and colleagues and contribute to previous empirical findings (Hobfoll, 1989, 2001; Hobfoll & Ford, 2007; Hobfoll & Lilly, 1993) by investigating school-related behavioural and biophysiological variables. Considering contextual differences between different school types—which are emphasized in the COR theory—the current results indicate that higher-track school students may be provided with more opportunities that encourage their behavioural and cognitive school engagement. However, it may also be true that students who generally tend to be engaged in school are more likely to attend higher-track schools to begin with. Nonetheless, engaged students interact with and form the school culture and environment accordingly and thereby may initiate more opportunities to engage in school for both themselves and their peers.

Considering gender differences, compared to boys, girls at both lower- and higher- track schools tend to cognitively engage in school. While girls at lower-track schools exhibit greater stress levels expressed by high levels of cortisol, boys at higher-track schools tend to exhibit higher levels of alpha-amylase. Additionally, girls at higher-track schools tend to engage in school more on a behavioural level and apply more grit compared to boys. Previous studies underline that girls generally exhibit higher school engagement (Frawley et al., 2014; Lam et al., 2016), but with respect to grit, previous studies did not identify any gender differences (Fleckenstein et al., 2014; Sigmundsson et al., 2020). However, girls tend to work more diligently over a longer period (Sigmundsson et al., 2017, 2018), which in the current study seems to apply to girls at higher-track schools. With respect to the bodily stress response, there are several studies that indicate females exhibiting higher levels of cortisol during stressful tasks.

Practical implications

This study reveals that students' bodily stress responses influence the degree to which they engage in school and apply grit in the classroom. Thereby, differences among students at higher- and lower-track schools as well as dissimilarities between girls and boys have been identified. As high levels of cortisol, alpha-amylase and oxidative stress indicate a bodily stress response that ties up resources by stimulating the body to return to a state of homeostasis, fewer resources are available to students, which, in turn, hinders their engagement and grit at school.

To support lower-track students' cognitive school engagement as well as higher-track students' behavioural school engagement and grit, it is necessary to support students to minimize the experience of excessive stress. The school day, as well as teaching and learning processes, should be designed to invite students to engage in school to ensure that they receive the greatest possible support for their development. In this regard, support from parents, teachers and classmates plays an essential role in the well-being of adolescents (Hoferichter et al., 2021). If expectations and pressure from parents and teachers are eliminated, a stress-free learning environment can be created in which students at higher-track schools benefit in terms of expressing grit and behavioural school engagement, and students at lower-track schools benefit with respect to high emotional and cognitive school engagement. Next to social support at home and at school, a healthy diet and physical activity are essential to dampen the damage that oxidative stress, cortisol and alpha-amylase can wreak on the cells and tissue of the body. Physical activity should be an integral part of the school day, not only because it supports the body in coping with stressors but also because it fosters team spirit within the school or on a class level. This, in turn, suppresses cortisol levels (Adams et al., 2013; Heinrichs et al., 2003).

Strengths, limitations and future directions

The current study is one of the few that (a) combined self-report data and biophysiological data of a healthy student cohort in Germany; (b) followed a cross-lagged panel design to detect how biophysiological stress markers affect school-related variables, that is, grit and school engagement over the school year, controlling for previous grit and engagement; (c) investigated school type differences; (d) and applied several biophysiological stress markers.

However, as with every empirical study, some limitations must be considered when interpreting the results, such as the relatively low reliability of some school engagement scales and the small sample size. In relation to low reliability, it is worth noting that other studies using the same measures with German samples yielded similar Cronbach's alphas (Bakadorova et al., 2020; Fleckenstein et al., 2014; Hoferichter et al., 2022; Schmidt et al., 2017). Due to the small sample size, no confirmatory factor analysis has been conducted to confirm fit and dimensionality, as well as confirming that any differences in later modelling are not due to differences in underlying measurement properties between the two groups. Unfortunately, this study did not survey the puberty status of the students, which could have accounted for the strong variability in this regard within the eighth grade. Future studies should include puberty as a control variable. Due to the exploratory design of the study and the limited statistical power possible, which might leave small effects undetected, all interpretations must be placed into perspective accordingly. As the current study applied a multi-group analysis, but not multi-level modelling, statements about school impacts cannot be drawn from the analysis.

Considering these limitations, it is recommended that future studies also apply multi-level modelling, investigate larger sample sizes that better enable tests of measurement invariance, conduct latent (item-level) modelling to correct for measurement errors and correlate parallel item residuals across time to reduce method bias. Additionally, it is advised that biophysiological stress markers be measured at several points and that students be followed over a longer period to test potential changes in their objective stress, grit and engagement throughout their academic careers. Overall, however, the present study lays an important foundation for understanding the role of different biophysiological stress markers on school engagement and grit for secondary school students at lower- and higher-track schools.

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CONFLICT OF INTEREST

All authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Frances Hoferichter: Conceptualization; Data curation; Funding acquisition; Project administration; Supervision; Writing – original draft; Writing – review & editing. **Diana Raufelder:** Data curation; Formal analysis; Methodology; Visualization; Writing – original draft; Writing – review & editing.

DATA AVAILABILITY STATEMENT

Data will be made available on justified request.

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