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Affective Reactivity to Real-life Acute Stress: The Role of Chronic Stress, Physical Activity, and Sleep

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AFFECTIVE REACTIVITY TO REAL-LIFE ACUTE STRESS:

THE ROLE OF CHRONIC STRESS, PHYSICAL

ACTIVITY, AND SLEEP

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Prior research indicates that exposure to chronic stress increases allostatic load and alters individuals' response to stressful situations, with evidence for both exaggerated and blunted emotional responses. Recent studies have also linked lifestyle factors such as poor sleep and insufficient physical activity with elevated negative mood in response to stress. The present study extends upon prior work by investigating interactions between chronic stress, physical activity, and sleep as predictors of affective reactivity during real-life sustained stress.

Students (N=637) were assessed during an academic semester and end-of-term final exam period. Self-report ratings of negative affect, acute stress levels, anxious and depressed mood, chronic stress, sleep habits, habitual physical activity, health and demographics were obtained. Hierarchical multiple regression analyses examined the extent to which chronic stress, habitual physical activity, and sleep, as well as their interactions predicted subsequent changes in negative affect and acute stress during the exam period.

Poorer sleep quality and shorter sleep duration prior to the exam assessment, but not habitual sleep duration or physical activity, predicted greater increases in acute stress and negative affect during exams. Higher levels of chronic stress and anxiety symptoms at baseline predicted greater affective reactivity to exams. These relations were partially mediated by poor sleep quality.

Findings highlight the importance of sleep and chronic stress in predicting individuals' affective response to real-life acute stress. Interventions that reduce chronic stress and improve sleep may help individuals' buffer against impairments to their affective health during stressful life episodes.

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CHAPTER 1:

INTRODUCTION

1.1 Overview

As pioneering stress researcher Hans Selye once articulated, “Complete freedom from stress is death” (1973). In other words, stress is not entirely avoidable. Everyone experiences stress to some degree, and stress can be adaptive in response to demanding situations. Stress helps individuals mobilize resources but when sustained and constant it can be detrimental (McEwen & Seeman, 1999). A variety of factors influence stress reactivity and make individuals more or less reactive to stress. When an individual perceives a situation as stressful, the brain signals a stress response (McEwen, 2008), activating the sympathoadrenal system, the Hypothalamic-Pituitary Adrenal (HPA) axis, and the release of stress hormones (Cryer, 1980). Over time, repeated activation of the stress response leads to increased allostatic load and damage to physiological and psychological health (McEwen & Stellar, 1993).

Allostatic load refers to the accumulated wear and tear on the body as a result of stress (McEwen, 1998). Increased allostatic load is associated with impairments in health over time (McEwen & Stellar, 1993). Individual differences in the way people respond to stress, however, can influence their allostatic load. Health-related behaviors, such as physical activity and sleep, can influence individuals’ stress reactivity (McEwen, 1998; McEwen, 2006). Prior stress research has explored both the benefits of health-promoting behaviors such as exercise (Willett

& Stampfer, 2013) and the consequences of unhealthy habits that impair health such as short sleep duration (Patel & Hu, 2008). Chronic stress is an additional factor that impairs individuals' health and influences the response to stressful situations (Juster et al., 2010).

1.2 Sleep

The adverse impact of sleep deprivation on mental health (Malik et al., 2014; Palmer & Alfano, 2017; Pires, Bezerra, Tufik, & Andersen, 2016; Porras-Segovia et al., 2018; Roberts & Duong, 2017; Zhai, Zhang, & Zhang, 2015) and physical health (Appelhans et al., 2013; Chaput, 2016; Devore et al., 2014; Itani, Jike, Watanabe, & Kaneita, 2017; Jackson, Redline, & Emmons, 2015; Li, Zhang, Huang, & Chen, 2017) has been extensively researched. Inadequate sleep has been associated with disrupted physiological processes in the body involved in brain functioning and control of metabolic and cardiovascular systems (Maggio et al., 2013; Meerlo, Sgoifo, & Suchecki, 2008). Insufficient sleep is also associated with a variety of health problems such as higher incidence of work-related accidents (Magnavita & Garbarino, 2017), psychiatric disorders (Baglioni et al., 2011) and decreased cognitive functioning (Kreutzmann et al., 2015; Soffer-Dudek, Sadeh, Dahl, & Rosenblat-Stein, 2011).

A considerable amount of research has focused on the relation between sleep and physiological stress reactivity in adults. Studies have utilized a variety of measures including salivary cortisol (e.g. Bassett et al., 2015; Massar, Liu, Mohammad, & Chee, 2017; Minkel et al., 2014; Vargas & Lopez-Duran, 2017), heart rate variability (e.g. Mezick, Matthews, Hall, Jennings, & Kamarck, 2014), skin conductance (e.g. Liu, Verhulst, Massar, & Chee, 2015), and blood pressure (e.g. Massar et al., 2017; Mezick et al., 2014; Williams, Cribbet, Rau, Gunn, & Czajkowski, 2013). Overall, findings suggest that impairments in sleep are related to an elevated stress response. However, the direction of change is unclear, with evidence for both exaggerated (Franzen et al., 2008; Franzen, Buysse, Dahl, Thompson, & Siegle, 2009; Franzen et al., 2011; Liu et al., 2015; Massar et al., 2017; Mezick et al., 2014; Minkel et al., 2014) and blunted (Bassett et al., 2015; Vargas & Lopez-Duran, 2017; Williams et al., 2013) physiological stress reactivity.

Several studies investigating the influence of sleep on affective stress reactivity indicate a relation between insufficient sleep and greater experiential affective reactivity following acute stress (Talbot et al., 2010). After just one night of sleep deprivation, healthy young adults report elevated negative mood (Franzen, Siegle, & Buysse, 2008). One study examining the impact of sleep loss on medical students' affective health found that sleep loss during nightshifts was associated with greater emotional responses to work stressors (Zohar, Tzischinsky, Epstein, & Lavie, 2005). Research examining the relation between poor sleep quality and affective reactivity links poor sleep to increased negative affect reactivity to a laboratory stressor (Williams et al., 2013). Additionally, greater insomnia symptoms have been linked to increased negative thoughts (Neitzert, Semler, & Harvey, 2007). Some research, however, indicates no significant relation between poor sleep quality and affective reactivity following acute stress (Wright et al., 2007).

Given that sleep deprivation and sleep problems are highly prevalent issues worldwide, (Gradisar, Gardner, & Dohnt, 2011), understanding the relation between components of sleep health and psychological stress reactivity is crucial (Watling, Pawlik, Scott, Booth, & Short, 2017). A recent review of the literature suggests that separate aspects of sleep (e.g. sleep duration, sleep quality) may differentially effect individuals' physiological response to stress (van Dalfsen & Markus, 2018). Thus, research is needed to elucidate our understanding of how different sleep factors influence stress reactivity. In efforts to examine the influence of both acute and chronic sleep deprivation on affective stress reactivity, the current study examines both habitual weekday sleep duration and sleep duration prior to an exam period assessment. Additionally, in order to consider the predictive role of sleep problems on affective health, the current study examines sleep quality prior to the exam assessment as an additional lifestyle factor. Recent research has pointed to the importance of examining both sleep duration and sleep quality in combination and in isolation from one another (Bin, 2016), as both are factors that contribute to individuals' overall sleep health.

1.3 Physical Activity

Physical activity is another health-related behavior associated with individuals' response to stress. Prior research suggests that physical activity may buffer against stress exposure through several physiological pathways, including improved cardiovascular functioning, lower cortisol levels, increased resistance to oxidative stress, and reduction of pro-inflammatory levels in the body (Huang et al., 2013). A wealth of literature has investigated the relation between physical activity and physiological stress reactivity, centered on the stress-buffering hypothesis (Cohen & Willis, 1985). The stress-buffering hypothesis suggests that physical activity protects individuals from the negative effects of stress by acting as a buffer against stress (Klaperski, 2017). Findings are uncertain, however, as some research links acute exercise to attenuated blood pressure responses to stress (e.g. Hamer, Taylor, & Steptoe, 2006), while other research has indicated no significant differences in blood pressure, heart rate, and cortisol responses to stress between sedentary and active individuals (Poole et al., 2011).

Recent studies examining the relation between physical activity and psychological stress reactivity indicate that inactive individuals display greater affective reactivity following acute stress than active individuals (Childs & De Wit, 2014; Endrighi, Steptoe, & Hamer, 2015). In one study, participants were randomized to an aerobic exercise or attention control condition (Rejeski, Thompson, Brubaker, & Miller, 1992). Following the exercise/control task, participants completed two stressor tasks. Results indicate that participants in the exercise group displayed fewer anxiety-related thoughts in anticipation of the interpersonal stressor and blunted blood pressure reactivity following an interpersonal stressor and cognitive stressor compared to the control group. Findings from this research suggest that exercise may dampen individuals' affective reactivity to acute stress, even after one acute session of physical activity (Rejeski et al., 1992).

In another study, the stress-buffering effect of physical activity was examined using a longitudinal assessment of 65 days during an academic semester (Flueckiger, Lieb, Meyer, Witthauer, & Mata, 2015). Physical activity, sleep quality, and dietary behavior were assessed on each day. Additionally, negative affect and stress intensity levels were reported. Results suggest that on days where stress levels were higher, greater amounts of physical activity and better sleep quality predicted a weaker association between stress and affect levels. These findings suggest that by targeting physical activity and sleep habits, individuals may be able to buffer the negative effects of stress on mood.

Although several studies indicate a relation between less frequent physical activity and a greater affective stress response, some research has indicated opposite findings. In one study, researchers examined the "Cross-Stressor Adaptation (CSA) hypothesis," a theory developed to describe the buffering effect of physical activity (Hamer, Taylor, & Steptoe, 2006). This hypothesis suggests that physical activity catalyzes physiological changes in the body that lead to reduced reactivity of the sympathoadrenal system and HPA-axis. To investigate the effects of physical activity on physiological and psychological stress responses, the Trier Social Stress Test

(TSST) was used as a psychosocial stressor (Klaperski, Von Dawans, Heinrichs, & Fuchs, 2013). Participants' stress reactivity was measured following the TSST. Consistent with expectations, individuals who were less active displayed greater physiological stress responses (higher cortisol reactivity and higher heart rate reactivity) to the TSST. Contrary to expectations, however, a higher decrease in mood following the TSST was reported for more physically active participants. Findings indicate a need to further examine experiential measures of affective reactivity following stress exposure. In the current study, both negative affect and acute stress reactivity were examined as self-report indicators of the affective response to stress.

1. 4 Relation between Physical Activity and Sleep

One major limitation to current research investigating the influence of health-related behavior on stress reactivity is the frequent use of health-related factors in isolation from one another. Research has indicated that physical activity may influence changes in sleep and vise-versa (Chennaoui, Arnal, Sauvet, & Léger, 2015). One recent study measured students' physical activity habits and sleep quality at one time-point during the end of the semester break and at four time-points during the subsequent end-of-term examination period (Wunsch, Kasten, & Fuchs, 2017). Increased physical activity during the exam period was associated with better sleep quality, well-being, and affect. A limitation to this study was that the baseline assessment was completed before the semester began, several months before the exam period assessment. It is possible that during these months, sleep habits and physical activity levels changed before they were measured again during the exam period. These findings, however, provide evidence that physical activity and sleep habits interact with one another to predict individuals' affect during periods of stress. In the present study, sleep and physical activity were examined as primary health-related lifestyle factors influencing affective reactivity both in isolation and in combination with one another.

1.5 Chronic Stress, Acute Stress, and Negative Affect

Prior research indicates that chronic stress is a major component influencing individuals' affective health. Individuals who report higher levels of chronic stress report a greater occurrence of daily stressors (Gouin et al., 2012) and increased psychological distress when faced with challenges (Lepore et al., 1997). Additionally, experiencing multiple stressors is associated with greater perceived demands of cognitive tasks completed during an end-of-term examination period (Evans et al., 1996). Individuals that report chronic stress from their parenting responsibilities report experiencing higher levels of negative mood during the day, with greater sleep disturbances strengthening this relation (da Estrela et al., 2018). Understanding chronic stress in addition to health-related lifestyle factors predicting individuals' affective health is of interest given prior research suggesting that chronic stressors may be more strongly related to an individual's mood than the acute stressors they experience (McGonagle & Kessler, 1990).

1.6 Chronic Stress and Health-Related Lifestyle Factors

Prior research indicates an influence of chronic stress on individuals' affective health (Chida & Hamer, 2008; Matthews, Gump, & Owens, 2001; Ockenfels et al., 1995). Few studies, however, have examined both chronic stress and health-related lifestyle factors in predicting individuals' response to stress (Gerber et al., 2013). In one study, the relation between chronic stress and health-related lifestyle factors was examined in a sample of police officers (Gerber et al., 2013). Using self-report measures, police officers rated their overall mental health, perceived physical fitness level, chronic stress level, and sleep habits. Researchers investigated whether police officers' mental health was dependent on chronic stress levels, perceived physical fitness, and sleep. They examined the relation between each factor (sleep, physical fitness, chronic stress) and mental health both independently and in interaction with one another. Results indicate that poor sleep and high chronic stress, but not perceived physical fitness, were associated with worse mental health. Furthermore, results indicate a significant three-way interaction between chronic stress, perceived physical fitness, and sleep. Among participants who reported good sleep, perceived fitness buffered against high chronic stress exposure. This suggests that with poor sleep habits and high chronic stress exposure, stress-buffering effects from physical fitness are not evident. If sleep habits are adequate, however, perceived fitness buffers against chronic stress. A limitation to this study was the use of categorical chronic stress, sleep, and perceived physical fitness variables. Dichotomizing continuous variables leads to several problems including loss of statistical power and loss of variability in scores (Altman & Royston, 2006). In the current study, chronic stress, sleep, and physical activity variables were continuous, improving the statistical method of data analysis.

1.7 Current Study

Recent studies examining the role of chronic stress, sleep, and physical activity on affective reactivity often use laboratory stressor tasks to induce stress in participants (e.g. TSST; Kirschbaum, Pirke, & Hellhammer, 1993) rather than examining periods of real-life stress. These laboratory tasks are often brief (e.g. sleep deprivation for one day), capturing the response to a brief stressor rather than the response to sustained stress. Few studies have considered the influence of chronic stress exposure and lifestyle factors together (Gerber et al. 2013), although prior research indicates that chronic stress exposure is a major component influencing individuals' reactivity to stressors (Chida & Hamer, 2008; Matthews et al., 2001; Ockenfels et al., 1995). The first study to examine chronic stress, sleep, and physical activity in both isolation and combination with each other and in association with mental health functioning employed a general measure of quality of life (from the 12-Item Short-Form Health Survey) rather than measures of affect (Gerber et al. 2013). This study examined singular components of sleep health and activity level rather than multiple aspects (e.g. sleep duration and sleep quality, moderate and vigorous physical activity) which may differentially influence individuals' affective and stress responses (Pilcher, Ginter, & Sadowsky, 1997). The current study aims to address these knowledge gaps. Use of an academic exam period as a stressor allows for an investigation of factors influencing individuals' real-life, sustained response to stress. Examination of chronic stress in combination with lifestyle factors allows for a more comprehensive understanding of how health-related behavior influences individuals' response to stress.

The present study examines the influence of chronic stress, sleep quality and duration, and habitual physical activity on the affective response to a period of sustained acute stress. In particular, a final exam period served as the sustained acute stress period and participants were assessed during an academic semester and final exam period (Figure 2).

Over and above other predictors, greater chronic stress during the semester was hypothesized to predict greater affective reactivity (negative affect and acute stress responses) during the exam period. Lower levels of habitual physical activity, shorter habitual sleep duration, and reduced acute sleep duration and sleep quality were expected to predict greater affective reactivity during exams.

Additionally, following earlier findings by Gerber et al. (2013), a three-way interaction between semester chronic stress, physical activity, and sleep (acute sleep duration and quality) was hypothesized. When sleep duration during the exam period was longer and/or sleep quality was better, greater habitual physical activity was predicted to buffer against semester chronic stress (see Figure 1 for hypothesized triple interaction). When acute sleep duration was shorter and/or sleep quality was poorer, physical activity was not hypothesized to buffer against semester chronic stress.

We hypothesized that significant lifestyle factors would also mediate the relation between semester chronic stress and exam period affective reactivity. Greater semester chronic stress levels were hypothesized to predict shorter sleep duration, poorer sleep quality, and less physical activity, with these deficits in turn a least partially mediating greater affective reactivity to the exam period.

CHAPTER 2:

METHOD

2.1 Participants

The sample consisted of 637 undergraduate students from Southern Methodist University (SMU). Students were recruited using the psychology subject pool and received course credit in their psychology courses for participating. Participants completed the study during the course of an academic semester. To be included in the study, participants had to be 18 years of age or older and have three final exams scheduled for the end of term final examination period. The SMU Institutional Review Board approved this study and data was collected during the 2016-2018 academic semesters. Informed consent was obtained prior to participation in the study.

2.2 Measures

a. Chronic Stress. The English translation of the Trier Inventory for the Assessment of Chronic Stress (TICS-E; Petrowski et al., 2018) was used to measure chronic stress exposure during the semester. The Trier Inventory for the Assessment of Chronic Stress contains 57 items in total and is a questionnaire assessing chronic stress over the last 3 months (Schulz & Schlotz, 1999). Each item is scored on a 5-point scale and higher overall summary scores represent greater levels of chronic stress exposure. The TICS-E has adequate reliability and internal consistency (α = .84 to .92; Petrowski et al., 2018).

b. Sleep Duration and Quality. An ad-hoc sleep questionnaire modeled after prior work from van Maanen and colleagues (2013) was used to measure sleep duration at each assessment time-point. This was used instead of a standard measure of habitual sleep quality (e.g. Pittsburgh Sleep Quality Index (PSQI); Buysse et al., 1989) because sleep quality the night prior to the exam period was the sleep quality variable of interest. "How many hours of sleep do you typically get on a weeknight" assessed during the semester provided a measure of habitual sleep duration. "How many hours of sleep did you get during the night" prior to the exam assessment provided information about sleep duration during the acute stress period. Sleep quality was measured as a composite score of sleep latency ("How quickly did you fall asleep during the evening/night"), frequency of nocturnal awakenings ("How frequently did you awake while sleeping during the night"), sleep latency after nocturnal awakenings ("How quickly did you fall asleep after awakening at night") feeling fit at rise time ("How fit or well-rested did you feel in the morning"), feeling tired during the day (How frequently were you tired"), and taking sleep medication ("Did you take any sleep medication in the past three days"). Scores on each item were calculated as a percentage out of 1.00, with an item score of 1 indicating the worst sleep quality and an item score of 0 indicating the best sleep quality. Items were added to compute a composite sleep quality score, with higher total scores indicating poorer quality of sleep and lower total scores indicating good sleep quality.

c. Physical Activity. A physical activity questionnaire modeled after the International Physical Activity Questionnaire (IPAQ; Craig et al., 2003) and physical activity items from the 2009 Behavioral Risk Factor Surveillance System survey was used to measure participants' physical activity (BRFSS; Nelson, Holtzman, Bolen, Stanwyck, & Mack, 2001). The questionnaire consists of 12 items measuring habitual physical activity levels during the past 6 months. The survey first asks whether participants engage in moderate and/or vigorous activities for at least 10 minutes at a time. Participants then indicate the days per week and total time (hours and minutes) per day they spend partaking in moderate and vigorous activities. A summary score for total time per week spent participating in moderate to vigorous activities (MVPA) was calculated as a measure of habitual physical activity. MVPA was scored following the IPAQ protocol for truncating activity in each category at a maximum of 3 hours per day (IPAQ Research Committee, 2005). Total weekly minutes of moderate physical activity and vigorous physical activity were then computed. Then, the following formula was used to compute MVPA: Total weekly minutes of moderate physical activity + 2(Total weekly minutes of vigorous physical activity). This allowed for vigorous physical activity to be double-weighted, following new guidance for calculating equivalent minutes of moderate and vigorous activity (Roberts, Townsend, & Foster, 2016).

d. Acute Stress. Participants rated their current stress levels at each time-point by responding to the question: “To what extent do you feel stressed?” An ad-hoc 10-point rating scale from “1- Not at all” to “10 - Extremely” was used.

e. Negative Affect. During each assessment time-point, current negative affect was assessed with the Positive Affect Negative Affect Schedule (PANAS; Watson, Clark, and Tellegen, 1988). The negative affect subscale of the PANAS consists of 10 items with five response options per item (each item scored on a 1-5 scale). Higher overall scores on the scale correspond to greater amounts of negative affect. The PANAS has adequate internal consistency ($\alpha = .85$) and Common Factor Analysis modeling suggests sufficient construct validity (Crawford & Henry, 2004).

f. Anxious and Depressive Mood. The depression subscale of the Hospital Anxiety and Depression Scale (HADS-S; Zigmond & Snaith, 1983) was used to assess semester depressive mood. To measure semester anxiety levels, the anxiety subscale of the Hospital Anxiety and Depression Scale was used (HADS-A; Zigmond & Snaith, 1983). Each subscale consists of seven items with four response options per item (each item scored on a 0-3 scale). The HADS is a valid measure of anxious and depressive mood in the general population (Bjelland, Dahl, Haug, & Neckelmann, 2002) and has adequate reliability (Herrmann, 1997).

g. Covariates. A general demographics and health information questionnaire was administered during the first session of the study. Age, sex, race and body mass index (BMI) was obtained from this survey and was included as covariates in each regression analysis. Race was coded as 0 for Caucasian and 1 for other. During the exam period assessment, participants reported the number of exams they had remaining. Day of the exam period assessment, number of exams participants had remaining, time of day during the semester and exam period. These variables were included as covariates in each regression analysis in addition to days between the two study assessments. Baseline measures of each outcome variable were controlled for in each regression analysis, allowing for affective reactivity to be examined.

2.3 Procedure

The procedure was approved by the Institutional Review Board at Southern Methodist University. A baseline assessment was conducted during the academic semester, when stress levels are typically lower than during the final exam period. After completing informed consent, participants completed a series of questionnaires online via Qualtrics including the PANAS, HADS, TICS-E, acute stress ratings, habitual physical activity, sleep habits, and demographics. The second assessment was scheduled during the end-of-term final exam period to measure participants' response to a period of sustained acute stress. The questionnaires participants completed in the second assessment included the sleep questionnaire, PANAS, and stress ratings.

2.4 Data Analytic Plan

Prior to conducting regression analyses, descriptive statistics were computed for each variable in the study. Day of the exam period and age were positively skewed (skewness >2) inverse linear transformations were computed these two study variables. For participants who completed 50% of a scale or more (started the measure but did not complete it), Expectation Maximization (EM) was used to impute missing items in the PANAS-N, HADS, TICS-E, and sleep quality scales (Dempster, Laird, & Rubin, 1977). Multiple imputation (MI; Little & Rubin, 1987) was then used to estimate individuals' total score on measures they did not fill out. Since the greatest percentage of missing data for a study variable was 32% (number of exams remaining), the number of imputed data sets was 32 (see Table 1 for percentage of data missing for each variable). SPSS Version 25 statistical software was used for all analyses.

a. Primary Analyses. Hierarchical multiple linear regression models were used to predict negative affect and acute stress reactivity during the exam period. The pooled model of each multiple regression model was computed using MI estimated values. As R Square estimates of the total variance accounted for by regression models are not available for pooled analyses, semipartial r^2 (r_{sp}^2) was calculated to estimate the unique variance accounted for by each model predictor. Lifestyle factors (sleep, physical activity) and chronic stress were centered at their mean prior to being entered into each model. This allowed for the main effects to be interpreted for the mean value of each lifestyle factor. Age, sex, race, and body mass index were entered in Step 1 of each model, together with additional control variables: day during the exam period, number of exams remaining, time of day, and number of days between the semester and exam period assessment. Next, total minutes of moderate to vigorous habitual physical activity, sleep duration prior to the exam assessment, habitual sleep duration, chronic stress level at baseline, and baseline negative affect/acute stress were included in Step 2. Controlling for baseline negative affect/acute stress in each model allowed for predictors of acute stress reactivity and negative affect reactivity to be examined. In addition, two-way interactions between chronic stress, exam period sleep, physical activity and their hypothesized triple interaction were entered into Step 2. To account for multiple comparisons in the analysis of the two dependent variables (negative affect and acute stress during the exam period), Bonferroni corrections were used (p = .025). Non-significant higher order interactions were dropped from each model. G*Power estimation indicated that the sample size of 637 participants was sufficient to detect a small effect size in a standard OLS multiple regression with power of 80% using p=.025 (Erdfelder, Faul, & Buchner, 1996).

Sleep quality during the final exam period was also examined as an additional aspect of sleep in predicting affective reactivity to exam stress. In this analysis, the exam period sleep quality variable replaced the exam period sleep duration variable used in the prior analysis. After this, hierarchical multiple linear regression analyses were conducted with both sleep quality and sleep duration as joint predictors in the negative affect reactivity and acute stress reactivity models to investigate the role of these aspects of sleep over and above each other.

b. Mediation Analyses. Lifestyle factors were examined as mediators of the relation between semester chronic stress and affective reactivity to exam stress. Specifically, it was hypothesized that greater chronic stress would lead to lower physical activity levels and poorer sleep habits, and these lifestyle factors would then predict greater affective reactivity to exams. To examine the mediating effect of these lifestyle factors, regression models controlling for age, sex, race, and body mass index were conducted. Day during the exam period, number of exams remaining, time of day during each assessment, and number of days between the semester and exam assessment were also controlled for. Two models were calculated, one with each affective reactivity variable (negative affect or acute stress) as the outcome. First, the affective reactivity outcome variable was regressed on semester chronic stress (TICS-E). Then, lifestyle factors that were significant predictors in the primary analyses were regressed on semester chronic stress. Next, each outcome variable was regressed on each significant lifestyle factor (one analysis for each lifestyle factor that was significant in the primary analyses), controlling for baseline affect and chronic stress. R Mediation was used to compute the confidence intervals for the indirect effect of the mediator using the distribution of the product of the coefficients method (Tofighi & MacKinnon, 2011). For significant mediators, the proportion of the effect mediated (P_M) was calculated. Although the paths in these mediation models may not be causal since the protocol did not have enough time points available to calculate a sophisticated longitudinal cross lag panel mediation model, they do represent the mediated effects if these paths are indeed causal.

c. Exploratory Analyses. Sensitivity analyses were conducted to compare the results of the analysis of the original data with the results of the regression models computed using multiple imputation. Additionally, sensitivity analyses were conducted controlling for students' psychostimulant and antidepressant medication use during the semester. To explore whether variables that are more closely tied to clinically relevant psychopathologies reflect the effects of chronic stress, additional exploratory analyses were conducted testing the relationship of semester anxiety and depressive symptoms with affective reactivity during the exam period. For that, the semester chronic stress variable (TICS-E) was replaced with semester anxious and depressive mood measured by HADS-D and HADS-A, respectively.

CHAPTER 3:

RESULTS

3.1 Primary Analyses

a. Baseline Characteristics. Demographic characteristics of the sample are displayed in Table 2, along with descriptive statistics for each measure in the study. Participants were predominantly female (69%) and Caucasian (74%). The mean age of participants was 19.69 (*SD* = 2.06).

b. Predictors of Negative Affect and Acute Stress Reactivity During Exams, Sleep Duration as Primary Sleep Component. Significant predictors of students' negative affect reactivity during the exam period were sleep duration prior to the exam assessment, chronic stress, and number of finals remaining (Table 3). Habitual weekday sleep duration and habitual physical activity levels did not emerge as significant predictors and no significant interactions between semester chronic stress, habitual physical activity levels, and sleep duration during the exam assessment were found (Table 3). For acute stress reactivity, significant predictors consistent with the negative affect reactivity model were observed (Table 4). Sex was also a significant predictor, with being female predicting greater acute stress reactivity during the exam assessment. After correcting for multiple tests using Bonferroni family-wise test correction, there were no significant interactions between chronic stress, sleep duration, and habitual physical activity levels. There was a trend towards significance between semester chronic stress level and sleep duration prior to the exam assessment, however (Table 4). Table 9 and Table 10 display the final simplified models with non-significant interactions dropped from each model.

c. Predictors of Negative Affect and Acute Stress Reactivity During Exams, Sleep Quality as Primary Sleep Component. The sleep duration variables (habitual and exam period sleep duration) were replaced with sleep quality prior to the exam assessment in each hierarchical regression model for negative affect and acute stress reactivity. Semester chronic stress significantly predicted greater negative affect reactivity (Table 5) and acute stress reactivity (Table 6). Consistent with the sleep duration models, number of exams remaining predicted greater acute stress and negative affect reactivity and being female was a significant predictor of greater acute stress reactivity. There were no significant interactions between sleep quality, chronic stress, and habitual physical activity levels in predicting greater negative affect reactivity (Table 5) and acute stress reactivity (Table 6). Final models are displayed in Table 11 and Table 12, which were simplified by removing non-significant interactions from each model.

d. Sleep Duration and Sleep Quality Prior to the Exam Assessment as Joint Predictors of Acute Stress and Negative Affect Reactivity. To examine the predictive role of exam period sleep quality and sleep duration (which were only moderately correlated, $r = .35$, $p < .001$) over and above each other, models with both sleep variables predicting negative affect (Table 7) and acute stress reactivity during exams (Table 8) were conducted. Each sleep variable significantly predicted affective reactivity to the exam period. Each sleep variable significantly predicted affective reactivity and stress reactivity to the exam period. Over and above other predictors in the negative affect reactivity model, sleep duration explained 2.1% unique variance, $r_{sp}^2 = .021$ while sleep quality explained 1.1% unique variance, $r_{sp}^2 = .011$. In the acute stress reactivity model, sleep duration explained 4.0% unique variance in the model, $r_{sp}^2 = .040$, while sleep quality explained 1.8% unique variance, $r_{sp}^2 = .018$.

3.2 Mediation Analyses

The relation between chronic stress during the semester and both negative affect and acute stress reactivity during the exam period was hypothesized to be partially mediated by significant lifestyle factors (sleep duration, sleep quality). In the sleep duration model, greater chronic stress during the semester predicted greater acute stress reactivity, *B* = 0.01, 95% CI: [0.01, 0.02], t(625) = 3.86, p < .001, and negative affect reactivity, *B* = 0.06, 95% CI: [0.04, 0.08], t(625) = 4.88, p < .001, during the exam period. Chronic stress during the semester, however, did not significantly predict sleep duration during the exam period, *B* = 0.01, 95% CI: [-0.010, 0.001], t(626) = 1.49, p = .137. Shorter sleep duration prior to the exam period assessment did not mediate the relation between greater semester chronic stress and greater negative affect reactivity, a*b = 0.003, 95% CI [-0.002, 0.009], and acute stress reactivity, a*b = 0.001, 95% CI [-0.001, 0.003].

Additional analyses were conducted to examine sleep quality prior to the exam assessment as a mediator of the relation between chronic stress during the semester and negative affect and acute stress reactivity (Figure 3). Greater chronic stress predicted poor sleep quality prior to the exam assessment, *B* = 0.01, 95% CI: [0.005, 0.009], t(626) = 6.73, p < .001, and poor sleep quality partially mediated the relation between greater semester chronic stress and greater negative affect reactivity, a*b = 0.014, 95% CI [0.007, 0.022], p < .05 (Figure 3). 24.1% of the effect of chronic stress on negative affect reactivity was explained by sleep quality ($P_M = .241$). Sleep quality was also a partial mediator of the relation between semester chronic stress and acute stress reactivity, a*b = 0.005, 95% CI [0.003, 0.007], $p < .05$, and the proportion of the effect mediated by sleep quality was 37.7% ($P_M = .377$; Figure 3).

3.3 Exploratory Analyses

a. Anxious and Depressed Mood as Predictors of Negative Affect and Stress Reactivity. Using the anxiety (HADS-A) and depression (HADS-D) subscales of the HADS, semester chronic stress (TICS-E) was replaced with symptoms of psychopathology. Semester anxiety symptoms (HADS-A), but not depressive symptoms (HADS-D), was a significant predictor of greater acute stress reactivity during the exam period (Table 14 and Table 16). Semester anxiety symptoms (HADS-A) predicted negative affect reactivity during the exam period, while depressive symptoms (HADS-D) did not (Table 13 and Table 15). Additional mediation analyses were completed to examine exam sleep duration and sleep quality as potential mediators of the relation between semester anxiety levels and affective reactivity during exams. Shorter sleep duration did not significantly partially mediate the relation between greater anxiety symptoms and greater acute exam stress reactivity, a*b = 0.005, 95% CI [-0.009, 0.019], or negative affect reactivity, a*b = 0.014, 95% CI [-0.027, 0.057]. Poor sleep quality prior to the exam period assessment, however, mediated the relation between greater anxiety symptoms and greater negative affect reactivity, a*b = 0.105, 95% CI [0.052, 0.170], $p < .05$. The proportion of the mediating effect of sleep quality on the relation between anxiety symptoms and negative affect reactivity during the exam period was 31.6% ($P_M = .316$). Controlling for sleep quality, the relation between anxiety symptoms and negative affect reactivity was no longer significant (c' path in Figure 4). Poor sleep quality also partially mediated the relation between greater anxiety symptoms and greater acute stress reactivity, a*b = 0.034, [0.022, 0.047]. 36.6% of the effect of anxiety symptoms on acute stress reactivity during the exam period was accounted for by sleep quality prior to the assessment (P_M = .366; Figure 4).

b. Sensitivity Analyses. Sensitivity analyses were conducted to compare the results of the original data with the regression models computed using multiple imputation. Using the original model, significant findings for key lifestyle factors remained significant. Additionally, when the acute stress and negative affect reactivity models were computed controlling for students' psychostimulant and antidepressant medication use during the semester (obtained from the demographics and health questionnaire), the key lifestyle factors remained significant predictors of negative affect and stress reactivity. Students' psychoactive medication use did not independently predict their affective response to the exam period.

CHAPTER 4:

DISCUSSION

4.1 Discussion of Findings

Using a naturalistic period of sustained acute stress, the present study sought to extend research investigating the role of chronic stress and lifestyle factors (physical activity, habitual sleep duration, exam period sleep duration, and exam period sleep quality) on individuals' affective response to a naturalistic stressor. Consistent with hypotheses, sleep duration and sleep quality prior to the final exam assessment and chronic stress during the semester predicted students' negative affect and acute stress reactivity to exams. Contrary to hypotheses, habitual weekday sleep duration and habitual levels of moderate and vigorous physical activity did not significantly predict students' response to the exam period. Additionally, no significant interactions between lifestyle factors and chronic stress were found.

Over and above each other, sleep quality and sleep duration were significant predictors of the affective response to exam stress, supporting prior research highlighting the importance of both sleep quality and sleep duration as sleep components determining individuals' health (Bin, 2016). Additionally, sleep quality mediated the relation between greater semester chronic stress and anxiety and affective reactivity during exams, suggesting that anxiety and chronic stress exposure during a semester contributes to later sleep problems and heightened affective reactivity to stress. Previous research examining sleep and health focuses on consequences of insufficient sleep and risk for physical disease (Bin, 2016). Both disturbed sleep and short sleep duration are associated with numerous physical health conditions including increased risk for cardiovascular disease (Rod et al., 2014) and diabetes (Mallon, Broman, & Hetta, 2005). Poor sleep quality has been associated with greater symptoms of anxiety and depression (Jansson-Fröjmark, & Lindblom, 2008; Neckelmann, Mykletun, & Dahl, 2007), increased risk for suicide (Bernert, Turvey, Conwell, & Joiner, 2014), and decreased quality of life (Léger, Scheuermaier, Philip, Paillard, & Guilleminault, 2001), while sleep deprivation is linked to greater negative mood symptoms including depression (Roberts, & Duong, 2014). Increasing our understanding of the influence of both sleep duration and quality independently and in combination with one another on individuals' response to stress, results indicate that sleep duration and sleep quality prior to the exam assessment play significant roles in predicting students' affective health.

Study findings indicate that chronic stress during the semester was associated with greater acute stress and negative affect reactivity to the exam period. The results are consistent with previous research investigating the relation between chronic childhood stressors (emotional abuse) and affective reactivity in adulthood, linking greater chronic childhood stress to increased depressive mood following stress exposure (Shapero et al., 2014). It may be that students with greater chronic stress levels feel less confident about preparing for exams while managing other responsibilities, and are more sensitive to deteriorations in mood as they interpret a greater accumulation of stress during these periods.

Consistent with prior research, we observed an increase in negative affect and stress during academic exams (Maarouf, Maarouf, Yosipovitch, & Shi, 2019; Singh, Goyal, Tiwari, Ghildiyal, Nattu, & Das, 2011; Trueba, Smith, Auchus, & Ritz, 2013; Weekes, Lewis, Patel, Garrison-Jakel, Berger, & Lupien, 2006). The increase was substantial, comparable to laboratory studies that rely on the induction of stress, such as the TSST (Hidalgo et al., 2015; Zeidner &

Ben-Zur, 2014). With the majority of past research utilizing laboratory-based stress tasks to examine the role of lifestyle factors in individuals' response to stress (e.g. Childs & De Wit, 2014; Endrighi et al., 2015; Minkel et al., 2012; Talbot et al., 2010; Zohar et al., 2005), the present study extends prior literature to provide information about how chronic stress and lifestyle factors interact to predict affective reactivity during a more naturalistic, and thus ecologically more valid situation.

A three-way interaction between semester chronic stress level, physical activity, and exam period sleep quality/duration was hypothesized in the current study. This hypothesis was not supported in the current study findings. These non-significant findings are inconsistent with prior research indicating that adequate sleep and good perceived physical fitness buffer against chronic stress in predicting mental health quality (Gerber et al. 2013). In this prior study, Gerber and colleagues provide evidence that perceived physical fitness acts as a buffer against stressors for police offers reporting few sleep problems (2013). In the current study, moderate to vigorous physical activity was used as a measure of habitual physical activity level, which may differ from individuals' perception of their overall fitness levels. Furthermore, Gerber and colleagues' study did not examine mental health during a period of increased stress, and examined the relation between chronic stress, sleep, perceived fitness and mental health in a police officer sample. Job related demands of police officers (physical ability, threat of violence) differ from academic stress that undergraduate students experience during an examination period. Police officers' reliance on their physical abilities to manage demands may lead to a greater buffering effect on stressors that they face (when perceived physical fitness is good and they rely on physical ability). Physical strength, however, is not utilized by undergraduates during final examinations and this may contribute to differences in the buffering of chronic stress. Additionally, it may be that major sleep disturbances across a semester, rather than habitual weekday sleep duration, play a role in contributing to individuals' affective response to an exam period. Prior research indicates that chronic sleep disturbances, such as insomnia disorder, are associated with high emotional reactivity, and this emotional reactivity may be a maintenance factor for poor sleep quality (Baglioni, Spiegelhalder, Lombardo, & Riemann, 2010). In the current study, however, no measure of habitual sleep quality was included.

Study findings suggest that sleep quality prior to the exam assessment, but not exam period sleep duration, mediates the relation between chronic stress and students' stress reactivity during the exam period. Prior research indicates that chronic emotional stress is a significant predictor of short sleep duration and is associated with poor sleep quality (Hicks, Fernandez, & Pellegrini, 2001). Thus, we anticipated that greater semester chronic stress would predict both poor sleep quality and short sleep duration during the exam period. As short sleep duration is one component contributing to poor sleep quality, sleep duration itself may not mediate the relation between semester chronic stress and affective reactivity to exams. A recent sleep medicine review suggests that sleep quality may be more predictive of physiological stress reactivity than changes in acute sleep duration (van Dalfsen, & Markus, 2018). It may be that short sleep duration's contribution to problems with achieving quality sleep (e.g. feeling unfit at rise time due to sleep deprivation) may explain this relation.

Number of exams remaining also predicted greater affective reactivity (acute stress and negative affect) to the exam period, with fewer exams remaining associated with less of an increase in negative affect and acute stress during the exam period. Most likely, the greater workload associated with more exams ahead results in greater negative affect and stress (Krantz, Berntsson, & Lundberg, 2005). Additionally, sex was a significant predictor of acute stress reactivity, with females reporting greater reactivity in stress during the exam period than males. Prior research indicates that women appraise events as more stressful than men and report greater negative affect levels (Lewis, Haviland-Jones, & Barrett, 2010). These greater reports of negative mood, however, may not reflect real sex differences in stress reactivity, as studies that eliminate the emphasis on gender roles (e.g. Barrett, Robin, Pietromonaco, & Eyssell, 1998) find no significant differences between men and women in affect levels (Lewis et al., 2010).

Exploratory analyses indicate that anxiety symptoms during the semester predicted affective responses to the exam period. These results are consistent with prior research indicating that anxious adults display a pattern of emotional hyper-reactivity, with greater negative mood responses to perceived threats (Goldin, Manber, Hakimi, Canli, & Gross, 2009) and greater negative reactivity to emotion (interpreting emotional experiences as aversive; Mennin, Heimberg, Turk, & Fresco, 2005; Turk, Heimberg, Luterek, Mennin, & Fresco, 2005). In the current study, sleep quality partially mediated the relation between greater semester anxiety levels and greater affective stress reactivity during the exam period. Providing evidence that greater anxiety symptoms lead to poor sleep quality during increased stress, findings relate to prior research investigating the relation between stress, variability in sleep duration, and fragmented sleep (Mezick et al., 2009). In Mezick and colleagues' previous research, the experience of stressful life events for individuals who report greater symptoms of anxiety and depression was associated with increased sleep problems (increased variability in sleep duration and sleep fragmentation; Mezick et al., 2009).

While significant relations between semester anxiety levels, sleep quality, and affective reactivity in the current study were found, depressive symptoms during the semester did not significantly predict affective reactivity (negative affect and acute stress) during the exam period. Research examining emotional reactivity and depression has supported the idea of emotion context insensitivity, which assumes that individuals with greater depressive symptoms exhibit a reduced reactivity to emotional cues (Rottenberg, 2005, Rottenberg, 2007). Studies examining the association between blunted reactivity and depressive symptoms have focused largely on clinical samples (Bylsma, Morris, & Rottenberg, 2008) while in the current study, students varied in the amount of depressive symptoms they reported and overall showed relatively low levels during the semester. Differences in response directions between healthy students with low or subclinical depressive mood and students with clinical levels of depression (greater affective reactivity compared to more blunted reactivity) may have contributed to the lack of association that was observed in the present study.

4.2 Limitations

The current study should also be interpreted in the light of its limitations. The use of self-report measures of sleep and physical activity may have yielded different findings from those potentially obtained with behavioral measures. Prior research has found that self-report measures of physical activity can lead to over-reporting of activity levels (Warnecke, 1997). However, this could explain our observed lack of association only if this would be an unsystematic influence inflating error variance. Previous studies have found that individuals with greater levels of negative affect report experiencing more sleep problems (worse sleep quality; Vitaliano et al., 1999). More objective measures of activity and sleep, such as accelerometry and polysomnography, can eliminate this bias and allow for an examination of specific (e.g. daily) patterns of sleep and activity during periods of stress (rather than measuring overall levels of activity and sleep).

Whereas this study sought to fill a gap in the literature regarding experiential indicators of stress and affective reactivity measures and their association with lifestyle factors, future research would ideally incorporate physiological, behavioral, and experiential measures. Investigating both physiological and psychological stress responses is critical as these are facets of health contributing to individuals' functioning and well-being (Spangler, Pekrun, Kramer, & Hofmann, 2002). Increasing our understanding of the influences of health-related behavior on physiological systems and psychological symptoms during periods of stress also has the potential to improve recommendations for care and interventions to support individuals during these critical periods.

Measurement of physical activity during the semester but not during the exam period may have also limited study findings. Since physical activity in the current study was measured during the academic semester on average 52 days before the end-of-term exam assessment, students' activity levels may have changed before the exam assessment. Short-term and habitual sleep duration during the semester may have differed from students' sleep duration during the exam period. Prior research suggests that activity levels change throughout an academic semester, with students exercising less at the end of the academic semester (Weidner, Kohlmann, Dotzauer, & Burns, 1996). As study findings suggest more proximal measures of sleep are important predictors of stress reactivity during the exam period, physical activity levels during the exam period may also have been better predictors of students' stress reactivity. Our assumption at study conception was that habitual activity of fitness levels rather than day-to-day fluctuations of activity would confer effects on affect reactivity. Although prior research has found associations between acute bouts of exercise and improved mood (Basso & Suzuki, 2017), research indicates that post-exercise mood improvements are twice as large in regular exercisers compared to non-exercisers, and non-exercisers experience more limited mood benefits (Hoffman & Hoffman, 2008). Additional research investigating the impact of accumulated physical activity on mental health indicates that long term bouts of physical activity lead to greater improvements in mood and anxiety than acute exercise bouts (Osei-Tutu & Campagna, 2005). Nevertheless, future academic stress studies should assess physical activity both during the semester and final exam period in order to account for changes in activity that may occur as the semester progresses. In future studies, measurement of physical activity during the semester can be optimized by having students wear activity trackers (e.g. Actigraphs) throughout an academic semester and exam period assessment, in order to obtain daily measures of physical activity.

It is also important to consider the characteristics of the sample when interpreting study findings. The sample was comprised of mainly young adult Caucasian females at a private southern university, highlighting the need for further research with individuals from a variety of ages and backgrounds (e.g. disease populations and older adults at heightened risk for insomnia and other health-related problems). Students in the sample reported an average of 700 minutes of moderate to vigorous activity per week (approximately 100 minutes per day on average). This average activity level is substantially higher than the World Health Organization physical activity guidelines of 150 minutes of MVPA per week (2010), and suggests that our sample is generally regularly physically active. Thus, the findings may be restricted in that limited variability in activity did not allow for an examination of both low and high levels of activity on students' affective response to sustained stress. Additionally, future studies should aim to investigate the role of other lifestyle factors, such as diet, on the response to sustained acute stress. Increased stress has been associated with unhealthy eating habits (Richardson, Arsenault, Cates, & Muth, 2015) and prior research indicates that unhealthy eating habits increase as the academic semester progresses, with a sharp increase in unhealthy eating around the end of an academic term (Wansink, Cao, Saini, Shimizu, & Just, 2013). Diet behavior may predict engagement in additional health related behavior during stressful periods and may interact to predict individuals' response to stress.

4.3 Summary, Future Directions, and Practical Implications

Despite limitations, the present study is the first of its kind to examine the role of chronic stress, sleep quality and sleep duration, and physical activity in predicting affective reactivity during a sustained period of acute naturalistic stress. In highlighting the importance of minimizing chronic stress and prioritizing good sleep before a challenging life situation, this study provides support for stress management interventions and maintaining a regular sleep schedule and practicing good sleep habits. Particularly during critical periods of performance, adequate sleep duration and sleep quality may serve as an effective way to manage mood and stress levels. Recent research examining the benefits of an "Eight Hour Sleep Challenge" for students indicates that students who slept over eight hours on average during a final exam period performed significantly better than students who slept less than eight hours (Scullin, 2019). With initial promising findings, further research is needed to investigate the benefits of lifestyle interventions across numerous domains of individuals' health (e.g. cognitive, affective, physiological, behavioral).

APPENDIX

Table 1. Percent of Missing Data for Each Study Variable

Variable	Missing data
Age (years)	0.00%
Sex (female)	0.16%
Race (Caucasian)	0.31%
BMI (kg/m^2)	3.92%
Physical activity (MVPA, minutes/week)	0.63%
Habitual weekday sleep duration (hours)	0.78%
Exam sleep duration (hours)	27.94%
Exam sleep quality	27.79%
TICS-E (0-228)	5.49%
PANAS-N baseline (10-50)	1.26%
PANAS-N exam period (10-50)	27.79%
Acute stress rating baseline (0-10)	1.57%
Acute stress rating exam (0-10)	27.79%
HADS-A baseline	0.00%
HADS-D baseline	0.00%
Day of final exam period	27.79%
Number of exams remaining	31.55%
Time between assessments (days)	27.63%
Time of day, baseline assessment	0.00%
Time of day, finals assessment	27.63%
Psychoactive medication use	0.00%

Note. Abbreviations*:* BMI, body mass index; MVPA, minutes of moderate and vigorous activity per week; TICS-E, English translation of the Trier Inventory for the Assessment of Chronic Stress; PANAS-N, Positive Affect Negative Affect Schedule – Negative Affect Subscale; HADS-A, Hospital Anxiety and Depression Scale – Anxiety subscale, HADS-D, Hospital Anxiety and Depression Scale – Depression subscale.

Table 2. Demographics and Descriptive Statistics for Study Measures

Variable	Mean/Percentage	SD	Min-Max	α
Age (years)	19.69	2.06	18 – 38	
Sex (female)	69%			
Race (White)	74%			
BMI (kg/m^2)	22.40	3.18	16.54 – 39.48	
Physical activity (MVPA, minutes/week)	699.47	636.62	0 – 3240	
Habitual weekday sleep duration (hours)	6.85	1.07	3 – 10.4	
Exam sleep duration (hours)	6.34	2.12	0 – 15	
Exam sleep quality (1.66-6)	3.18	0.77	1.66 – 5.50	.633
TICS-E (0-228)	84.59	31.83	2 – 169	.953
PANAS-N baseline (10-50)	16.29 (63rd percentile)	7.01	10 – 44	.902
PANAS-N exam period (10-50)	23.92 (90th percentile)	8.84	10 – 50	.903
Acute stress rating baseline (0-10)	3.10	2.12	1 – 10	
Acute stress rating exam (0-10)	6.08	2.36	1 – 10	
HADS-A semester (0-21)	7.17	4.24	0 – 20	
HADS-D semester (0-21)	3.73	2.77	0 – 18	.831
				.713
Day of final exam period	4.16	1.37	3 – 12	
Number of exams left	1.61	0.71	1 – 4	
Time between assessments (days)	52.64	27.47	9 – 103	
Time of day, semester assessment	32% morning, 68% afternoon			
Time of day, finals assessment	34% morning, 66% afternoon			
Psychoactive medication	17.7% current use			
Psychostimulant medication	10.7% current use			
Antidepressant medication	8.8% current use			

Note. Abbreviations*:* BMI, body mass index; MVPA, minutes of moderate and vigorous activity per week; TICS-E, English translation of the Trier Inventory for the Assessment of Chronic Stress; PANAS-N, Positive Affect Negative Affect Schedule – Negative Affect Subscale; HADS-A, Hospital Anxiety and Depression Scale – Anxiety subscale, HADS-D, Hospital Anxiety and Depression Scale – Depression subscale.

Table 3. Explained Variance in Negative Affect Reactivity During Final Exams, Sleep Duration Model (N = 637)

Predictor	*B*	SE	t	p	r_{sp^2} [b]
Age[a]	27.46	85.16	0.32	.747	<.001
Sex	1.13	0.81	1.40	.162	.003
Race	-0.37	0.84	0.43	.664	<.001
BMI	0.04	0.12	0.33	.744	<.001
Number of exams remaining	1.22	0.52	2.34	.019*	.009
Time between assessments (days)	-0.02	0.01	1.47	.142	.004
Time of day finals	1.09	0.82	1.33	.186	.003
Time of day baseline	0.04	0.74	0.05	.963	<.001
Day of finals[a]	0.07	5.68	0.01	.990	<.001
MVPA	0.00	0.00	0.34	.732	<.001
Habitual sleep duration	0.08	0.37	0.22	.823	<.001
Exam sleep duration	-0.83	0.18	4.68	<.001***	.038
TICS-E	0.05	0.01	4.26	<.001***	.028
PANAS-N baseline	0.28	0.06	4.84	<.001***	.042
TICS-E X MVPA	0.00	0.00	1.33	.184	.003
TICS-E X exam sleep duration	0.00	0.01	0.54	.593	<.001
MVPA X exam sleep duration	0.00	0.00	0.58	.559	.001
MVPA X exam sleep duration X TICS-E	0.00	0.00	0.15	.878	<.001

Note. Abbreviations: See Table 2; Results from multiple linear regression analysis predicting negative affect reactivity during the exam period; [a] = Inverse transformed variable; [b] = r_{sp^2} is semipartial r^2; * p < .025, *** p<.001.

Table 4. Explained Variance in Acute Stress Reactivity During Final Exams, Sleep Duration Model (N = 637)

Predictor	*B*	SE	t	p	r_{sp^2}[b]
Age[a]	-35.85	22.77	1.57	.116	.004
Sex	0.60	0.22	2.68	.008*	.013
Race	-0.35	0.24	1.48	.139	.004
BMI	0.00	0.03	0.04	.971	<.001
Number of exams remaining	0.58	0.14	4.14	<.001***	.029
Time between assessments (days)	0.00	0.00	1.06	.291	.002
Time of day finals	0.32	0.22	1.47	.142	.004
Time of day baseline	-0.03	0.20	0.15	.884	<.001
Day of finals[a]	1.86	1.66	1.12	.262	.002
MVPA	0.00	0.00	1.48	.140	.003
Habitual sleep duration	-0.07	0.10	0.65	.514	.001
Exam sleep duration	-0.29	0.05	6.27	<.001***	.063
TICS-E	0.01	0.00	3.30	.001**	.019
Acute stress baseline	0.04	0.05	0.75	.454	.001
TICS-E X MVPA	0.00	0.00	1.09	.278	.002
TICS-E X exam sleep duration	0.00	0.00	2.14	.032†	.008
MVPA X exam sleep duration	0.00	0.00	0.02	.988	<.001
MVPA X exam sleep duration X TICS-E	0.00	0.00	0.90	.368	.001

Note. Abbreviations: See Table 2; Results from multiple linear regression analysis predicting acute stress reactivity during the exam period; [a] = Inverse transformed variable; [b] = r_{sp^2} is semipartial r^2; † <.05, *p < .025, ** p < .005, *** p<.001.

Table 5. Explained Variance in Negative Affect Reactivity During Final Exams, Sleep Quality Model (N = 637)

Predictor	*B*	SE	t	p	r_{sp^2} [b]
Age[a]	46.53	84.69	0.55	.583	<.001
Sex	1.39	0.80	1.73	.084	.001
Race	0.50	0.84	0.59	.554	.001
BMI	0.09	0.12	0.81	.417	.001
Number of exams remaining	1.19	0.52	2.30	.022*	.009
Time between assessments (days)	-0.02	0.01	1.69	.092	.005
Time of day finals	0.77	0.83	0.93	.353	.002
Time of day baseline	-0.06	0.75	0.08	.934	<.001
Day of finals[a]	2.00	5.55	0.36	.718	<.001
MVPA	0.00	0.00	0.58	.565	.001
Exam sleep quality	2.01	0.48	4.19	<.001***	.029
TICS-E	0.04	0.01	3.27	.001**	.016
PANAS-N baseline	0.28	0.06	4.90	<.001***	.041
TICS-E X MVPA	0.00	0.00	1.34	.182	.003
TICS-E X exam sleep quality	0.01	0.01	0.41	.682	<.001
MVPA X exam sleep quality	0.00	0.00	0.99	.324	.002
MVPA X exam sleep quality X TICS-E	0.00	0.00	0.82	.414	.001

Note. Abbreviations: See Table 2; Results from multiple linear regression analysis predicting negative affect reactivity during the exam period; [a] = Inverse transformed variable; [b] = r_{sp^2} is semipartial r^2; *p < .025, ** p < .005, *** p<.001.

Table 6. Explained Variance in Acute Stress Reactivity During Final Exams, Sleep Quality Model (N = 637)

Predictor	*B*	SE	t	p	r_{sp^2} [b]
Age[a]	-29.81	23.16	1.29	.198	.003
Sex	0.68	0.22	3.07	.002**	.017
Race	-0.02	0.24	0.10	.922	<.001
BMI	0.02	0.03	0.58	.566	.001
Number of exams remaining	0.56	0.14	4.00	<.001***	.027
Time between assessments (days)	-0.01	0.00	1.48	.140	.004
Time of day finals	0.18	0.22	0.84	.403	.001
Time of day baseline	-0.07	0.21	0.33	.743	<.001
Day of finals[a]	2.36	1.61	1.46	.145	.004
MVPA	0.00	0.00	0.91	.361	.001
Exam sleep quality	0.73	0.13	5.52	<.001***	.053
TICS-E	0.01	0.00	2.28	.023*	.009
Acute stress baseline	0.05	0.05	1.01	.313	.002
TICS-E X MVPA	0.00	0.00	1.12	.265	.002
TICS-E X exam sleep quality	-0.01	0.00	1.49	.135	.004
MVPA X exam sleep quality	0.00	0.00	0.56	.579	<.001
MVPA X exam sleep quality X TICS-E	0.00	0.00	0.82	.414	.001

Note. Abbreviations: See Table 2; Results from multiple linear regression analysis predicting acute stress reactivity during the exam period; [a] = Inverse transformed variable; [b] = r_{sp^2} is semipartial r^2; *p < .025, ** p < .005., *** p<.001.

Table 7. Explained Variance in Negative Affect Reactivity During Final Exams, Predicted Jointly by Exam Period Sleep Quality and Sleep Duration, (N = 637)

Predictor	*B*	SE	t	p	r_{sp^2} [b]
Age [a]	23.61	83.88	0.28	.778	<.001
Sex	1.18	0.80	1.48	.140	.004
Race	-0.07	0.84	0.09	.930	<.001
BMI	0.05	0.12	0.46	.645	<.001
Number of exams remaining	1.19	0.51	2.33	.020*	.009
Days between assessments	-0.02	0.01	1.74	.082	.005
Time of day, finals	0.90	0.81	1.10	.272	.002
Time of day, baseline	0.15	0.74	0.20	.840	<.001
Day of finals [a]	0.74	5.48	0.14	.893	<.001
MVPA	0.00	0.00	0.41	.684	<.001
TICS-E	0.05	0.01	3.65	<.001***	.020
PANAS-N baseline	0.28	0.06	4.93	<.001***	.042
Exam sleep quality	1.32	0.50	2.64	.009*	.011
Exam sleep duration	-0.65	0.19	3.49	.001**	.021

Note. Abbreviations: See Table 2; Results from multiple linear regression analysis predicting negative affect reactivity during the exam period; [a] = Inverse transformed variable; [b] = r_{sp^2} is semipartial r^2; *p < .025, ** p < .005, *** p<.001.

Table 8. Explained Variance in Acute Stress Reactivity During Final Exams, Predicted by Exam Period Sleep Quality and Sleep Duration, (N = 637)

Predictor	*B*	SE	t	*p*	r_{sp^2} [b]
Age [a]	-34.91	22.49	1.55	.121	.004
Sex	0.62	0.22	2.82	.005*	.014
Race	-0.21	0.23	0.89	.375	.001
BMI	0.01	0.03	0.17	.864	<.001
Number of exams remaining	0.59	0.14	4.29	<.001***	.003
Days between assessments	-0.01	0.00	1.47	.143	.058
Time of day, finals	0.28	0.22	1.28	.200	.003
Time of day, baseline	-0.02	0.20	0.08	.936	<.001
Day of finals [a]	1.87	1.58	1.18	.238	.003
MVPA	0.00	0.00	1.34	.182	.003
TICS-E	0.01	0.00	2.74	.006*	.012
Baseline acute stress level	0.04	0.05	0.79	.433	.001
Exam sleep quality	0.46	0.14	3.34	.001**	.018
Exam sleep duration	-0.24	0.05	4.94	<.001***	.040

Note. Abbreviations: See Table 2; Results from multiple linear regression analysis predicting acute stress reactivity during the exam period; [a] = Inverse transformed variable; [b] = r_{sp^2} is semipartial r^2; *p < .025, ** p < .005, *** p<.001.

Table 9. Explained Variance in Negative Affect Reactivity During Final Exams, Final Model (N = 637)

Predictor	*B*	SE	t	p	r_{sp^2} [b]
Age[a]	22.02	85.27	0.26	.796	<.001
Sex	1.14	0.81	1.42	.157	.003
Race	-0.44	0.84	0.53	.599	<.001
BMI	0.04	0.12	0.37	.711	<.001
Number of exams remaining	1.21	0.52	2.33	.020*	.009
Time between assessments (days)	-0.02	0.01	1.54	.124	.004
Time of day finals	1.05	0.82	1.29	.200	.003
Time of day baseline	0.12	0.74	0.17	.867	<.001
Day of finals[a]	0.02	5.66	0.00	.997	<.001
MVPA	0.00	0.00	0.40	.687	<.001
Habitual sleep duration	0.07	0.37	0.19	.852	<.001
Exam sleep duration	-0.83	0.18	4.65	<.001***	.037
TICS-E	0.05	0.01	4.43	<.001***	.030
PANAS-N baseline	0.28	0.06	4.82	<.001***	.041

Note. Abbreviations: BMI, body mass index; MVPA, minutes of moderate and vigorous activity per week; TICS-E, English translation of the Trier Inventory for the Assessment of Chronic Stress; PANAS-N, Positive Affect Negative Affect Schedule – Negative Affect Subscale; Results from multiple linear regression analysis predicting negative affect reactivity during the exam period.[a] = Inverse transformed variable; [b] = r_{sp^2} is semipartial r^2; * p < .025, *** p<.001.

Table 10. Explained Variance in Acute Stress Reactivity During Final Exams, Final Model (N = 637)

Predictor	*B*	SE	t	p	r_{sp^2} [b]
Age[a]	-36.70	22.75	1.61	.107	.004
Sex	0.60	0.22	2.70	.007*	.013
Race	-0.37	0.24	1.57	.118	.004
BMI	0.00	0.03	0.02	.984	<.001
Number of exams remaining	0.59	0.14	4.20	<.001***	.030
Time between assessments (days)	0.00	0.00	1.15	.252	.002
Time of day finals	0.34	0.22	1.53	.126	.004
Time of day baseline	-0.02	0.20	0.12	.905	<.001
Day of finals[a]	1.88	1.65	1.14	.255	.003
MVPA	0.00	0.00	1.35	.177	.003
Habitual sleep duration	-0.07	0.10	0.67	.504	.001
Exam sleep duration	-0.29	0.05	6.20	<.001***	.062
TICS-E	0.01	0.00	3.46	.001**	.021
Acute stress baseline	0.04	0.05	0.68	.499	.001

Note. Abbreviations: See Table 9; Results from multiple linear regression analysis predicting acute stress reactivity during the exam period; [a] = Inverse transformed variable; [b] = r_{sp^2} is semipartial r^2; * $p < .025$, ** $p < .005$, *** $p < .001$.

Table 11. Explained Variance in Negative Affect Reactivity During Final Exams, Sleep Quality, Final Model

Predictor	*B*	SE	t	p	r_{sp^2}[b]
Age[a]	34.83	84.50	0.41	.680	<.001
Sex	1.38	0.81	1.71	.087	.005
Race	0.38	0.84	0.45	.654	<.001
BMI	0.10	0.12	0.86	.388	.001
Number of exams remaining	1.17	0.51	2.27	.024*	.008
Time between assessments (days)	-0.02	0.01	1.83	.068	.005
Time of day finals	0.63	0.82	0.77	.442	.001
Time of day baseline	0.05	0.75	0.06	.952	<.001
Day of finals[a]	2.07	5.55	0.37	.709	<.001
MVPA	0.00	0.00	0.57	.568	.001
Exam sleep quality	1.99	0.48	4.18	<.001***	.029
TICS-E	0.04	0.01	3.51	<.001***	.018
PANAS-N baseline	0.28	0.06	4.90	<.001***	.041

Note. Abbreviations: See Table 9; Results from multiple linear regression analysis predicting negative affect reactivity during the exam period; [a] = Inverse transformed variable; [b] = r_{sp^2} is semipartial r^2; * p < .025, *** p<.001.

Table 12. Explained Variance in Acute Stress Reactivity During Final Exams, Sleep Quality, Final Model (N = 637)

Predictor	*B*	SE	t	p	r_{sp^2}[b]
Age[a]	-30.93	23.04	1.34	.180	.003
Sex	0.69	0.22	3.13	.002**	.017
Race	-0.04	0.23	0.17	.864	<.001
BMI	0.02	0.03	0.69	.492	.001
Number of exams remaining	0.58	0.14	4.11	<.001***	.029
Time between assessments (days)	-0.01	0.00	1.56	.120	.004
Time of day finals	0.18	0.22	0.85	.395	.001
Time of day baseline	-0.05	0.21	0.25	.800	<.001
Day of finals[a]	2.39	1.60	1.50	.135	.004
MVPA	0.00	0.00	1.04	.299	.002
Exam sleep quality	0.70	0.13	5.41	<.001***	.051
TICS-E	0.01	0.00	2.40	.017*	.010
Acute stress baseline	0.05	0.05	1.00	.320	.002

Note. Abbreviations: See Table 9; Results from multiple linear regression analysis predicting acute stress reactivity during the exam period; [a] = Inverse transformed variable; [b] = r_{sp^2} is semipartial r^2; * p < .025, ** p < .005, *** p<.001.

Table 13. Explained Variance in Negative Affect Reactivity During Final Exams, Anxiety Symptoms (HADS-A) as a Predictor, (N = 637)

Predictor	*B*	SE	t	*p*	r_{sp^2} [b]
Age [a]	40.70	84.22	0.48	.629	.001
Sex	1.12	0.81	1.38	.169	.003
Race	0.20	0.83	0.24	.807	<.000
BMI	0.07	0.12	0.64	.524	<.000
Number of exams remaining	1.20	0.51	2.36	.019*	.012
Day between assessments	-0.03	0.01	1.94	.053	.005
Time of day finals	0.69	0.82	0.85	.395	.002
Time of day baseline	0.23	0.74	0.31	.755	.001
Day of finals [a]	0.72	5.55	0.13	.897	<.000
MVPA	0.00	0.00	0.40	.689	<.000
Exam sleep quality	1.49	0.50	3.00	.003**	.015
Exam sleep duration	-0.65	0.19	3.50	.001**	.023
HADS-A	0.24	0.10	2.45	.015*	.009
PANAS-N baseline	0.30	0.06	5.13	<.001***	.045

Note. Abbreviations: Abbreviations: BMI, body mass index; MVPA, minutes of moderate and vigorous activity per week; TICS-E, English translation of the Trier Inventory for the Assessment of Chronic Stress; PANAS-N, Positive Affect Negative Affect Schedule – Negative Affect Subscale; PANAS-PA, Positive Affect Negative Affect Schedule – Positive Affect Subscale, HADS-A, Hospital Anxiety and Depression Scale – Anxiety subscale, HADS-D, Hospital Anxiety and Depression Scale – Depression subscale; Results from multiple linear regression analysis predicting negative affect reactivity during the exam period. [a] = Inverse transformed variable; [b] = r_{sp^2} is semipartial r^2; * p < .025, ** p < .005, *** p<.001.

Table 14. Explained Variance in Acute Stress Reactivity During Final Exams, Anxiety Symptoms (HADS-A) as a Predictor, (N = 637)

Predictor	B	SE	t	p	r_{sp^2}
Age [a]	-25.90	23.36	1.11	.268	-.045
Sex	0.58	0.21	2.82	.005*	.112
Race	-0.15	0.23	0.66	.512	-.027
BMI	0.00	0.03	0.10	.922	.004
Exams left	0.61	0.15	4.08	.001**	.190
Day between assessments	-0.01	0.00	1.55	.122	-.063
Time of day finals	0.24	0.21	1.15	.253	.048
Time of day semester	-0.01	0.21	0.03	.975	-.001
Day of finals [a]	1.76	1.54	1.14	.256	.049
MVPA	0.00	0.00	1.39	.165	.057
Exam sleep quality	0.45	0.15	3.09	.002**	.132
Exam sleep duration	-0.24	0.05	4.95	.001**	-.200
HADS-A	0.07	0.03	2.28	.024*	.103
Semester acute stress	0.04	0.06	0.69	.493	.031

Note. Abbreviations: See Table 13; Results from multiple linear regression analysis predicting acute stress reactivity during the exam period. [a] = Inverse transformed variable; [b] = r_{sp^2} is semipartial r^2; * p < .025, ** p < .005, *** p<.001.

Table 15. Explained Variance in Negative Affect Reactivity During Final Exams, Depressive Symptoms (HADS-D) as a Predictor, (N = 637)

Predictor	*B*	SE	t	*p*	r_{sp^2} [b]
Age [a]	49.89	84.32	0.59	.554	.001
Sex	1.45	0.81	1.81	.071	.006
Race	0.30	0.85	0.35	.725	<.001
BMI	0.07	0.12	0.63	.529	.001
Number of exams remaining	1.23	0.51	2.41	.016*	.009
Day between assessments	-0.03	0.01	1.94	.052	.006
Time of day finals	0.73	0.82	0.90	.370	.002
Time of day baseline	0.24	0.75	0.33	.745	<.001
Day of finals [a]	1.20	5.56	0.22	.829	<.001
MVPA	0.00	0.00	0.48	.632	<.001
Exam sleep quality	1.77	0.50	3.53	<.001***	.021
Exam sleep duration	-0.63	0.19	3.34	.001**	.020
HADS-D	0.04	0.15	0.26	.795	<.001
PANAS-N baseline	0.36	0.06	6.32	<.001***	.070

Note. Abbreviations: See Table 13; Results from multiple linear regression analysis predicting negative affect reactivity during the exam period. [a] = Inverse transformed variable; [b] = r_{sp^2} is semipartial r^2; * p < .025, ** p < .005, *** p<.001.

Table 16. Explained Variance in Acute Stress Reactivity During Final Exams, Depressive Symptoms (HADS-D) as a Predictor, (N = 637)

Predictor	*B*	SE	t	*p*	r_{sp^2} [b]
Age [a]	-32.18	22.68	1.42	.156	.003
Sex	0.64	0.22	2.90	.004**	.015
Race	-0.13	0.23	0.56	.575	<.001
BMI	0.01	0.03	0.27	.787	<.001
Number of exams remaining	0.59	0.14	4.31	<.001***	.030
Day between assessments	-0.01	0.00	1.62	.105	.004
Time of day finals	0.24	0.22	1.09	.275	.002
Time of day baseline	0.01	0.21	0.07	.948	<.001
Day of finals [a]	2.13	1.57	1.36	.176	.003
MVPA	0.00	0.00	1.29	.198	.003
Exam sleep quality	0.55	0.14	4.06	<.001***	.028
Exam sleep duration	-0.23	0.05	4.73	<.001***	.037
HADS-D	0.01	0.04	0.30	.765	<.001
Baseline acute stress	0.09	0.05	1.87	.063	.006

Note. Abbreviations: See Table 13; Results from multiple linear regression analysis predicting acute stress reactivity during the exam period. [a] = Inverse transformed variable; [b] = r_{sp^2} is semipartial r^2; ** p < .005, *** p<.001.

Figure 1. Graphs depicting the hypothesized triple interaction between chronic stress, physical activity, and sleep duration/sleep quality

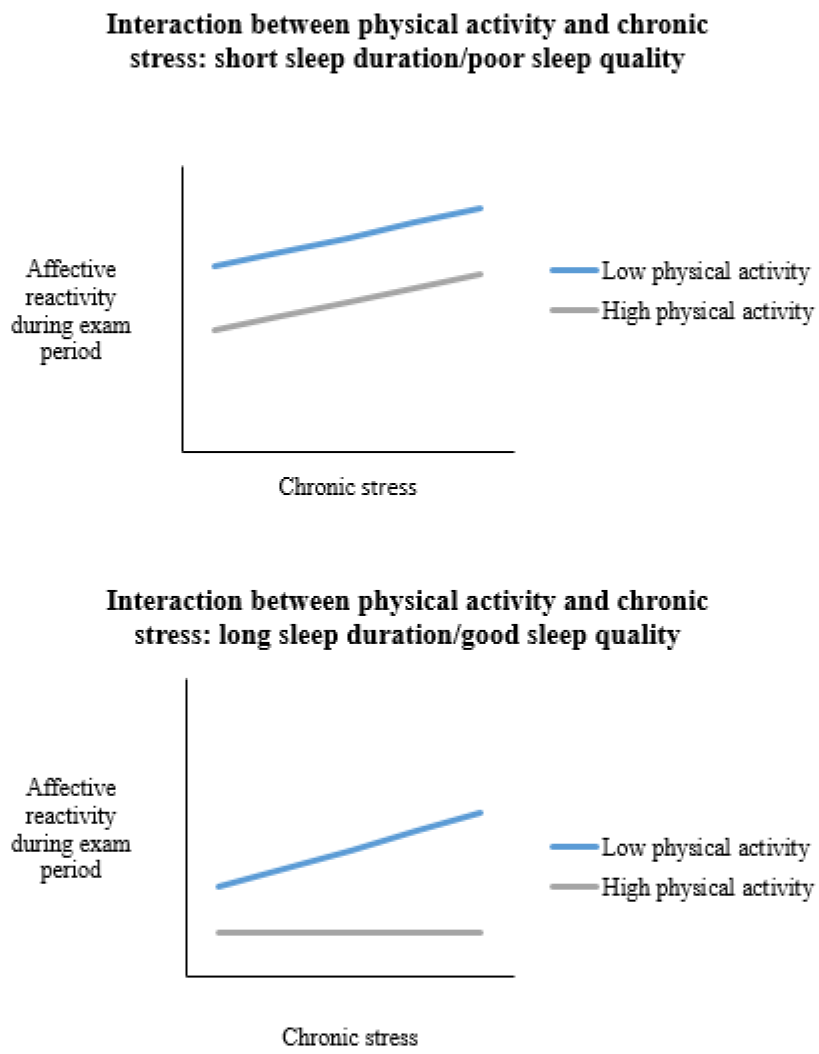
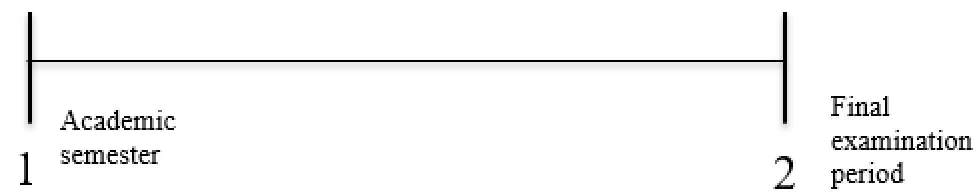
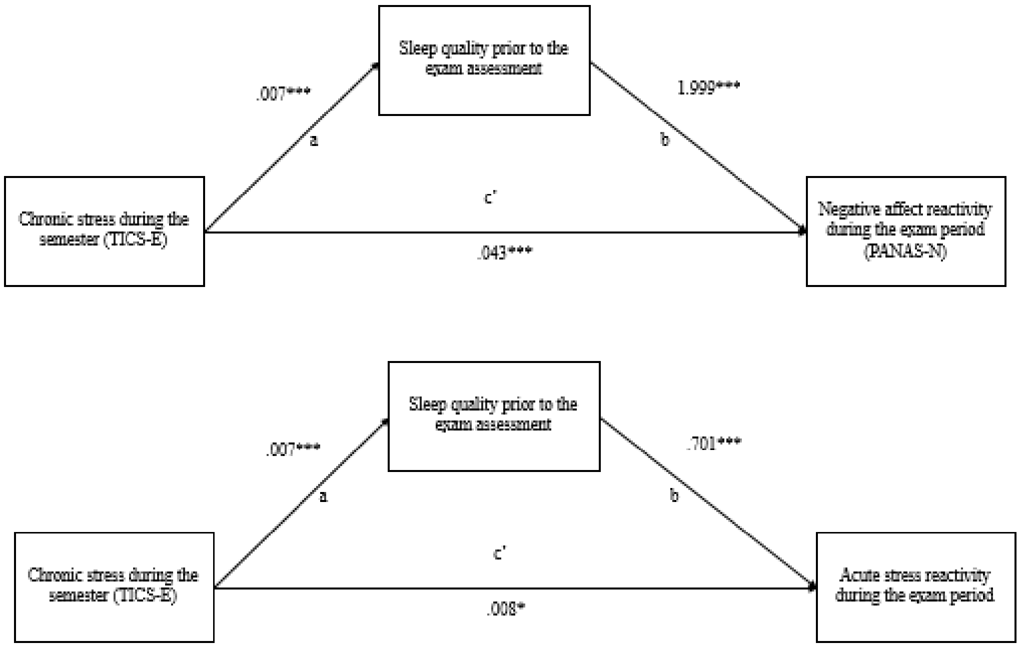


Figure 2. Participants were assessed at two time-points: first during an academic semester and second during an end-of-term final examination period



Note. A demographic and health survey, habitual sleep duration, physical activity, chronic stress, anxiety level, and depressive symptoms were measured at the first timepoint. Sleep quality and sleep duration prior to the exam assessment were measured during the second time point. Negative affect and acute stress ratings were assessed at each timepoint. Students completed the first assessment on average 52 days before the final exam period.

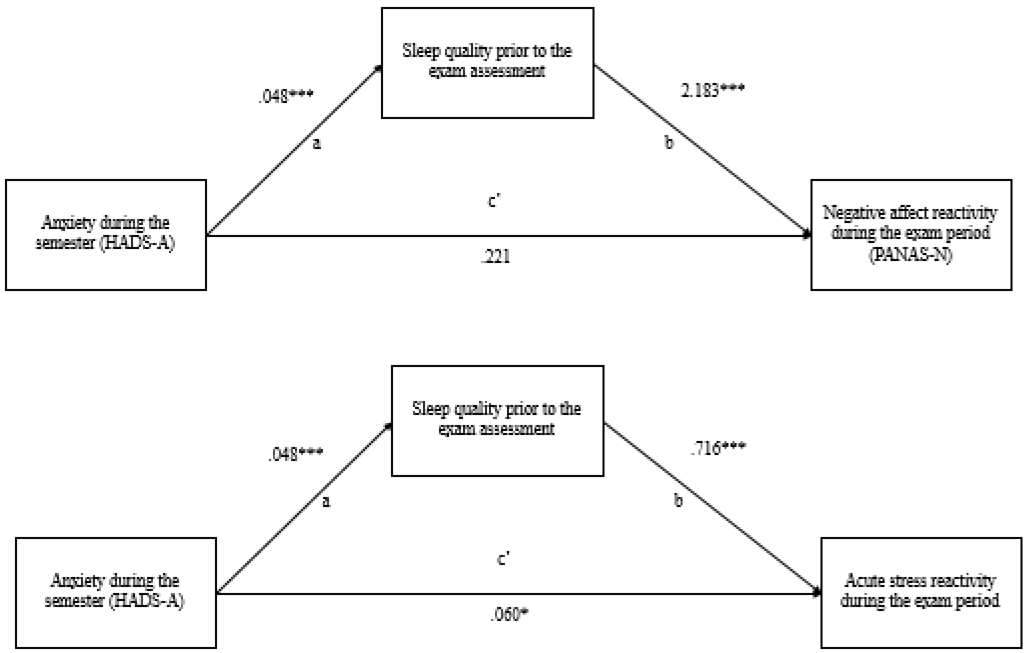
Figure 3. Significant models for sleep quality mediating the relation between chronic stress during the semester and negative affect and acute stress reactivity during the exam period



Note. Control variables not shown in the figures, which were included in the models predicting both the mediator and outcome. Control variables included age, sex, race, body mass index, number of exams remaining, day during the exam period, time of day during each assessment, and number of days between the semester and exam assessment.

* p < .025, *** p < .001.

Figure 4. Significant models for sleep quality mediating the relation between anxiety symptoms during the semester and negative affect and acute stress reactivity during the exam period



Note. Control variables not shown in the figures, which were included in the models predicting both the mediator and outcome. See Table 11 for a list of each control variable included.

* $p < .025$, *** $p < .001$.

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