THE ROLE OF SLEEP IN ADOLESCENTS' DAILY STRESS RECOVERY:

NEGATIVE AFFECT SPILLOVER AND POSITIVE AFFECT

BOUNCE-BACK EFFECTS

By

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Submitted to the

Faculty of the College of Arts and Sciences

of American University

in Partial Fulfillment of

the Requirements for the Degree of

Master of Arts

In

Psychology

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Date July 14, 2017

2017

American University

Washington, D.C. 20016

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ABSTRACT

Although there is much research on sleep and emotion, few studies have examined the role of sleep as a potentially important context for stress recovery from one day to the next. Such daily processes might also be particularly important to adolescents, an age-group notorious for its lack of sufficient sleep. Eighty-nine adolescents recorded their emotions and stress for two-weeks through daily surveys. Sleep was monitored with Fitbit devices. Results show that objectively measured sleep (total sleep time, latency to sleep onset, and accumulated sleep debt) moderated affective responses to previous-day stress, suggesting that sleep quantity could have an impact on overnight stress recovery. Moreover, we found that sleep variables not only moderated cross-day negative affect spillover effects but cross-day positive affect *bounce-back* effects. Specifically, with more sleep, adolescents' morning positive affect on days following high stress tended to "bounce-back" to the levels that were common following low stress days. Sleep seemed to help them recover from the emotional effects of the stressor. In contrast, if sleep was short following high stress days, adolescent positive affect remained low on the following morning. We did not find evidence that subjective sleep quality moderated spillover/ bounce-back effects. This research highlighted the importance of considering sleep and stress as daily processes to fully understand both daily contextual factors of stress recovery and the dynamic cross-day relationships between stress, sleep, and affect.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

CHAPTER 1

INTRODUCTION

Although there has been much research conducted on individual differences in daily stress reactivity (Bolger & Zuckerman, 1995; Gunthert, Cohen, & Armeli, 1999; Mroczek & Almeida, 2004; O'Neill, Cohen, Tolpin, & Gunthert, 2004), less research has focused on the *process* of daily stress recovery. What are the contextual factors that play into healthy emotional recovery from daily stress? It is important to understand processes of stress recovery because the ability to bounce back from a stressor has important implications for the duration of stress reactivity, and consequently, on emotional well-being. The research that does exist on recovery from daily stressors has focused on negative affect spillover effects of stressors from one day to the next (Bolger & Zuckerman, 1995; Gunthert, Cohen, Butler, & Beck, 2007; Marco & Suls, 1993). In other words, to what degree do the emotional consequences of experiencing a stressor linger into the next day? Researchers have considered trait-level differences that might cause variance in spillover effects, and therefore, the ability to recovery from stress (Affleck, Tennen, Urrows, & Higgins; 1994; Bolger & Zuckerman, 1995; Marco & Suls, 1993). However, few researchers have investigated daily-level processes that might impact everyday fluctuations in stress recovery. One such daily process that might be important is sleep. Given the importance of sleep on emotional processing and functioning (Kahn, Sheppes, & Sadeh, 2013; Walker & van der Helm, 2009), and its natural temporal position in the spillover paradigm (sleep periods occur in the timeframe between daily assessments), it would seem reasonable to consider the role of sleep on stress spillover effects. Yet, so far, researchers have largely ignored sleep as a factor in everyday stress and emotion research. In this study, we investigated the role of daily sleep on stress recovery processes in a daily diary study of adolescents, an age cohort that is notorious for poor sleep.

Daily Process Designs and Everyday
Stress Recovery

In the last thirty years, researchers have often studied everyday stress reactivity using daily process designs, which require participants to provide daily assessments of naturally occurring stress and affect over the course of days or weeks. Since each participant's daily level of stress and negative affect is compared to his or her own average levels across the study, researchers are able to examine unique within-person relationships between stress and affect (Bolger et al., 2003; Gunthert & Wenze, 2012). Typically, researchers use these daily data to measure the relationship between concurrent stress and affect, or stress reactivity (Affleck et al., 1994; Bolger, DeLongis, Kessler, & Schilling, 1989). However, stress recovery processes might matter as well. This daily diary metholody also allows for cross-day lagged analyses, in which researchers examine how stress on day *t-1* is related to fluctuations in negative affect on day *t.* If experiencing above average stress on day *t-1* is followed by an increase in negative affect on day *t* (or sometimes a failure to return to baseline), there is said to be a "spillover" effect, which maybe suggestive of inadequate stress *recovery* (Marco & Suls, 1993). Because the temporal relationship stress and affect is pre-determined in spillover analyses, they might provide more insight into causal relationships than simply measuring stress reactivity.

Moreover, investigating cross-day stress recovery processes through spillover effects might also have practical benefits. It could be important to not only understand how people respond to stressors immediately, but also whether they are having a prolonged response, which could eventually erode resources. The potential deleterious effects of poor emotional recovery could be considered through the lens of allostatic load, or the amassing of wear and tear on the body as it continues to handle ongoing stressors (McEwen & Stellar, 1993). Depleted resources could increase vulnerability to other emotional health difficulties.

Thus far, a number of researchers have found evidence of spillover effects using daily process designs. Some have found that negative events were related to increased negative affect and anxiety the following day (Gable, Reis, & Elliot, 2000; Nezlek & Gable, 2001). There is also evidence that individual differences may influence levels of mood spillover. For instance, those low in social support exhibited more negative mood spillover from previous day stressors (Affleck et al., 1994), whereas high social support seemed to serve as a buffer against mood spillover from past events (Caspi, Bolger, & Eckenrode, 1987). A number of studies have also found that those who are prone to negative affectivity or depression have more difficulty with stress recovery. Specifically, those high in neuroticism, compared to those low in neuroticism, report more distress on days following high stress or more conflict (Bolger & Zuckerman, 1995; Marco & Suls, 1993; Suls, Green, & Hillis, 1998). In some cases, it may be the combination of trait-level dimensions and characteristics of daily events that influences spillover. Gunthert and colleagues (2007) found that individuals high in depression experienced greater increases in negative thought and affect only on days following interpersonal stress compared to those low in depression. A propensity for affective spillover might also prospectively influence outcomes. For example, depressed patients who exhibited more negative affective spillover had a slower response rate to cognitive therapy (Cohen et al., 2008).

Yet, there are also some studies that have instead found that the emotional consequences of stress do not carry into the next day (Bolger, DeLongis, Kessler, & Schilling, 1989; David, Green, Martin, & Suls, 1997; Stone & Neale, 1984). Some even found that next-day mood was enhanced following high distress days versus low distress days (Bolger et al. 1989; Delongis, Folkman, & Lazarus, 1988; Williams, Suls, Alliger, Learner, & Wan, 1991). Perhaps in those cases there was a contrast effect, meaning when the current situation feels better in comparison to a previously stress situation, mood might improve (Marco & Suls, 1993). A contrast effect might signify successful emotional recovery from a stressor.

Role of Sleep in Stress and Emotion Processes

Given these inconsistent findings, it might be important to consider the contextual factors that facilitate the occurrence of either emotional spillover (inadequate recovery) or lack of emotional spillover (more successful recovery). Some researchers have posited that the end of a stressful day and beginning of a new one, or even what comes between those two days (e.g., sleep), could provide a “psychological break” that promotes emotional recovery (David et al., 1997; Williams et al., 1991). Thus, perhaps sleep could play a role in whether or not a spillover effect is exhibited on a given day. However, very few studies have actually investigated the role of sleep in daily stress recovery processes. Bearing in mind the abundance of evidence that sleep impacts mood and emotional processes, this gap in the literature is surprising. Specifically, studies have shown that people who experienced a night of sleep deprivation reported less positive affect and greater negative affect than subjects who had a normal night of sleep (Franzen, Siegle, & Buysse, 2008; Talbot, McGlinchey, Kaplan, Dahl, & Harvey, 2010). A meta-analysis by Pilcher and Huffcutt (1996) revealed that the detrimental impact of sleep deprivation on mood is even greater than that on cognitive or motivational processes. On the other hand, good quality sleep predicts lower negative affect and higher positive affect the next day (Hamilton et al., 2008).

While the research on sleep and stress *recovery* is lacking, there have been studies on the impact of sleep on more immediate stress reactivity. Some of these studies have focused on physiological and neurological reactivity to negative stimuli. Much of this evidence comes from lab-based experiments in which participants undergo sleep deprivation and are compared to normal sleep controls. In such experiments, a number of researchers have found that sleep deprivation is related to heightened physiological or neurological reactivity towards negative stimuli and experiences. For example, compared to normal sleep controls, sleep-deprived participants: had significantly higher heart rates and blood pressure during mental and physical stress tests (Franzen, et al., 2011; Yang, Durocher, Larson, DellaVella, & Carter, 2012), had greater pupil dilations both when viewing and anticipating negative images (Franzen, Buysse, Dahl, Thompson & Siegle, 2009), and exhibited 60% greater amygdala reactivity to negative pictures and decreased connectivity between the amygdala and the medial prefrontal cortex, which is responsible for top-down inhibitory processes (Yoo, Gujar, Hu, Jolesz, & Walker, 2007).

The research on subjective emotional reactivity generally converges on similar findings that poor sleep increases reactivity to stressors. Some researchers have found that poor quality sleep and sleep loss are related to increased negative affect and decreased positive affect, but only when a daily stressor is present. Conversely, in the absence of a stressor, negative affect is generally low regardless of sleep quality or duration (Hamilton, Catley, & Karlson, 2007; Zohar, Tzischinsky, Epstein, & Lavie, 2005). Others have found that when confronted with mild stress, emotional reactivity increased only for those under sleep deprivation, whereas when confronted with severe stress, emotional reactivity was equally high for those who experienced sleep deprivation and normal sleep (Minkel et al., 2012). This finding suggests that conditions of poor sleep might lower the threshold for which an experience is perceived as stressful.

There is only one known study that has addressed the issue of sleep and stress recovery. Hamilton and colleagues (2008) used a daily process design to follow sleep, affect, and pain in women diagnosed with fibromyalgia for 30 days. They found that when the number of daily stressors was high and sleep was at or below a person's average sleep time, negative affect increased and positive affect decreased the next evening. Therefore, under conditions of lower sleep time and higher stress, there was a next-day spillover effect of negative affect, as well as a dampening of positive affect. However, when sleep was above average, a high number of previous day stressors did not predict negative or positive affect the next evening. Together, these findings suggest that lower amounts of sleep might inhibit recovery processes, whereas higher amounts of sleep might promote stress recovery. Longer sleep may provide a fresh start by helping to break the link between events and emotions across days. However, when sleep is too short, individuals may not be able to reap the restorative benefits of sleep and are left continuing to experience the emotional consequences of yesterday's stress the next day. Further, when sleep is poor, people might have more awake time in bed to ruminate on the day's problems.

Still, this study focused only on a specific sample of women with a physical health-related condition. It is unclear of whether these findings would be applicable to a broader population. Moreover, while a strength of this study was its daily process design, it relied on daily self-reported measures of sleep. Evidence has shown that participants are not very accurate when recording their sleep time on their own. Some studies show that participants tend to over-report their total sleep time on sleep records as compared to using objective measures, such as actigraphy (Bradshaw, Yanagi, Pak, Peery, & Ruff, 2007; Lauderdale, Knutson, Yan, Lui, & Rathouz, 2008), whereas other studies showed that participants underestimated their total sleep time and overestimated their sleep latency (Wicklow & Espie, 2000). One study of adolescents found that participants perceived more total sleep and less wake after sleep onset than actigraphy

(Short, Gradisar, Lack, Wright, & Carskadon, 2012). Therefore, relying solely on participants to record sleep could lead to unreliable measures of sleep time.

Not only would it be essential to obtain objective measures of sleep time, but it might be important to consider how patterns of sleep across nights impact emotional processes. In particular, there is some evidence that sleep debt, or the accumulation of multiple nights of shortened sleep, is more detrimental to stress reactivity than a single night of short sleep. For example, Dinges and colleagues (1997) found that young adults whose sleep was restricted to five hours a night for seven consecutive days reported progressively decreased mood with each day. A study with rats showed that sleep debt, rather than one night of restricted sleep, impacted stress reactivity through hormones in the hypothalamic-pituitary-adrenal (HPA) axis. Rats that were restricted to four hours of sleep for one night did not differ from normal sleep controlled rats in adrenocorticotropic hormone (ACTH) response, a key component of the HPA-axis, following a stress test. However, rats that were restricted to four hours of sleep a night for eight consecutive days showed an attenuated ACTH response, which suggests that chronic sleep restriction might cause changes to biological stress regulation mechanisms (Meerlo, Koehl, Van der Borght, & Turek, 2002).

Evidence in a human sample from Hamilton and colleagues (2008) corroborated findings that sleep debt may have more bearing on stress and emotional responses than one night of short sleep. They found that mounting sleep debt, not sleep duration, predicted increased negative affect the subsequent day. Furthermore, other researchers found that when participants were partially sleep deprived (restricted to four hours of sleep) for five consecutive nights, they showed greater amygdala reactivity to scared faces compared to when they were allowed eight hours of sleep, but no change in reactivity to happy faces. They also reported a significant reduction in mood under high sleep debt (Motomura et al., 2013). The deleterious effect of sleep debt on emotional health could also be considered a form of allostatic load (McEwen & Stellar, 1993). As the number of days of restricted sleep piles up, managing and recovering from emotional stress may become increasingly difficult. Thus, it would seem important to consider the accumulating effect of repeated nights of partial sleep deprivation on stress recovery, as well as single nights of shortened sleep.

Sleep in Adolescents

In addition to studying various dimensions of sleep, it might be particularly helpful to study how sleep impacts stress recovery in a population susceptible to poor sleep, namely adolescents. Adolescents generally do not receive as much sleep as they need. Sleep experts recommend that adolescents sleep for 8 to 10 hours a night based on meta-analyses of sleep research and expert panel consensuses (Hirshkowitz et al., 2015; Paruthi et al., 2016). However, about 70% of adolescents are getting less than 8 hours of sleep a night, and much of that percentage is getting substantially less than 8 hours. Average sleep changes from 8.4 hours per night in sixth grade to 6.9 hours per night in 12th grade. The decrease in number of hours of sleep is mostly attributed to progressively later bedtimes despite similar wake times with increasing age (National Sleep Foundation, 2006). Research has also suggested that adolescents are going to bed about an hour and 45 minutes later on weekend nights than on weekend nights. These drastic and rapid shifts in sleep times between weeknights and weekend nights can have an effect akin to experiencing jetlag every week (Carskadon, 2011).

According to Carskadon (2011), delayed sleep in adolescence is the result of the “perfect storm” of biopsychosocial factors (p. 637). One biological change that contributes to a later bedtime for adolescents is a delayed onset of melatonin, a hormone that is associated with circadian rhythms and induces sleepiness, with increasing stages of puberty and age (Carskadon, Wolfson, Acebo, Tzischinsky, & Seifer, 1998). Later secretion of melatonin for adolescents may partially explain why adolescents do not get tired until later in the evening and why going to bed earlier is not a realistic solution for adolescents to get more sleep (Carskadon, 2011; Wolfson & Carskadon, 1998). Moreover, there is some evidence that adolescents' circadian period (or internal day length) is longer than 24 hours for adolescents, which also promotes later bedtimes (Carskadon, Labyak, Acebo, & Seifer, 1999) and that sleep pressure takes a longer time to build up in adolescents than in younger children (Jenni, Acherman, & Carskadon, 2005; Taylor et al., 2005). Additionally, there are several psychosocial factors that promote later bedtimes, and consequently less sleep, in adolescents. For instance, later adolescent bedtimes may be a function of both choice, as adolescents exercise increased autonomy over their bedtime, and necessity, as the academic demands of high school keep adolescents up late doing homework (Gangwisch et al. 2010, Short et al., 2011). Furthermore, adolescents' engagement in electronic devices at night could impede on sleep through increased physiological arousal from the activities in which adolescents are engaging, as well as the blue lights electronics emit (Cain & Gradisar, 2010; Cajochen et al., 2005). Research has reported that electronic use prior to bedtime is associated with taking longer to fall asleep, less total sleep time, worse sleep quality, and greater daytime sleepiness (Cain & Gradisar, 2010; Lemola, Perkinson-Gloor, Brand, Dewald-Kaufmann, & Grob, 2015; Munezawa et al. 2011).

If adolescents are consistently going to bed late during the week for these reasons, they are likely accumulating significant sleep debt. Given the existing research that suggests that sleep debt has negative ramifications on stress responses and emotional processes, adolescents may experience enhanced emotional difficulties and trouble recovery from stress. There is already some evidence that poor sleep might be particularly problematic for adolescents, who report having less control over their mood following sleep loss, potentially because their prefrontal cortex has not fully developed (Dahl & Lewin, 2002). Indeed, researchers have found that sleep-deprived adolescents report less positive affect and show lower positivity ratios (ratio of positive to negative emotions) compared to rested adolescents (Dagys et al., 2012). Adolescents in a sleep-restricted condition, who were allowed 6.5 hours in bed per night for five nights, reported higher levels of anxiety, anger/hostility, confusion, and irritability. Moreover, these adolescents and their parents reported that they had less emotion regulation ability than those who experienced normal sleep (Baum et al., 2014). Finally, there is some evidence that the emotional toll of sleep deprivation more greatly impacts adolescents than adults. By analyzing emotions through vocal expression, researchers found that sleep-deprived adolescents showed greater decreases in positive affect relative to adults (McGlinchey et al., 2011). As such, adolescents are a particularly important group to investigate the role of poor sleep on stress and emotion recovery processes.

Overview and Hypotheses

In this study, we investigated sleep as a contextual factor that may impact daily stress-related negative affect spillover effects, which we believed would have implications for daily stress recovery processes, in adolescents. Although most research in this literature has focused on negative affect, we thought it was also important to consider how overnight changes in positive affect might reflect stress recovery. Sleep issues, particularly an accumulation of sleep debt across the school week, are endemic to high school students, so additionally, we wished to broadly gain a better understanding of how adolescents are naturally sleeping in their everyday lives through this research. We hypothesized that on nights when sleep time is lower and previous-day stress is higher, individuals will experience more negative affect spillover and a greater dampening of positive affect the next morning. Additionally, because of the number of studies that have shown that emotional recovery is harder for those higher in neuroticism (Bolger & Zuckerman, 1995; Marco & Suls, 1993; Suls et al., 1998), we wished to explore whether those high in neuroticism may be more vulnerable to the impact of sleep on stress-related affective spillover effects. More specifically, we expected to see that:

1. Objectively measured sleep would interact with previous-day stress to impact negative affect spillover/ positive affect dampening effects. We investigated objectively measured sleep through three measures: total sleep time, sleep latency period, and sleep debt. We hypothesized that when sleep latency was higher, total sleep time was lower, and sleep debt was higher, people would experience more morning negative affect (more spillover) and less morning positive affect (more dampening), as previous-day stress increased. Conversely, we hypothesized that when sleep latency was lower, total sleep time was higher, and sleep debt lower, people would experience less negative affect (less spillover) and more positive affect (less dampening), as previous-day stress increased. Evidence of such findings would suggest that longer sleep promotes stress recovery whereas shorter sleep interferes with stress recovery processes
2. Subjective sleep quality would also impact negative affect spillover / positive affect dampening effects. We hypothesized that when *perceived* sleep quality was lower, there would also be more morning negative affect (more spillover) and less morning positive affect (more dampening) as previous-day stress increased, and that when *perceived* sleep quality was higher, there would be less morning negative affect (less spillover) and more morning positive affect (less dampening) as previous-day stress increased.

3. Finally, we conducted exploratory analyses to test whether stress-related affective spillover effects following less sleep were stronger for those high in neuroticism.

CHAPTER 2

METHOD

Participants

Participants were 99 adolescents recruited from high school psychology classes in Montgomery County, Maryland. Of these adolescents, one withdrew from the study before completing any surveys, two failed to complete any surveys, one did not complete the baseline survey, and six did not record objective sleep data. These participants were removed from all analyses, leaving a final sample of 89 adolescents. The final sample included 46 (51.7%) girls, 42 (47.2%) boys, and one who declined to respond on gender (1.1%). They ranged in age from 15 to 19 (*M* = 16.62, *SD* = .81, age of one participant is unknown). Ten (11.2%) were sophomores, 43 (48.3%) were juniors, and 36 (40.4%) were seniors in high school. We also had a racially/ ethnically diverse sample; 39.3% percent of participants self-identified as Hispanic/ Latino, 21.3% as African American, 16.9% as Caucasian, 11.2% as Asian, and 10.1% as multiracial or other (one participant did not indicate race/ethnicity).

Measures

Neuroticism

The Big Five Inventory for Children (BFI-C: John, Donahue, & Kentle, 1991) includes an 8-item Neuroticism subscale that assesses a predisposition toward negative emotionality. Adapted from the Big Five Inventory for adults, this self-report measure is rated on a 5-point scale from 1 (disagree strongly) to 5 (agree strongly). In our sample, the Neuroticism subscale showed acceptable internal consistency ($\alpha = .78$).

Daily Subjective Sleep Quality

Each morning, we asked participants to assess their sleep quality by answering "Did you sleep well last night?" from 1 (no) to 7 (very) in a daily survey each morning. Other researchers have used this question to assess sleep quality in the past (Hamilton et al., 2007).

Daily Stress Appraisal

Each evening, we asked participants to appraise the overall stressfulness of their day by answering the question, "Overall, how stressful was your day?" on a scale from 1 (not at all) to 7 (extremely), which has been used to measure daily stress in previous research studies (Armeli, O'Hara, Covault, Scott, & Tennen, 2016).

Daily Affect

We assessed evening and morning negative affect using items from the Positive and Negative Affect Schedule – Expanded Form (PANAS-X: Watson & Clark, 1994). Participants were asked to rate the extent to which they felt each affective state "at this moment" on a scale from 1 (not at all) to 7 (extremely). We created a score of overall negative affect (NA) from the mean ratings of eight NA items (i.e. three items from the sadness subscale (lonely, sad, and blue), two items from the fear subscale (anxious and nervous), and three items from the hostility subscale (hostile, angry, and irritable). Internal consistency scores were good for evening NA ratings (α=.82) and morning NA ratings (α=.79). We also created a score of overall positive affect (PA) from the mean ratings of six PA items (i.e. joyful, happy, interested, enthusiastic, relaxed, and calm). Internal consistency scores were also good for evening PA ratings (α=.86) and morning PA ratings (α=.87).

Objective Sleep Measures

Participants wore a Fitbit ® Flex (Fitbit, Inc., San Francisco, California) on their wrists for 15 nights for the purposes of recording their sleep. The Fibit is an accelerometer, which is an activity monitor that uses built-in sensors to measure physical movement in one-minute epochs. Participants activated the Fitbit "sleep mode" by tapping their Fitbits when they were ready to start falling asleep and deactivated sleep mode the same way when they had woken up for the final time in the morning. We asked participants to sync their Fitbits daily to pre-assigned Fitbit accounts in order to upload their sleep data to the Fitbit computer/ smartphone application. The Fitbit application uses a proprietary algorithm to analyze motion and determine when participants were asleep or awake while the Fitbit was in sleep mode. Fitbit can calculate sleep parameters that include: (a) *time of sleep onset*- the first minute identified as sleep, (b) *sleep latency*- the amount of time between activation of sleep mode and sleep onset, (c) *total sleep time*- the amount of time in minutes during sleep mode that the algorithm identified participants as being asleep. Using the *total sleep time* data, we calculated an additional variable (d) *sleep debt* – the number of consecutive days that a participant recorded less than six hours of sleep a night. Six hours is a typical cutoff used for calculating sleep debt (Hamilton et al., 2008).

Although Fitbits were designed as consumer products, we believed that they would serve as good research tools for sleep due to the low cost and ease of use of the actual device and online applications for high school students. A previous study showed that Fitbits demonstrated strong intra-device reliability across three nights. It also showed that Fitbits and actigraphy, currently the gold standard for non-invasive sleep monitoring, both overestimated total sleep time and underestimated amount of time awake after sleep onset compared to polysomnography. In other words, both Fitbit and actigraphy showed good sensitivity for detecting actual sleep, in relation to polysomnography, but worse specificity for detecting non-sleep (Montgomery-Downs, Insana, & Bond, 2012). Another study with adolescents and children found that compared to polysomnography, Fitbit showed adequate sensitivity and accuracy, but again showed worse specificity (Meltzer, Hiruma, Avis, Montgomery-Downs, & Valentin, 2015).

Not only do some researchers believe that Fitbits are an appropriate and inexpensive alternative to actigraphy (Montgomery-Downs et al., 2012), Fitbits have an added bonus of including event markers for sleep, or the ability for individuals to indicate on the device itself when they are going to sleep. Conversely, standard actigraphs often do not include event markers, so when used alone, the sleep period is completely reliant on participants' ability to report on what time they attempted to fall asleep and woke up, which is not always accurate (Bradshaw et al., 2007; Lauderdale et al., 2008; Wicklow & Espie, 2000). Therefore, while actigraphy could provide more precise data within a designated sleep period (although there is not enough data yet to say), its reliance on self-report to determine that sleep period is a weakness, particularly for the measurement of sleep latency. The relative ease of tapping a Fitbit over self-recording sleep and wake times would seem to be a benefit of this measurement tool.

In our research lab, we conducted a brief validity test between Fitbit and actigraphy, in which six lab members wore Fitbits and actigraphs on their wrists for seven nights. We found a strong correlation ($r = .833$, $p < .001$) in total sleep time between the Fitbits and actigraphs, which suggested that Fitbit was consistently recording similar daily fluctuation in sleep as actigraphy, despite recording slightly different total sleep times. Because our study focused on the impact of daily fluctuations in sleep on stress recovery, we believed that it was the ability to accurately capture how one night's sleep differs from the next that mattered more than the precise number of minutes of sleep. However, precision and accuracy of time measurement would certainly still matter for some sleep variables, specifically sleep debt. To check whether Fitbit was systematically over or underestimating total sleep time, we checked the average discrepancy between the measures. On average, Fitbit overestimated sleep by 13.36 minutes (*SD* = 43.34 minutes) compared to actigraphy. There was an 87.2% agreement between Fitbit and actigraphy in the measurement of total sleep time as above or below six hours (the cutoff for a night of sleep debt). All cases of disagreement were due to Fitbit recording sleep as more than six hours and actigraphy counting sleep as under six hours, which was in line the data that suggested Fitbit tended to overestimate sleep. Therefore, some caution is warranted in that, by using Fitbits, there were likely some nights that were not counted toward the sleep debt total that may have indeed been less than six hours. Overall, though, the 87% agreement is certainly high enough that we believed that the Fitbit was an appropriate measurement tool for sleep time in this study. We believe that any inaccuracy of the Fitbit is likely much lower than the inaccuracy that comes with subjective reports of sleep time (we are currently working to test this idea in another study).

Procedure

We presented the research project to psychology classes at a local high school. We provided consent forms and informational packets for the students to share with their parents. We then returned to the high school for the next three days and enrolled students in the study upon receipt of signed consent forms from students and parents. Participants then received their study materials, including instructions for completing daily online surveys, a Fitbit, a Fitbit user guide, and login information for pre-assigned Fitbit accounts, which participants needed in order to sync their Fitbits to their accounts and upload their sleep data to the Fitbit application. Participants also received verbal instructions about using and syncing their Fitbits and provided contact information (e-mail addresses and/ or cell phone numbers) to receive links to daily surveys.

On the first night, participants completed an online baseline survey that collected information such as demographics, depression and anxiety symptoms, self-esteem, neuroticism, life events, and sleep patterns/ habits. Participants were also asked to start recording their sleep that night with the Fitbit for the next two weeks. Participants were told to record their sleep by activating the sleep mode when they were ready to start trying to fall asleep (e.g. right after they turn their lights out and are ready to close their eyes) and deactivating sleep mode when they had woken up for the last time (e.g. after they have stopped snoozing) and were ready to get out of bed for the day. Participants were told to sync their Fitbits to their assigned online Fitbit accounts daily through a smartphone or computer application in order to upload their sleep data to their accounts, where their data could be stored, analyzed, and accessed by the research team. The sleep parameters that Fitbit could measure included: what time participants fell asleep (time of sleep onset), how long they took to fall asleep (sleep latency) and the number of times they woke up or entered into very light sleep during the sleep period (number of awakenings). The program then used this information to calculate the amount of total sleep time participants received during sleep mode.

Participants also completed brief daily online surveys each morning and evening for the next 14 days. Participants received links to evening surveys via automated text message and/or e-mail at 8 PM each evening. Participants were instructed to respond to the survey as close to bedtime as possible. Evening surveys measured a variety of daily processes including: number and type of stressors and positive events that occurred that day, the desirability of their best and worst events, overall stressfulness of the day, momentary NA and PA, and other daily emotional and cognitive experiences. Participants also received text messages and/or emails with morning survey links each morning at 5 AM. They were asked to respond to the survey as close as possible to their wake time, and at a maximum within three hours of waking. Any survey completed after three hours of waking was excluded for the final analyses. Morning surveys collected self-reported measures of sleep, including perceived bedtime, wakeup time, and sleep latency in minutes, and a subjective rating of sleep quality. Morning surveys also asked participants to report on their current level of NA and PA.

During the two-week period, researchers monitored the participants' daily progress on their daily surveys and sleep recordings. If researchers noticed that participants had not uploaded their Fitbit sleep data in three days, researchers contacted the participants and ask them to sync their Fitbits to their online accounts through their smartphone or computer applications. At the end of the two-week period, researchers returned to the high school to collect Fitbits. Participants were provided with compensation according to the number of surveys completed. Participants received $10 for completing the baseline survey, $.50 for each morning survey completed, $1.50 for each evening survey completed, and a $5 bonus for completing at least 24 out of the potential 28 daily surveys. Participants completed an average of 12.19 (*SD* = 2.22) of 14 morning surveys and 12.46 (*SD* = 2.43) of 14 evening surveys. Participants recorded sleep on an average of 12.06 nights (*SD* = 2.91).

Data Analysis

Due to the hierarchical structure of our data (i.e. daily morning and evening assessments nested within participants), we used hierarchical linear modeling (HLM; Bryk & Raudenbush, 1992) to analyze our data. Our main research question was whether sleep might moderate any stress-related affective spillover/dampening effects. First, we built our model off of one that other researchers have used to estimate affective spillover (Cohen et al., 2008; Gunthert et al. 2007). An example of this model at Level 1 is:

$$Morning\ NA_{ij} = b_{0i} + b_{1i}(Evening\ NA_{ij-1}) + b_{2i}(stress_{ij-1}) + e_{ij}$$

where for participant *i,* Morning NA$_{ij}$ is the level of morning NA on day *j;* the intercept b_{0j} is the average level of morning NA across days; b_{1i} is the slope of the relationship between NA on evening *j-1* and morning NA on day *j* while controlling for stress on day *j-1*; b_{2i} is the slope of the relationship between stress on day *j-1* and morning NA on day *j* while controlling for evening NA on day *j-1*; and e_{ij} is the error. Therefore, each participant would have a distinct regression parameter that represents his/her unique relationship between morning NA and previous-day stress. In this case, there would be evidence for a spillover effect if the slope b_{2i} were significantly different from 0. Controlling for previous-day affect is important when examining affective spillover because it allows us to see continued change in affect after the initial reaction to stress (same-day emotional reactivity).

Next, we added sleep variables to this model at Level 1. While we still controlled for previous-evening affect, we also controlled for the effects of school day vs weekend in all of our analyses because participants' sleep varies as a function of whether or not they had school the following day (previous research suggests that there is an approximately one to two hour difference in sleep time on school vs. weekend days (Carskadon, 2011). School days might impact both sleep times and stress levels. Therefore all analyses including daily sleep also included a dummy-coded control variable called "no school", where 0 was the occurrence of a normal school morning and 1 was the occurrence of a non-school day or late school start time (e.g. weekend, snow day, or snow delay) on day *j*.

In order to examine sleep as a moderator, we created interaction terms between stress ratings from evening *j-1* and each individual sleep variables from that night, specifically, sleep latency, total sleep time, sleep debt, and subjective sleep quality (all predictors were group-mean-centered). We examined the unique impact of each interaction between stress and the individual sleep variables on morning *j* affect (negative and positive affect, predicted separately). An example of one of our main analyses, using total sleep time (TST), previous-day stress, and the interaction between total sleep time and previous-day stress (in addition to control variables) as predictors of morning negative affect at Level 1 would be:

$$\text{Morning NA}_{ij} = b_{0j} + b_{1j}\left(\text{stress}_{ij-1}\right) + b_{2j}\left(\text{TST}_{ij}\right) + b_{3\text{j}}\left(\text{stress}_{ij-1}\text{ x TST}_{ij}\right) +$$

$$b_{4j}\left(\text{Evening NA}_{ij-1}\right) + b_{5j}\left(\text{non} - \text{school day}_{ij}\right) + e_{ij}$$

Furthermore, an additional benefit of HLM is that we can also look at how within-person relationships at level 1 can vary depending on between-person characteristics at Level 2. Specifically, we were curious about whether the relationship between sleep and affective spillover varies as a function of trait-level neuroticism. To explore the role of neuroticism, entered neuroticism grand-mean-centered into the equation at the between-person level.

CHAPTER 3

RESULTS

Descriptive Statistics

Using HLM, we were able to find the means and standard deviations of our key daily variables using the intercept term in an unconditional Level 1 model. The descriptive statistics of our key variables across all days, on school days only and on non-school days only can be found in Table 1. Of note, across the days, mean total sleep time in our sample was about 390 minutes (6.5 hours), but was only about 359 minutes (just under 6 hours) on school days. Moreover, 34% of our sample (within one standard deviation below the mean) received between 257 minutes (about 4.25 hours of sleep) and 359 minutes of sleep on an average school night. Indeed, it is concerning that about 16% of the sample was getting *less* than 4.25 hours of sleep on a given school night. On an average non-school night, adolescents received 7.36 hours of sleep.

Table 1. Means and Standard Deviations of Baseline and Daily Variables (N = 89) and School Day Differences in Means Among Key Variables

	Overall *M*	Overall *SD*	School Days *M*	School Days *SD*	Non-School Days *M*	Non-School Days *SD*
Baseline Variables						
Neuroticism	24.08	6.35	-	-	-	-
Daily Variables						
SL	13.88[a]	16.58	14.74†	18.32	12.42†	11.75
TST	390.02[a]	118.97	359.13**	102.51	441.77**	116.48
SD	0.64[a]	0.88	0.80**	0.88	0.38**	0.61
SSQ	4.64	1.27	4.45**	1.23	4.92**	1.20
AM NA	1.63	0.50	1.70**	0.51	1.57**	0.46
PM NA	1.72	0.64	1.76†	0.64	1.67†	0.57
AM PA	3.36	0.89	3.24**	0.82	3.55**	0.87
PM PA	3.33	1.00	3.27*	1.02	3.44*	0.90
Overall stress	3.04	1.31	3.35**	1.25	2.59**	1.17

Note: SL = sleep latency; TST = total sleep time; SD = sleep debt; SSQ = subjective sleep quality; AM NA = morning negative affect; PM NA = evening negative affect; AM PA = morning positive affect; PM PA = evening positive affect

[a]Units for SL and TST are minutes; for SD, units are the number of consecutive days with TST under six hours. **p*<0.05. ***p*<0.01. ****p*<0.001.

Preliminary Analyses: Sleep and Other Daily Variables

We found that our adolescents' experiences of sleep, mood and stress were generally different between school days and non-school days (see Table 1). Sleep was significantly better in terms of longer total sleep time, less sleep debt, and greater sleep quality on non-school days versus school days. Sleep latency was marginally shorter on non-school days, as well. Affect was also generally better on non-school days, with significantly lower morning NA, higher morning and evening PA, and marginally lower evening NA. Overall stress was significantly lower on non-school days.

In addition, we found some significant relationships between aggregated sleep variables (see Table 2). Total sleep time and sleep debt were moderately correlated, which was to be expected as sleep debt is derived from total sleep time. Total sleep time was positively correlated with aggregated morning PA and inversely correlated with aggregated overall stress of day. Conversely, sleep debt was inversely correlated with morning PA and positively correlated with overall stress of day. Sleep latency was not significantly correlated with total sleep time, sleep debt, any affect ratings, or overall stress. However, sleep quality was significantly correlated with all sleep measures (positively correlated with total sleep time and negatively correlated with sleep latency and sleep debt), all affect ratings, and overall stress. Moreover, morning NA ratings and morning PA ratings were inversely correlated, as were evening NA ratings and evening PA ratings to each other (see Table 2).

Table 2. Correlations Among Key Study Variables

	1	2	3	4	5	6	7	8	9
1. SL	-								
2. TST	-0.04	-							
3. Sleep debt	0.004	-0.59**	-						
4. SSQ	-0.10**	0.30**	-0.24**	-					
5. AM NA	0.05	-0.01	-0.04	-0.19**	-				
6. PM NA	0.02	0.01	-0.04	-1.11**	0.63**	-			
7. AM PA	-0.04	0.07*	-0.08*	0.46**	-0.14*	-0.05	-		
8. PM PA	-0.04	-0.01	-0.01	0.28**	0.001	-0.18**	0.59**	-	
9. Overall stress	0.02	-0.14**	0.08*	-0.18**	0.26**	0.43**	-0.09**	-0.14**	-

Note: SL = sleep latency; TST = total sleep time; SSQ = subjective sleep quality; AM NA = morning negative affect; PM NA = evening negative affect; AM PA = morning positive affect; PM PA = evening positive affect; *p<0.05. **p<0.01. ***p<0.001.

Preliminary Analyses: Demographic and Personality Variables

We also examined whether average levels of these variables varied as a function of certain between-person characteristics (Level 2). We first investigated gender in our daily variables. Girls recorded more total sleep time (γ_{01}= 28.31, *SE* = 13.530, *t*(86) = 2.116, $p < .05$). Girls also reported significantly lower morning positive affect (γ_{01}= -.575, *SE* = .231, *t*(85) = -2.492, $p < .05$) and significantly lower evening positive affect (γ_{01}= -.479, *SE* = .222, *t*(86) = -2.154, $p < .05$) than boys.

Next, we looked at whether there were any differences in sleep and mood across the two weeks between racial/ethnic groups. We did not find any racial group differences in aggregated sleep latency ($F(4, 83) = .561$, $p = .692$), total sleep time ($F(4, 83) = .661$, $p = .621$), or sleep quality ($F(4, 83) = 1.333$, $p = .264$). Furthermore, there were no group differences in aggregated ratings of overall stress $F(4, 83) = .374$, $p = .827$), morning NA ($F(4, 83) = .1.455$, $p = .223$), morning PA ($F(4, 83) = .733$, $p = .572$), evening NA ($F(4, 83) = 1.029$, $p = .397$), or evening PA ($F(4, 83) = 1.208$, $p = .314$). Because we did not find any racial differences between our main variables, particularly our outcome variables, we did not control for race as a potential confound in our main analyses.

We also considered whether our daily variables varied by neuroticism. The mean neuroticism score in our sample was 24.08 and standard deviation was 6.35. We found a significant inverse relationship between neuroticism and subjective ratings of sleep quality (γ_{01}= -.050, SE = .014, $t(86) = -3.608$, $p < .001$). However, there was no significant relationship between objective sleep measures and neuroticism (sleep latency: γ_{01}= .080, SE = .126, $t(86) = .634$, $p = .528$; total sleep time: γ_{01}= .153, SE = 1.110, $t(86) = .138$, $p =.891$; sleep debt: γ_{01}= -.009, SE = .010, $t(86) = -.895$, $p = .373$). Therefore, although people higher in neuroticism may not actually be getting worse sleep than those lower in neuroticism, their perception of their sleep is worse. Unsurprisingly, neuroticism was also positively linked to both morning and evening ratings of NA (AM NA: γ_{01}= .038, SE = .012, $t(86) = 3.115$, $p < .01$; PM NA: γ_{01}=.039, SE = .012, $t(86) = 3.288$, $p < .01$), positively linked to ratings of overall stress (γ_{01}= .052, SE = .014, $t(86) = 3.698$, $p < .001$), and negatively linked to both morning and evening PA (AM PA: γ_{01}= -.058, SE = .017, $t(86) = -3.392$, $p < .01$; PM PA: γ_{01}= -.049, SE = .017, $t(86) = -2.815$, $p < .01$).

Preliminary Analyses: Stress Reactivity

Although we did not make formal hypotheses regarding within-day affective reactivity to stress, we thought it would be beneficial to document whether within-day stress reactivity effects existed in our sample and whether sleep moderated these effects. Before understanding spillover effects, it is helpful to show that NA does seem to be higher/ PA does seem to be lower on high stress days. Controlling for school-day effects, we found that same-day stress significantly predicted increased evening NA (*b* = .176, *SE* = .020, *t*(88) = 8.592, *p* < .001) and decreased evening PA (*b* = -.139, *SE* = .031, *t*(88) = -4.530, *p* < .001). Therefore, we found evidence for within-day stress reactivity. We next added each sleep variable to the regression separately. We found that same-day stress remained a significant predictor of evening NA and evening PA regardless of which sleep variable was used as a control (see Tables 3 and 4). Furthermore, only a significant interaction emerged between same-day stress and sleep debt in predicting evening PA (*b* = -.065, *SE* = .031, *t*(88) = -2.107, *p* < .05). The interaction suggested that when sleep debt was high, there is a stronger inverse relationship between same-day stress and evening PA than when sleep debt was low. We did not find any other significant interactions between sleep and same-day stress on negative affect (see Tables 3 and 4).

Table 3. Multilevel Regression: Effects of Sleep and Same-Day Stress on Evening Negative Affect (Stress Reactivity)

	B Coefficient	Standard Error	*T* Ratio
Sleep Latency (SL) Model			
Step 1: Main Effects			
Average within-person slope for same-day stress (b_{01})	0.176***	0.022	7.931
Average within-person slope for SL (b_{02})	0.0004	0.001	0.574
Step 2: Within-person Interaction			
Average within-person slope for same-day stress x SL (b_{03})	0.002	0.001	1.254
Total Sleep Time (TST) Model			
Step 1: Main Effects			
Average within-person slope for same-day stress (b_{01})	0.173***	0.022	7.976
Average within-person slope for TST (b_{02})	0.00005	0.0002	0.254
Step 2: Within-person Interaction			
Average within-person slope for same-day stress x TST (b_{03})	-0.0003	0.0002	-1.533
Sleep Debt (SD) Model			
Step 1: Main Effects			
Average within-person slope for same-day	0.174***	0.022	7.955

stress (b_{01})			
Average within-person slope for SD (b_{02})	0.005	0.025	0.218
Step 2: Within-person Interaction			
Average within-person slope for same-day Stress x SD (b_{03})	0.027	0.026	1.019
Subjective Sleep Quality (SSQ) Model			
Step 1: Main Effects			
Average within-person slope for same-day stress (b_{01})	0.181***	0.022	8.362
Average within-person slope for SSQ (b_{02})	-0.0001	0.018	-0.006
Step 2: Within-person Interaction			
Average within-person slope for same-day stress x SSQ (b_{03})	-0.001	0.019	-0.041

Note: All of the above are separate regression models. Coefficients are unstandardized.
School day was controlled in all analyses.
**p*<0.05. ***p*<0.01. ****p*<0.001.

Table 4. Multilevel Regression: Effects of Sleep and Same-Day Stress on Evening Positive Affect (Stress Reactivity)

	B Coefficient	Standard Error	*T* Ratio
Sleep Latency (SL) Model			
Step 1: Main Effects			
Average within-person slope for same-day stress (b_{01})	-0.161***	0.031	-5.148
Average within-person slope for SL (b_{02})	-0.003*	0.001	-2.092
Step 2: Within-person Interaction			
Average within-person slope for same-day stress x SL (b_{03})	0.001	0.001	1.271
Total Sleep Time (TST) Model			
Step 1: Main Effects			
Average within-person slope for same-day stress (b_{01})	-0.156***	0.031	-4.968
Average within-person slope for TST (b_{02})	-0.0003	0.0003	-1.149
Step 2: Within-person Interaction			
Average within-person slope for same-day stress x TST (b_{03})	-0.0001	0.0003	-0.307
Sleep Debt (SD) Model			
Step 1: Main Effects			
Average within-person slope for same-day stress (b_{01})	-0.158***	0.031	-5.065
Average within-person slope for SD (b_{02})	0.060	0.045	1.318

Step 2: Within-person Interaction			
Average within-person slope for same-day Stress x SD (b_{03})	-0.065*	0.031	-2.107
Subjective Sleep Quality (SSQ) Model			
Step 1: Main Effects			
Average within-person slope for same-day stress (b_{01})	-0.144***	0.032	-4.507
Average within-person slope for SSQ (b_{02})	0.059*	0.027	2.141
Step 2: Within-person Interaction			
Average within-person slope for same-day stress x SSQ (b_{03})	-0.021	0.016	-1.360

Note: All of the above are separate regression models. Coefficients are unstandardized.
School day was controlled in all analyses.
*p<0.05. **p<0.01. ***p<0.001.

Affective Spillover

Before testing our main hypotheses, we first wanted to investigate the presence of daily stress-related affective spillover/dampening in our sample. We found that the average within-person relationship between previous-day stress and morning NA, controlling for previous-evening NA, was not significant (b = .018, SE = .015, t(86) = 1.182, p = .241). Likewise, we did not find a significant relationship between previous-day stress and morning PA, while controlling for previous-evening PA (b = -.011, SE = .021, t(86) = -.530, p = .597). Therefore, on average, we did not find any NA spillover effects or PA dampening effects related to previous-day stress alone. In general, students were showing emotional recovery from their stressors by the subsequent morning.

Main Effects of Sleep and Previous-Day Stress on Emotions

We next added each sleep variable separately to our analyses to test the main effects of both sleep and previous-day stress on morning emotions (see Table 5). We found that sleep latency marginally predicted higher morning NA (b = .002, SE = .001, t(86) = 1.780, p = .079) and sleep quality significantly predicted lower morning NA (b = -.068, SE = .015, t(86) = -4.506, p < .001). On the other hand, all sleep variables appeared to have a significant main effect on morning PA. Worse sleep latency and sleep debt predicted lower morning PA (sleep latency: b = -.005, SE = .002, $t(86) = -2.715$, $p < .01$; sleep debt: b = -.102 SE = .042, $t(86) = -2.452$, $p < .05$), whereas higher total sleep time and sleep quality predicted higher morning PA (total sleep time: b = .001 SE = .0004, $t(86) = 3.529$, $p < .001$; sleep quality: b = .257 SE = .027, $t(86) = 9.385$, $p < .001$; see Table 6).

Table 5. Multilevel Regression: Effects of Sleep and Previous-Day Stress on Morning Negative Affect (Stress Recovery)

	B *Coefficient*	Standard Error	*T* Ratio
Sleep Latency (SL) Model			
Step 1: Main Effects			
Average within-person slope for previous-day stress (b_{01})	0.024	0.017	1.432
Average within-person slope for SL(b_{02})	0.002†	0.001	1.78
Step 2: Within-person Interaction			
Average within-person slope for previous-day stress x SL (b_{03})	0.005*	0.002	2.410
Step 3: Between-person moderation			
Effect of neuroticism on within-person slope for previous-day stress x SL (b_{31})	-0.0001	0.0003	-0.306
Total Sleep Time (TST) Model			
Step 1: Main Effects			
Average within-person slope for previous-day stress (b_{01})	0.022	0.017	1.330
Average within-person slope for TST (b_{02})	-0.0001	0.0002	-0.620
Step 2: Within-person Interaction			
Average within-person slope for previous-day stress x TST (b_{03})	-0.0002†	0.0001	-1.813
Step 3: Between-person moderation			
Effect of neuroticism on within-person slope for previous-day stress x TST (b_{31})	-0.00001	0.00002	-0.431
Sleep Debt (SD) Model			
Step 1: Main Effects			
Average within-person slope for previous-day stress (b_{01})	0.021	0.017	1.263
Average within-person slope for SD (b_{02})	0.016	0.022	0.730
Step 2: Within-person Interaction			
Average within-person slope for previous-	0.054*	0.021	2.544

day stress x SD (b_{03})			
Step 3: Between-person moderation			
Effect of neuroticism on within-person slope for previous-day stress x SD (b_{31})	-0.0002	0.003	-0.063
Subjective Sleep Quality (SSQ) Model			
Step 1: Main Effects			
Average within-person slope for previous-day stress (b_{01})	0.017	0.015	1.103
Average within-person slope for SSQ (b_{02})	-0.068***	0.015	-4.506
Step 2: Within-person Interaction			
Average within-person slope for previous-day stress x SSQ (b_{03})	-0.013	0.014	-0.926
Step 3: Between-person moderation			
Effect of neuroticism on within-person slope for previous-day stress x SSQ (b_{31})	-0.001	0.002	-0.681

Note: All of the above are separate regression models. Coefficients are unstandardized.
Previous-evening NA and school day were controlled in all analyses.
†p<0.1. **p*<0.05. ***p*<0.01. ****p*<0.001.

Table 6. Multilevel Regression: Effects of Sleep and Previous-Day Stress on Morning Positive Affect (Stress Recovery)

	B Coefficient	Standard Error	*T* Ratio
Sleep Latency (SL) Model			
Step 1: Main Effects			
Average within-person slope for previous-day stress (b_{01})	-0.007	0.025	-0.282
Average within-person slope for SL(b_{02})	-0.005**	0.002	-2.715
Step 2: Within-person Interaction			
Average within-person slope for previous-day stress x SL (b_{03})	0.001	0.002	0.810
Step 3: Between-person moderation			
Effect of neuroticism on within-person slope for previous-day stress x SL (b_{31})	0.0001	0.0003	0.235
Total Sleep Time (TST) Model			
Step 1: Main Effects			
Average within-person slope for previous-day stress (b_{01})	-0.003	0.024	-0.107
Average within-person slope for TST (b_{02})	0.001***	0.0004	3.529
Step 2: Within-person Interaction			
Average within-person slope for previous-day stress x TST (b_{03})	0.0004*	0.0002	2.111
Step 3: Between-person moderation			
Effect of neuroticism on within-person slope	0.00002	0.00003	0.637

for previous-day stress x TST (b_{31})			
Sleep Debt (SD) Model			
Step 1: Main Effects			
Average within-person slope for previous-day stress (b_{01})	0.002	0.025	0.071
Average within-person slope for SD (b_{02})	-0.102*	0.042	-2.452
Step 2: Within-person Interaction			
Average within-person slope for previous-day stress x SD (b_{03})	-0.080**	0.026	-3.111
Step 3: Between-person moderation			
Effect of neuroticism on within-person slope for previous-day stress x SD (b_{31})	0.002	0.003	0.571
Subjective Sleep Quality (SSQ) Model			
Step 1: Main Effects			
Average within-person slope for previous-day Stress (b_{01})	-0.010	0.020	-0.494
Average within-person slope for SSQ (b_{02})	0.257***	0.027	9.385
Step 2: Within-person Interaction			
Average within-person slope for previous-day stress x SSQ (b_{03})	-0.005	0.020	-0.274
Step 3: Between-person moderation			
Effect of neuroticism on within-person slope for previous-day stress x SSQ (b_{31})	0.003	0.003	0.906

Note: All of the above are separate regression models. Coefficients are unstandardized.
Previous-evening PA and school day were controlled in all analyses.
**p*<0.05. ***p*<0.01. ****p*<0.001.

Taken together, these results suggest that sleep impacts morning affect, but that objective and subjective markers of sleep have different patterns of results. Whereas less sleep, as indexed by longer sleep latency, shorter total sleep time, and greater sleep debt, was related to lower morning PA, we did not find significant relationships between objective sleep measures and morning NA. However, it appears that subjective measures of sleep (i.e. sleep quality) predicted both morning NA and PA.

Interactive Effects of Objective Sleep and Previous-Day Stress on Morning Emotions

Next, we examined our first hypothesis that the interaction between objective sleep and previous-day stress would impact morning affect. More specifically, we believed that less objective sleep following higher stress days would be associated with more morning NA (more spillover) and less morning PA (more dampening). At Level 1, we entered the interactions between previous-day stress and each sleep variable in the regression separately, while also controlling for school day effects and previous-evening affect.

Indeed, we found a significant within-person interaction effect between sleep latency and previous-day stress on morning NA, (b = .005 SE = .002, $t(86) = 2.410$, $p < .05$). Specifically, when sleep latency was lower, morning NA decreased as previous-day stress increased. This inverse relationship suggests that better conditions of sleep (e.g. taking less time to fall asleep) might be related to improved mood when it is needed (e.g. higher stress days). Conversely, when sleep latency was higher, morning NA increased as previous-day stress increased. This positive relationship suggests that taking more time to fall asleep could be associated with less recovery from high stress, as morning mood worsens (see Figure 1). It also seemed that the effect of sleep latency on morning NA was particularly mattered for recovery from highly stressful day. When previous-day stress was high and adolescents fell asleep quickly that night, there was a greater decrease in NA from previous-evening to morning than when they took longer to fall asleep. In other words, there was less NA spillover when sleep latency was short. However, the change in NA from previous-evening to morning was much smaller when previous-day stress was low regardless of sleep latency (see Figure 2). The interaction between previous-day stress and sleep latency did not predict morning PA (b = .001 SE = .002, $t(86)$ = .810, p = .420).

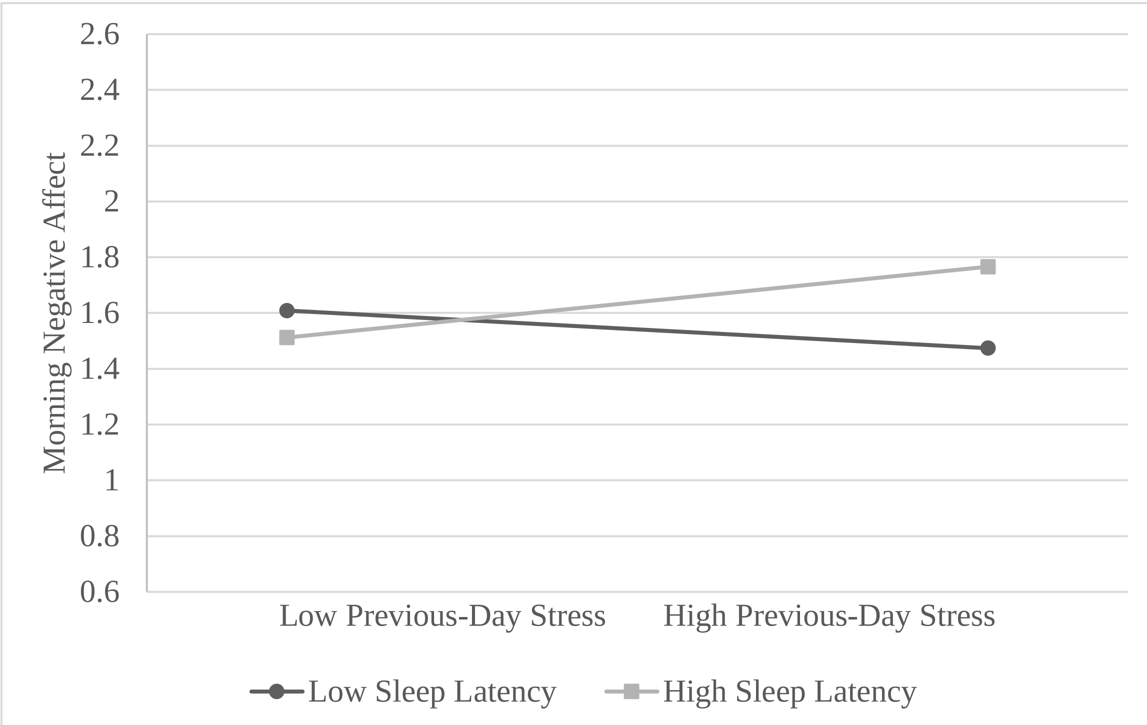

Figure 1. Interaction between Previous-day Stress and Sleep Latency Predicting Morning Negative Affect

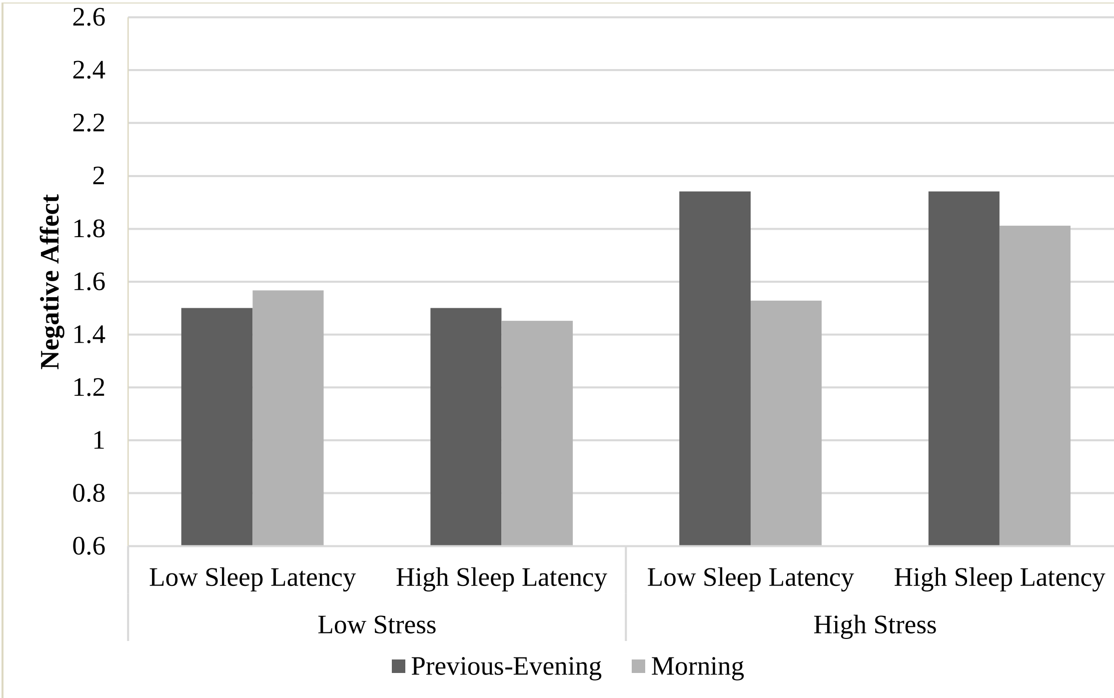

Figure 2. Change in Negative Affect from Previous-evening to Morning by Stress and Sleep Latency

Next, we investigated whether total sleep time was associated with morning NA spillover in response to previous day's stress. We found that the interaction effect of total sleep time and previous-day stress on morning NA was only trending in significance, but that the direction of the trend did indicate that lower total sleep time was related to more NA and higher total sleep time was related to less NA when previous-day stress was high (b = - .0002, SE = .0001, t(86) = -1.813, p = .073).

We found that the interaction between total sleep time and previous-day stress did significantly predict morning PA (b = -.0004, SE = .0002, t(86) = 2.111, p < .05). When previous-day stress was lower, less total sleep time corresponded with lower PA than when previous day-stress was higher. This difference grew as previous-day stress increased, such that when total sleep time was shorter, morning PA became even lower as previous-day stress increased and when total sleep time was longer, morning PA in fact became even higher as previous-day stress increased (see Figure 3). We wanted to break this finding down a little further to understand how PA was actually changing between previous-evening and morning. The spillover analyses do not show the full picture, because previous-evening affect is controlled. So when we see an “increase” in PA in the morning, it could reflect simply a return to baseline levels of lower PA that tend to occur on high stress days (as opposed to further worsening of PA in the morning) or it could reflect an increase above baseline. Figure 4 shows morning and evening levels of affect on high and low stress days, with the moderating effect of total sleep time. Indeed, on higher stress days, PA is lower in the evening. However, if participants had more sleep, morning PA “bounces back” to the levels of PA one would expect after a low stress day. When there is less total sleep time, however, the morning PA remains suppressed. Hence, it seemed that having longer sleep following higher stress was related to a PA bounce-back effect that might have mitigated the adverse emotional consequences of a stressful day.

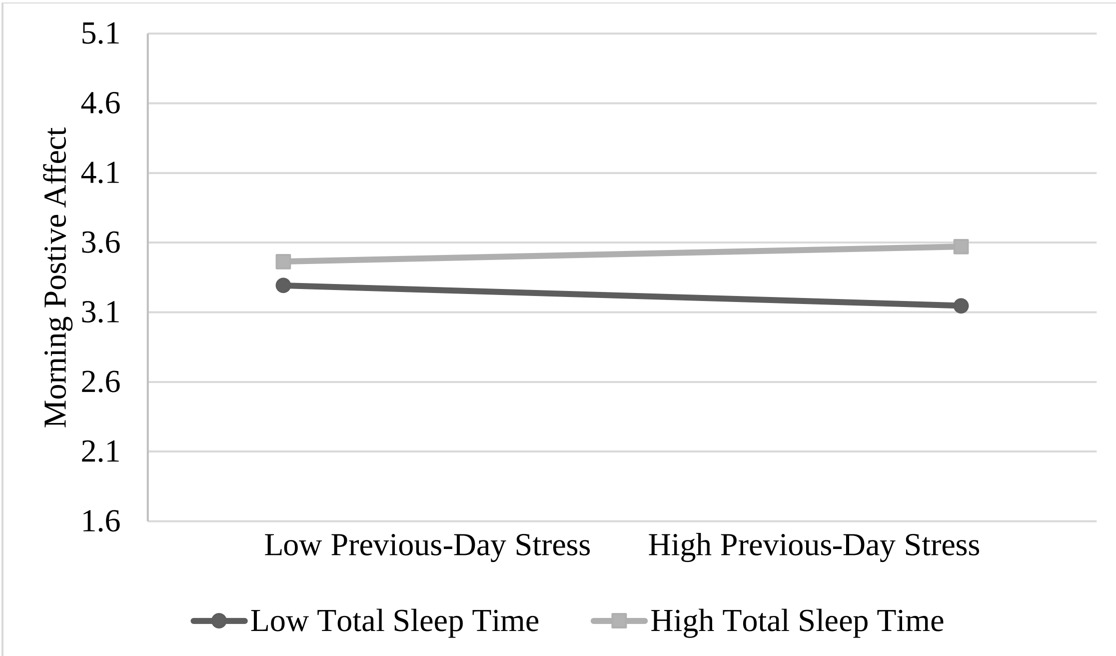

Figure 3. Interaction between Previous-day Stress and Total Sleep Time Predicting Morning Positive Affect

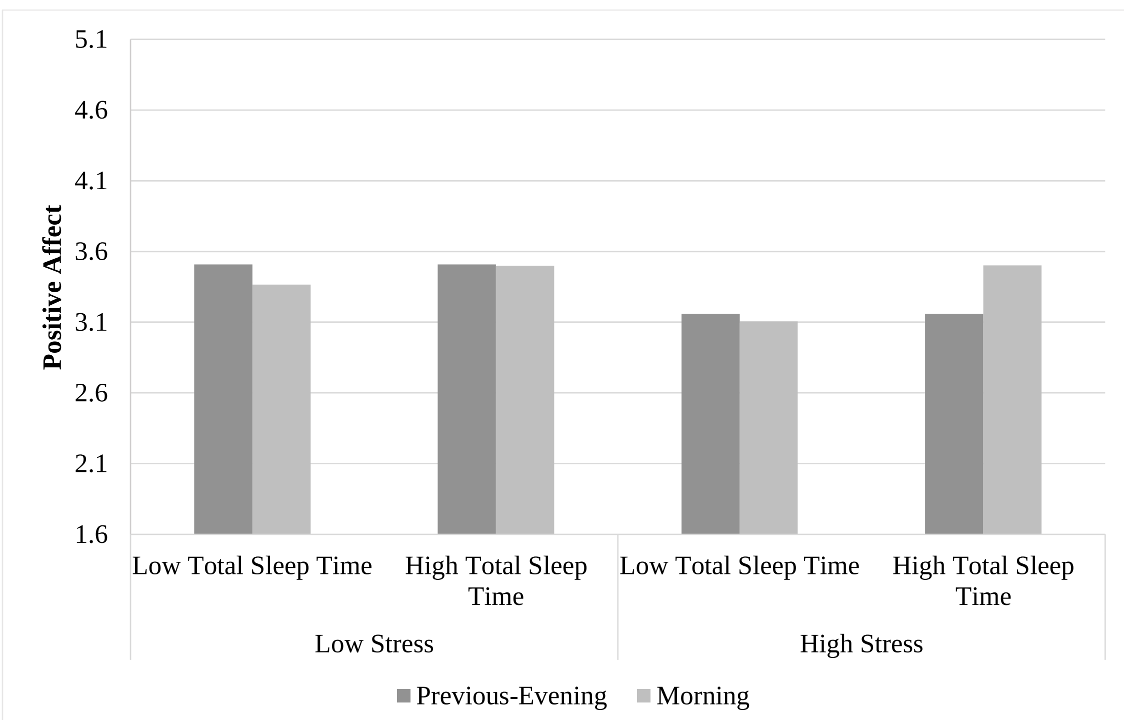

Figure 4. Change in Positive Affect from Previous-evening to Morning by Stress and Total Sleep Time

Finally, we investigated the role of our last objective sleep measure- sleep debt. We found that the interaction between previous-day stress and sleep debt significantly predicted morning NA (b = .054, SE = .021, $t(86) = 2.544$, $p < .05$). When sleep debt was higher, the relationship between previous-day stress and morning NA was positive, meaning that within the context of mounting sleep debt, there was more NA spillover (less recovery) as yesterday's stress increased. However, when sleep debt was lower, morning NA was similar regardless of previous-day stress, suggesting that lower sleep debt has less of an influence on NA spillover effects (and therefore recovery) than higher sleep debt (see Figure 5). Comparing adolescents' previous-evening and morning NA ratings, we found that NA ratings were similar between the two time points when previous-day stress was low, meaning amount of sleep debt did not seem to matter in changing NA overnight. However, when previous-day stress was high, NA decreased overnight, but this decrease was greater (i.e. more recovery) when sleep debt was lower as opposed to higher (see Figure 6). Thus, it seems that higher stress in combination with mounting sleep debt is associated with more NA spillover, as morning mood continues to worsen in response to previous-day high stress, whereas lower sleep debt is associated with less NA spillover, perhaps as more sleep helps to lessen cross-day ties between stress and mood. Together, these findings suggest that sleep debt could be related to the stress recovery process.

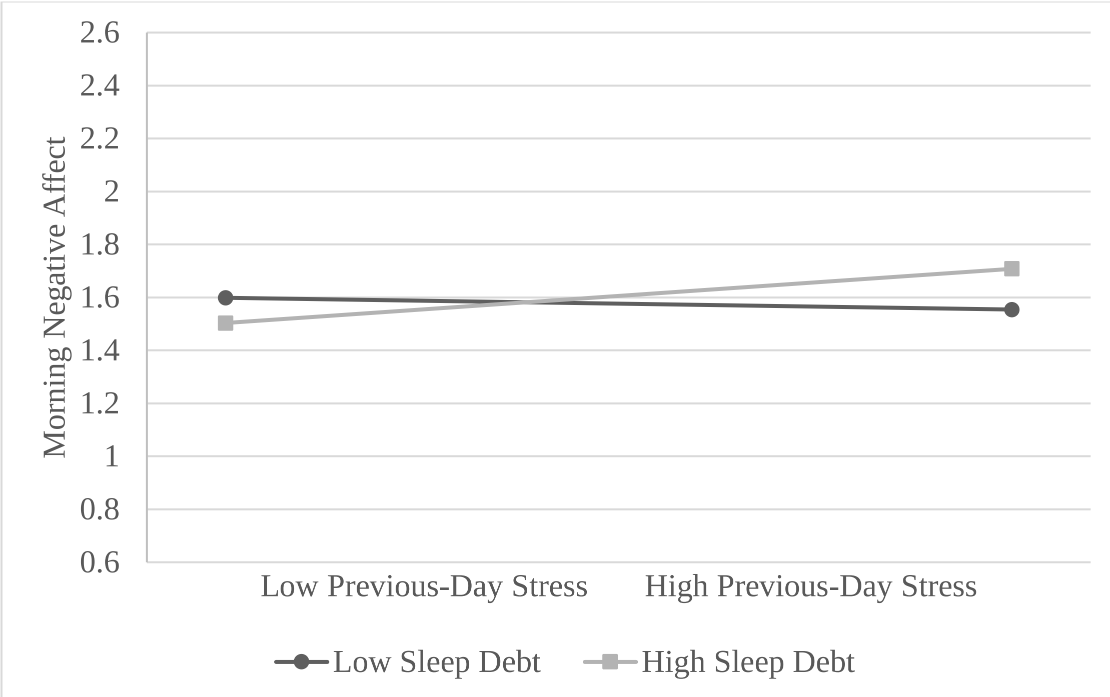

Figure 5. Interaction between Previous-day Stress and Sleep Debt Predicting Morning Negative Affect

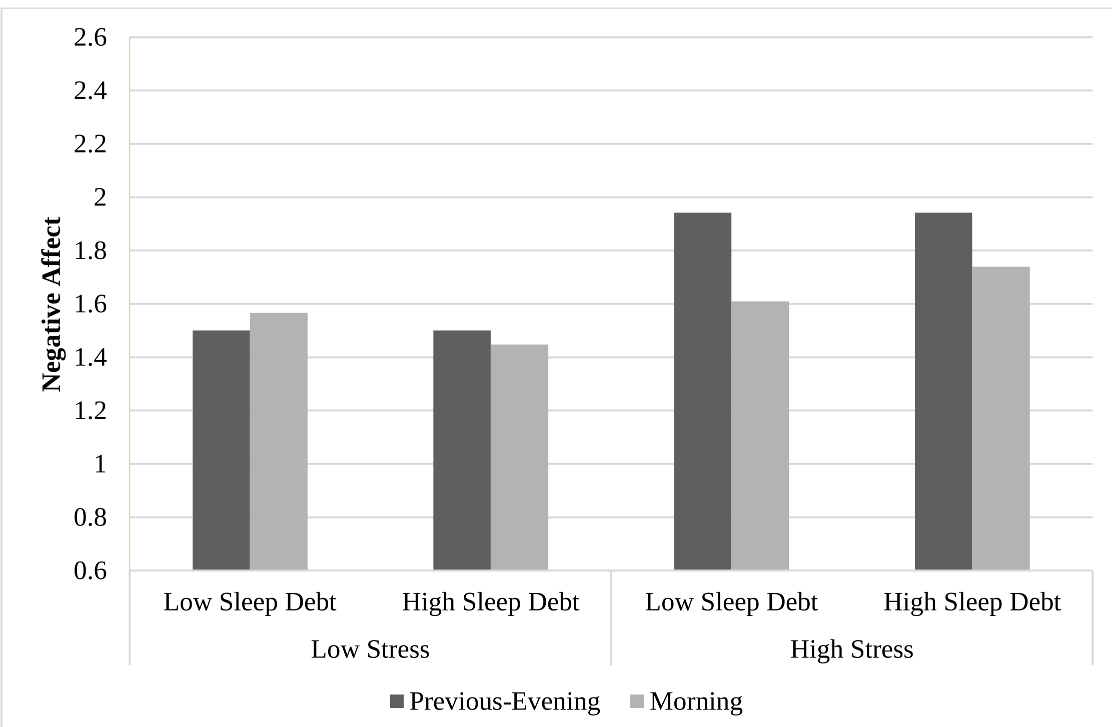

Figure 6. Change in Negative Affect from Previous-evening to Morning by Stress and Sleep Debt

Similarly, we found a significant interaction between sleep debt and previous-day stress on morning PA in the opposite direction (b = -.080, SE = .026, $t(86)$ = -3.111, p < .01). Here, when previous-day stress was low, morning PA was similar regardless of sleep debt. However, as previous-day stress increased, morning PA decreased at higher levels of sleep debt, but morning PA increased at lower levels of sleep debt (see Figure 7). Looking more closely, we see that PA remains low between previous-evening and morning when stress and sleep debt are both higher. In contrast, when previous-day stress was higher and sleep debt was lower, morning PA not only increased from previous-evening PA but also increased to the level of PA reported on low stress days (see Figure 8). Again, it appears that in times of higher stress, having more consecutive nights of adequate sleep (e.g. lower sleep debt) is associated with a PA bounce-back effect (more recovery), whereas having more consecutive nights of short sleep (e.g. higher sleep debt) is associated with continued PA suppression (less recovery).

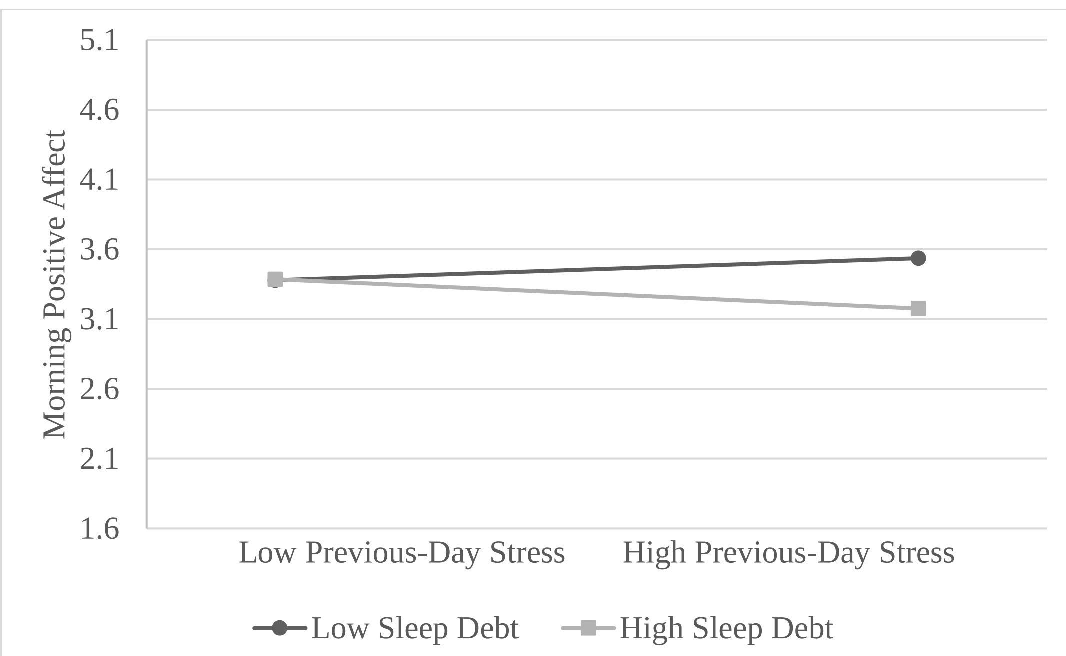

Figure 7. Interaction between Previous-day Stress and Sleep Debt Predicting Morning Positive Affect

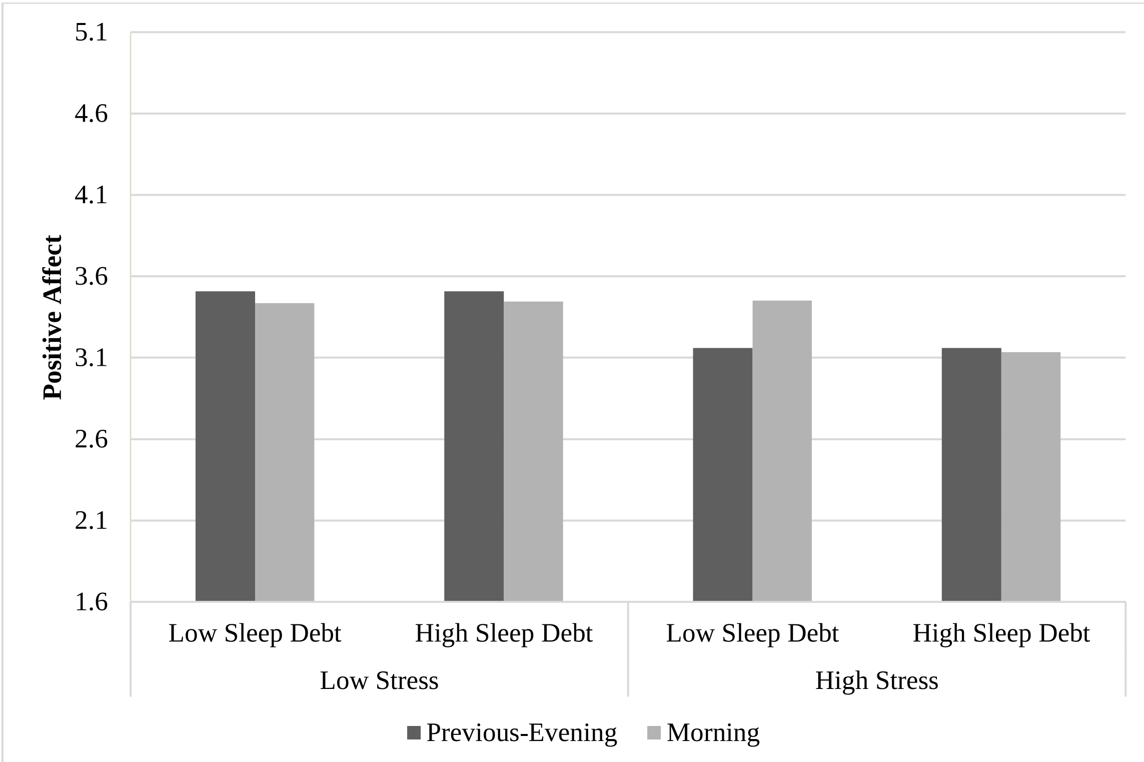

Figure 8. Change in Positive Affect from Previous-evening to Morning by Stress and Sleep Debt

As a follow-up, we investigated the next-day implications of gaining a single night of sleep debt (under six hours of sleep) by creating a dichotomous short sleep/ long sleep time variable, coded 0 when total sleep time was under six hours for any single night ("short sleep") and 1 when total sleep time was six hours or more ("long sleep"). There was no significant main effect of short/long sleep time on morning NA (b = - .040, SE = .035, t(86) = -1.155, p = .251) nor significant interaction between previous-day stress and short/long sleep (b = -.050, SE = .032, t(86) = -1.569, p = .120). These findings suggest that accruing one night of sleep debt did not have an impact on NA spillover. However, there was a significant main effect of short/long sleep time on morning PA, such that PA was higher on mornings when adolescents had at least six hours of sleep than on mornings when adolescents had less than six hours of sleep (b = .228, SE = .075, t(86) = 3.031, $p < .01$). There was also a significant interaction between previous-day stress and short/long sleep time on morning PA ($b = .142$, $SE = .046$, $t(86) = 3.069$, $p < .01$). When previous-day stress was low, PA was similar regardless of whether the adolescent received over or under six hours of sleep. However, as previous-day stress increased, getting under six hours of sleep predicted a decrease in PA, whereas getting at least six hours of sleep predicted an increase in PA (see Figure 9). Moreover, the data indicate that longer sleep is associated with a morning PA bounce-back. When high stress is followed by one night of long sleep, morning PA increases to levels of PA seen on low stress days. Conversely, when high stress is followed by one night of short sleep, morning PA remains as low as previous-evening PA. On low stress days, short vs. long sleep seems to have little impact on overnight changes in PA (see Figure 10). Taken together, we see evidence that accruing one night of sleep debt might have a greater influence a next-day PA bounce-back than on NA spillover.

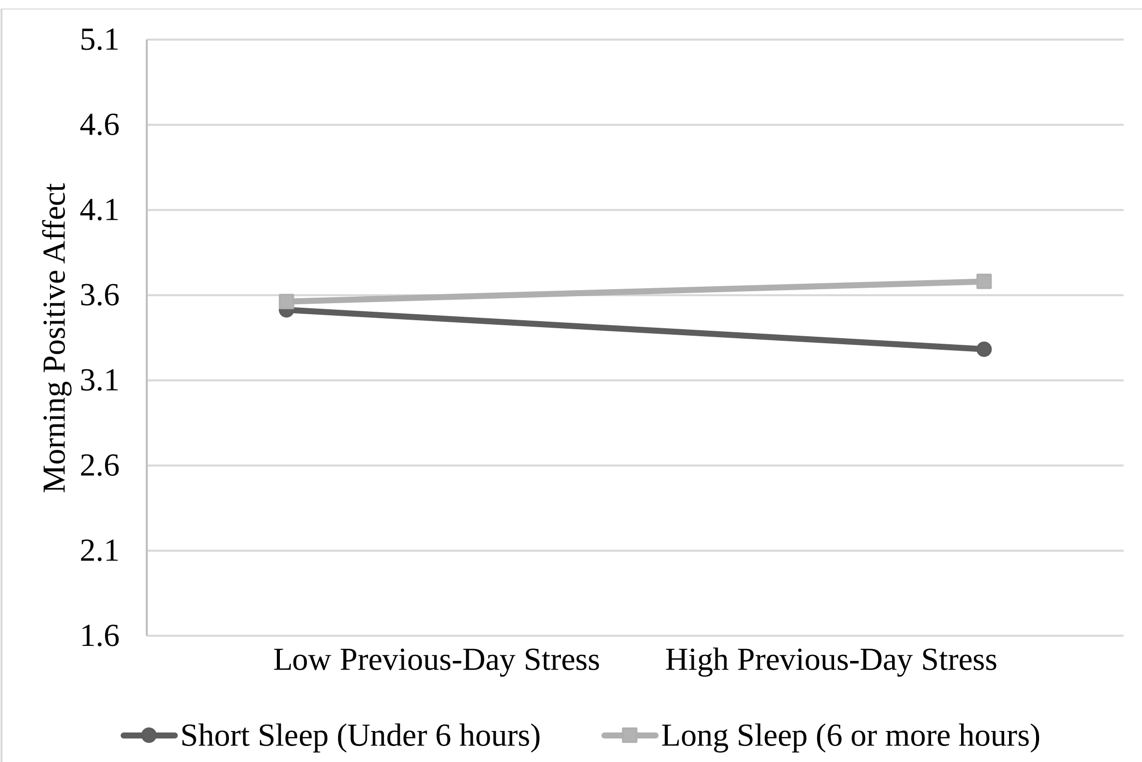

Figure 9. Interaction between Previous-day Stress and Short/Long Sleep Predicting Morning Positive Affect

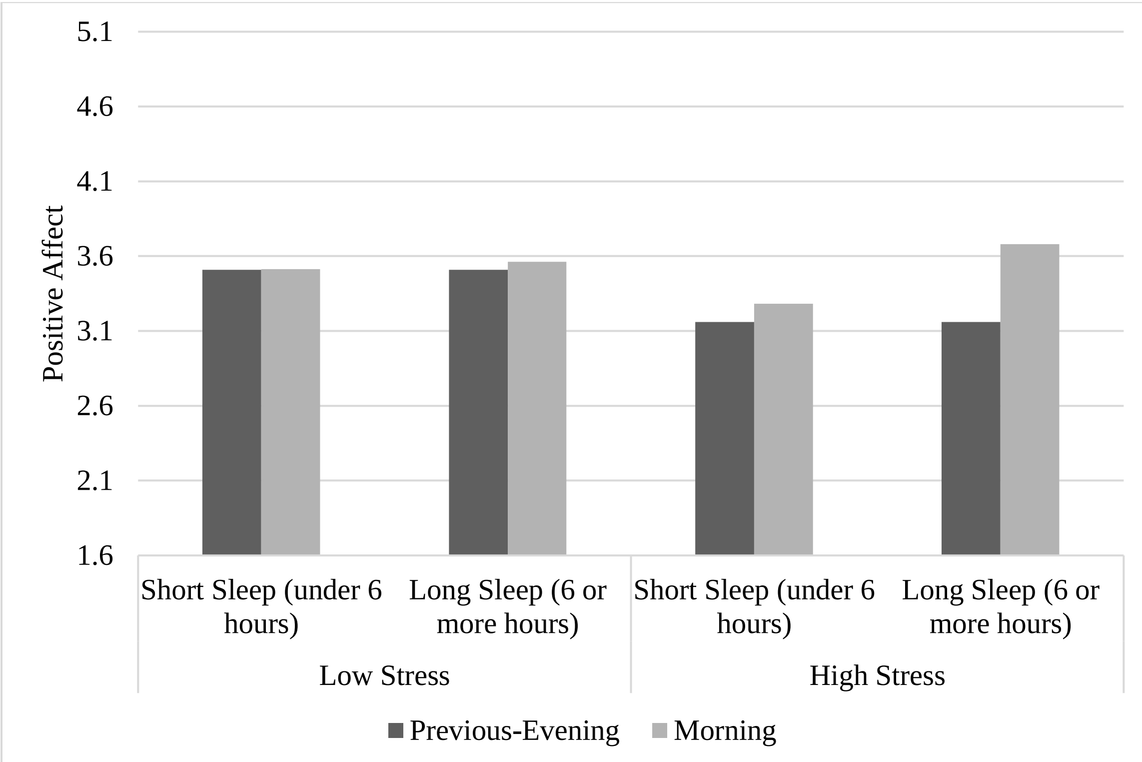

Figure 10. Change in Positive Affect from Previous-evening to Morning by Stress and Short/Long Sleep

Interactive Effects of Subjective Sleep and Previous-Day Stress on Morning Emotions

Next we tested our hypothesis that subjective ratings of sleep would also show that good quality sleep facilitated stress recovery, whereas poor quality sleep would restrict stress recovery. Interestingly, we did not find a significant interaction between subjective ratings of sleep and previous-day stress on either morning NA (b = -.013, SE = .014, t(86) = -.926, p = .357) or PA (b = -.005, SE = .0020, t(86) =-.274, p = .785).

Neuroticism as a Level 2 Moderator

Finally, we explored the role of trait-level neuroticism on the relationship between sleep, previous-day stress, and morning affect. In these exploratory analyses, we entered neuroticism at Level 2, or the between-subject level, to each of our main analyses. We found that the interactions between all of the sleep variables and previous-day stress had similar effects on morning NA and PA regardless of level of neuroticism (see Tables 5 and 6). Therefore, we did not find any evidence that trait-level neuroticism moderates the relationship of sleep and previous-day stress on morning emotions.

Supplemental Analyses

We also wanted to investigate whether sleep-related NA spillover/ PA bounce-back effects extended into the next evening, not just the next morning. Towards this goal, we conducted another series of HLM analyses, controlling for school-day effects, previous-evening affect, and same-day stress. First, we found that previous-day stress did not predict evening NA (b = -.006, SE = .015, t(88) = -.372, p = .711) or evening PA (b = .041, SE = .027, t(88) = 1.540, p = .127). These findings suggest that, in general, there were no stress-related NA spillover or PA bounce-back effects into the next evening. Next, we looked at whether sleep served as a significant moderator. We used interactions between previous-day stress and sleep variables to predict evening NA and PA, separately. Interestingly, we did not find evidence of any evening NA spillover related to sleep (see Table 7). For evening PA, we only found that the interaction between sleep debt and previous-day stress marginally predicted evening PA (b = -.072, SE = .038, t(88) = -1.885, p = .063). Here, it appears, unexpectedly, sleep impacted evening PA only when previous-day stress was lower and specifically that evening PA was lower when sleep debt was lower than when sleep debt was higher (see Table 8).

Table 7. Multilevel Regression: Effects of Sleep and Previous-Day Stress on Evening Negative Affect (Stress Recovery)

	B *Coefficient*	Standard Error	*T* Ratio
Sleep Latency (SL) Model			
Step 1: Main Effects			
Average within-person slope for previous-day stress (*b*$_{01}$)	-0.002	0.019	-0.106
Average within-person slope for SL(*b*$_{02}$)	0.0003	0.0007	0.404
Step 2: Within-person Interaction			
Average within-person slope for previous-day stress x SL (*b*$_{03}$)	-0.0006	0.0008	-0.760
Total Sleep Tine (TST) Model			
Step 1: Main Effects			
Average within-person slope for previous-day stress (*b*$_{01}$)	-0.003	0.017	-0.180
Average within-person slope for TST (*b*$_{02}$)	0.0003†	0.0001	1.817
Step 2: Within-person Interaction			
Average within-person slope for previous-day stress x TST (*b*$_{03}$)	-0.000001	0.00012	-0.007
SD Model			
Step 1: Main Effects			
Average within-person slope for previous-day stress (*b*$_{01}$)	-0.004	0.019	-0.192
Average within-person slope for SD (*b*$_{02}$)	-0.005	0.022	-0.234
Step 2: Within-person Interaction			
Average within-person slope for previous-day stress x SD (*b*$_{03}$)	0.002	0.020	0.096
SSQ Model			
Step 1: Main Effects			
Average within-person slope for previous-day stress (*b*$_{01}$)	-0.005	0.016	-0.343
Average within-person slope for SSQ (*b*$_{02}$)	-0.019	0.020	-0.959
Step 2: Within-person Interaction			
Average within-person slope for previous-day stress x SSQ (*b*$_{03}$)	-0.021	0.013	-1.648

Note: All of the above are separate regression models. Coefficients are unstandardized.
Previous-evening NA and school day were controlled in all analyses.
†p<0.1. **p*<0.05. ***p*<0.01. ****p*<0.001.

Table 8. Multilevel Regression: Effects of Sleep and Previous-Day Stress on Evening Positive Affect (Stress Recovery)

	B *Coefficient*	Standard Error	*T* Ratio
Sleep Latency (SL) Model			
Step 1: Main Effects			
Average within-person slope for previous-day stress (b_{01})	0.032	0.032	1.016
Average within-person slope for SL(b_{02})	-0.002	0.001	-1.556
Step 2: Within-person Interaction			
Average within-person slope for previous-day stress x SL (b_{03})	0.001	0.001	0.708
Total Sleep Time (TST) Model			
Step 1: Main Effects			
Average within-person slope for previous-day stress (b_{01})	0.034	0.032	1.057
Average within-person slope for TST (b_{02})	-0.0001	0.0003	-0.433
Step 2: Within-person Interaction			
Average within-person slope for previous-day stress x TST (b_{03})	0.0002	0.0002	1.225
Sleep Debt (SD) Model			
Step 1: Main Effects			
Average within-person slope for previous-day stress (b_{01})	0.042	0.030	1.391
Average within-person slope for SD (b_{02})	0.122	0.046	2.676
Step 2: Within-person Interaction			
Average within-person slope for previous-day stress x SD (b_{03})	-0.072†	0.038	-1.885
Subjective Sleep Quality (SSQ) Model			
Step 1: Main Effects			
Average within-person slope for previous-day stress (b_{01})	0.047†	0.026	1.823
Average within-person slope for SSQ (b_{02})	0.036	0.028	1.281
Step 2: Within-person Interaction			
Average within-person slope for previous-day stress x SSQ (b_{03})	-0.024	0.021	-1.187

Note: All of the above are separate regression models. Coefficients are unstandardized.
Previous-evening PA and school day were controlled in all analyses.
†$p<0.1$. *$p<0.05$. **$p<0.01$. ***$p<0.001$.

CHAPTER 4

DISCUSSION

The present study was a two-week naturalistic study of everyday sleep, emotion, and stress processes in a sample of adolescents. Our findings indicate that for adolescents, less objective sleep was generally associated with more stress-related NA spillover and less PA bounce-back, whereas more objective sleep was associated with less stress-related NA spillover and more PA bounce-back. We also found that different objective sleep variables served as moderators for NA versus PA overnight changes. Specifically, sleep latency only predicted stress-related NA spillover, whereas total sleep time only predicted stress-related PA bounce-back. Sleep debt moderated both stress-related NA spillover and PA bounce-back. Insofar that stress-related NA spillover/ PA bounce-back effects are indicative of daily stress recovery processes, our findings would suggest that, on an average night, objectively less sleep would hinder stress recovery from one day to the next. Conversely, our data suggest that objectively more sleep promotes daily stress recovery, not just through a reduction of NA spillover, but also through a boost in PA the next morning. However, we did not find evidence to support our hypothesis that subjective sleep quality would also moderate spillover effects. That is, objective sleep indices seem to have a more significant impact on stress recovery than subjective sleep. Furthermore, we did not find evidence that sleep impacted stress-related NA spillover/ PA bounce-back differently for those high and low in neuroticism.

A more general aim of our study was also to gain a better understanding of high school students' sleep habits in their everyday life. We found that adolescents in our sample are sleeping well below the expert recommendation of 8 to 10 hours of sleep a night (Hirshkowitz et al., 2015; Paruthi et al., 2016). During the week, adolescents received just under six hours of sleep on average, meaning about half our sample accrued a night of sleep debt on any given school night. Even more disconcerting, not only did 34% of students receive between 4.25 and six hours of sleep a night, but 16% of students received less than 4.25 hours of sleep a night. These data illuminate both the pervasiveness and intensity of weekday sleep deprivation in our adolescent sample. Average total sleep time was over an hour longer on non-school days than school days, supporting research that has shown that sleep changes between weekends and weekdays (Carskadon, 2011). Nevertheless, on weekends, our adolescent sample's average total sleep time was still below recommendation. In general, we found that sleep was marginally or significantly better on all measures (e.g. sleep latency, total sleep time, sleep debt, and sleep quality) on non-school days. We also found that mood was better and stress was less severe on non-school days. The poor sleep profiles of our adolescents seemed to further exemplify the problematic nature of sleep in this population and to justify the importance of studying how sleep, or lack thereof, impacts adolescents' daily lives.

Of particular interest is how sleep impacts the ability to manage and recover from everyday stress in adolescents. In the current literature on cross-day stress recovery, researchers have found evidence both for and against the existence of NA spillover effects (Bolger et al., 1989; Bolger & Zuckerman, 1995; David et al., 1997; Marco & Suls, 1993; Nezlek & Gable, 2001; Stone & Neale, 1984). However, with consideration for the strong literature on sleep's impact on emotional processing (Franzen et al., 2007; Hamilton et al.; 2007; Zohar et al.; 2005), and particularly for adolescents (Dagys et al., 1997; Dahl & Lewin, 2002; McGlinchey et al., 2011), it seemed important to investigate whether sleep might provide a special daily context that would help predict the occurrence of stress-related affective spillover effects. For example, in our study, we did not find stress-related spillover effects into the next morning on a whole. This finding suggests that on an average day, adolescents are not carrying over yesterday's stress into today and that they are generally recovering from stress overnight. However, when we entered sleep as a moderator, we discovered that NA spillover effects become more pronounced as amount of sleep decreases. Moreover, sleep may be specifically important for stress processing on the recovery end. We did not see strong evidence of sleep impacting same-day stress reactivity. Thus, examining stress recovery through the lens of sleep offered us a different picture of the process that we might have ignored otherwise.

We also found that investigating overnight changes in PA, which is often ignored in the stress-related affective spillover literature, produced new insights about the influence of sleep on cross-day stress recovery. Based on findings from Hamilton et al., (2008) that showed less sleep following high stress predicted lower next-day positive affect, we hypothesized that less sleep would predict a greater decrease in PA (more PA dampening) than more sleep. As we typically do with NA, we had conceptualized changes in PA from a deficit model. That is to say, we were focusing on the degree of overnight PA loss, believing that a larger overnight PA decrease (more dampening) would suggest less ability to let go of yesterday's stress and therefore less stress recovery. However, we seemed to be overlooking the idea that stress recovery via PA could actually be about capitalization, rather than loss. Indeed, we found that it was not so much that, under conditions of less sleep and high stress, adolescents experienced a greater decrease in PA, but that they missed an opportunity to gain a morning PA boost, as they would have if they received more sleep. In other words, adolescents need enough sleep in order to benefit from a PA bounce-back effect. These findings suggest that we might not necessarily examine daily stress recovery from the viewpoint of how much worse morning PA dampening was following short sleep, but rather how much of a potential PA bounce-back was absent when sleep was too short.

Moreover, similar to the work by Hamilton and colleagues (2008), our study highlighted the importance of sleep debt on spillover effects. Researchers have also suggested that mounting sleep debt is particularly problematic for adolescents' emotional well-being and ability to engage in emotion regulation (Baum et al., 2014; Dagys et al., 2012). We found evidence that sleep debt might have a greater impact on stress recovery than a single night of poor sleep. Specifically, whereas we did not find that restricted sleep on any one particular night moderated stress-related NA spillover, we did find that an accumulation of nights with under six hours of sleep did predict more NA spillover. As such, it is possible that in general, adolescents have enough resilience to recover from a stressful day despite insufficient sleep on one night, but that an accrual of sleep loss across nights might begin to wear down recovery processes for NA. On the other hand, we had evidence that even a single night of sleep debt, in addition to a series of nights, could hinder PA bounce-back. These findings could suggest that there could be a lower threshold for when the combination of short sleep and high stress begins to have adverse outcomes for PA than for NA.

In general, one may wonder why it is important to consider morning mood, and therefore to study spillover or bounce back effects. While there is some limited research that suggests that depressed patients who experience more NA spillover show slower recovery rates in therapy (Cohen et al., 2008), there is not a lot in the current literature that shows outcomes for those who generally exhibit more spillover or on days when worse mood carries over. However, there is some indication that morning ratings of hostility predicted more stress generation that day (Sahl, Cohen, & Dasch, 2009). Thus, it is possible that a worse morning mood could set into emotion other cascading events throughout the day. In the future, we can further examine how morning emotions predict subsequent daily experiences, as well as whether a tendency to exhibit spillover/ bounce back effects predicts future emotional health outcomes.

Our research further contributes to the literature through its use of objective sleep measures, as opposed to exclusively relying on subjective reports of total sleep time. We do also note that our findings diverge from Hamilton et al. (2008), in that we did not find subjective sleep ratings to have an effect on NA spillover/ PA bounce-back. Our findings that only objectively measured sleep, and not subjective sleep quality, moderated stress-related NA spillover/ PA bounce-back effects underscore the importance of using objective sleep measures in addition to subjective sleep measures.

Still, we only found that sleep moderated stress-related spillover/bounce-back effects for morning affect but not for evening affect. Whereas sleep significantly impacts how one feels in response to yesterday's stress in the morning, that effect might become weaker as the day wears on and same-day stressors become more salient than yesterday's. Despite our results that spillover/bounce-back effects might be short-lived within a day, morning mood is still likely important for setting a person up for the rest of the day. Moreover, our evening rating of affect asked adolescents to report on their mood "at this moment". Perhaps if we had measured affect across the day, we would have seen more evidence of stress-related affective spillover/bounce-back effects in relation to sleep, but that mood specific to the end of the day is more strongly associated with the stress of that day. In the future, we might consider using multiple assessments in a day to examine how the effects of previous-day stress and sleep diminish, for example, through an ecological momentary assessment (EMA) design rather than through daily diary monitoring.

Although we did not make formal hypotheses regarding the role of neuroticism on sleep's impact on stress-related affective spillover, it was interesting to find that neuroticism did not have any role. Other researchers have proposed that those high in neuroticism experience more spillover effects than those low in neuroticism (Bolger & Zuckerman, 1995; Marco & Suls, 1993; Suls et al., 1998), and that those high in neuroticism, including adolescents, tend to have more sleep difficulties (Calkins, Hearon, Capozzoli, & Otto; 2013; Danielsson, Jansson-Fröjmark, Linton, Jutengren, & Stattin, 2009; Gau; 2000). Of course, both of these are main effects, and we were making hypotheses about an interaction. It seemed reasonable to wonder whether those high in neuroticism were more sensitive to the effects of sleep loss, given that they are more affectively labile in general (Kamen, Pryor, Gaughan, & Miller, 2010). However, our findings seem to suggest that sleep affects stress recovery processes across levels of neuroticism.

While our study demonstrated several strengths, particularly in its combined use of a daily process design and objective sleep monitoring in a diverse sample of adolescents, there were also some limitations. First, although we did objectively measure sleep, there is not yet a substantial body of research that supports Fitbits as a valid sleep-monitoring device. However, based on evidence that subjective reports of sleep can be quite unreliable (Bradshaw et al., 2007; Lauderdale et al., 2008; Short et al., 2012), we believe that using Fitbit was better than relying solely on subjective measures of sleep. In the future, we hope to further conduct research to determine if Fitbit is a valid sleep-monitoring device by comparing it directly to actigraphy and subjective sleep reports. Another limitation of the study was that while we asked participants to complete their morning surveys as close to waking as possible, we included any survey completed within their first three hours of waking without controlling for any possible stressors that could have occurred during that time. Mood upon waking could look different from mood three hours later if something major happened in that time. Therefore, it is possible that morning mood could already reflect stress reactivity, not just spillover. In the future, we may also consider asking participants to report on whether any morning stressful events occurred.

Moreover, though daily diary designs have the benefit of capturing stress and sleep naturalistically, the inability to manipulate and control variables may weaken claims about causality. For example, while we interpreted our data as showing that shorter sleep impacted more stress-related spillover/ less bounce back, it is also possible that relationships between sleep, stress, and emotions are actually spurious and better explained by some unmeasured variable. For this reason, lab-based studies that manipulate sleep and study these variables are also important compliments to naturalistic research.

We also acknowledge that this form of data collection can lend itself to the possibility of running many analyses, and therefore our significant findings could be the result of potential type I error. However, we kept a liberal approach to our analyses because we were investigating a novel idea and in fact believed that running our preliminary analyses would help to show more specificity for the role of sleep on stress recovery processes, rather than stress in general. However, of course, it would be important to replicate these findings in a future study.

In conclusion, the present study provided evidence for the moderating role of sleep on everyday stress recovery processes. In general, we found that, following higher stress days, less objective sleep that night predicted more morning NA spillover and less morning PA bounce-back, whereas more objective sleep predicted less morning NA spillover and more morning PA bounce-back. Subjective sleep did not significantly moderate the relationships between previous-day stress and morning affect. We believe that these findings highlight the importance of considering adolescent sleep in daily stress recovery processes and have implications for how sleep can influence everyday emotional functioning.

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