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The Effect of Sleep Deprivation on the Ability to Reappraise Negative Situations

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The Effect of Sleep Deprivation on the Ability to Reappraise Negative Situations

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Abstract

Sleep and emotion regulation are important components of mental health and may function interdependently in the development and maintenance of mental health disorders. Unfortunately, there is limited experimental work on the impacts of sleep deprivation on reappraisal, a common emotion regulation strategy, in adults. Furthermore, increases in negative and decreases in positive affect are often associated with sleep loss. This study aimed to examine the relation between sleep deprivation and emotion regulation by asking adults to reappraise a series of vignettes before and after a randomly assigned night of sleep deprivation or normal sleep. Additionally, measures of self-reported emotion regulation and affect were collected before and after sleep manipulation. Participants were 76 undergraduate students (39 men, M_{age} = 19.14; *SD* = 1.26). Results suggest sleep-deprived participants struggled to reappraise as indicated by more negative valence, as predicted. Additionally, there was a decrease in arousal, contrary to hypotheses. Furthermore, sleep-deprived participants experienced less positive affect compared to their baseline measures and the control group at post-manipulation, as predicted. Both groups showed a decrease in negative affect across timepoints. Lastly, contrary to predictions, there were not significant differences in self-reported reappraisal as a function of sleep condition. This study addresses a key gap in the extant literature and informs our understanding of the consequences of sleep loss on reappraisal and affect, factors germane to the development, maintenance, and treatment of mental illness.

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The Effect of Sleep Deprivation on the Ability to Reappraise Negative Situations

The impact of sleep on emotion regulation is crucial to understand because of the profound effect both factors play in mental health and well-being. Sleep, or the lack thereof, has a tremendous impact on individual physical and mental health as well as economic and public safety considerations (Luyster et al., 2012; Wells & Bradley, 2012). Additionally, deficits in emotion regulation, specifically reappraisal, are associated with poor mental health outcomes (Campbell-Sills et al., 2014; Goldin et al., 2012; Joormann & Siemer, 2014). To better understand this relation, a novel study was conducted in which adults were randomized to a night of sleep deprivation or a full night of sleep to evaluate effects on reappraisal of a series of vignettes. Secondary aims were focused on the causal effects of sleep deprivation on self-reported emotion regulation and affect.

Sleep: Background and Significance

Due to the risk of numerous physical health consequences such as heart disease, stroke, diabetes, impaired immune function, and death, as well as depression, pain, accidents and errors, the American Academy of Sleep Medicine recommends adults get at least 7 hours of sleep regularly (Watson et al., 2015). Additionally, sleep loss impairs the ability to identify specific emotions (Killgore et al., 2017) and is linked to suicidal risk behavior (Porras-Segovia et al., 2019). Unfortunately, about a third of Americans do not get enough sleep (National Sleep Foundation, 2018). For this reason, it is imperative we fully understand the consequences of sleep loss, including within the domain of emotion regulation. Furthermore, the lack of ethnic and racial diversity in the present literature means we are missing the people that are most likely to be impacted by sleep issues because sleep problems disproportionately impact those who experience health disparities (Jackson et al., 2020).

There are many approaches to sleep manipulation in the experimental literature such as sleep deprivation (at least a full night of wakefulness), sleep restriction (reduced sleep duration), and sleep fragmentation (interrupted sleep) all of which may have different impacts on mood and cognition and may not share underlying mechanisms (Short & Banks, 2014). The current study employed a sleep deprivation protocol in which participants were asked to stay awake for a full night with the goal of addressing a current gap in the literature. To limit confusion, sleep loss will be used as an umbrella term to refer broadly to these varying approaches to sleep manipulation and naturalistic sleep deficits; the terminology used by researchers will be used when describing methods from specific studies.

Reappraisal as a Key Emotion Regulation Strategy

Emotion regulation is defined by scholars as the ability to modify or influence emotions (Gross, 2014). Gross' modal model of emotion regulation posits a person-specific interaction with the environment. A person is continuously exposed to new situations in which they decide where to focus attention, followed by appraisal or interpretation of the situation. Lastly, the person has an emotional response. There are multiple simultaneous systems at work to alter the interaction and modify or regulate emotions associated with it. Firstly, a person may decide to select or adjust the situation, for instance by choosing whom to speak to at a social gathering. Furthermore, they can control attentional deployment by, for example, deciding to focus on their conversation with a friend instead of the entire party. A person may also engage in cognitive change by taking the perspective of someone else or challenging the interpretation of a situation, such as reappraisal, which is laid out in detail below. Lastly, one can engage in response modulation to regulate the emotional response associated with the appraisal.

Reappraisal is a type of emotion regulation strategy in which one attempts to change the interpretation of a stimulus to modify the course of an emotional response before it happens (Gross, 2008). It is also a technique used in cognitive-behavioral therapies and involves reframing an interpretation of a situation that may result in a maladaptive response into a more adaptive interpretation (Goldin et al., 2017; Gross, 1998; Morris et al. 2015; Smits et al., 2012). For instance, an initial appraisal of a situation may trigger an unwanted emotion ("my partner did not return my text because they are cheating" resulting in anger) which in turn may result in problematic behaviors (starting a fight when the partner gets home). Reappraisal of a situation may look like considering other possibilities ("maybe they did not see the text") or acknowledging one can cope if the appraisal is true ("if they are cheating, I have made it through heartbreak before and can do it again").

Reappraisal is important to study because reduced frequency and effectiveness of reappraisal is a key transdiagnostic variable (Cludius, et al. 2020). For instance, those with anxiety disorders have biological and psychological vulnerabilities that result in using detrimental emotion regulation strategies such as avoidance, but studies have shown anxious individuals often see beneficial reductions in subjective distress from using reappraisal (Campbell-Sills et al., 2014). A study of 75 adults with social anxiety in which patients were randomized to a waitlist control or cognitive behavioral therapy found increases in reappraisal efficacy mediated the effect of treatment on symptoms even at the 1-year follow up (Goldin et al., 2012). Additionally, those with major depressive disorder are less likely to engage in reappraisal and more likely to employ rumination, though they may struggle with effectively implementing reappraisal (Joormann & Siemer, 2014). For example, in a study comparing 191 outpatients with depression to 267 adults from the general population, researchers found 1)

depressed individuals were less likely to use reappraisal and 2) positive reappraisal (e.g. acknowledging all of your newly found free time when an appointment was cancelled last minute) was negatively associated with depressive symptoms (Lei et al., 2014). Finally, there is some evidence that emotion regulation difficulties as well as the relation between emotion regulation and mental health may vary by race (Morelen et al., 2013), most likely because of systemic differences in experience and socioeconomic status (De France & Evans, 2020). For example, one study found that the greater the experiences of racial discrimination the less likely African American undergraduates were to report using reappraisal strategies (Riley et al., 2020).

Reappraisal is primarily studied in two ways. Self-report measures with supporting psychometric evidence include the Cognitive Emotion Regulation Questionnaire (CERQ; Garnefski et al., 2001; Garnefski & Kraaij, 2006) and Emotion Regulation Interview (Werner et al., 2011). These are useful tools to understand the frequency with which adults attempt to reappraise and their perceptions of success. Alternatively, behavioral tasks can be utilized in which participants are instructed in how to reappraise and then exposed to standardized stimuli such as images (Reddy et al., 2017; Zhang et al. 2021), scripts (Zeier et al., 2020), or an idiographic stimulus such as the Autobiographical Emotion Regulation Task (Speed et al., 2020). As the outcome variable is typically self-reported affectivity following efforts to reappraise, these methods illuminate the outcome or effectiveness of reappraisal. Ideally, researchers should implement both self-report and behavioral measurement strategies to better understand the spectrum of perceived reappraisal frequency and success, as well as impact on affectivity measured in real time. Based on the strong psychometric support, this study employed the CERQ as a measure of self-reported emotion regulation.

Sleep, Emotion Regulation, and Reappraisal

Sleep and emotion regulation generally are bidirectionally related (Vandekerckhove & Wang, 2018) although more experimental work is needed to determine the causal impacts of sleep on the ability to regulate emotions (Palmer & Alfano, 2017). From a neurobiological perspective, the effect of sleep deprivation on emotion regulation may manifest as a deficit in the connectivity between the prefrontal cortex and amygdala (Yoo et al., 2007). Nowak and colleagues found reduced amygdala and prefrontal connectivity after a week of naturalistic sleep loss during a resting state fMRI in a sample of 55 German men between the ages of 20 and 48 years (2020). Zhang and colleagues (2019a) found a higher theta/beta ratio in the frontal region of the brain, a proposed biomarker of emotion regulation, during a resting-state task in sleep-deprived adults compared to a control group. Self-report studies similarly support a link between sleep and emotion regulation (Baum et al., 2014; Pickett et al., 2015). For example, in one study, 52 undergraduate students completed self-report measures of avoidance before and after being randomly assigned to a night of sleep deprivation or sleep as usual (Campbell et al., 2022). Findings indicated sleep-deprived participants evidenced poorer self-reported avoidance in social cognitive and behavioral domains as well as non-social cognitive and behavioral domains as measured by the Cognitive Behavioral Avoidance Scale (CBAS) compared to their baseline measures and the sleep as usual group. Acute sleep deprivation was not, however, related to an index of behavioral avoidance.

The current study focuses on the emotion regulation strategy of reappraisal, a nascent literature. A recent meta-analysis evaluated 64 studies measuring the effects of sleep restriction or deprivation on mood, emotion, and emotion regulation (Tomaso et al., 2020), seven of which examined the role of sleep loss on emotion regulation. All of these studies used sleep restriction

as the sleep manipulation. In the analysis, emotion regulation strategies were categorized as adaptive or maladaptive, defined by potentially wanted or unwanted consequences in the long term, respectively. Sleep plays a role in emotional control (Baum et al, 2014; Danilewitz et al, 2014; Gruber et al., 2012), catastrophizing (Talbot et al., 2010), and maladaptive and adaptive strategies used during an unsolvable puzzle task (Miller et al., 2015; Schumacher et al., 2017). Only one study by Reddy and colleagues (2017) examined reappraisal specifically. In the study, adolescents were asked to reappraise positive, negative, and neutral photos from the International Affective Picture System (IAPS) after sleep restriction or a full night of sleep. Reappraisal instructions included several examples such as thinking of a positive explanation, remembering things will get better over time, or reminding oneself the stimulus is not real. To measure the consequences of reappraisal, researchers computed a reactivity score in which valence and arousal ratings were averaged across image types. Although they found no group differences in reactivity to positive and neutral images following reappraisal, there was a moderate group difference in reactivity to negative images such that the sleep restricted group had higher reactivity than the control group. Lastly, the authors found no difference in effectiveness of reappraisal, a score derived from subtracting the mean valence for negative-viewed images from the mean valence for the negative-reappraised items, across sleep conditions. These data suggest restricted sleep negatively influences adolescents' ability to reappraise negative cues. Overall, Tomaso and colleagues concluded from their meta-analysis that sleep restriction had a small, negative effect on adaptive strategies and no effect on maladaptive strategies (2020). Notably, with the exception of Talbot and colleagues' (2010) study that included a group of 20 adults in their evaluation of the effects of sleep restriction on catastrophizing, all of the studies in the

meta-analysis were conducted with youth. Additionally, all studies included used sleep restriction (cf., sleep deprivation), suggesting a substantial gap in the literature.

In another relevant study, Mauss and colleagues (2013) measured sleep quality in a sample of 156 primarily white men. Participants were then administered a video reappraisal task in which they were presented with an initial neutral film clip followed by three sad film clips and asked to reappraise one. Reappraisal was measured by change in sadness from baseline to ratings made following reappraisal of the sad clip, and poor sleep quality was linked with lower ability to reappraise with a small-medium effect size. These data accord with Reddy et al. (2017) and indicate that sleep quality may influence reappraisal processes.

On the other hand, in two studies, Zhang and colleagues (2021) found subjective sleep quality did not predict negative affect or emotion regulation. In the first study, 68 adults completed daily sleep diaries for a week leading up to an experimental task in which they were presented with neutral and negative images. They were instructed to watch, rethink, or distract during the observations. Valence and arousal ratings were averaged to create a composite affect score. Physiological measures including skin conductance and facial electromyography were also collected. Zhang and colleagues found subjective sleep ratings did not correlate with negative affect or successful distraction or reappraisal. In a second study, 204 adults with chronic back pain completed daily ratings of sleep quality which were averaged across the collection period. In the experimental phase, participants were asked to respond, watch, reframe, or rethink while being exposed to thermal pain induction. Again, researchers found no significant relation between perceptions of sleep quality and affect or regulation.

Neurobiological work on the link between sleep and reappraisal is mixed. One study found self-reported deficits in the ability to reappraise caused by partial sleep restriction without

significant changes in prefrontal or amygdala connectivity or activity (Tamm et al., 2019). The study involved 47 young and older adults (ages 20-30 years and 65-75 years, respectively) completing an fMRI reappraisal task after a full night of sleep and a night of 3 hours of sleep. After sleep restriction, participants reported less success in the ability to reappraise, but there were no corresponding changes in brain activity. Relatedly, Zhang and colleagues conducted a study in which 51 adults were randomly assigned to a night of normal sleep or sleep deprivation before completing an emotion regulation task that asked them to either observe, distract, reappraise, or suppress negative images from the IAPS (2019b). They found reappraisal and distraction, but not suppression, reduced centroparietal late positive potential amplitudes (which reflect effectiveness of emotion regulatory efforts) after sleep deprivation. However, sleep deprivation did not impact self-reported effectiveness in emotion regulation as determined by comparing valence and arousal ratings during passive viewing and active regulation of negative IAPS images. Lastly, Minkel and colleagues (2012) found subjective sleep quality as measured by the Pittsburgh Sleep Quality total score (Buysse et al., 1989) correlated positively with medial prefrontal activity but not perceptions of reappraisal success.

In addition to the small number of studies in this area, the extant work has some important methodological limitations. First, Zhang and colleagues (2021) computed a reactivity score of combined valence and arousal, which may be problematic given valence and arousal are different dimensions of core affect (Lang et al., 1990; Russell, 2003) with distinct neural correlates (Kensinger & Corkin, 2003) and regulating emotions to feel calmer (arousal) may look different than trying to feel more positively (valence). Additionally, the task was oriented around regulating differently valanced photos without manipulating the arousal of the photos, which may also limit the full picture of regulating an emotional experience. In fact, most literature in

this domain uses IAPS images as the main stimulus to reappraise (Minkel et al., 2012; Tamm et al., 2019; Reddy et al., 2017; Zhang et al., 2019b; Zhang et al., 2021). The current study aims to further this body of literature by examining valence and arousal separately as well as using situational vignettes. Second, generalizability of these findings is limited. Much of the work conducted on sleep and reappraisal has included a primarily white American (Reddy et al., 2017; Tomaso et al., 2020; Zhang et al., 2021), and Chinese samples (Zhang et al., 2019da; Zhang et al., 2019b). Furthermore, most studies examined adolescents or young adults (Tomaso, et al. 2020). To best understand the relation between sleep and emotion regulation, a wider age range is necessary because of the decreases in total sleep time (Grandner, 2012) and increases in emotional well-being, stability, and complexity (Carstensen et al., 2011) across the lifespan. Finally, as noted earlier, there is limited work using experimental, acute sleep deprivation protocols, which have the benefit of evaluating causal links between sleep loss and reappraisal. The current study is designed to address these gaps in the literature. Additionally, as detailed next, a secondary aim is to replicate and extend prior work on the effects of sleep deprivation on affect.

Sleep and Affect

Much of the literature suggests sleep loss reduces positive affect (Talbot et al., 2010; de Wild-Hartmann et al., 2013) and increases negative affect (Babson et al., 2010; Baum et al., 2014; Palmer et al., 2017), though some studies have found contradicting evidence (Zhang et al., 2021). Specifically, in addition to measuring anxiety during a catastrophizing task, Talbot and colleagues administered the Positive and Negative Affect Scale – Child (PANAS-C; Laurent et al., 1999) to adolescents, mid-adolescents, and adults after sleep extension and sleep restriction and found a significant reduction in positive affect across all age groups after sleep restriction

(2010). Furthermore, Babson and colleagues randomly assigned 88 adults to a night of sleep deprivation or normal sleep then compared negative affect as measured by the Mood and Anxiety Symptom Questionnaire subscales before and after the sleep condition (2010). They found the sleep- deprived group showed significant increases in negative affective states relative to the control group. Similarly, reducing sleep debt via sleep extension resulted in mood improvements concomitant with suppression of amygdala activity in 16 healthy men (Motomura et al., 2017). Authors of the meta-analysis described above (Tomaso et al., 2020) concluded sleep loss had a medium effect on negative mood and a large effect on positive mood. These changes in mood have been found in adolescents (Reddy et al., 2017) and college students (Campbell et al., 2022). Furthermore, a study of 94 adults who completed sleep diaries over a 2-week period demonstrated higher increases in anxious arousal after nights where they obtained four hours of sleep or less (Bean & Ciesla, 2021). Importantly, restricted sleep had a smaller effect than a full night of sleep deprivation (Tomaso et al., 2020). The literature would benefit from replication of these findings in adult samples.

Current Study

Primary Hypotheses

The goal of this study is to examine the relation between sleep deprivation and reappraisal effectiveness (operationalized as self-reported valence and arousal ratings) to a series of vignettes. A repeated measures design was utilized. The between-subjects factor was condition (sleep-deprived, full sleep) and the within-subjects factor was time (baseline, post-manipulation). We expected participants in the sleep deprivation condition to report more negative valence and arousal at post-manipulation compared to their baseline and the control group at post-manipulation.

Secondary Hypotheses

The effects of the sleep manipulation on self-reported reappraisal were also evaluated. The CERQ has been used in previous work to measure self-reported emotion regulation (Garnefski et al., 2001; Garnefski et al., 2002; Garnefski & Kraaij, 2006) and is useful in assessing if reappraisal is a typical strategy utilized. We predicted that those in the sleep deprivation group would self-report less likelihood to use reappraisal as measured by the reappraisal subscale of the CERQ at post-sleep manipulation compared to their baseline measures and the control group at post-manipulation.

The last hypothesis tested positive and negative affect in relation to sleep deprivation. Participants in the sleep deprivation group were predicted to experience higher negative affect and lower positive affect as measured by the PANAS-X at post-sleep manipulation compared to their baseline measures and the control group at post-manipulation.

Method

Design Considerations

Sample Considerations

Much of the research on sleep and emotion regulation is conducted using adolescent or early-adult samples (Tomaso et al., 2020) despite the fact the prefrontal cortex is not fully developed until at least age 25 (Arian et al., 2013) and there is evidence that emotion regulation improves with age (Carstensen et al., 2011). For this reason, a broader age range is necessary to fully understand the role of sleep loss in emotion regulation. The best way to obtain a wider range is to recruit participants from the local community (in addition to matriculating college students for course credit). The recruitment aim was to have 50% of the sample from the

community with an emphasis on matriculating participants from historically marginalized groups. This is typically accomplished through partnerships with community stakeholders. However, there were logistical issues to consider. Namely, participants are entitled to adequate compensation for participation in research. Due to financial restrictions, a limited number of participants could receive financial compensation. Funding constraints were such that no more than 38 community members could be enrolled. Secondly, as detailed below, social distancing and remote work made it difficult to implement community outreach recruitment strategies and thus we were not able to meet the recruitment needs of the study in a reasonable timeframe. Instead, online recruitment methods were implemented such as sharing the screening survey on social media. Although the online format may introduce doubts as to the adherence to study procedures since participants were not directly observed, there were several benefits that outweigh this risk. Namely, COVID-19 posed a risk to in-person data collection, whereas online collection limited resource constraints for participants and researchers. Additionally, online procedures reduced safety concerns as participants were not required to find transportation after a night of sleep deprivation.

Baseline Sleepiness

A number of factors were considered in the design of the current study. Ultimately, decisions were made that maximized internal and external validity while balancing pragmatic concerns. Acknowledging the strength of the effect of sleep deprivation may be dampened if participants are sleepy coming into the study, several methods were considered. One of the most common and robust methods to regulate sleepiness before sleep randomization is to ask participants to maintain a consistent sleep schedule (Seo, et al. 2021) that is usually consistent across participants (e.g., an 8-hour sleep opportunity) or employ an idiographic schedule

determined by participants' sleep practices monitored using actigraphy and/or sleep diaries. While robust, this method can be burdensome and raised concerns of substantial attrition, particularly considering the online format of the current study. The goal of this method is to limit the amount of sleep debt a participant has coming into the study and may also be met via self-report. For example, screening for a consistent and adequate sleep schedule, such as scoring a two or above on the Sleep Disorders Symptom Checklist- 25 item "my bedtime or waketime varies by more than 3 hours" or reporting on the average hours of sleep participants obtain would shed light on a participant's current schedule. While a consistent sleep schedule is a key component in daytime alertness, there are other factors (e.g., sleep apnea, disrupted sleep) that may lead to daytime sleepiness (Ghandi et al., 2021). The third option considered was to measure daytime sleepiness at baseline and exclude those who endorsed high sleepiness before the study. This method was selected for the current study because it is the least burdensome to participants and measures sleepiness directly instead of relying on other relevant factors.

Script Presentation

When considering the experimental task, there were two main considerations; 1) the task must be repeatable from baseline to post-sleep manipulation in order to account for baseline responding, and 2) participants, especially those in the sleep deprivation condition, must be able to stay awake and focus on the task for the duration of the study. The Script-Based Reappraisal Test consists of three sets of 10 scripts: self-anger, other-anger, and fear (Zeier et al., 2020). Due to the limitations in Qualtrics, scripts can be randomized within but not across administrations, therefore, the type of script must be equivalent across days. In the original study, participants completed two of the three script sets as well as a questionnaire battery, resulting in a 75-minute completion time. This seemed an excessive amount of time; especially because participants

would not be in a laboratory-based setting, they may have difficulty sustaining attention for that period. As each script takes about four minutes to complete, five scripts at each timepoint, resulting in a task lasting about 20 minutes, were utilized for the current study. Additionally, this allows for one script type to be used, increasing comparability across timepoints. When considering script type, ease of reappraisal was a key consideration because participants would only be instructed once on how to reappraise and had no researcher feedback. From a face validity perspective, the *other-anger* scripts were the most amenable to reappraisal efforts.

Online Community Recruitment Challenges

The primary method of obtaining a diverse sample in terms of racial identity and age was through online recruitment. However, several unanticipated challenges presented themselves. Firstly, when the screening survey was made available, the survey was spammed by bots. This was quickly rectified by including a captcha at the beginning of the screening survey. It was also observed that people would take the survey multiple times in what appeared to be attempts to be deemed eligible for the study. As most of the screener questions involved yes/no responses in which the eligible response is “yes”, many responders would select “yes” for every question, which would terminate the screening survey when they selected “yes” for a question that required a “no” response (ex. the question that assesses for suicidality, psychosis, and bipolar disorder). When the survey ended, they would make another submission within minutes, changing their response. Several participants did this multiple times until they completed the entire survey.

In other cases, participants did not accurately report their time zone. To control for circadian differences, it was crucial that participants completed the study between 0900 and 1100 in their own time zone. Discrepancies were noticed by the location information collected in

Qualtrics, time stamps in email communication, and unusual observations via Zoom such as seeing it was nighttime outside the participant's window even though it was early afternoon in their reported time zone. In several cases, people would discontinue communication after they were informed that a consent appointment via phone or Zoom was required. To address the issue, additional screening questions were added: 1) Are you currently located in the United States, and 2) What time zone are you located in? This had little impact on suspicious screener entries. It was determined that online submissions could not be considered reliable, and community-based online recruitment was abandoned. Considerations for future work are addressed in the Discussion.

Participants

Participant eligibility criteria were selected for safety (e.g., excluding those who might experience significant negative effects of acute sleep deprivation, such as participants with a history of mania), scientific (e.g., reducing confounds such as taking sleep medication that may obscure findings), and pragmatic (e.g., stable internet connection) reasons. Criteria are delineated in Table 1. A total of 227 screening surveys were submitted. One-hundred and twelve people consented to participate, 108 completed baseline surveys, and 76 completed the study (See Figure 1 for details related to Study Flow).

Participants were 76 adults (*n* = 37 females; average age = 19.14 years, range = 18-24), primarily White, (*n* = 67), and non-Hispanic[1] (*n* = 70); see Table 2 for complete demographic information). Recruitment efforts targeted the University of Arkansas undergraduate pool via Sona Systems as well as community members recruited through online recruitment strategies

[1] "Hispanic" was the terminology used in the survey, and thus was reported here. The term "Latine" may be a more preferable way to capture ethnicity and will be used in future work.

such as posting on social media. Participants were matriculated between February and October 2022. Recruitment efforts were primarily online due to concerns about additional shutdowns related to the COVID-19 pandemic.

Measures

For the measurement timeline, see Table 3. Demographic information including age, sex, race/ethnic identification, sexual orientation, relationship status, family income, parent education, primary language, and veteran status was collected.

Screening Measures

Safety Concerns. To determine safety, participants were presented with a description of the eligibility criteria for the study, indicating that those with suicidal risk behavior or at risk for psychosis and/or mania were ineligible. Statements were adapted from the well-established Columbia Suicide Severity Rating Scale ("Have you wished you were dead or wished you could go to sleep and not wake up"", "Have you actually had any thoughts of killing yourself?"; Posner et al., 2009), and the Diagnostic Interview for Anxiety, Mood, and OCD and Related Neuropsychiatric Disorders (DIAMOND) screening tool ("I have had sensory experiences that others could not understand such as:…"; Tolin et al., 2016). After being presented with the statements, participants were asked if they still met criteria given the previous statements. They were also asked if there was any medical reason they should not stay up for a full night, and to agree not to drive after their normal bedtime if they were assigned to the sleep deprivation group. See Appendix A for the screener.

Sleep Apnea. To screen for obstructive sleep apnea (OSA), the STOPBANG (Snore, Tired, Observed not breathing, blood Pressure, BMI, Age, Neck circumference, Gender) was

administered at screening. This eight-item questionnaire has high predictive validity (Nagappa et al., 2015; Tan et al., 2016) and is often used in research settings. Participants with a score of five or above were excluded due to high risk of OSA.

Descriptive Measures

Psychiatric Symptoms. The ACORN (Brown et al., 2015) is a 14-item measure assessing common mental health symptoms and is commonly used in outpatient treatment settings. Questions include "in the past two weeks (14 days), how often did you: feel tense or nervous?" and are rated on a *Never* to *Very often* scale. Participant responses are averaged. A score of two or higher indicates clinically significant psychiatric symptoms. Concurrent and construct validity as well as test-retest reliability are considered adequate. Alpha for this study was 0.88.

Sleep Disorder Symptoms. The Sleep Disorders Symptom Checklist- 25 (SDSCL; Klingman et al., 2017) is a 25-item measure designed to assess for six sleep disorders in a primary care setting including items such as "I snore" and "I have been told that I walk, talk, eat, act strangely or violently when I sleep." Responses are scored on a scale of 0 (*Never)* - 4 (*>5 Times / Week)* and higher scores indicate more sleep challenges. A full examination of psychometric properties is in progress (Klingman et al., 2017). However, it has demonstrated a strong utility in identifying those at risk for sleep disorders in research and clinical settings. Alpha for this study was 0.79.

Sleepiness. The Epworth Sleepiness Scale (ESS; Johns, 1991) is an 8-item questionnaire with items such as "watching TV" and "sitting and talking to someone" scored from 0 (*would never doze)* - 3 *(high chance of dozing)* such that higher scores indicate more daytime sleepiness.

This measure has shown adequate test-retest reliability (Johns, 1992), internal consistency (van der Heide et al., 2015), and construct validity when compared to multiple sleep latency tests (Chervin, Aldrich, Pickett, & Guilleminault, 1997). Alpha for the current study was 0.63 comparable to prior work (Campbell et al., 2022) though other work has demonstrated slightly higher internal consistency (Johns, 1992).

The Stanford Sleepiness Scale (SSS; Hoddes et al., 1972) is a single-item measure in which participants endorse how sleepy they are in a given moment. Responses range from 1 (*Feeling active, vital, alert, or wide awake*), to 7 (*no longer fighting sleep, sleep onset soon; having dream-like thoughts*). The construct validity and reliability of the measure are considered adequate (Hoddes et al., 1973).

Emotion Regulation. The State Difficulties in Emotion Regulation Scale (S-DERS) is a 21-item measure designed to assess state emotion dysregulation specifically for the use in repeated-measures experiments. The measure consists of four factors: nonacceptance, modulation, awareness, and clarity. The questionnaire consists of items such as "my emotions feel out of control" that are scored on a 1 (*Not at all*) to 5 (*Completely*) scale. Construct validity, convergent validity, and internal consistency are considered adequate (Lavender et al., 2015). Alpha for this study was 0.88.

Vividness of Visual Imagery. The Vividness of Visual Imagery Questionnaire (VVIQ; Marks, 1973) is a 16-item measure designed to capture the clarity of visual imagery. Given the study involves imagining the events described in vignettes, this measure was used to ensure the effectiveness of random assignment. Participants were asked to imagine something, such as a relative or friend, then they were asked to rate the vividness of their mental image on a scale from 1 (*perfectly clear and as vivid as normal vision*) to 5 (*no image at all, you only "know" that*

you are thinking of an object). Internal consistency, test-retest reliability, and construct validity is considered adequate (McKelvie, 1995). Alpha for this study was 0.83.

Working Memory. To assess general challenges in executive function after sleep deprivation, a working memory task, specifically an N-Back task, was administered at post-manipulation. In this task, participants were presented with alternating letters and simple arithmetic problems they were asked to solve. The sequence of letters and problems became incrementally longer. Impaired accuracy is observed in sleep-deprived adults compared to controls (Choo et al., 2005; Martínez-Cancino et al., 2015; Terán-Pérez et al., 2012) even when participants are presented with emotional stimuli (Gerhardsson et al., 2019). The goal of this task was to increase confidence in the inference that challenges in reappraisal after sleep deprivation were due directly to sleep loss and not solely due to changes in executive function.

Objective Measure of Wakefulness. Although previous studies have implemented at-home sleep manipulation procedures (Babson et al., 2010; Campbell et al., 2022; Cox et al., 2020), the validity of this method is limited by the fact that participants are not directly observed. To address this concern, a subset of sleep-deprived participants wore actiwatches over the course of their sleep manipulation night. Actigraphy is a wrist-worn device that detects light and movement to determine if the wearer has fallen asleep and for how long. A recent review found actigraphy adequately identifies sleep onset and is appropriate for monitoring sleep in a research context (Scott et al., 2020).

Emotion Regulation Efforts. The Emotion Regulation Interview (ERI; Werner et al., 2011) is a three-question measure assessing participants' emotion regulation efforts. This interview was modified for the current study. Firstly, the questions were adapted to a self-report format conducive to the online set up of the current study. Secondly, as this study focused on

reappraisal, questions pertaining to other forms of emotion regulation (e.g., attention deployment, situation selection) were not included. Participants were asked if they 1) understood the instructions and 2) how successful they were at reappraising as requested. Participants then explained what they did to reappraise and rated how much time they spent focusing on reappraising (0% - 100%). An added question concerning relatability of the stimuli also was included (See Appendix B).

Primary Measures

Affect. The Positive and Negative Affect Schedule- Expanded Form (PANAS-X; Watson & Clark, 1999) is a 60-item questionnaire that measures categorical emotions. Specifically, it measured positive and negative state affect as well as 11 specific affective states. Participants rate different emotions, such as "irritable" and "lively" on a scale from 1 (*very slightly or not at all*) to 5 (*extremely*). Composite scores for General Negative Affect and General Positive Affect are comprised of the sum of the appropriate items. It has demonstrated adequate construct validity and internal consistency. In the current study, the PANAS-X positive alpha was 0.87 and the PANAS-X negative alpha was 0.88.

Cognitive Emotion Regulation. The Cognitive Emotion Regulation Questionnaire (CERQ; Garnefski et al., 2001) is a 36-item measure in which participants rate how often they have specific thoughts related to pleasant and unpleasant emotions on a scale of 1 (*almost never*) to 5 (*almost always*). There are eight subscales, including positive reappraisal. Internal consistency, test-retest reliability after 14 months, factorial validity, and construct validity are considered adequate (Garnefski et al., 2002). As this measure is under copyright, specific instructions are not included here. This measure is typically used as a trait measure. However, this trait-like preference for one strategy selection can be influenced by internal and external

factors (Garnefski et al., 2002). For this reason, this measure was administered before and after sleep manipulation to determine if sleep loss would impact general use of reappraisal. Additionally, it was used to determine group differences at baseline. Permission to use this measure was obtained on June 16th, 2021. Alpha for this study was 0.88.

Valence and Arousal. The Self-Assessment Manikin (SAM; Lang et al., 1990) is a widely-used self-report scale that draws on a dimensional model of emotion. It measured current valence and arousal anchored by five visual manikins depicting positive to negative valence and low to high arousal (e.g., frowning at one end of the spectrum; smiling at the other end), resulting in a range of 1-9. Participants report their current emotional valence (SAM-V) and arousal (SAM-A) by placing a mark on or between each mannikin. The SAM is widely used in experimental psychopathology research (Bynion & Feldner, 2017).

Experimental Task

Script-Based Reappraisal Test. The Script-Based Reappraisal Test (Zeier et al., 2020) is a set of 30 written scripts describing normal activities related to self-anger, other-anger, and fear. In this task, participants are presented with the script and are instructed to imagine the situation is happening to them (20 seconds). Then, participants start the ideation phase (60 seconds) in which they are asked to reappraise. Participants then complete SAM ratings before the recording phase (90 seconds) in which they document all the reappraisals that occurred during the ideation phase (Zeier et al., 2020). Reappraisal inventiveness can be measured by rating participants' number of reappraisals (fluency) and/or number of distinct reappraisals (flexibility) and these data will be used as an independent secondary analysis. Scripts were developed in German and translated into English using Google Translate then modified for grammar and cultural relevance (ex. a script about a skiing trip was changed to bicycling; See

Appendix C). This study only utilized the other-anger scripts (see *Design Considerations* for rationale).

Procedures

All study procedures were conducted online. See Appendix D for study timeline.

Screening Phase

Interested participants completed an online screening Qualtrics survey. If the participant met safety and eligibility requirements, they were contacted to confirm interest, review and sign a digital consent form, and schedule a time to complete the experimental portion of the study. They were instructed to pick two consecutive days such that 1) they had 90-minute windows between 0900-1100 on both days to complete the surveys, 2) they had no responsibilities or engagements on day two that would be negatively impacted by sleep deprivation (ex. work, long-distance driving), and 3) they were able to obtain adequate sleep for the few days leading up to the study.

Experimental Phase

Baseline. Participants completed a series of questionnaires including the ESS, SSS, CERQ, PANAS-X, VVIQ, and S-DERS. In order to participate in the experimental phase, participants were required to score a 10 or lower on the ESS to ensure participants were not sleep-restricted before the manipulation. If participants scored above a 10, researchers were notified via Qualtrics and the participant was contacted to reschedule their study procedures. Importantly, no participants scored above the threshold. Participants then completed five randomized other-anger scripts from the Script-Based Reappraisal Test. All participants were presented with the following during the instruction phase: “Imagine the situation presented is

happening to you. Try to imagine it as vividly as possible." During the reappraisal phase, participants viewed the following instructions:

> "Think about this situation in a different way, that decreases negative emotion. For example, you might try to think that things will get better over time or think of a positive explanation" (Reddy et al., 2017).

Lastly, they completed the Emotion Regulation Interview. Completion of the survey took place between 0900-1100.

Sleep Condition. After completing the baseline survey, participants were randomized to a full night of sleep or a full night of sleep deprivation. If assigned to a night of full sleep, participants were asked to adhere to an 8-hour sleep opportunity. If assigned to a night of sleep deprivation, participants were asked to stay awake from the time of their baseline survey until after their post-manipulation survey the next day. To confirm adherence, sleep-deprived participants were required to answer a brief survey every hour as has been done in prior work (see Appendix E; Babson et al., 2010; Cox et al., 2020; Campbell et al., 2022). If participants missed more than one check in and/or endorsed more than 90 minutes of sleep throughout the night, they were excluded from the study. Thirty-two participants were excluded between timepoints for various reasons (see Figure 1).

Post-Sleep Manipulation. After the randomization night, participants confirmed adherence to their sleep condition and overnight instructions via a Qualtrics survey. Participants completed the post-manipulation survey, which consisted of the SSS, CERQ, S-DERS, VVIQ, PANAS-X, the five-remaining other-anger scripts of the Script-Based Reappraisal Test, and the ERI, at the same time they completed their baseline survey.

Participants from the Sona System received their full Psychology credit allotment as compensation for completing the study (eight credits). Community participants were offered a $25 gift card for completing the entire study. Participants who completed the overnight check-ins were entered into a drawing for the chance to win one of two $50 gift cards (one entry per check-in completed).

Results

Analytic Approach

The effect of sleep restriction in adolescents on emotion regulation is considered small (Tomaso et al., 2020). However, this effect size was determined using multiple studies measuring adaptive and maladaptive forms of emotion regulation (e.g. reappraisal, catastrophizing). Additionally, the effect size of the SBRT is considered medium (Zeier, et al, 2020). An *a priori* power analysis using G-Power was calculated using a medium effect size (f = .25), alpha level of .05 and power of .9. Results of the power analysis suggested a total sample size of 76. The partial eta squared for the primary analyses suggested a small-to-medium effect size. Less than 5% of data were missing. Missing data were replaced using mean replacement.

Two factorial ANOVAS with repeated measures were conducted to examine within-subjects effects (baseline to post-manipulation), between-subjects effects (sleep deprivation versus eight hours of sleep), and interactions. For primary hypotheses, SAM-V and SAM-A ratings were averaged across experimental trials on each day such that each participant had a single valence and arousal score at both timepoints. Secondary hypotheses were tested using the reappraisal subscale from the CERQ and the positive and negative affect subscale scores from the PANAS-X. Pairwise contrasts with a Tukey adjustment were conducted for interactions

specifically comparing the means of sleep-deprived participants at baseline compared to sleep-deprived participants at post-manipulation as well as both groups at post-manipulation. Before conducting the primary analyses, assumptions were checked. Homogeneity of variance was confirmed using Levene's test. Normality was confirmed using Jarque-Bera test. All outcome measures met normality assumptions except for PANAS-X Negative scores. Specifically, PANAS-X Negative scores exhibited right skew and a leptokurtic distribution. A log transformation was implemented, after which scores met normality assumptions.

Manipulation Check: Actigraphy

To determine the effectiveness of the sleep manipulation, visual inspections of actigraphy were compared to self-report ratings of total sleep from the hourly check ins and from the post-manipulation survey. A total of 10 participants assigned to the sleep deprivation condition (26% of sleep-deprived participants) received actiwatches. One actiwatch ran out of battery and did not collect data. For six participants, no sleep was detected by actigraphy, and no sleep was reported, suggesting participants adhered to manipulation instructions. One participant did not complete any check-ins, but no sleep was detected by actigraphy and no sleep was reported at post-manipulation. In one instance, the actiwatch identified 360 minutes of sleep. However, the actiwatch indicated the participant was asleep during the times they completed their web-based check-ins and the participant's self-report indicated they adhered to the sleep condition. It is possible that in this case, the actiwatch misinterpreted low activity for sleep as the participant could not simultaneously respond to the survey and be asleep. Lastly, one participant reported 210 minutes of sleep when reported sleep was totaled from the check in surveys, then 120 minutes of sleep on the post-manipulation survey, and the actigraphy detected 360 minutes of sleep. While it is unclear which measure (repeated measures throughout the night, self-reported

estimation after the sleep manipulation, or physiological assessment) was the most accurate, all three successfully identified this participant as ineligible to continue. Based on this information, monitoring adherence to sleep deprivation via online check-ins and sleepiness ratings on the Stanford Sleepiness Scale were considered adequate.

Hypothesis Testing

Preliminary Analyses

Zero-order correlations among all continuous study variables were computed (Table 4). Importantly, measures of sleepiness were positively correlated. The S-DERS and PANAS-N were positively correlated and the CERQ-Reappraise was positively correlated with PANAS-P. Notably, scores on the VVIQ positively correlated with Perceived Success during the Emotion Regulation Interview suggesting those that were better able to mentally visualize imagery were more likely to believe they were successful at reappraising during the experimental task. Second, groups were compared in terms of the theoretically relevant variables measured at baseline to check that random assignment effectively equated groups (i.e. mental health symptoms, sleep disorder symptoms, emotion regulation abilities, clarity of visual imagery, and sleepiness; Table 5). Data indicated the groups were equated on all variables and that descriptive statistics accord with similar samples in prior work (Campbell et al., 2022). Furthermore, task comprehension was confirmed to be similar across groups by baseline ratings of the ERI. On average, participants rated their understanding of the task as high (81.09 on a 100-point scale). Post-manipulation descriptive statistics can be found in Table 6.

Primary Hypotheses

Concerning valence, there was a significant effect of time ($F(1, 74) = 11.23$, $p = 0.001$), condition ($F(1, 74) = 6.55$, $p = 0.012$), and significant interaction ($F(1, 74) = 13.83$, $p < 0.001$). Pairwise contrasts demonstrate that sleep-deprived participants at post-manipulation reported more negative valence compared to their baseline ($t(148) = 4.19$, $p < 0.001$) and the control group at post-manipulation ($t(148) = 4.27$, $p < 0.001$; see Figure 2).

In regards to arousal, there was a significant effect of time ($F(1, 74) = 18.93$, $p < 0.001$), condition ($F(1, 74) = 5.08$, $p = 0.027$), and significant interaction ($F(1, 74) = 8.31$, $p = 0.005$). Pairwise contrasts demonstrate that sleep-deprived participants at post-manipulation reported less arousal compared to their baseline ($t(148) = 3.80$, $p = 0.001$) and the control group at post-manipulation ($t(148) = 3.43$, $p = 0.004$; see Figure 3).

Secondary Hypotheses

Self-Reported Reappraisal. There were no significant effects of time ($F(1, 74) = 1.31$, $p = 0.257$) or condition ($F(1, 74) = 0.32$, $p = 0.573$), nor was there an interaction ($F(1, 74) = 0.11$, $p = 0.744$) suggesting sleep deprivation did not affect self-reported reappraisal (Figure 4).

Affect. Concerning the PANAS-X Positive subscale, there was a significant effect of time ($F(1, 74) = 161.02$, $p < 0.001$), condition ($F(1, 74) = 11.52$, $p < 0.001$), and significant interaction ($F(1, 74) = 13.71$, $p < 0.001$). Pairwise contrasts demonstrate that sleep-deprived participants at post-manipulation reported less positive affect compared to their baseline ($t(148) = 8.15$, $p < 0.001$) and the control group at post-manipulation ($t(148) = 4.79$, $p < 0.001$; see Figure 5). In regards to the log-transformed PANAS-X Negative subscale, there was a significant effect of time ($F(1, 74) = 41.47$, $p < 0.001$) but no effect of condition ($F(1, 74) = 0.28$, $p =$

0.600), or interaction ($F(1, 74) = 2.65$, $p = 0.108$) such that participants reported less negative affect after sleep manipulation (see Figure 6).

Post Hoc Analyses

Working Memory Task

To evaluate the role of sleep-related impacts on working memory, a t-test was conducted comparing performance of the sleep-deprived participants to the control group. Although, as expected, findings suggested some working memory impairment in the sleep deprivation group, group differences did not reach conventional levels of significance (t (73.36) = 1.93, $p = 0.06$). However, as this finding is not in accordance with the substantial literature that suggests working memory is negatively impacted by sleep loss, follow-up analyses were conducted.

Factorial ANCOVAS with repeated measures were conducted to examine if valence and arousal findings were held after covarying for working memory performance. Concerning valence, there was a significant effect of time ($F(1, 74) = 4.83$, $p = 0.031$) and a significant interaction between condition and time ($F(1, 74) = 5.76$, $p = 0.019$). There were no significant effects of condition ($F(1, 74) = 1.07$, $p = 0.296$) or working memory scores ($F(1, 74) = 1.66$, $p = 0.202$). Concerning arousal, there was a significant interaction between condition and time ($F(1, 74) = 16.77$, $p < 0.001$). There were no significant effects of time ($F(1, 74) = 0.84$, $p = 0.363$), condition ($F(1, 74) = 2.23$, $p = 0.140$) or working memory scores ($F(1, 74) = 0.06$, $p = 0.802$). These data suggest a similar pattern of findings is obtained for the primary study hypotheses when controlling for working memory.

Vividness of Visual Imagery

While interpreting the primary findings, it was considered that the ability to mentally picture the scenarios after sleep deprivation may be impaired and thus could account for some of the differences in reappraisal across groups. A paired-sample t-test of VVIQ scores at post-manipulation identified a significant difference between the sleep deprivation and the full sleep groups ($t(68.55) = -5.04$, $p < 0.001$) such that the sleep deprived participants noted more difficulty visualizing.Factorial ANCOVAS with repeated measures were conducted to examine if valence and arousal findings were held after covarying for mental imagery vividness change scores. Specifically, post-manipulation VVIQ scores were subtracted from baseline VVIQ scores. Concerning valence, there was a significant effect of time ($F(1, 74) = 4.70$, $p = 0.033$) and a significant interaction between condition and time ($F(1, 74) = 5.36$, $p = 0.024$). There were no significant effects of condition ($F(1, 74) = 1.08$, $p = 0.303$) or VVIQ change scores ($F(1, 74) = 0.025$, $p = 0.875$). Concerning arousal, there was a significant interaction between condition and time ($F(1, 74) = 18.16$, $p < 0.001$). There were no significant effects of time ($F(1, 74) = 0.85$, $p = 0.359$), condition ($F(1, 74) = 2.27$, $p = 0.137$) or VVIQ change scores ($F(1, 74) < 0.01$, $p = 0.945$). These data suggest a similar pattern of findings is obtained for the primary study hypotheses when controlling for VVIQ scores.

Discussion

Sleep loss and difficulties regulating emotion may be interdependent factors that impact mental health. This study implemented an experimental, repeated-measures design to examine the effects of sleep deprivation on reappraisal and affectivity. Results of the current study are mixed.

Interpretation of Findings

With regard to the first hypothesis, that sleep deprivation would negatively impact reappraisal effectiveness (operationalized as self-reported valence and arousal ratings), findings partially supported hypotheses. First, as expected, sleep-deprived participants had more difficulty reappraising as indicated by more negative valence compared to their baseline and the control group at post-manipulation. This is consistent with prior work (Reddy et al., 2017; Tomaso et al., 2020) and suggests that when sleep-deprived, reappraisal efforts were less helpful in terms of reducing the negative valence of scripts as compared to participants who slept normally. These findings meaningfully extend the current literature in both conceptual and methodological ways. Specifically, this study examined valence and arousal separately, as opposed to a combined reactivity score. Additionally, this study utilized a full night of sleep deprivation compared to sleep restriction. Findings from this study are an initial step toward understanding challenges with emotion regulation in a therapy setting. By better recognizing sleep as a factor in the ability to reappraise, therapists can help patients navigate when to use certain strategies. Notably, however, the current sample was unselected; a useful next step in this important area of work would be to matriculate a clinical sample (e.g., individuals with depressive and/or anxious symptomatology) to determine whether the current findings generalize and provide empirical data pertinent to clinical samples.

Unexpectedly, sleep deprivation resulted in a *decrease* in arousal ratings following reappraisal. The hypothesis that arousal would increase was predicated on several considerations. Firstly, the task presents scripts that are designed to elicit anger at another person, thus it was expected that failure to regulate the elicited emotion would result in more anger and therefore more arousal. Notably, the literature to date is not uniform in terms of sample and methodology (Campbell et al., 2021, Reddy et al., 2017; Zhang et al., 2021), such that it was difficult to make

a clear prediction. Thus, studies that do not examine sleep were also considered. This study has demonstrated that the body of knowledge about emotion regulation in a well-rested population may not apply as clearly to sleep-deprived people. Second, given work suggesting sleep increases negative affectivity, it was reasoned that sleep-deprived participants would evidence greater (anger-related) arousal.

It is also important to note that the task employed was designed from the orientation of the categorical model of emotion while the measurement of reappraisal effectiveness is a tool grounded in the dimensional model of emotion. The categorical model of emotion posits there are shared and distinct emotional states such as happiness and anger (Ekman, 1992; Ekman & Friesen, 1971; Ekman et al., 1969). Emotions in general day-to-day are often referred to in this manner, making it easy for participants to understand. On the other hand, while there is a common language here, there is not necessarily uniform experience. One person's experience of sadness may more strongly resemble another person's experience of despair. Often, discrete emotions are interpreted by context and individual perspectives thus can vary not only across but within individuals (Barrett et al., 2009). The dimensional model of emotion posits that there are two dimensions (valence and arousal) that make up an emotional experience (Russell, 1980; Russell, 2003; Russell & Bullock, 1985). This method may be less familiar to participants but reduces the likelihood of idiographic interpretation of emotional experiences. These models are in opposition to one another, thus making predictions across models is challenging. While there is prior work that attempts to map the dimensional model on to discrete emotions (Christie & Friedman, 2004; Holger et al., 2012) doing so may muddy predictions by oversimplifying the emotional experience. Furthermore, neurobiological findings suggest a network of neural

functioning that best fits with a dimensional approach is most likely, as there are no direct mappings between discrete emotions and specific brain regions (Hamann, 2012).

There is some evidence suggesting the effects of sleep loss on arousal may be dose dependent. It is possible that more extreme bouts of sleep deprivation result in limited access to resources necessary for an arousal state (Engle-Friedman, 2014). In other words, sleep deprivation results in an energy deficit that inhibits the body's ability to experience arousal and the accompanying physiological changes without pronounced effort and motivation. The prediction of increased arousal after sleep deprivation was partially predicated on the fact that the scripts are designed to elicit anger. Anger is characterized by negative valence and high arousal; thus it was predicted that difficulty in regulating anger would result in elevated arousal. However, data were not collected about the experience of discrete emotions, thus we cannot be certain that participants experienced anger specifically and not another negatively valenced, but not necessarily high-arousal emotion such as annoyance or even sadness. It is possible that because being sleep-deprived is a low-arousal state to begin with, participants were more likely to experience low arousal emotions with a negative valence such as sadness. It might be worth considering analyzing valence and arousal change scores from baseline to post task, such as an area under the curve analytic approach, instead of the average rating across tasks as was done here. Lastly, the instructions provided to participants specifically said to "think about this situation in a different way, that decreases *negative* emotion" (emphasis added) as has been done in prior work (Reddy et al., 2017). It is possible that by stating "decrease negative emotion", we inadvertently provided instruction that applies more to valence of emotion than arousal. Future research may consider designing the instructional set to also include arousal-specific details, such as "increase feelings of calm."

The distinctions between valence and arousal may explain the inconsistencies in the literature to date. Valence and arousal have been noted to have a "weak V-shaped relation at the nomothetic level" such that people are more likely to experience high levels of valence (positive or negative) when they are experiencing high levels of arousal (Kuppens et al., 2013, p. 17). However, this tenuous relation can be influenced at both the nomothetic level as well as the level of the individual. For instance, the V-shaped relation is often seen as asymmetric most likely due to positivity offset or negativity bias (Kuppens et al., 2013). This is particularly pertinent considering poor sleep is associated with greater negativity bias (Gobin et al., 2015). Furthermore, idiographic factors such as personality, cultural background, and prior learning can influence the individual experience of valence and arousal (Kuppens et al., 2013). With that in mind, it is possible that idiographic experiences of sleep deprivation, such as subjective experience of sleepiness, could result in experiences of valence and arousal moderated by the aforementioned idiographic factors. Thus, it is pertinent to continue to observe valence and arousal separately to monitor if the V-shaped relation holds after sleep loss.

Participants' self-reported tendencies to engage in reappraisal were not impacted by sleep deprivation as indicated by no main effects of time or condition as well as no interaction. This could be explained by the fact that cognitive emotion regulation strategies are somewhere between state-like and trait-like. People have a tendency to consistently implement some strategies over others. However, this is not as stable of a characteristic as something like personality traits (Garnefski et al., 2002). The use of a specific emotion regulation strategy can be changed by internal and external factors. In the case of this study, sleep deprivation did not appear to impact the general tendency to use reappraisal. These findings lend themselves to the idea that sleep deprivation may impact the *ability*, but not the *intent* to use reappraisal. The use

of a trait measure to identify changes in state appraisal is a notable limitation of the study, though the null findings suggest there was not a reporting bias due to sleep deprivation. Future work may usefully employ indices validated to capture state-like changes in the intention to use reappraisal strategies as a function of sleep deprivation.

Finally, findings regarding affect were mixed. Positive affect findings were consistent with other work such that sleep-deprived participants experienced less positive affect at post-manipulation compared to their baseline measures and control participants at post-manipulation. Unexpectedly, however, negative affectivity decreased for both groups and no significant interaction was observed. At face value, these data suggest that sleep deprivation blunts positive but not negative affectivity, at least in the context of reappraising anger-eliciting vignettes. This possibility merits further research. However, the findings related to negative affectivity are not consistent with prior work, which generally suggests acute sleep deprivation amplifies negative affectivity. There are several explanations for this pattern of results. Firstly, it is possible that the PANAS positive scale is assessing a combination of high valence and high arousal, such as "enthusiastic" and "excited" while the PANAS negative scale predominantly captures negative valence and high arousal (Kuppens et al., 2013), such as "afraid", "scared", and "hostile." These limit our understanding of how low arousal emotions such as "calm" or "sadness" may be impacted. If valence and arousal are affected by sleep deprivation differently, it would be helpful to specifically assess negative and positive emotions that vary in arousal. For instance, instead of two scales, positive and negative, we use four: positive/low arousal, positive/high arousal, negative/low arousal, negative/high arousal. Additionally, there was potentially a floor effect of negative affect as evidenced by the low range compared to the possible range of responses and the right-skewed distribution. Based on the significant differences at timepoints but not by

condition, there may have also been an effect of habituation. This might suggest a future study design in which participants complete both sleep conditions in a randomized order.

Strengths and Limitations

This study meaningfully builds on prior work in several ways. Firstly, valence and arousal were examined separately. This is critical as they are independent but related constructs and the non-uniform nature of the extant literature may be due, in part, to combining these measures. Additionally, to our knowledge this is the first study examining reappraisal effectiveness after a night of full sleep deprivation. This is important to elucidate the nature and magnitude of the effects of sleep loss. Full sleep deprivation is often considered "the hammer" to determine if effects are discernable. Building on the current study, future work would benefit from evaluating more naturalistic doses of sleep loss, such as chronic sleep loss, or circadian misalignment in relation to reappraisal effectiveness. Additionally, studies examining if additional sleep, such as a daytime nap, may improve emotion regulation, will elucidate how to manage changes in the ability to reappraise. It is important to note this study used measures of sleepiness as confirmation of the manipulation check. While sleepiness is often positively associated with sleep debt also known as homeostatic pressure, they are separate constructs and may have different impacts on emotion regulation. Future studies would benefit from establishing consistent sleep schedules before sleep deprivation to better clarify the role of homeostatic pressure in reappraisal.

Another key strength of the current study is the experimental design in which sleep was manipulated to evaluate causal effects on outcomes. Remote sleep manipulation poses a unique set of challenges. For instance, activities that may impact sleep or wake cannot be restricted or monitored. However, actigraphy findings suggest the overnight check-ins successfully identified

participants who did and did not adhere to their sleep condition. Actigraphy was less likely to pick up small bursts of sleep that participants reported (ex. dozing off for 10 minutes), and more likely to pick up larger bouts of sleep. Without actigraphy, these larger bouts of sleep are easily identified by missed check-ins. While future work would benefit from in-lab sleep deprivation and monitoring, preliminary studies that utilize remote sleep manipulation with check-ins do appear to be sufficiently reliable.

A hallmark challenge in sleep research is addressing the possibility that sleep loss affects participants' ability to adhere to study protocol rather than the constructs of interest per se. Included in the current study was a direct evaluation of working memory following the sleep manipulation given reappraisal requires working memory to hold on to the presented situation and mentally manipulate that information to change the affective response. Despite previous work suggesting sleep deprivation negatively impacts working memory (Choo et al., 2005; Gerhardsson et al., 2019; Martínez-Cancino et al., 2015; Terán-Pérez et al., 2012), differences between groups did not reach conventional levels of significance in the current study. Importantly, as this task was completed remotely, we cannot be sure that participants strictly adhered to study instructions and did not use external memory aids. Post hoc analyses suggest that working memory did not account for the current findings. However, future studies should employ tasks that rely as little as possible on working memory and account for possible variability in analyses. For instance, real-time experimental tasks compared to tasks that require reflection may clarify the contribution of working memory in reappraising after sleep deprivation.

Additionally, there are limitations related to the Script Based Emotion Regulation Task. Although groups were equated in terms of their ability to visualize, this study relied on an

emotion regulation task that required participants to engage in mental imagery. While post hoc analyses demonstrated that changes in mental imagery did not account for the current findings, deficits in that domain do play a role and should be experimentally controlled. Future studies would benefit from using in-person emotion regulation tasks requiring less use of imagination such as regulating affect while presenting to a person with a neutral expression. Furthermore, baseline findings from the emotion regulation interview suggest some participants did not fully understand the task. In-person laboratory assessments would provide researchers with the opportunity to ensure participant comprehension of instructions prior to task deployment. Lastly, the scripts were originally meant to generalize to a wide sample. However, the final sample was comprised exclusively of undergraduate students. To increase the likelihood that participants relate to the scripts, specific populations should be targeted for recruitment and scripts should be tailored to the population of interest.

Online recruitment was a cornerstone for meeting this study's recruitment goals. However, challenges such as bots, participants submitting multiple screeners, and unreliable reporting regarding time zones, made online recruitment unreliable. Future studies would benefit from grassroots community recruitment such as having community leaders and organizations distribute the screening link instead of having the link available to the global public. Another challenge is ethical financial compensation. Compensation for this study was evaluated based on local monetary value. While the compensation was not considered coercive in this context, it is possible that the amount may be significantly more coercive (or, in contrast, less incentivizing) in other economic contexts. It should also be noted that the multi-step nature of the study (screening survey, consent appointment, and two experimental days) appeared to be a significant burden to participation. While the online nature of the study reduced some burden such as travel,

it still presented scheduling challenges and required significant time on the part of participants. Future studies will need to weigh the benefits of consistent personal communication with participants and the scheduling burden of those communications.

Conclusion

This repeated-measures design found sleep deprivation impacted some aspects of reappraisal effectiveness and affect. As sleep disturbances are common, especially in the context of mental health disorders, understanding how sleep relates to the ability to regulate emotions is imperative. Findings from this study support prior work suggesting sleep loss results in less positive affect and challenges in emotion regulation. It highlights the need for further investigation into relation of sleep loss and the desire to regulate emotions, as well as differences in the regulation of valence versus arousal.

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Table 1: Eligibility Criteria

1. Age: 18-60 years.
2. Suicidal Risk Behavior: no current active or passive suicidality.
3. Mania: no history of mania.
4. Medical conditions: no self-reported medical reasons that would make it unsafe to stay awake overnight.
5. Must be located in the United States.
6. Psychosis: no history of psychosis.
7. Safety behaviors: must agree to avoid driving after their regular bedtime until they can sleep after post-manipulation survey (if assigned to sleep deprivation condition).
8. Ability to provide informed consent and comply with all requirements of the protocol.
9. Access to stable internet connection.
10. Medications: no current use of sleep medications.
11. Sleepiness: must score below a 10 on the Epworth Sleepiness Scale at baseline.

Table 2a: Demographic Information

	Full Sample	Full Sleep	Sleep Deprivation
Age	19.14 (*SD*=1.26)	19.08 (*SD*=1.12)	19.21 (*SD*=1.4)
Sex			
Female	37	22	15
Male	39	16	23
Race			
American Indian	0	0	0
Asian/Asian American	0	0	0
Black	3	1	2
Pacific Islander	0	0	0
White	67	34	33
More than one race	5	2	3
Prefer not to say	1	1	0
Ethnicity			
Hispanic	6	3	3
Non-Hispanic	70	35	35

Table 2b: Social Demographic Information

	Full Sample	Full Sleep	Sleep Deprivation
Sexual Orientation			
Asexual	3	2	1
Bisexual/Pansexual	7	3	4
Gay/Lesbian	5	2	3
Heterosexual	58	29	29
Questioning	1	0	1
Prefer not to say	2	2	0
Relationship Status			
Single	48	23	25
In a Relationship	28	15	13
Family Income			
Less than 30k	13	5	8
30k-100k	34	20	14
Greater than 100k	29	13	16
Parent Education			
College Degree	61	34	27
No College Degree	15	4	11
Primary Language			
English	74	37	37
Spanish	2	1	1
Veteran Status			
Yes	1	0	1
No	75	38	37

Table 2c: Sleep Descriptive Information

	Full Sample	Full Sleep	Sleep Deprivation
Bed Partner			
Yes	11	3	8
No	65	35	30
Work Shift			
First (9am-5pm)	8	1	7
Second (4pm-12am)	6	2	4
Third (12am-8am)	0	0	0
Part time	11	6	5
Don’t Work/Retired	43	25	18
Work from Home/Flexible	8	4	4

Table 3: Measurement Timeline

Measure	Baseline	Post-Manipulation
A Collaborative Outcome Resource Network	X	
Sleep Disorders Symptoms Checklist- 25	X	
Epworth Sleepiness Scale	X	
Vividness of Visual Imagery Questionnaire	X	X
Stanford Sleepiness Scale	X	X
Cognitive Emotion Regulation Questionnaire	X	X
Positive and Negative Affect Scale -X	X	X
State Difficulties in Emotion Regulation Scale	X	X
Self-Assessment Manakin	X	X
Emotion Regulation Interview	X	X

Table 4: Baseline Measures Correlations

	1	2	3	4	5	6	7	8	9	10	11
1. Epworth Sleepiness Scale	x	0.63*	0.43*	0.48*	0.42	0.25*	-0.15	0.25*	-0.3	-0.16	-0.13
2. A Collaborative Outcome Resource Network	x	x	0.52*	0.37*	0.67*	0.04	-0.02	0.73*	-0.11	-0.13	0.23*
3. Sleep Disorders Symptom Checklist - 25	x	x	x	0.42*	0.34*	0.01	-0.04	0.36*	-0.04	-0.14	-0.23*
4. Stanford Sleepiness Scale	x	x	x	x	0.35*	0.21	-0.20	0.43*	-0.09	0.10	-0.03
5. State Difficulties in Emotion Regulation Scale	x	x	x	x	x	0.12	-0.09	0.73*	0.04	-0.10	-0.28*
6. Vividness of Visual Imagery Questionnaire	x	x	x	x	x	x	-0.3	0.06	-0.11	-0.14	-0.29*
7. Positive and Negative Affect Scale- Positive	x	x	x	x	x	x	x	0.04	0.34*	-0.07	.0.09
8. Positive and Negative Affect Scale- Negative	x	x	x	x	x	x	x	x	-0.04	-0.08	-0.14
9. Cognitive Emotion Regulation Questionnaire- Reappraise	x	x	x	x	x	x	x	x	x	0.05	0.07
10. Emotion Regulation Interview- Understanding	x	x	x	x	x	x	x	x	x	x	0.57*
11. Emotion Regulation Interview- Perceived Success	x	x	x	x	x	x	x	x	x	x	x

Table 5: Baseline Measures by Sleep Condition

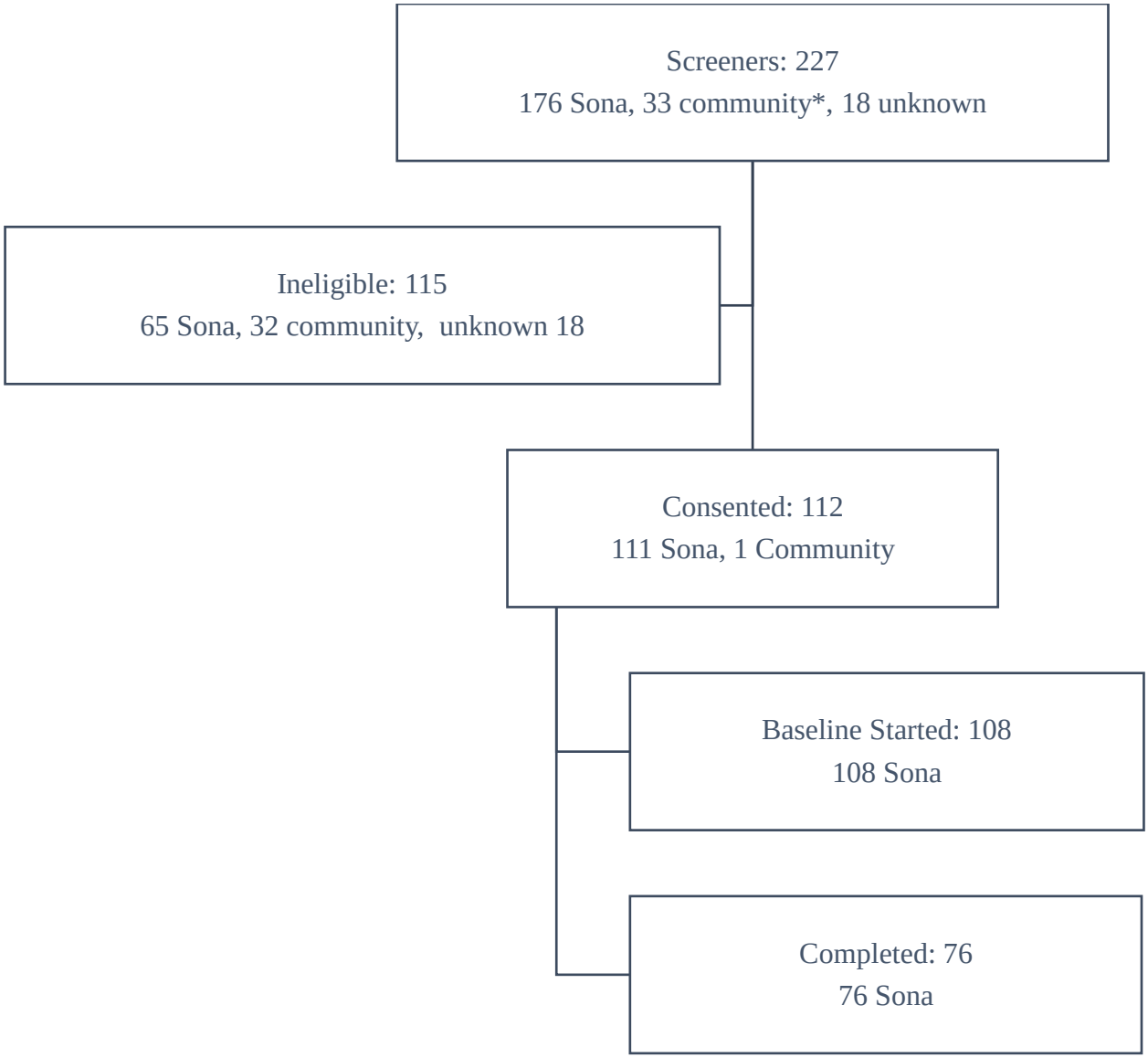
	Full Sample	Full Sleep	Sleep Deprivation
Epworth Sleepiness Scale	6.71 (3.16)	6.34 (3.61)	7.08 (2.63)
A Collaborative Outcome Resource Network	0.96(0.57)	1.00(0.58)	0.92(0.57)
Sleep Disorders Symptoms Checklist- 25	19.49 (9.13)	18.32 (9.98)	20.66 (8.15)
Stanford Sleepiness Scale	2.66 (0.97)	2.71 (0.96)	2.61 (1.00)
State Difficulties in Emotion Regulation Scale	43.09 (11.21)	42.37 (10.96)	43.82 (11.55)
Vividness of Visual Imagery Questionnaire	7.7 (3.25)	7.32 (2.61)	8.08 (3.79)
Positive and Negative Affect Scale			
Positive	28.96 (6.73)	29.82 (7.55)	28.11 (5.77)
Negative	19.34 (6.45)	19.61 (6.83)	19.08 (6.13)
Cognitive Emotion Regulation Questionnaire Reappraise	13.08 (3.32)	12.82 (3.47)	13.34 (3.19)
Emotion Regulation Interview			
Understanding	81.09(19.35)	80.61 (16.32)	81.58(22.19)
Perceived Success	63.28(23.17)	65.03(21.87)	61.53(24.56)

Note: T-tests indicated the groups were equated across all variables.

Table 6: Post-Manipulation Measures by Sleep Condition

	Full Sample	Full Sleep	Sleep Deprivation
Stanford Sleepiness Scale	4.11(1.92)	2.82(1.45)	5.39(1.41)
State Difficulties in Emotion Regulation Scale	41.63(10.6)	41.45(11.83)	41.83(9.24)
Vividness of Visual Imagery Questionnaire	9.7(3.96)	7.71(2.91)	11.68(3.89)
Positive and Negative Affect Scale			
Positive	19.25(7.73)	22.89(8.45)	15.51(4.60)
Negative	15.68(5.85)	15.24(6.69)	16.13(4.91)
Cognitive Emotion Regulation Questionnaire Reappraise	12.76(3.75)	12.59(4.08)	12.93(3.44)
Emotion Regulation Interview			
Understanding	86.16(18.64)	90.13(16.58)	82.18(19.93)
Perceived Success	68.63(24.28)	75.95(21.36)	61.32(25.08)
Working Memory Task	6.72(2.24)	7.21(2.09)	6.24(2.29)

Figure 1: Study Flow



*Note: Screener count of Sona vs Community is likely inaccurate such that Sona participants are over-reported. When asked in the survey, “Sona” was the first choice and in many cases, people and “bots” that submitted multiple responses would select the first response available for every question. Additionally, this number does not align with available Sona slots.

Reasons for exclusion included current location outside of USA (*n* = 7) refusal to agree not to drive after sleep deprivation (*n* = 1), medical concerns (*n* = 16), and increased risk (*n* = 6). Participants with multiple submissions without being instructed to do so (5 participants accounting for 12 surveys) and/or no contact information (*n* = 16) were not eligible. There were

18 instances in which the survey was started, but no answers were recorded. Lastly, 39 participants were not consented because they could not be contacted.

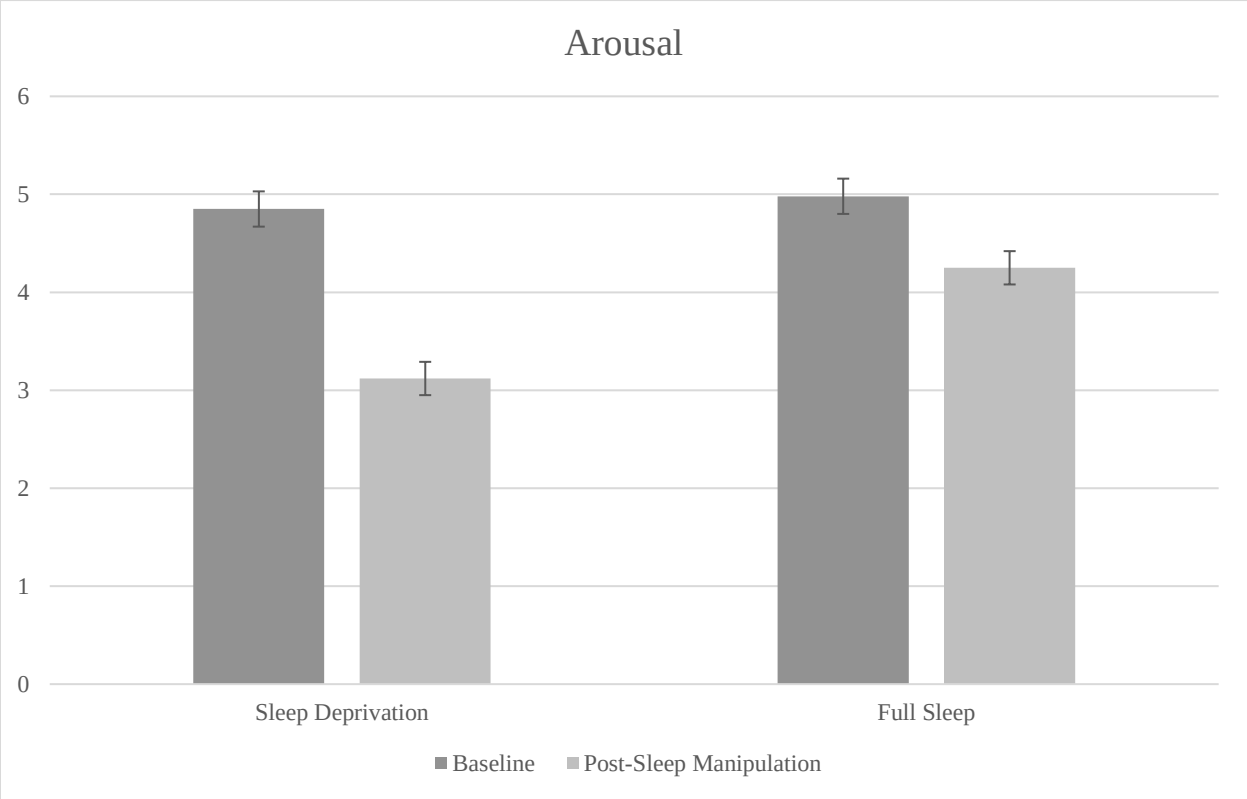
Thirty-two participants were excluded after starting baseline for the following reasons: missing check-ins or completing them at the wrong time (n = 9), endorsing more than 90 minutes of sleep (n = 6), endorsing suicidality[2] (n = 2), completing baseline or post-manipulation outside of the study window (n = 4), completing a survey in multiple sittings (n = 3), and withdrawing from the study (n = 8). All participants were asked to refrain from caffeine, alcohol, and drugs that may impact the sleep or wake cycle until after their post-manipulation visit and confirmed doing so at the start of the study session following the sleep manipulation.

[2] At the beginning of the study, a question was included in the ACORN that assessed thoughts of death and dying. Two participants endorsed passive suicidality. For their safety, they were immediately contacted, provided with resources, and withdrawn from the study. As these participants were university students, they were provided with local information. Due to concerns about our ability to provide resources to participants across the country, the suicidal risk-related questions were removed from the protocol. Additionally, we enforced the requirement that participants must complete the baseline questionnaire within two weeks of completing the screening questionnaire to be sure that the risk assessment was up-to-date. Twelve participants needed to complete a second or third screening survey before their baseline visit to be sure they were still eligible. Those 12 surveys are not included in the count above.

Figure 2: Valence Results

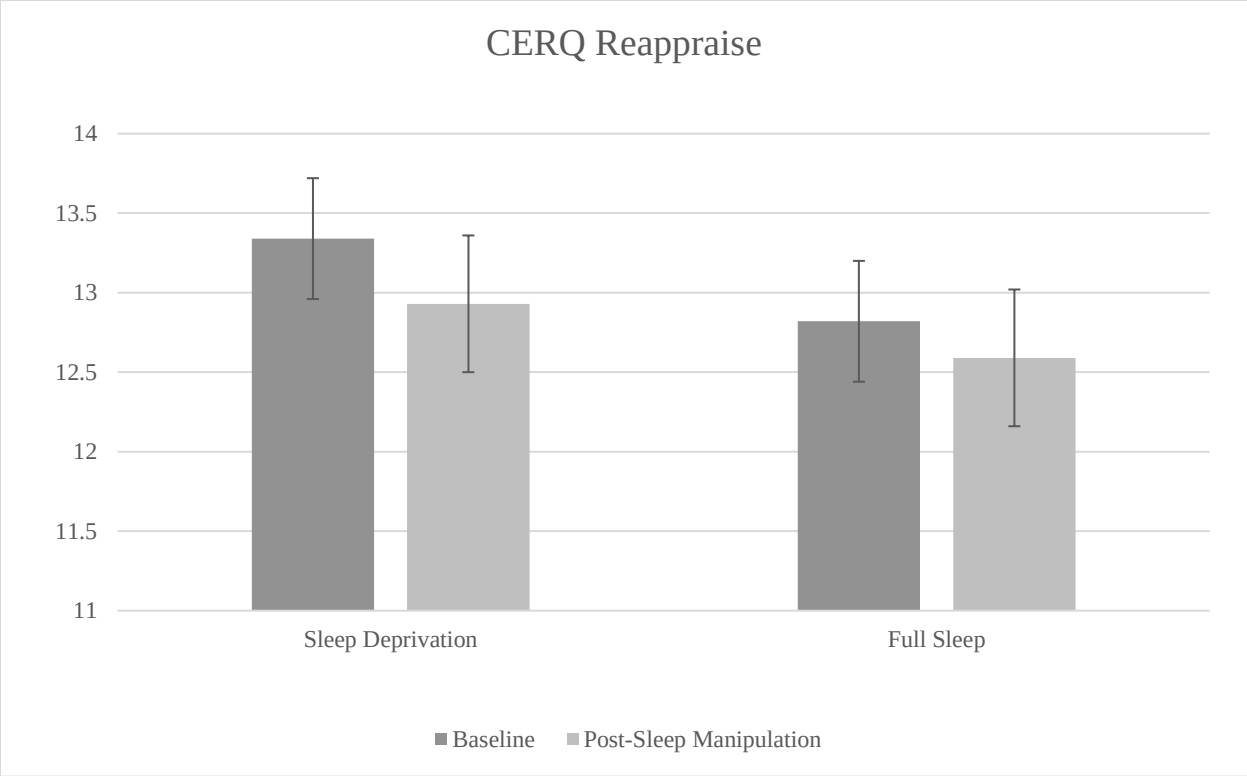
There was a significant effect of time ($F(1, 74) = 11.23$, $p = 0.001$), condition ($F(1, 74) = 6.55$, $p = 0.012$), and significant interaction ($F(1, 74) = 13.83$, $p < 0.001$). Pairwise contrasts demonstrate that sleep-deprived participants at post-manipulation reported more negative valence compared to their baseline ($t(148) = 4.19$, $p < 0.001$) and the control group at post-manipulation ($t(148) = 4.27$, $p < 0.001$). Error bars are standard error.

Figure 3: Arousal Results



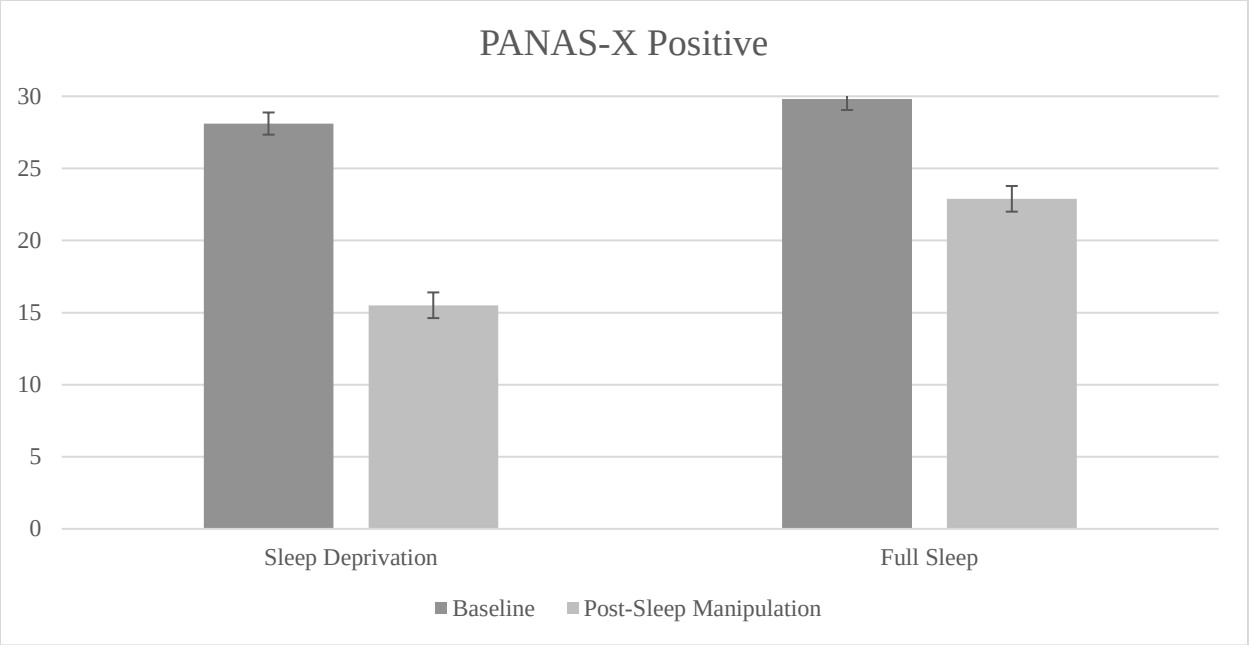
There was a significant effect of time ($F(1, 74) = 18.93$, $p < 0.001$), condition ($F(1, 74) = 5.08$, $p = 0.027$), and significant interaction ($F(1, 74) = 8.31$, $p = 0.005$). Pairwise contrasts demonstrate that sleep-deprived participants at post-manipulation reported less arousal compared to their baseline ($t(148) = 3.80$, $p = 0.001$) and the control group at post-manipulation ($t(148) = 3.43$, $p = 0.004$). Error bars are standard error.

Figure 4: Self-Reported Emotion Regulation Results



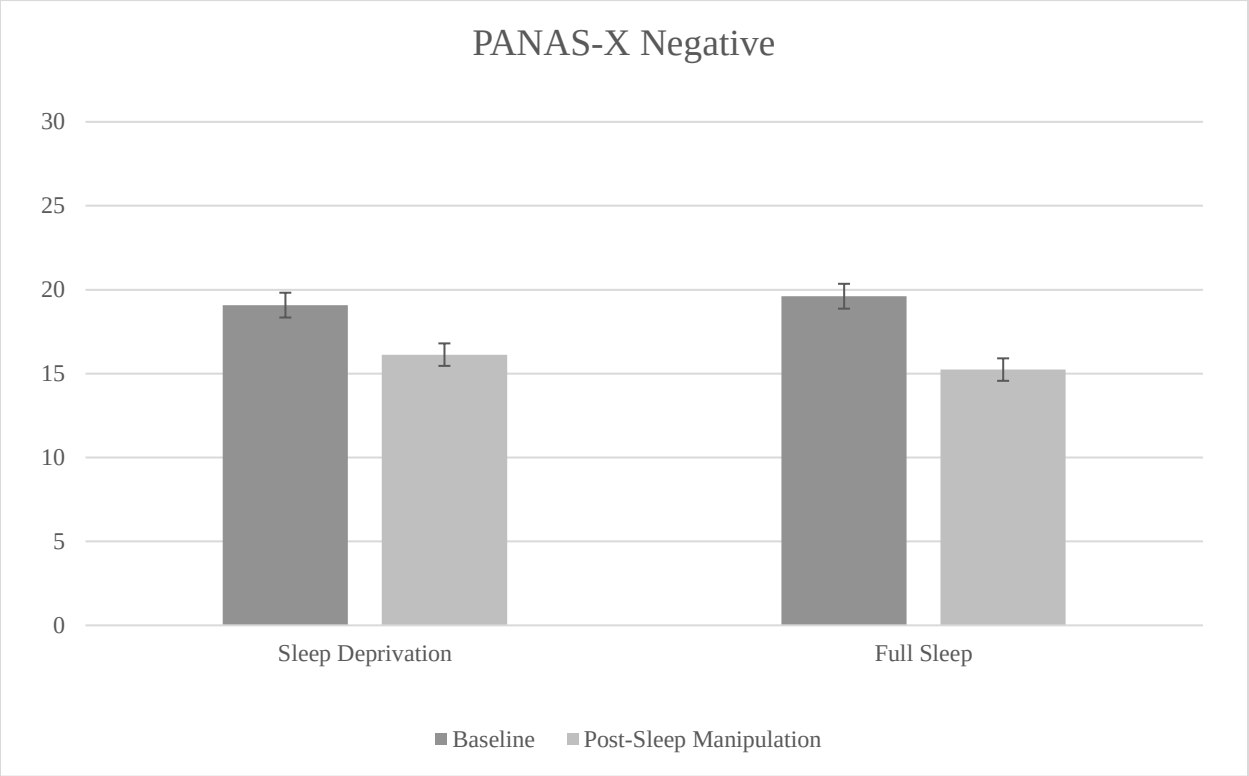
There were no significant effects of time ($F(1, 74) = 1.31$, $p = 0.257$), condition ($F(1, 74) = 0.32$, $p = 0.573$), or interaction ($F(1, 74) = 0.11$, $p = 0.744$) suggesting sleep deprivation did not affect self-reported ability to reappraise. Error bars are standard error.

Figure 5: Positive Affect Results



There was a significant effect of time ($F(1, 74) = 161.02$, $p < 0.001$), condition ($F(1, 74) = 11.52$, $p < 0.001$), and significant interaction ($F(1, 74) = 13.71$, $p < 0.001$). Pairwise contrasts demonstrate that sleep-deprived participants at post-manipulation reported less positive affect compared to their baseline ($t(148) = 8.15$, $p < 0.001$) and the control group at post-manipulation ($t(148) = 4.79$, $p < 0.001$). Error bars are standard error.

Figure 6: Negative Affect Results



PANAS-X Negative scores exhibited right skew and a leptokurtic distribution. A log transformation was implemented, after which, scores met normality assumptions. There was a significant effect of time ($F(1, 74) = 41.47$, $p < 0.001$) but no effect of condition ($F(1, 74) = 0.28$, $p = 0.600$), or interaction ($F(1, 74) = 2.65$, $p = 0.108$) such that both groups reported less negative affect after sleep manipulation. Error bars are standard error.

Appendix A: Screening Questionnaire

Are you currently between the ages of 18 and 60 years?

[ ] Yes [ ] No (exclude)

Being awake for more than 18 hours is as dangerous as driving drunk. **Do you agree not to drive** past your normal bedtime until you are able to sleep after the completion of the study if you are assigned to a night of sleep deprivation?

[ ] Yes [ ] No (exclude)

Is there any medical reason, either as you have been told by a doctor or from your own experience, why you should not stay up for a full night?

[ ] Yes (exclude) [ ] No

Are you currently located in the United States of America?

[ ] Yes [ ] No (exclude)

What time zone are you currently in?

- Hawaii-Aleutian Standard Time
- Alaska Daylight Time
- Pacific Standard Time
- Mountain Standard Time
- Arizona Standard Time
- Central Standard Time
- Eastern Standard Time

As a part of this study, some participants will be asked to stay up all night. Sleep deprivation can make some mental health and physical health issues worse. Below is a list of such concerns, please review them carefully.

For your own safety, you will not be eligible to participate if you have experienced the following:

- Thoughts/wishes to be dead or to go to sleep and not wake up in the past 3 months.
- Thoughts about killing or hurting yourself in the past 3 months.
- Sensory experiences that others could not understand, such as
    - Hearing sounds that others could not hear, such as voices or music.
    - Seeing things others couldn't see, such as colors, animals, people, or spirits.
    - Having unusual sensations in your body such as a feeling of electric shocks or bugs on you.
    - Smelling odors that others couldn't smell, such as vomit, feces, or something rotting.
- A period of 4 or more days when your mood was so good or elevated, like you were on the top of the world, that it caused problems for you, or people thought you weren't your usual self.

Have you experienced any of the issues just listed?

[ ] Yes (exclude- provide resources) [ ] No

Appendix B: Emotion Regulation Interview

- How well did you understand the instructions to think about the situations in a different way, that decreases negative emotion?
    - 0 (not at all) – 100 (completely understood)
- How successful were you in reappraising (thinking about this situation in a different way, that decreases negative emotion) the situations?
    - 0 (not successful) – 100 (completely successful)
- Explain in your own words what you did to think differently about the situation. What specifically did you think about the situations to decrease negative emotion?
- When you were reappraising, what percent of the time did you try to think about the situations differently to decrease negative emotion? Please answer with a percentage with 0% meaning you spent no time changing how you were thinking, and 100% meaning you spent the whole time changing how you were thinking.
- To what degree would you identify with what was happening in the situations?
    - 0 (Not at all) – 100 (Completely)

Appendix C: Script-Based Reappraisal Test Scripts

Other-Anger

1. You have been building large flower bed in your front yard. After months of painstaking care, the first flowers finally start sprouting. When you leave the house on a Sunday morning, you walk past your garden. You find several empty beer bottles and a devastated flower bed.

2. You are planning to take the bus to an important meeting. As you approach the bus stop, you see the bus already waiting with the doors closed. You go to the bus driver's door to signal that you want to board, but instead he laughs at you and drives away.

3. You are walking down the sidewalk when you notice a group of teenagers making fun of someone with a physical disability. You approach the teenagers and confront them about their behavior. In response, they say: "don't be so sensitive, it's funny!"

4. You are at the movies watching an exciting film when two other viewers start talking loudly behind you. When you finally ask them if they can talk more quietly, they smirk condescendingly and say "Shut your mouth, loser!" and throw popcorn at you.

5. You are running a stand at the flea market and you are talking to the owner of the stand next to you. As he looks at your merchandise, he spills his coffee on your stand and irreversibly damages a very rare and valuable book. He walks away, saying: "That was just junk anyway."

6. "You are in a supermarket in front of the wine rack. A customer next to you picks up a bottle of red wine and drops it. The bottle breaks and some of the wine gets on your

clothes. When a supermarket employee comes by and asks how that happened, the customer points at you and says, “they bumped into me!”

7. You’re taking an evening bike ride along the bike trail. Another cyclist comes racing behind you and clips your back tire, causing you to crash and sprain your ankle, preventing you from biking for a week. When you ask the cyclist about his behavior, he says: “Slow people like you need to just move out of the way!”

8. You are at the train station and want to get to your platform. As you run down the stairs someone bumps into you, causing your laptop bag to slip out of your hand and fall down the stairs. When you ask the passer-by to pay for your broken laptop, he replies: “You should watch where you’re going!” and gets on the next train.

9. “You are taking the bus with a colleague to submit an important project. Suddenly you notice that your colleague has forgotten the folder at the bus stop, and you both fail the project. After the incident, your supervisor speaks to you: “You cannot forget the project folder again!” and your colleague sits there silently.

10. You are trying to work on a project that is due tomorrow. You’re finding it difficult to concentration since two of your next-door neighbors are playing loud music. When you ask the two of them if they can turn the music down, one of the neighbors replies: “You can’t tell me what to do!”

Self-Anger

1. You have been playing the lottery with the same numbers – your lucky numbers – for a long time. During your coffee break, you and your colleague look up the winning

lottery numbers. You are excited to see that your lucky numbers have been drawn until you suddenly remember you forgot to buy a ticket this time.

2. You're that the beach. You decide to go home so you start to pack up your things. When you get to your house, you can't find your house-key. As you ponder where it might be, you remember you put it on your towel and that it was probably lost when you shook it out.

3. You spent the day shopping. After purchasing two bags of clothes, you take the bus to go home. You get off at your stop. By the time you realize that you forgot your bags on the bus, you can already see it driving away in the distance.

4. You drive to the airport to go on vacation and stop for gas on the way. Instead of filling up with gasoline, you accidentally fill up with diesel. When you realize your mistake, you have to call roadside assistance to have them pump out the tank. You miss your flight.

5. You receive an email informing you of your million-dollar prize. You open the email and are asked to click a link to receive it. You're curious about the prize and click the link. Your computer then crashes and you are no longer able to turn it on.

6. You are renovating your bedroom. You meet your neighbor by chance and start a conversation with him. Since he's also recently renovated, he asks you how your project is going. When you show him your progress, you knock over a bucket of paint and ruin your new flooring.

7. After a long day at work, you come home late in the evening. You open the door of your house and when you enter you notice that the entire floor is wet. When you go

into the kitchen, you see more water on the floor. You realize that you forgot to turn off the faucet to the sink when you left this morning.

8. “You are tidying up and decide to file all of your documents. You create a stack with important documents and one with unimportant documents. When you’re done sorting you shred the entire stack of unimportant documents. When you go to file your important documents in folders, you notice that you mixed up the stacks.
9. You have bought a rare book and decide to show it off to your friends with pride. To celebrate, you decide to make a toast. You take a bottle of champagne and carefully open it. The cork shoots out and the champagne begins to foam. Your new book is soaked through with some foam.
10. You decide to go for a walk. You open the apartment door and meet your neighbor, and the two of you start carrying on a conversation. After your neighbor says goodbye, you close the door and are about to leave when you realize you left your keys on the dresser in the hallway.

Fear

1. You have had a toothache for a few days and decide to see a dentist. After examining your teeth, the doctor explains you urgently need a root canal due to advanced inflammation. The treatment will take about two hours and is often painful, as the dentist has to drill through the tooth to the root.
2. You are walking home by yourself from a party at night. You are unfamiliar with this part of the city and you get lost. Trying to find your way home, you walk down a dark

park in a remote area. As you walk a several feet, you see a group of drunk young men approaching you.

3. You cut your finger deeply while cooking. In the hospital, nurse has examined your finger, and you are waiting to speak with the doctor. You hear the nurse describing the situation to the doctor and the doctor muttering something about an amputation.

4. You take the elevator alone to the sixth floor of a high-rise building. Suddenly you hear a loud bang and realize that the elevator has stopped between the floors. The light then flickers briefly and finally goes out. You are in complete darkness when you hear a deafening alarm.

5. You are taking a walk through a busy park. As you walk, you see a person playing with their dog. As you walk past the two of them, the dog suddenly runs towards you. It stops in front of you, barks and bares its teeth. It does not seem to respond to the calls of its owner.

6. You are swimming in a large lake. After swimming a long way out, roughly in the middle of the lake, a water plant catches your legs and prevents you from moving. The harder you kick, the greater the resistance.

7. "You are in an airplane on a long-haul flight. After a few hours you suddenly feel strong turbulence and oxygen masks fall out of the hatches in the cabin ceiling. The cabin lights begin to flicker and the aircraft takes a dive. An announcement sounds: "One of our engines has failed. We have to make an emergency landing!"

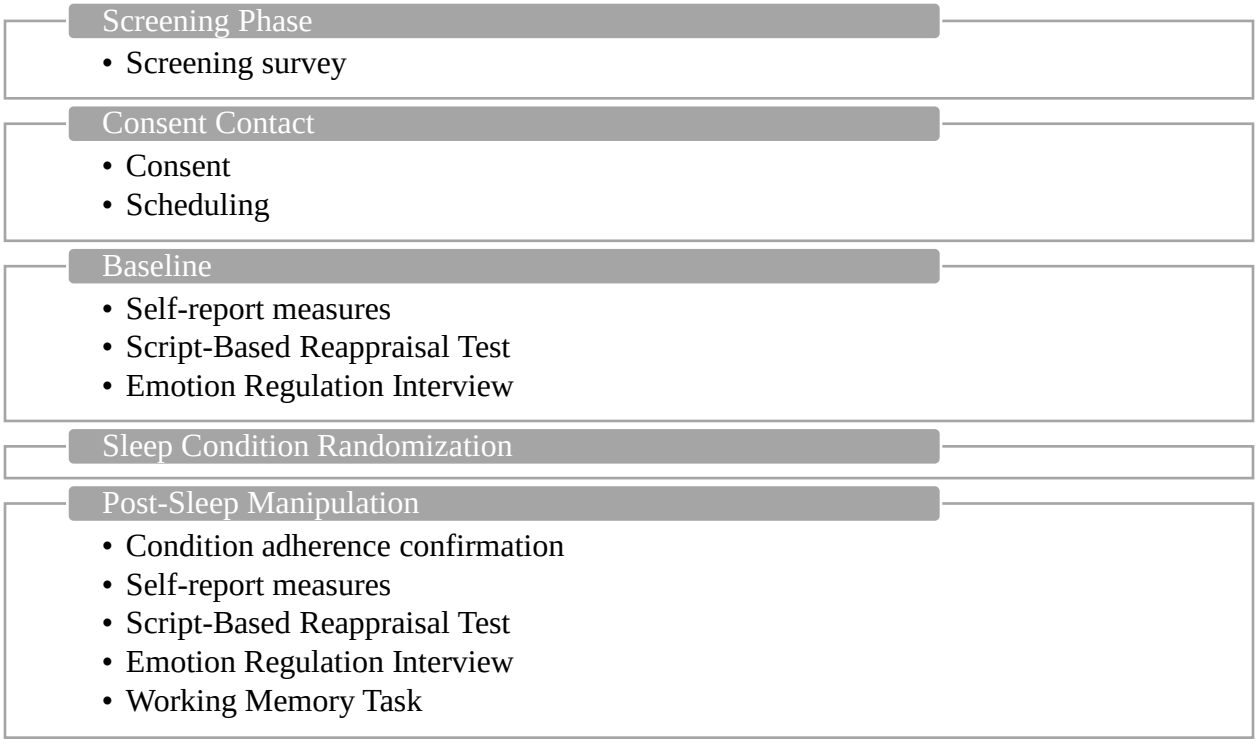
8. You are at an amusement park and have decided to ride a new roller coaster. After waiting in line for a short time, you board the ride and the car starts moving. As the track

slowly reaches the highest point of the incline, you notice that the safety bracket has not been properly attached and is becoming more and more loose.

9. You are at the bank and to withdraw money. You are standing in line in front of the ATM. Just before your turn, two masked and armed men storm into the bank. They fire a warning shot, go to the counter, and threaten the bank clerk with an assault rifle.

10. You are going on vacation and finally land at the airport after being on a plane for several hours. You decide to take a taxi from the airport to your hotel. You drive for a while until you realize that the taxi driver is stopping in a remote area. After you stop, three armed men come up to you.

Appendix D: Study Timeline



Appendix E: Overnight Check-ins

1) Have you slept since the last check-in?
    a. If yes, how many minutes?
2) How sleepy do you feel? (scale 0-100)
3) What activities have you been doing to keep yourself awake?

Appendix F. IRB Approval Letter

UNIVERSITY OF ARKANSAS

To:	Becca Campbell
From:	Douglas J AdamsJustin R Chimka, Chair IRB Expedited Review
Date:	02/18/2022
Action:	**Expedited Approval**
Action Date:	02/18/2022
Protocol #:	2110361189A001
Study Title:	A Study of the Relation Between Sleep and Thinking Patterns
Expiration Date:	10/10/2022
Last Approval Date:	02/18/2022

The above-referenced protocol has been approved following expedited review by the IRB Committee that oversees research with human subjects.

If the research involves collaboration with another institution then the research cannot commence until the Committee receives written notification of approval from the collaborating institution's IRB.

It is the Principal Investigator's responsibility to obtain review and continued approval before the expiration date.

Protocols are approved for a maximum period of one year. You may not continue any research activity beyond the expiration date without Committee approval. Please submit continuation requests early enough to allow sufficient time for review. Failure to receive approval for continuation before the expiration date will result in the automatic suspension of the approval of this protocol. Information collected following suspension is unapproved research and cannot be reported or published as research data. If you do not wish continued approval, please notify the Committee of the study closure.

Adverse Events: Any serious or unexpected adverse event must be reported to the IRB Committee within 48 hours. All other adverse events should be reported within 10 working days.

Amendments: If you wish to change any aspect of this study, such as the procedures, the consent forms, study personnel, or number of participants, please submit an amendment to the IRB. All changes must be approved by the IRB Committee before they can be initiated.

You must maintain a research file for at least 3 years after completion of the study. This file should include all correspondence with the IRB Committee, original signed consent forms, and study data.

cc: Ellen W Leen-Feldner, Investigator
Eric Hinson Mann, Key Personnel
Annamarie T. Nguyen, Key Personnel
Riley Gournay, Key Personnel
Sydney Caroline Woychesin, Key Personnel
Parker E. Williams, Key Personnel
Caroline Michele Yenzer, Key Personnel
Grace Carol Barnett, Key Personnel
Ashley M. Miller, Key Personnel
Tori Jane Henderson, Key Personnel