SLEEP AND SAVORING: THE INFLUENCE OF SLEEP RESTRICTION ON POSITIVE EMOTION REGULATION

by

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DEDICATION

This project is dedicated to my father, Thomas Powell, and my uncle, Marc Powell, who have been unwavering sources of support and whose advice and insight are my most cherished resources.

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ABSTRACT

Although previous research broadly demonstrates that sleep loss leads to reductions in positive affect, relatively few studies examine the impact of sleep loss on low and high arousal positive affective processes, the regulation of positive emotions, or the influence of different sleep stages. The current study sought to build on previous findings that suggest slow wave and rapid eye movement stages of sleep may have distinct influences on affect by examining the effects of sleep restriction on positive affect, reactivity, and regulation (i.e., savoring and dampening). Thirty-four participants (50% female, ages 18-25 years) were included in final analyses. Participants completed a healthy night of sleep (9h time in bed) and a night of sleep restriction (4h time in bed). Sleep was restricted between participants in two ways, early in the night to primarily restrict slow wave sleep and later in the night to primarily restrict rapid eye movement sleep. Following both a night of normal sleep and the night of sleep restriction, participants completed questionnaires to measure positive affect, and a video task which instructed them react normally or to savor while watching positive affect-inducing videos. After each video, participants reported on their feelings of valence, arousal, and high and low arousal positive affect. Savoring and dampening strategies utilized during the task were also reported. Following sleep restriction participants reported diminished high and low arousal positive affect compared to when they were well-rested. Participants also reported less positive reactivity to the videos when they were sleep restricted compared to when they were well-rested after both reacting normally and after savoring. However, participants experienced greater increases in positive affect when savoring compared to when they were instructed to react after sleep restriction. Slow wave sleep loss was related to marginally reduced positive affect compared to loss of rapid eye movement sleep, but no other effects of type of sleep restriction emerged. This study indicates that sleep loss results in diminished high and low arousal positive affect and blunted reactivity to positive stimuli, but that engaging in intentional up-regulation strategies may help buffer the negative effects of sleep loss.

INTRODUCTION

The importance of sleep for optimal socioemotional functioning has become increasingly highlighted by researchers, clinicians, and public health officials (Simon et al., 2020; Irwin, 2015), and is one possible explanatory mechanism for why sleep disturbances contribute to the development of numerous mental health disorders, such as depression and anxiety (McMakin & Alfano, 2015; Palmer et al., 2018; Silk et al., 2007). Sleep and affective disorders likely influence one another through bi-directional processes, yet longitudinal studies suggest that sleep problems are an antecedent to affective problems and mood disorders, and that these effects may cascade across development (Gregory & O'Connor, 2002; Gregory et al., 2008; Matamura et al., 2014; Shanahan et al., 2014). Inadequate sleep has the potential to disrupt many domains of affective functioning that increase risk for psychiatric disorders. Prior research has found that inadequate sleep may result in more intense negative emotions, less intense positive emotions, and altered emotion regulation abilities that may be less effective at modifying negative emotional responses (Vandekerckhove & Wang, 2018; Watling et al., 2017). Additionally, recent evidence indicates that sleep seems to impact positive emotions more strongly than negative emotions (Alfano et al., 2020; Palmer et al., manuscript under review; Palmer et al., in press; Tomaso et al., 2021), but emotion regulation strategies related to positive emotion have not been explored. The current study will include an experimental sleep restriction paradigm to elucidate how sleep loss, and different types of sleep loss, impact positive affect, emotional reactivity to positive stimuli, and the regulation of positive emotions. This fills a major gap in the literature, which has primarily focused on the regulation of negative emotions as a mechanism underlying sleep-based emotional disruptions.

Impact of Inadequate Sleep on Positive Affect and Positive Emotional Reactivity

Extensive empirical evidence recognizes the comorbidity of sleep problems and affective disorders that are characterized by altered emotional experiences (Alvaro et al., 2013; Simon et al., 2020; Taylor et al., 2005). Sleep disturbances are frequently observed in conjunction with affective dysfunction in both healthy individuals and clinical populations, including generalized anxiety disorder, major depression, bipolar disorder, and post-traumatic stress disorder (PTSD; Alfano et al., 2009; Dahl & Harvey, 2007; Ranum et al., 2019). For example, troubled sleep is a prominent symptom of depression (Fang et al., 2018), which is a disorder characterized by anhedonia and/or experiences of blunted positive affect (Clark & Watson, 1991).

Emotional processes are likely a mechanism linking sleep and psychopathology (Vandekerckhove et al., 2011). Emotional processes include affect, which refers to one's current emotional state (American Psychiatric Association, 2022). Emotional reactivity refers to emotional experiences that are more transient in nature, referring to the relatively temporary changes or reactions to one's subjective experience, behavior, and physiology in response to internal or external events that allows an individual to meet demands in their environment (Gross & John, 2003).

Emotion research historically focused on negative affect and negative emotional processing. Yet, negative emotional experiences only represent one side of the affective coin. An increasing number of empirical studies are being conducted on daily positive experiences and affective processes (Bolger et al., 2003; Gable & Reis 2010; Heininga & Kuppens, 2021; Jose et al., 2012; Starr & Hershenberg, 2017) and the significance of positive affective processing for overall psychological well-being and mental health has been clearly demonstrated.

Altered positive emotional experiences are associated with risk for several psychiatric disorders, such as depression, bipolar, social anxiety, schizophrenia, eating disorders, and substance use (Feldman et al., 2008; Gruber et al.,2008; Heller et al., 2009; Kaye et al., 2009; Watson & Naragon-Gainey, 2010; Yoon et al., 2009). Positive emotion dysfunction also uniquely predicts illness trajectories in psychopathology (Bijttebier et al., 2012; Carl et al., 2013, 2014; Gilbert et al., 2013; Nelis et al., 2016, 2018). Additionally, even in the absence of psychopathology, experiencing positive emotion is important for everyday life and wellbeing. The broaden and build theory posits that positive emotions broaden the scopes of attention, cognition, and behavior, and that positive emotions build physical, intellectual, and social resources. Positive emotions may trigger expanded thought-action repertoires which have indirect, long-term benefits that aid in the development of durable personal resources (Fredrickson, 1998, 2001, 2004).

Further, in addition to affective states that might range from negative to positive (often referred to as valence), emotions can also be organized on a continuum of arousal, which refers to intensity (Russell, 1980). Regarding positive affect, high arousal states including emotions such as excited or proud (Schiebe et al., 2013). On the other end of the spectrum, low arousal positive affect consists of affective states such as calm, relaxed, and content (Fredrickson & Cohn, 2008). Within everyday experiences, most positive affective states consistent of moderate and low arousal (Diener et al., 1985; Scheibe et al., 2013; Zelenski & Larsen, 2000). Notably, low arousal positive affect uniquely predicts life satisfaction, depression, mindfulness, anxiety, and stress above and beyond high arousal positive affect (McManus et al., 2019). However, sleep research has almost exclusively relied on studies examine high arousal positive affect (Tomaso et

al., 2020) using scales such as the Positive and Negative Affective Schedule (PANAS-PA; Watson et al. 1988) or Profile of Mood States (POMS; McNair et al., 1971). Because low arousal positive affect is less frequently measured, it may be that some studies fail to accurately capture the entirety of an individual's positive affective state.

Just as the importance of positive emotion for healthy psychological functioning has been historically neglected in empirical research relative to negative emotion, the relationship between sleep and positive emotion has also been relatively neglected overall (Gilbert, 2012; Ong et al., 2017). However, studies do suggest detrimental effects of sleep disruption on positive mood in adults (Bonnet, 1985; Bouwmans et al., 2017; Buysse et al., 2007; Dinges et al., 1997; Konjarski et al., 2018; Zohar et al., 2005), as well as daily positive emotional reactivity in both healthy and mood-disordered individuals (O'Leary et al., 2017). However, in studies that examine both positive and negative affect together, positive affect appears to be particularly vulnerable to sleep disturbance, more so than negative affect. For example, one study in adolescents found that one night of sleep deprivation resulted in decreased positive affect, but not negative affect (Reddy et al., 2017). Other experimental studies in pediatric and adult studies find similar disruptions to affect, with stronger effects for positive compared to negative affect (Alfano et al., 2020; Talbot et al., 2010; Tempesta et al., 2020; Rossa et al., 2014; Vriend et al., 2013), although most have solely examined high arousal positive affect and have omitted low arousal positive emotions.

Studies in adults further support altered neural and behavioral reactivity to positive stimuli. Gujar and colleagues (2011b) found that sleep deprivation was associated with amplified mesolimbic reward-relevant reactivity toward pleasure-evoking stimuli, and these neural changes were accompanied by an increase in the number of emotional stimuli judged as pleasant. Other

research has suggested that following total sleep deprivation, positive emotional memories are more poorly consolidated, whereas negative emotional memories remain relatively unchanged (Walker, 2009; Walker & Stickgold, 2006). More recently, Tempesta and colleagues (2020) found that five nights of partial sleep restriction more strongly impacted emotional reactivity for positive stimuli compared to negative stimuli. Sleep deprived individuals perceived both pleasant and neutral pictures in a more negative way following sleep-restriction condition, but there were no differences in ratings of negative stimuli. These combined findings contend that sleep loss imposes distinct imbalances to positive emotional processing, more so than negative emotional processing. However, less is known regarding how different types of positive affect (i.e., low and high arousal) are affected by sleep loss, or how the type of sleep loss may influence positive emotional reactivity.

Sleep and Emotion Regulation

Emotion regulation involves a range of explicit and implicit behaviors or cognitions that attempt to control mood/affect or reactivity (i.e., which emotions are experienced, when they occur, and how they are experienced; Gross & Feldman, 2011). Emotion regulation goals frequently include decreasing or increasing the intensity and duration of negative emotion or positive emotion (Gross, 2015; see Figure 1). The most common regulatory goals are pro-hedonic and include decreasing negative emotion or increasing positive emotion. In contrast, contra-hedonic goals including increasing negative emotion or decreasing positive emotion (Wilms et al., 2021). Much more is understood regarding sleep and the ability to down-regulate negative emotions, whereas very little is understood regarding the ability to up- or down-regulate positive emotion following sleep loss.

Figure 1. Example emotion regulation goals (adapted from Gross, 2015)

	Decrease	**Increase**
Negative Emotion	Reappraising a negative event by reflecting on a silver lining	Ruminating on previous failures before an important exam
Positive Emotion	Suppressing laughter while watching a serious film	Reminiscing on a great vacation with a friend

Impaired emotion regulation is characteristic to most clinical models of psychopathology, including anxiety and depression (Clark & Watson, 1991; Hofmann et al., 2012). Many studies find that poor sleep quality and shorter sleep duration contributes to impaired emotion regulation abilities of negative emotions (Gruber & Cassoff, 2014; Mauss et al., 2013; Palmer et al., 2018; Williams et al., 2017). These findings have been replicated across correlational, longitudinal, and experimental research designs (Baum et al., 2014; Cote et al., 2015; Gruber et al., 2012; Reddy et al., 2017; El-Shiekh & Buckhalt, 2005; Tavernier & Willoughby, 2015; Zhang et al., 2019). For example, in adolescents, mild sleep restriction to 6.5 hours leads to increased self-reported emotion regulation problems by both parents and adolescents compared to when sleeping as normal (Baum et al., 2014). As such, emotion regulation has been implicated as a possible mechanism linking sleep loss and psychopathology. Poor sleep impairs emotion regulation, which in turn leads to more psychopathology symptoms, such as depression (Hom et al., 2016; O'Leary et al., 2017; Palmer et al., 2018; Van Beveren et al., 2018). Emotion regulation difficulties and sleep problems are also linked to anxiety disorders (Klumpp et al., 2017; Palmer et al., 2018; Tsypes et al., 2013) and PTSD (Mantua et al., 2018; Pickett et al., 2016).

Given that sleep deprivation profoundly influences executive functions, which are essential for the cognitive control of emotion (Alhola & Polo-Kantola, 2007; Durmer & Dinges, 2005;

Goel et al., 2009; Nilsson et al., 2005), and leads to a reduction in the prefrontal-amygdala connection which aids in emotion regulation processes (Yoo et al., 2007; Krause et al., 2017; Killgore, 2013), these sleep-loss related effects may have an additive influence which contributes to impaired emotion regulation and increased psychiatric risk. In line with these broad neurobiological deficits after sleep loss that may directly impair regulatory abilities, studies have shown that many specific emotion regulation strategies (e.g., rumination; Palmer & Alfano, 2017) are reliably associated with sleep. However, evidence for other emotion regulation abilities (e.g., cognitive reappraisal) is mixed (Mauss et al., 2013; Palmer et al., 2018; Reddy et al., 2017; Schwarz et al., 2013; Shermohammed et al., 2020; Zhang et al., 2019). Given these inconsistencies in the literature across different forms of regulation, there is clear value in exploring how sleep relates to specific strategies and across different emotional contexts.

Currently, several major limitations in the sleep and emotion regulation literature exist. Most notably, despite an emerging body of research showing that sleep loss results in stronger effects on positive emotion compared to negative emotion, studies have focused solely on sleep and the regulation of negative emotion, and it is unknown how sleep may impact the regulation of positive emotions. While some limited longitudinal and experimental data exists (Mauss et al., 2013; Reddy et al., 2017; Schwarz et al., 2013; Shermohammed et al., 2020; Tavernier & Willoughby, 2015; Tomaso et al., 2021), most studies investigating emotion regulation have been correlational in nature and rely on self-reported trait emotion regulation. Studies which primarily rely on self-reported tendency to regulate emotions (i.e., trait level emotion regulation) are likely more susceptible to reporting and recall biases. These studies are different than work which measures an individual's emotional reactivity and ability to regulate emotions in the

moment (Gratz & Roemer, 2004; Gross, 2015; Palmer & Alfano, 2017), which can be measured *in vivo* using behavioral tasks.

Positive Emotion Regulation

A broad term that has been used to categorize strategies that up-regulate positive experiences is savoring. Savoring includes any type of positive emotion regulation strategy which involves attending to positive experiences in a way that serves to generate, maintain, or maximize positive affect (Bryant et al., 2005, 2011; Bryant & Veroff, 2007; Feldman et al., 2008; Gentzler et al., 2010; 2016; Langston, 1994; Tighe et al., 2021). There are three essential components to savoring: it involves a sense of immediacy (i.e., focusing on the present), a focused and mindful connection to the event (i.e., enhanced attentional focus on the pleasurable aspects of the ongoing experience), and feeling unrestricted from societal and/or esteem needs. On the other hand, dampening responses to positive experiences may down-regulate positive affect through cognitive patterns (e.g., downplaying the significance of a positive event; Bryant & Veroff, 2007).

Several aspects of health, including perceived physical health and wellbeing, are positively associated with savoring in adults (Geiger et al., 2017; Hurley & Kwon, 2013; Jose et al., 2012; Palmer & Gentzler, 2019; Quoidbach et al., 2010; Ramsey & Gentzler, 2014; Smith et al., 2020; Smith & Hollinger-Smith, 2015) and youth (Gentzler et al., 2019). Savoring may also extend the affective benefits of positive emotions, which may alleviate symptoms of mental health disorders, such as anxiety and depression (Bryant & Veroff, 2017; Forbes et al., 2009; Parrott, 1993). Conversely, dampening is associated with negative domains of health and psychological wellbeing. For instance, individuals with low self-esteem tend to use dampening strategies more

often to decrease their positive mood, possibly as a way of preserving and maintaining stability within their negative perspectives (Li et al., 2017; Wood et al., 2003). Dampening is related to the maintenance of depressive symptoms (Raes et al., 2012) and both depressed and remitted patients self-report more dampening tendencies compared to healthy individuals (Werner-Seidler et al., 2013). Further, both savoring and dampening have been shown to moderate the relationship between daily life events and depressive symptoms. On days when dampening is high, positive uplifting experiences are less closely associated with positive mood, indicating this type of dampening response to positive affect may serve to disrupt any beneficial emotional aspects of positive experiences. However, on comparatively lower uplifting days, savoring appears to buffer against an increase in depressive symptoms (Li et al., 2017).

In healthy adults, experimentally induced positive emotion regulation strategies increases positive affect (Bryant et al., 2005; Quoidbach et al., 2010). For example, participants were instructed to take a daily 20-minute walk during which they should "try to notice as many positive things around them as they could (e.g., flowers, sunshine, music), to acknowledge each of these things in their mind when they noticed it, and to identify what it was about each thing that made it pleasurable" (Bryant & Veroff, 2007, p. 184–185). Those randomly assigned to take on a positive focus during daily walks showed greater increases in happiness after one week compared to participants assigned to take on a negative focus during daily walks and to those only assigned to take daily walks without instruction. Another intervention, the Positive Affect Sustainment and Simulation (PASS) module, is focused on making the most of positive experiences by using savoring to enhance and sustain positive affective states. At three different time periods across two weeks, participants in the PASS condition were asked to write about a

recent positive experience using specific savoring strategies, such as ‘‘replaying’’ the positive event in their mind while recalling specific details about the event (e.g., sights, sounds, smells). The intervention moderately alleviated depressive symptoms and increased positive affect from pre- to post-participation in adults (McMakin et al., 2011). While many interventions involve multiple sessions or weeks of training, several studies have also successfully induced savoring in the short-term. For example, adults experienced increased positive affect when instructed to up-regulate positive emotion while thinking about a previous positive event compared to those in a neutral control task (Palmer & Gentzler, 2019).

Sleep and Positive Emotion Regulation

To date, the relationship between sleep and positive emotion regulation is largely unknown. Across two correlational studies of undergraduate students, self-reported sleep disturbances were associated with more dampening and less savoring based on self-reported trait questionnaires (Powell et al., 2021). Similar recent correlational findings have also emerged, with negative associations between self-reported sleep disturbance and savoring in adults ages 20-80 years (Tighe et al., 2022) and in adolescents (Bower et al., 2019). However, due to the correlational nature of these designs, it is unclear whether better sleep contributes to an enhanced ability to savor, whether savoring may promote better sleep, or if both sleep and savoring are influenced by other factors (e.g., social experiences, mental health and stress, physical health status).

While savoring has only been tested in a limited capacity relative to sleep, mindfulness studies give some additional clues to the relationship between sleep and positive emotion regulation. Although mindfulness and savoring are distinct constructs, they overlap in several domains, such as actively attending to an experience. Mindfulness is differentiated from savoring

in that savoring is focused specifically on positive emotional experiences (Bryant & Veroff, 2007), whereas mindfulness is centered on non-judgmental awareness and attention to the present moment, whether positive, negative, or neutral (Baer et al., 2006; Kiken et al., 2017). Mindfulness and sleep quality are positively correlated in healthy adults (Ding et al., 2020) and mindfulness may have a buffering effect on affective function following sleep loss (Creswell et al., 2019; Felder et al., 2018; Howell et al., 2008).

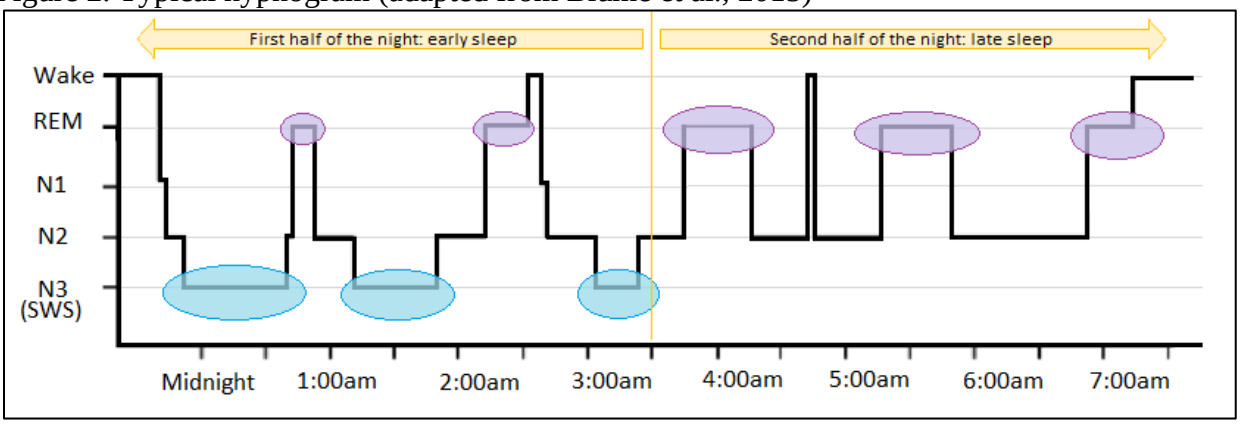
In sum, sleep is robustly linked with altered experiences of positive emotion, including positive mood and reactivity. Positive emotion regulation (i.e., savoring) may be one factor contributing to these differences in positive emotional experiences. However, there is a lack of studies testing associations between sleep and positive emotion regulation, representing a major gap in the research literature. This may be one mechanism by which sleep disruption is associated with reduced experiences of positive affect and long-term mental health difficulties. The current study will examine how experimentally induced sleep restriction changes the ability to increase positive emotion when asked to savor.

Sleep Architecture and Emotional Processes

While sleep loss has been linked with numerous aspects of daytime emotional experiences in prior literature, sleep is not uniform across the night. Sleep architecture refers to the basic structural organization of typical sleep (see Figure 2). There are two types of sleep, non-rapid eye-movement (NREM) sleep and rapid eye-movement (REM) sleep. NREM sleep is further divided into stages N1, N2, and N3. The typical sleep architecture of healthy adults is depicted in Figure 2. The composition of each cycle changes across the sleep period. N1 is typically very brief, lasting only several minutes a night, and is usually only observed at the beginning of sleep.

N2 sleep may last for 10-25 minutes during the first sleep cycle, and each N2 stage become longer throughout the night. Collectively, healthy adults spend about half their sleep time in N2 sleep. N3, or slow wave sleep (SWS), occurs primarily in the first half of the night. During the early sleep cycles, N3 stages commonly last for 20-40 minutes, and decrease in duration throughout the night, giving way to increased time spent in rapid eye REM sleep the second half of the night. Healthy adults typically spend about 20% of the night in SWS and 25% of the night in REM sleep (Ohayon et al., 2004).

Figure 2. Typical hypnogram (adapted from Blume et al., 2015)



Changes to sleep timing and sleep architecture appear to be differentially associated with positive and negative affective processing (Baglioni et al., 2016). However, much of what is understood regarding sleep architecture alterations and affective dysfunction comes from the psychopathology literature (Murkar & De Koninck, 2018; Papadimitriou & Linkowski, 2005). For instance, individuals higher in anxiety experience less SWS (Fuller et al., 1997), and depressed individuals routinely exhibit shortened latency to REM sleep, increased amount of REM sleep, and increased REM density (Palagini et al., 2013). When REM sleep is restricted in

depressed individuals, mood often improves, although improvements are transient, and mood returns to baseline following return to normal sleep (Gillin et al., 2001; Wirz-Justice & Van den Hoofdakker, 1999; Wirz-Justice et al., 2005). Alternatively, when REM sleep is restricted in non-depressed populations the opposite pattern is observed, mood worsens (Glosemeyer et al., 2020). Although emphasis is often placed on REM sleep, reductions in SWS have also been observed in depression (Armitage et al., 2000). In previous research the relationship between sleep loss during different sleep stages and daytime functioning has been investigated through the use of selective sleep restriction or deprivation protocols, which can be achieved through sleep-stage dependent wakings, or through selectively restricting sleep in the first part of the night (primarily restricting SWS) or in the latter half of the night (primarily restricting REM sleep).

The Sleep to Remember, Sleep to Forget (SFSR) model places emphasis on sleep-based memory consolidation, which is presumed to occur during REM sleep (Walker & van der Helm, 2009). REM sleep may be more important for successfully processing memories for emotionally salient experiences and de-coupling the emotional tone from an associated memory, and this may in turn benefit next day emotional reactivity and regulation. That is, REM sleep may also aid in recalibrating one's sensitivity to specific emotions the subsequent day and function to set a "clean slate" in preparation for the emotional events of the next day. Reactivity to negative stimuli is amplified throughout the day without sleep, but participants who reached REM sleep during an intervening nap experienced decreased negative emotional reactivity and enhanced positive reactivity (Gujar et al., 2011a). While associations between REM sleep and positive emotion and emotion regulation specifically have not been explored, it may be that the sleep-

related consolidation of emotionally salient memories paired with the decoupling of emotional tone that occurs during REM sleep re-modulates emotional reactivity, thus benefitting next-day emotion reactivity and regulation of positive emotions.

Few studies have assessed sleep architecture alterations and positive emotional reactivity or regulation in healthy sleepers. Finan and colleagues (2015) evaluated changes in mood and sleep architecture following a forced awakening (FA) experimental manipulation versus a restricted sleep opportunity comparison condition (RSO). Because the RSO condition and FA condition were matched in overall amount of sleep loss, the primary difference between groups was the type of sleep that was manipulated in their experimental design. FA produced a larger reduction in SWS compared to RSO, and the change in SWS mediated the effect of FA on positive mood. In another study (Finan et al., 2017), one night of FA decreased positive affect and a significant amount of variance in this effect was also accounted for by reductions in SWS. Moreover, FA decreased attentional bias to positive affective stimuli. However, Finan and colleagues (2017) additionally found in the that within-subject changes in REM sleep also mediated the effects of sleep condition on positive affect, indicating that SWS may not uniquely contribute to the effect of sleep loss on positive affect. Building on these findings, a recent meta-analysis suggests that SWS loss results in a significant reduction in positive affect, but loss of REM sleep does not (Palmer et al., under review).

In sum, some evidence suggests that REM sleep may be important for subsequent emotional functioning (e.g., Gujar et al., 2011), and some experimental evidence strongly suggests that SWS may be particularly important for positive affect, but studies examining the role of SWS loss compared to REM sleep loss on emotional outcomes are still limited. The present study aims

to test this hypothesis by comparing the effect of selective REM sleep restriction and selective SWS restriction on positive mood/affect, emotion reactivity, and emotion regulation the following day.

Current Study

Building on studies suggesting that sleep loss may more strongly impact positive compared to negative emotions, and preliminary correlational evidence showing that subjective sleep quality is associated with self-reported savoring (Bower et al., 2019; Powell et al., 2021), the goal of the current study was to understand the effects of selective REM sleep restriction and/or selective SWS restriction on next-day positive affect, emotion reactivity, and positive emotion regulation, compared to a night of healthy sleep. This study uses a split-night protocol, which have been found to differentially restrict SWS (early sleep restriction, ESR) or REM (late sleep restriction, LSR; Casey et al., 2016; Gais et al., 2000; Menz et al., 2016; Parry et al., 2019; Tilley & Wilkinson, 1984; Wagner et al., 2001; Wu et al., 2008, 2010).

First, replicating prior research, this study measures the effect of restricted sleep compared to healthy sleep on positive affect and positive emotional reactivity, but building on prior studies also measures the effect of restricted sleep on both low and high arousal positive affect. Second, extending prior research that has primarily focused on the regulation of negative emotions, this study examines how sleep loss may influence the regulation of positive emotions. Finally, the use of a split-night sleep restriction protocol addresses the current gap in understanding the differential influence of loss of SWS and REM sleep on positive emotional experiences.

Aim 1

Replicating prior experimental research, this study examined how sleep restriction impacts positive mood compared to healthy sleep. Expanding on prior research suggesting that SWS may have more profound effects on positive affect, the role of SWS or REM sleep and effects on low and high arousal positive affect will also be examined (e.g., Finan et al., 2017, 2019).

Aim 1, Hypothesis 1a. Sleep restriction will lead to lower levels of high arousal positive mood compared to a healthy night of sleep.

Aim 1, Hypothesis 1b. Reductions in high arousal positive mood following sleep restriction will be stronger for the ESR group compared to the LSR group.

Aim 1, Hypothesis 2a. Sleep restriction leads to lower levels of low arousal positive mood compared to a healthy night of sleep.

Aim 1, Hypothesis 2b. Reductions in low arousal positive mood will be stronger for the ESR group compared to the LSR group.

Aim 2

The second aim of this study was to examine how sleep restriction impacts positive reactivity compared to healthy sleep and to explore differential effects of SWS and REM loss. Positive emotional reactivity was measured using reports of valence (i.e., degree of feelings of pleasantness vs. unpleasantness), arousal, high arousal positive affect, and low arousal positive affect after being presented with positive emotional stimuli (i.e., positive movie clips).

Aim 2, Hypothesis 1a. Sleep restriction will lead to reports of reduced pleasantness (e.g., valence reports) in response to positive emotional stimuli compared to a healthy night of sleep.

Aim 2, Hypothesis 1b. Participants in the ESR group will experience the largest reductions in valence ratings after sleep restriction, compared to the LSR group.

Aim 2, Hypothesis 2a. Sleep restriction will lead to lower reports of arousal compared to a healthy night of sleep in response to positive emotional stimuli, indicating a reduction in arousal.

Aim 2, Hypothesis 2b. The reduction in arousal after sleep restriction will be strongest for those in the ESR group compared to the LSR group.

Aim 2, Hypothesis 3a. Sleep restriction will result in lower levels of high arousal positive emotion in response to positive emotional stimuli compared to a healthy night of sleep.

Aim 2, Hypothesis 3b. The reductions in high arousal positive emotion in response to positive stimuli after sleep restriction will be strongest for those in the ESR compared to the LSR group.

Aim 2, Hypothesis 4a. Sleep restriction will lead to reductions in low arousal positive emotion in response to positive emotional stimuli compared to a healthy night of sleep.

Aim 2, Hypothesis 4b. Participants in the ESR will experience greater reductions in low arousal positive emotion in response to the emotional stimuli compared to participants in the LSR group.

Aim 3

The third and final aim was to examine how sleep restriction impacts the ability to up-regulate positive emotions (i.e., savor) compared to healthy sleep and explore how SWS and REM differentially affect positive emotion regulation using a behavioral savoring task (i.e., instructions to savor while viewing positive movie clips). The effectiveness of the up-regulation

of positive emotion was measured using reports of valence, arousal, high arousal positive affect, and low arousal positive affect. After the task, participants also reported on their actual savoring and dampening during the task.

Aim 3, Hypothesis 1a. Sleep restriction will lead to a reduction in reports of pleasantness (i.e., valence) after being asked to savor compared to a healthy night of sleep.

Aim 3, Hypothesis 1b. Participants in the LSR group will experience less of a reduction in valence reports after sleep restriction compared to the ESR group.

Aim 3, Hypothesis 2a. Sleep restriction will lead to lower levels of reported general arousal compared to a healthy night of sleep when participants are asked to savor.

Aim 3, Hypothesis 2b. Participants in the ESR will experience greater reductions in arousal compared to those in the LSR group.

Aim 3, Hypothesis 3a. Sleep restriction will result in reductions in high arousal positive emotion when instructed to savor compared to a healthy night of sleep.

Aim 3, Hypothesis 3b. Participants in the ESR group will experience larger reductions in high arousal positive mood when savoring after sleep restriction compared to participants in the LSR group.

Aim 3, Hypothesis 4a. Sleep restriction will lead to a reduction in low arousal positive emotion in response to savoring when compared to a healthy night of sleep.

Aim 3, Hypothesis 4b. Participants assigned to the ESR group will experience greater reductions in low arousal positive emotion when savoring after sleep restriction when compared to participants in the LSR group.

Aim 3, Hypothesis 5a. Compared to a night of healthy sleep, participants will self-report engaging in less savoring and more dampening strategies during the savoring task after a night of sleep restriction.

Aim 3, Hypothesis 5b. After a night of sleep restriction, participants in the ESR group will experience greater reductions in savoring and more dampening during the savoring task based on self-reported strategy use compared to those in the LSR group.

METHOD

Participants

The current study utilized a within-subjects, counterbalanced, crossover design. Participants were undergraduate students recruited through the Montana State University SONA system. Participant age ranged between 18 - 25 years old (M = 19.03, SD = 1.49). Half of were female (n = 17) and the majority identified as white (n= 30, 88.24%; Biracial or mixed race, n = 3, 8.82%; Other, n = 1, 2.94%) and ethnicity was primarily non-Hispanic (n = 33, 97.06%).

Inclusion and Exclusion Criteria

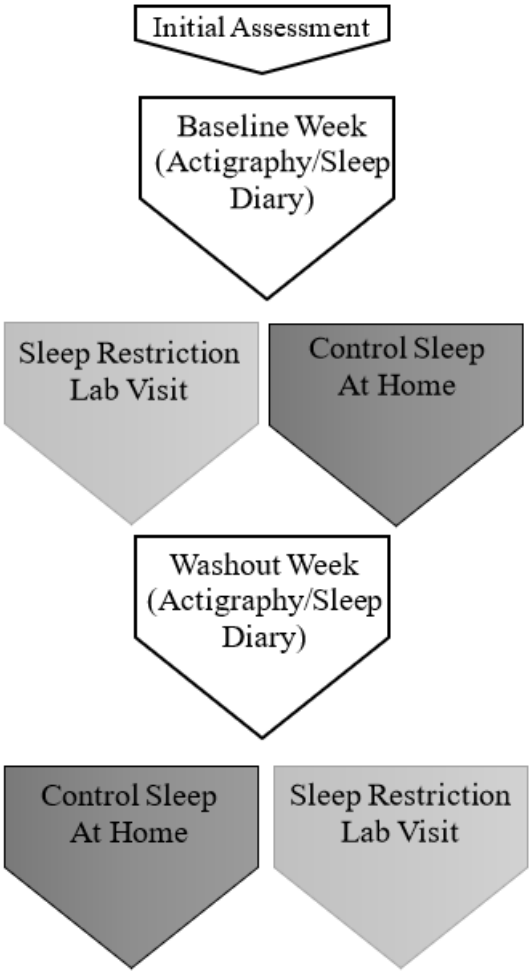
To be included in the study participants were required be a non-smoker/nicotine user, low caffeine user (< 2 cups of coffee or equivalent per day), maintain a regular sleep schedule with sleep onset and offset times within 21:00 and 10:00 with an average normal bedtime between 21:00-24:00 (based on self-report at the in-take assessment and actigraphy during the first week of actigraphy), a Pittsburgh Sleep Quality Index Total score < 5, a self-reported and actigraphy-measured average sleep duration of 7+ hours a night, but no more than 11 hours (Hirshkowitz et al., 2015), and an Epworth Sleepiness Scale score < 10. Additional exclusion criteria included a current diagnosis of any psychiatric or sleep disorder (based on self-report), a suspected sleep disorder (determined by a structured clinical interview), any chronic illness or medical condition that impacts their sleep (e.g., TBI, epilepsy, psoriasis, GERD, asthma), or the current use of any medications affecting sleep and/or mood (e.g., SSRIs). Individuals who have a BMI of greater than 35 or who were currently pregnant were also excluded, because obesity and pregnancy have been associated with poor sleep quality (Beccuti & Pannain, 2011; Facco et al., 2010). These

inclusion and exclusion criteria were chosen to ensure that participants are relatively healthy sleepers and to minimize any chronic sleep restriction that may occur leading up to the experimental night (Finan et al., 2017). Participants who completed the study and returned all study equipment received extra credit for a psychology course.

Procedure

The first portion of the study was an in-lab preliminary in-take screening. After completing informed consent, height and weight was measured, and participants completed a series of questionnaires which assessed demographics, sleep patterns, and other inclusion/exclusion criteria, surveys about mood and affect, and a structured diagnostic sleep interview. Participants then completed the first baseline week (approximately 7 nights) of actigraphy to verify that typical sleep was within the appropriate window (21:00 to 10:00) and to ensure a healthy sleep duration leading up to the first experimental night. During this week of actigraphy, participants also completed sleep diaries each morning and evening to verify and account for any artifacts in the actigraphy data.

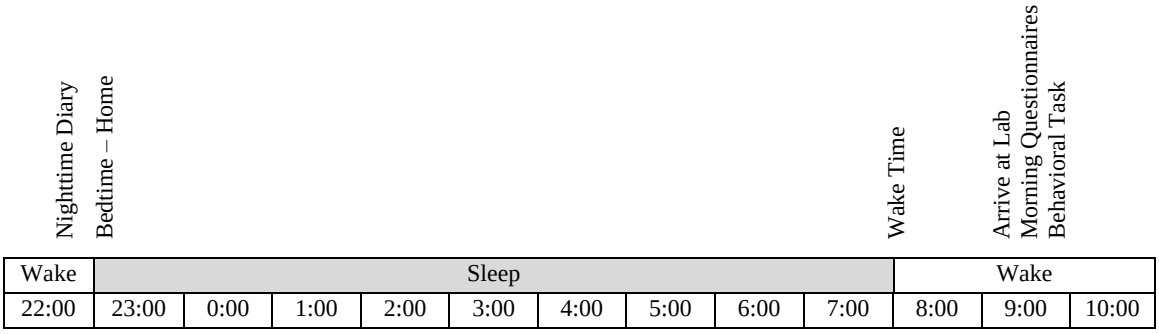
Figure 3. Experimental Overview



Participants were randomly assigned to a sleep restriction condition (ESR or LSR) and to a counterbalanced order (sleep restriction or control night first) after their first assessment. Participants wore an actigraph during both the control and experimental night to verify compliance with the assigned sleep condition. Participants were masked to the order of their conditions until the morning of their experimental night and were also masked to their group until they arrived in the lab for the sleep restriction night. Participants served as their own controls and completed their control night at home, where they were allowed up to a 9-hour sleep

opportunity (Figure 4). Sleep studies commonly use at-home sleep protocols and verify compliance with objective actigraphy data (Dickinson & McElroy, 2017; Gerhadsson et al., 2018; Stroemel-Scheder & Lautenbacher, 2021).

Figure 4. Control night sleep



Sleep was restricted between-subjects in the laboratory using a split-night sleep restriction paradigm to target the restriction of either 1) SWS (in the ESR condition), or 2) REM (in the LSR condition). Sleep restriction models sleep loss in a way that may have greater ecological validity than total sleep deprivation, such that sleep restriction is more like the type of real-world sleep loss that individuals are likely to experience (Tilley & Wilkinson, 1984). The effectiveness of split-night protocols is based on the sequential and partially circadian-dependent nature of SWS and REM sleep. The first half of the night is largely dominated by SWS, whereas REM sleep is dominant in the second half of the night. Studies vary slightly in their split-night SR methodology; however, most studies restrict sleep in line with the methodology adopted in this study (Casey et al., 2016; Gais et al., 2000; Menz et al., 2016; Parry et al., 2019; Tilley & Wilkinson, 1984; Wagner et al., 2001; Wu et al., 2008, 2010).

During the early sleep restriction (i.e., early-night wake time; ESR) condition participants experienced later sleep timing and were allowed to sleep between 4:00 – 8:00 am, in the late sleep restriction (LSR) participants were allowed to sleep between 23:00 – 3:00 (see Figures 5 and 6). In the day leading up to their control night and in-lab overnight visit, participants were restricted from napping, caffeine use, alcohol use, any drug/medication use or nicotine use, and strenuous physical activity. Participants were provided standardized snacks, caffeine-free drinks, and a standardized breakfast during their time in the lab.

Figure 5. Early sleep restriction condition

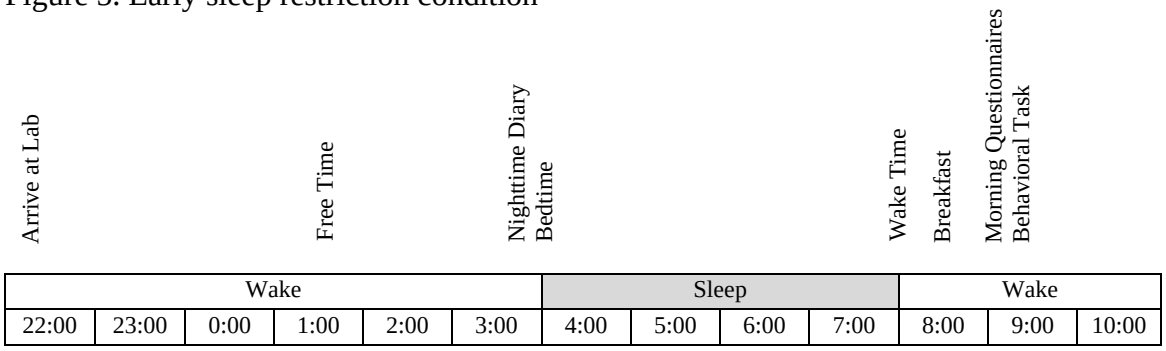
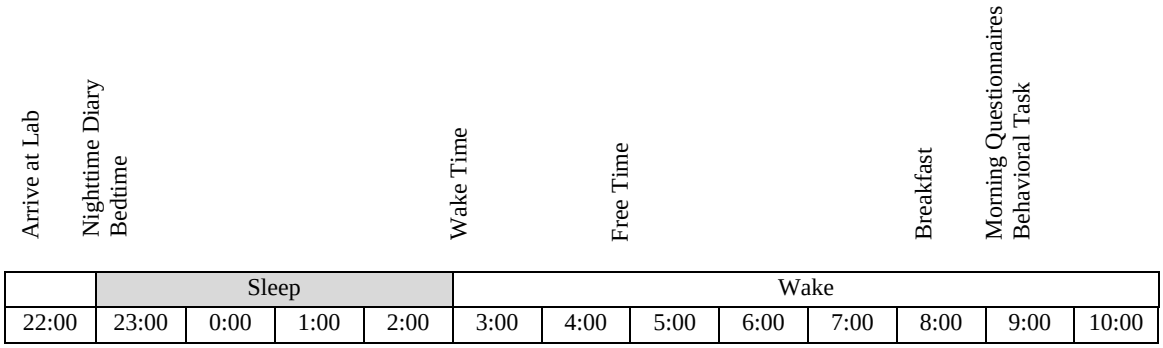


Figure 6. Late sleep restriction condition



The second portion of the study consisted of a second week of home sleep monitoring, which served as a washout week for participants who underwent a sleep restriction paradigm in their first night and to again ensure that participants are well-rested leading up to the second experimental night.

Following each overnight, participants completed a behavioral assessment, including questionnaires and a positive emotion reactivity and savoring task. The behavioral assessment began at approximately 9:00 (1 hour after waking for the control and ESR conditions, and approximately 5 hours after waking for the LSR condition). This maintained a consistent time for the behavioral assessment across conditions/groups, based on well-documented circadian effects on positive affective experiences (Hasler et al., 2012; Miller et al., 2015). At the beginning of the behavioral assessment, participants completed a series of questionnaires on an iPad or tablet about their sleepiness and mood.

After completing the questionnaires, participants viewed a series of positive emotion film clips. Each video clip ranged from 1:45-3:00 minutes in length, and participants viewed a total of 6 randomized videos during each morning assessment. They viewed 6 different videos at each morning assessment. Half of these videos were preceded by instructions to just watch the video as usual. The other half of the videos were preceded by instructions to savor the video. All videos were chosen to be similar in content (i.e., nature-focused, no humans and minimal attention to wildlife) and were selected based on normative affective ratings. From an original pool of 30 videos, 10 individual raters viewed and rated each video on valence, arousal, and high and low arousal positive affect. Raters also gave feedback on the accompanied music and tone of the videos. Scores were averaged across raters, and 12 videos were selected for the experimental

task based on valence (M = 6.3, range = 6.00 – 6.89), general arousal (M = 4.67, range = 3.89 – 5.22), high arousal positive affect (M = 26.73, range = 21.67 – 32.89) and low arousal positive affect (M = 10.34, range = 9.00 – 12.44). Nature-related stimuli were chosen based on prior savoring research that has focused on nature-related experiences (e.g., savoring walk interventions; Bryant et al., 2011; Bryant & Veroff, 2007; Sato et al., 2018) and research which shows nature-based scenery is sufficient to induce both high and low arousal positive emotion (Maffei & Angrilli, 2019; Sato et al., 2018). The order of the videos across the two assessments, and within assessment, was randomized to minimize any order effects. Additionally, video instructions (savor/up-regulate or view neutrally) was randomized across all videos.

The neutral instructions provided an opportunity to assess positive emotion reactivity (without explicit instructions to regulate emotions). The instructions that displayed preceding the neutral/reactivity videos stated: "You are about to see a short video clip. During this clip, watch the video as usual." The savoring instructions were adapted from previous savoring interventions, which ask participants to focus on the positive details of the experience (Bryant et al., 2011; Bryant & Veroff, 2007). The specific savoring instructions preceding the savoring videos stated: *"*While you are watching this video, try to notice and explicitly acknowledge each image or sensation that you find pleasurable. Identify your positive feelings and explicitly label them in your mind. Actively build a memory of the positive experience associated with what you are viewing" (edited from Bryant & Veroff, 2007). Short-term savoring interventions such as this have generated momentary increases in positive affect in previous studies (Palmer & Gentzler, 2018; Palmer & Gentzler, 2019; Palmer et al., in press).

After each video, participants provided a brief report of how they were currently feeling, using the Self-Assessment Manikin (Bradley & Lang, 1994) in which participants were asked to rate the valence, or pleasantness, of the emotional state elicited by the clip, and the arousal experienced while viewing videos. Participants also reported on how they were currently feeling using the PANAS-PA and PANAS-Serenity scales.

At the conclusion of the videos, participants were asked about their savoring (5 items) and dampening (5 items) during the behavioral task using a modified state version of the Responses to Positive Affect scale (Feldman et al., 2008).

Measures

Initial Assessment Questionnaires

Structured Clinical Interview for Sleep Disorders-Revised (SCISD-R). The SCISD-R is a semi-structured interview for diagnosing sleep disorders according to the Diagnostic Statistical Manual, fifth edition (APA, 2022). The SCISD-R assesses medical and mental health history in addition to sleep patterns and allows researchers to systematically obtain sleep history and identify the presence of suspected sleep disorders. Further, the SCISD-R covers medications and substances that can impact sleep including indicator of the substance, how often it is taken or used, dose, and duration of use. The sleep symptoms assessed include symptoms consistent with insomnia, hypersomnolence disorder, circadian rhythm sleep-wake disorders, obstructive sleep apnea (OSA), hypopnea syndrome, restless legs syndrome, nightmare disorder, REM sleep arousal disorders, REM sleep behavior disorder, and narcolepsy (Taylor et al., 2018).

The interview includes a minimum of 20 and to up to 51 questions depending on the participant's responses and takes 10 to 20 minutes to administer. The SCISD has excellent

interrater reliability for insomnia (r = 1.0) and restless legs syndrome (r = 0.83); very good reliability for nightmare disorder (r = 0.78) and obstructive sleep apnea hypopnea (r = 0.73); and good reliability for hypersomnolence (r = 0.50) and circadian rhythm sleep-wake disorders (r = 0.50; Taylor et al., 2018). The current version, the SCISD-R, was revised to be consistent with the DSM-5 (Pruiksma et al., 2020). Participants completed this interview with a trained research assistant to determine eligibility.

Pittsburgh Sleep Quality Index (PSQI). Participants completed the PSQI (Buysse et al., 1989), which consists of 19 self-rated items which cover seven domains of sleep quality in the past month: sleep latency, sleep duration, sleep disturbances, use of sleep medication, daytime dysfunction, subjective sleep quality and habitual sleep efficiency. The seven domain scores are summed to yield a global PSQI score, where a score >5 indicates poor sleep (Buysse et al., 1989). The PSQI has strong internal consistency (Cronbach's α = .70 - .83; Mollayeva et al., 2016), and good convergent and divergent construct validity (r = .69 - .77; Carpenter & Andrykowski, 1998).

Epworth Sleepiness Scale (ESS). The ESS is a widely used subjective measure of trait daytime sleepiness, which participants completed to determine eligibility. The measure consists of a list of eight situations in which an individual rates their tendency to become sleepy on a scale of 0, no chance of dozing, to 3, high chance of dozing. Scores can range from 0 to 24. A higher ESS score reflects a higher average sleep propensity in daily life, or higher daytime sleepiness. The questionnaire has a high level of internal consistency (Cronbach's α = 0.88; Johns, 1991) and is a reliable measure of day-time sleep propensity (*rho* = .56; Johns, 1994).

Positive and Negative Affect Schedule-Expanded Form. The Positive and Negative Affect Schedule-Expanded Form (PANAS-X; Watson et al., 1988; Watson & Clark, 1994, 1997, 1999), which is a 60-item self-report instrument that comprises a positive affect scale, a negative affect scale, and 11 additional affective subscales. Participants completed the high arousal positive affect, low arousal positive affect, and negative effect subscales. Participants were asked to indicate to what extent they are feel a particular emotion over the last week on a 5-point Likert scale, where 1 = "Very Slightly or Not at All" and 5 = "Extremely" (Watson et al., 1988; Watson & Clark, 1994, 1999). The PANAS-X has been well-validated with Cronbach's α ranging from .75-.94 for all subscales. Ample evidence supports the discriminant validity of the positive affect scales, and it has been shown to be a reliable measure for repeated-measures designs (Boyle et al., 2015).

Additional Measures. Several additional measures during the intake were collected as a part of this project for future analyses, although they are not included in the current proposal. This includes measures of psychiatric symptoms, emotional experiences, and sleep patterns including the Brief Symptom Inventory (Derogatis & Melisaratos, 1983), Center for Epidemiological Studies Depression Scale-Revised (CESDS-R; Radloff, 1977), State Trait Anxiety Inventory (STAI; Spielberger et al., 1983), Dispositional Positive Affect Scale (DPAS; Shiota et al., 2006), Response to Positive Affect scale (RPA; Feldman et al., 2008), Savoring Beliefs Inventory (Bryant, 2003), Snaith-Hamilton Pleasure Scale (Snaith et al., 1995), Behavioral Inhibition and Activation Scale (Carver & White, 1994), Temporal Experience of Pleasure Scale (Gard et al., 2006), and the Smith Composite Scale of Morningness (Smith et al., 1989).

At-Home Measures and Experimental Night Measures

Sleep Diary. Participants completed the National Sleep Foundation (NSF) Sleep Diary during the actigraphy weeks in the morning upon waking and at nighttime prior to going to bed (National Sleep Foundation, 2021). The NSF sleep diary is commonly used in sleep research, and sleep diaries are necessary to help identify artifacts and/or discrepancies in actigraphy data. Participants were provided with a printed QR code for the morning and nighttime diary that they could keep next to their bed, which they could scan with any smart phone or internet-capable tablet. Electronic sleep diaries present several benefits in comparison to paper sleep diaries, such as automated scoring and reducing "parking lot syndrome", when an individual retrospectively completes several diary days at the same time prior to returning them to the lab. Sleep diaries were be used in this to verify actigraphy data (Carney et al., 2012). Participants also completed brief measures of state savoring, emotion regulation, and affect during the evening sleep diaries.

Actigraphy. Actigraphy is an objective and non-invasive measure of movement that can be used to distinguish between sleep and wake states. These accelerometer-based devices are worn on the wrist, similar to a wristwatch, and feature an event marker using a small button on the side of the actigraph face to determine periods when the participant is in bed (Ancoli-Israel et al., 2003). Validation studies comparing actigraphy devices to polysomnography report agreement rates that range between 85-95% (Sadeh, 2008, 2011; Rupp & Balkin, 2011, Meltzer et al., 2012; Weiss et al., 2010). Actigraphs (Micromotion Loggers, Ambulatory Monitoring, Inc.) were provided to participants during their initial lab visit and were worn continuously, 24-hours a day throughout the experiment, apart from bathing and/or swimming. During the initial lab visit participants were instructed on how to use the actigraph, including how to properly care for it and when to press the event marker (e.g., when going to bed, waking up, prior to removing

for showering, etc.) throughout the experiment. Actigraphs were worn during the baseline and washout weeks to ensure healthy sleep duration and timing, and to ensure compliance with nap restrictions. Participants also wore the actigraph watch on the experimental and control nights to ensure compliance with the assigned sleep condition.

In-Lab Morning Questionnaire

Karolinska Sleepiness Scale (KSS). The KSS measures the subjective level of sleepiness at a particular time during the day. The KSS is not a measure of 'trait' sleepiness, rather it is a measure of sleepiness in the moment (Akerstedt & Gillberg, 1990). It is a 10-point scale (1 = extremely alert, 2 = very alert, 3 = alert, 4 = Rather alert 5 = neither alert nor sleepy, 6 = some signs of sleepiness, 7 = sleepy, but no effort remaining awake, 8 = Sleep, but some effort to remain awake, 9 = extremely sleepy, great effort to keep awake, fighting sleep, 10 = extremely sleepy, can't remain awake) and scores on the KSS increase with longer periods of wakefulness. The KSS is widely used by researchers and clinicians and is highly correlated to electroencephalographic (EEG; r = .26-.40) and behavioral variables that also measure alertness (r = .56; Akerstedt & Gillberg, 1990; Horne & Baulk, 2004; Kaida et al., 2006).

Positive Affect. Positive affect was measured on the morning after each sleep manipulation and also after each video using a subset of the PANAS-X (Watson et al., 1988; Watson & Clark, 1994, 1997, 1999). Participants were asked to indicate to what extent they are feeling a particular emotion "right now" on a 5-point Likert scale, where 1 = "Very Slightly or Not at All" and 5 = "Extremely". Participants report on the positive affect subscale, which was designed to measure high and moderate positive affect (10 items: attentive, active, alert, excited, enthusiastic, determined, inspired, proud, interested, strong), which assesses primarily high and

moderate arousal positive affect. To measure low arousal positive affect, the serenity subscale was used (3 items: calm, relaxed, and at ease), which measures low arousal positive affect.

Valence and Arousal. Valence and arousal were measured using a Self-Assessment Manikin (SAM), which is a non-verbal graphic-based assessment that measures emotional states, such as pleasantness (valence) and arousal (Bradley & Lang, 1994; Bynion & Feldner, 2020). Low valence values represent feeling more pleasant and higher values represent feeling more unpleasant. Lower arousal values represent feeling more excited (e.g., more aroused) and higher values represent feeling more calm (less aroused).

Savoring and Dampening. At the conclusion of all 6 videos, participants were asked about their savoring and dampening during the behavioral task using a modified state version of the Responses to Positive Affect scale (Feldman et al., 2008). Each item was presented, and participants were asked to indicate: "During the task, when you were asked to "notice and explicitly acknowledge each image or sensation that you find pleasurable, identify your positive feelings and explicitly label them in your mind, and actively build a memory of the positive experience associated with what you are viewing", did you…" on a scale of 1 – 4 where 1 = Almost never, 2 = Sometimes, 3 = Often, and 4 = Almost always. The 6 savoring items were: Think about how happy you feel, think about how strong you feel, think about how you feel up to doing everything, notice how you feel full of energy, savor the moment, and think about how proud you are of yourself (Cronbach's $\alpha = 0.84$). The 4 dampening items were: Think "I don't deserve this", remind yourself these feelings won't last, think "this is too good to be true", and think about how hard it is to concentrate (Cronbach's $\alpha = 0.42$).

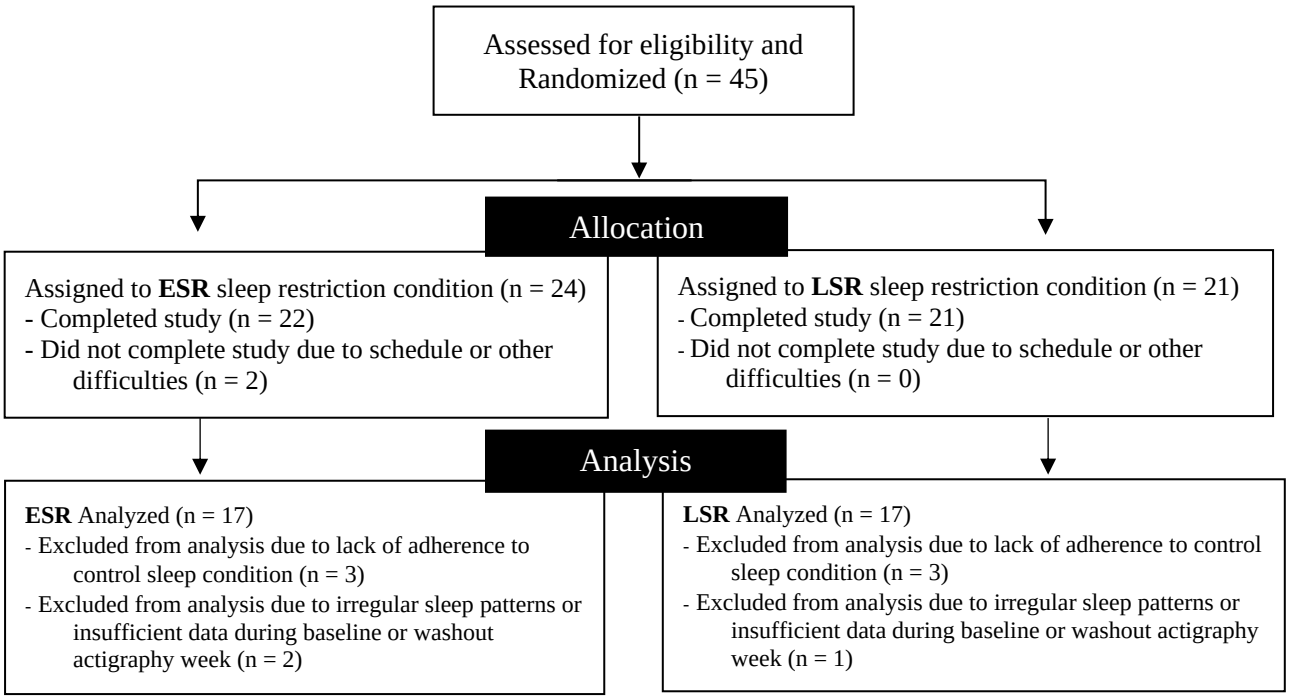
Power, Sample Size, and Missing Data

Sample size was calculated *a priori* using MorePower (Campbell & Thompson, 2012). The suggested sample size was 36 to detect a large mixed effect using a partial eta² = .18, 80% power, and 5% error probability. The effect size estimate was based on a prior meta-analysis (Tomaso et al., 2021) which reported a large effect of sleep loss on positive mood (hedges g = -.93). The magnitude of Hedges' g is interpreted using the conventions of small (0.2), medium (0.5), and large (0.8); transformation to partial eta² for MorePower analyses was done using Lenhard and Lenhard's (2016) effect size calculator.

Forty-three participants completed the full two weeks of data collection. Nine total participants were removed from analyses. Six of these participants were removed because they slept less than 7 hours on their control night, 2 were removed due to irregular sleep schedules during baseline/washout week, and 1 was removed because they slept less than 7 hours on their control night and also had an irregular sleep schedule during baseline/washout week. Figure 7 shows a flow chart of participants, including when and why individuals were excluded.

Thirty-four participants were eligible to be included in the final analyses. Two additional participants were removed from analyses for Aim 2 and Aim 3 due to missing savoring behavioral task responses after either their control or experimental nights. Missing behavioral task data was due to program errors when utilizing e-prime to run the task.

Figure 7. Screening and participation



Analytic Plan

The current study is a mixed 2 x 2 x 2 design, with participants serving as their own controls. The type of sleep restriction, early sleep restriction (ESR) versus late sleep restriction (LSR), was manipulated between-subjects using random assignment. Sleep condition (sleep restriction versus healthy control night) was randomly counterbalanced for each participant across their two overnights, and emotion regulation during the behavioral task (savoring versus neutral/reactivity) was manipulated within-subject by randomizing presentation throughout the behavioral assessment (Finan et al., 2017).

First, to ensure that the sleep restriction manipulation was successful, differences in the sleepiness (measured using the KSS) following overnight lab visits were compared using a paired samples t-test. Significantly higher KSS scores (i.e., greater sleepiness) were expected

following the sleep restriction condition compared to a normal night of sleep. Additionally, differences in total sleep duration collected by actigraphy was analyzed across conditions using paired and independent samples *t*-tests to verify compliance with the sleep restriction and control night conditions, and to assess any differences in sleep that occurred across the ESR and LSR conditions. It was expected that participants would sleep significantly less in the sleep restriction condition (4-hour sleep opportunities) compared to control night (9-hour sleep opportunity). It was also expected that the total sleep duration from the ESR and LSR would be similar to one another. Differences that emerged in total sleep duration in the LSR and ESR conditions on the experimental night were controlled for in all analyses. Other sleep variables extracted from actigraphy, including sleep timing, sleep onset latency, sleep efficiency, and wake after sleep onset were also examined across conditions.

To determine if the behavioral savoring task successfully increased positive affect, a series of paired *t*-tests were conducted on the differences in the savoring versus neutral/reactivity conditions in high arousal positive affect, low arousal positive affect, arousal, and valence. Significantly greater pleasantness, arousal, high arousal positive affect, and low arousal positive affect are expected following savoring as compared to neutral reactivity videos. Between-group comparisons (independent samples *t*-tests) were also conducted on all intake sleep measures, sociodemographic characteristics, and emotion measures to ensure that random assignment to the ESR and LSR condition was successful. Preliminary analyses also consisted of basic data checks for outliers and assumptions of normality, homogeneity of variance, and sphericity.

To address the first aim of the current study and replicate previous studies that examine how sleep restriction impacts positive affect compared to healthy sleep and expand on research

suggesting that SWS may have more profound effects on positive affect compared to other types of sleep, two 2 (sleep condition: restriction versus control) x 2 (SR type: ESR versus LSR) mixed ANOVAS were conducted, with high arousal and low arousal positive affect (measured using the PANAS) as outcome variables. Main within-subject effects of sleep condition are expected, such that low arousal positive affect and high arousal positive affect would be reduced following a night of restricted sleep compared to a healthy night of sleep (Aim 1, Hypotheses 1a and 2a). Additionally, an interaction between condition and restriction type was expected, such that high and low arousal positive affect would be reduced to a significantly further extent following ESR as compared to LSR (Aim 1, Hypotheses 1b and 2b).

To address the second aim, how sleep restriction affects positive emotion reactivity, a series of 2 (SR type: ESR versus LSR) x 2 (sleep condition: restriction versus control) mixed ANOVAs will be conducted for neutral task videos only, with valence, arousal, high arousal positive affect, and low arousal positive affect as outcome variables. It was expected that valence, arousal, high arousal positive affect, and low arousal positive affect would be reduced following a night of restricted sleep compared to a healthy night of sleep reflecting lower emotional reactivity (Aim 2, Hypotheses 1a, 2a, 3a, & 4a). Additionally, valence, arousal, high arousal positive affect, and low arousal positive affect would show greater reductions in the ESR compared to the LSR group, reflecting lessened emotional reactivity when SWS is reduced compared to when REM is reduced (Aim 2, Hypotheses 1b, 2b, 3b, & 4b).

To examine the third aim of the study, how sleep restriction impacts savoring and explore how SWS and REM sleep restriction effect the regulation of positive emotions, series of 2 (SR type: ESR versus LSR) x 2 (sleep condition: restriction versus control) x 2 (task: reactivity

versus regulation) mixed ANOVAs will be conducted, with valence, arousal, high arousal positive affect, and low arousal positive affect as outcome variables. It was expected that a two-way interaction between sleep condition and regulation will emerge, where participants would experience increased valence, arousal, high arousal positive affect, and low arousal positive affect after savoring compared to the reactivity condition, but this effect would be smaller after sleep restriction compared to a night of healthy sleep (Aim 3, Hypotheses 1a, 2a, 3a, 4a). A two-way interaction between SR type and regulation was also expected, LSR participants would experience increased valence, arousal, high arousal positive affect, and low arousal positive affect after savoring compared to the reactivity condition and compared to reactivity and regulation conditions following ESR (Aim 3, Hypotheses 1b, 2b, 3b, 4b).

Additionally, a three-way interaction between condition, task, and sleep restriction type was expected to emerge. While it was expected that all participants will experience a reduction, in valence, arousal, high arousal positive affect, and low arousal positive affect when savoring after sleep restriction compared to a night of healthy sleep, it was expected that this reduction would be greatest for the ESR group. In other words, compared to the LSR, the ESR group would experience greater reductions in valence, arousal, high arousal positive affect, and low arousal positive affect when savoring compared to the reactivity condition after sleep restriction.

Finally, to examine participants subjective savoring and dampening experiences during the savoring task, two 2 (SR type: ESR versus LSR) x 2 (sleep condition: restriction versus control) mixed effects ANOVAs were conducted, with self-reported savoring and dampening after the task as outcome variables. It was expected that in both models, main effects of condition would emerge, and participants would report that they engaged in less savoring and more

dampening after sleep restriction compared to a healthy night of sleep (Aim 3, Hypothesis 5a). Additionally, an interaction between condition and sleep restriction type was expected to emerge, where the ESR would experience greater reductions in savoring and greater increases in dampening after sleep restriction after sleep restriction when compared to the LSR group (aim 3, Hypothesis 5b).

RESULTS

Preliminary Analyses

Descriptive statistics are presented for all intake variables, across both sleep restriction groups and conditions in Table 1. Participants in the two sleep restriction conditions, ESR and LSR, were not significantly different in age (t = 1.53, df = 32, p = 0.14, 95 % CI = -0.25, 1.78), PSQI (t = 0.11, df = 29, p = 0.91, 95 % CI = 1.27, 1.41), ESS scores (t= -0.42, df = 32, p = 0.68, 95 % CI = 2.06, 1.36), BSI scores (t = -1.44, df = 32, p = 0.16, 95 % CI = -9.79, 1.67), trait high arousal PANAS (t = -0.57, df = 32, p = .57, 95 % CI = -5.88, 3.31), or trait low arousal PANAS scores (t = 0.22, df = 32, p = .83, (% % CI = 1.23, 1.52).

Table 1. Initial assessment measures. *Note: PSQI = Pittsburgh Sleep Quality Index; ESS = Epworth Sleepiness Scale, BRS = Brief Symptom Inventory, Trait NA – PANAS = Trait Negative Affect – Positive and Negative Affect Scale; Trait High PA = Trait High Positive Arousal, Trait Low PA = Trait Low Positive Arousal.*

	Overall				**ESR**				**LSR**			
	Mean	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**	**Mean**	**SD**	**Min**	**Max**
PSQI	3.9	1.8	1	8	3.94	1.53	1	7	3.87	2.1	1	8
ESS	3.71	2.42	0	10	3.53	2.24	0	8	8	17	3.88	2.64
BSI	50.03	8.34	35	66	48	7.72	35	61	52.06	8.66	35	66
Trait High PA	34.65	6.48	17	47	34.29	6.24	19	43	35	6.87	17	47
Trait Low PA	10.76	1.94	4	15	10.76	2.39	4	15	10.76	1.44	8	13

Sleep Manipulation Checks

Descriptive statistics are presented for all sleep variables in Table 2. Experimental groups were compared across total sleep time (TST), wake after sleep onset (WASO), sleep onset latency (SOL), and sleep efficiency (SEFF) to ensure there were no differences in sleep measures at baseline and during the washout and experimental nights, and to confirm that randomization

was effective. As expected, participants had significantly shorter TST during experimental sleep restriction conditions compared to the control night (t = -25.83, df = 33, p < .001, 95 % CI: -278.23, -237.60), and participants in the ESR condition slept significantly more than participants in the LSR condition by 20.29 minutes (see Table 2 for all ESR and LSR comparison statistics for each sleep variable). Because of this difference in ESR and LSR, TST on the experimental night was included as a covariate in all primary analyses comparing these conditions. There were no differences in TST between groups in the week leading up to the experimental night (i.e., pre-experimental week), the week leading up the control night (i.e., pre-control week), or between the two sleep restriction conditions on their control nights. Further, there was no difference in TST when comparing pre-control and pre-experimental weeks (t = -1.63, df = 31, p = 0.11, 95% CI =-22.56, 2.52). Participants had significantly more WASO during their control night compared to sleep restriction (t = -5.76 df = 33, p < .001, 95 % CI: -48.07, -22.93). There was also no difference in WASO in the pre-control week compared to the pre-experimental week for all participants (t = -0.04, df = 31, p = 0.97, 95 % CI = -7.48, 7.19). There were no significant differences in WASO between the ESR and LSR conditions in their pre-control week, pre-experimental week, control, or experimental night. There were no significant differences in SOL between the ESR and LSR conditions in their pre-control week, pre-experimental week, control, or experimental night. There were also no SOL differences between the pre-control and pre-experimental weeks or between control and sleep restriction. SEFF was significantly higher on the sleep restriction night compared to the control night (t = 4.06, df = 28, p < .001, 95 % CI: 2.58, 7.82). There were no other differences in SEFF when comparing control and sleep restriction nights (t = 0.56, df = 31, p = 0.58, 95 % CI = -0.93, 1.63) or ESR and LSR.

Participants reported on their subjective sleepiness using the KSS as sleep restriction manipulation checks. KSS scores are on a 10-point scale, 1 being “extremely alert” to 10 being “extremely sleepy, can’t remain awake”. KSS scores were significantly higher following a night of sleep restriction (M = 6.83, SD = 1.71) compared to a night of normal sleep (M = 3.44, SD = 1.13; t = -9.31, df = 33, p < .001, 95 % CI = -4.12, -2.64). KSS scores were not different between ESR (M = 6.94, SD = 1.56) and LSR (M = 6.71, SD = 1.90; t = 0.38, df = 16, p = 0.71, 95 % CI = -1.08, 1.55).

Table 2. Descriptive statistics for sleep variables. *Notes: ESR = Early Sleep Restriction, LSR = Late Sleep Restriction, TST = Total Sleep Time, WASO = Wake After Sleep Onset, SOL = Sleep Onset Latency, SEFF = Sleep Efficiency. TST, WASO, and SOL are reported in minutes, SEFF is percentage, which his calculated by dividing the time amount of total sleep time (in minutes) by the total amount of time in bed (in minutes).*

	Overall				ESR				LSR				
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Comparisons (ESR/LSR)
Pre-Control Week													
TST	457.22	44.55	201	777	447.21	46.96	207	777	467.22	41.02	201	654	t = -1.28, df = 30, p = .021, 95 % CI =51.8, 11.8
WASO	39.03	27.73	5	139	37.17	33.49	5	139	40.89	21.45	9.5	92.67	t = 0.37, df = 30, p = 0.71, 95% CI = -24.0, 16.6
SOL	19.72	17.88	6.14	98.57	23.08	22.66	6.14	98.57	16.37	11.09	7	46	t = 1.06, df = 30, p = 0.30, 95 % CI = -6.2, 19.6
SEFF	92.53	5.48	71.95	98.91	92.81	6.68	71.95	98.91	92.24	4.16	80.27	98.1	t = 0.29, df = 30, p = 0.77, 95 % CI = -3.4, 4.6
Pre-Experimental Week													
TST	445.5	43.11	213	647	454.16	44.01	175	646	468.29	54.7	305	603	t = -0.5, df = 32, p = 0.57, 95 % CI = 39.1, 21.8
WASO	37.71	24.83	5.67	101	36.19	27.69	7.71	101	39.22	22.35	5.67	74.58	t =-0.35, df = 32, p = .73, 95 % CI =-20.6, 14.6
SOL	17.77	11.96	4.17	58.5	18.5	12.78	5.79	58.5	17.04	11.42	4.17	45.83	t = 0.35, df = 32, p = 0.73, 95 % CI = -7.0, 9.9
SEFF	92.46	5.1	60.22	100	92.81	5.95	76.32	98.27	92.11	4.24	85.56	98.91	t = 0.39, df = 27, p = .70, 95 % CI = -2.9, 4.3
Control Night													
TST	468.29	54.7	305	603	468.65	59.2	305	544	467.94	51.63	359	603	t =-0.04, df = 32, p = 0.97, 95 % CI =-38.1, 39.5
WASO	42.18	38.89	0	149	38.53	40.18	1	142	45.82	38.42	0	149	t = 0.35, df = 32, p = 0.59, 95 % CI = -34.8, 20.1
SOL	20.45	19.9	5	81	22.21	21.5	5	81	18.8	18.88	5	68	t = 0.46, df = 27, = - 0.65, 95 % CI = -11.9, 18.8
SEFF	91.49	8.04	68.23	100	92.3	8.54	68.23	99.79	90.74	7.76	70.67	100	t = 0.52, df = 27, p = 0.61, 95 % CI = -4.65, 7.77
Experimental Night													
TST	210.38	19.8	162	236	220.53	12.75	186	236	200.24	20.67	162	226	t = 3.45, df = 32, p = 0.001, 95 % CI: 8.3, 32.3
WASO	6.68	7.44	0	25	4.47	6.48	0	25	8.88	7.87	0	25	t = -1.79, df = 32, p = 0.08, 95 % CI = -9.5, 0.6
SOL	14.56	11.95	5	72	12.41	5.84	8	32	16.71	15.83	5	72	t =-1.05, df = 32, p = 0.30, 95 % CI =-12.6, 4.0
SEFF	96.89	3.48	88.66	100	98.02	2.85	88.94	100	95.77	3.76	88.66	100	t = 1.97, df = 32, p = 0.06, 95 % CI =-0.1, 4.6

Aim 1

The goal of Aim 1 was to replicate the existing literature and examine positive affect following sleep restriction compared to a normal night of sleep, in addition to extending this research to examine how type of restriction influences both high and low arousal positive affect. Two 2 (Restriction type: LSR, ESR) x 2 (Sleep night: SR, Control) ANCOVAs were conducted with high and low arousal positive affect on the morning after the control and sleep restriction nights as outcome variables and total sleep time during the experimental night included as a covariate, and all reported effect sizes are generalized eta-squared.

Table 3. Descriptive statistics for morning assessment affect. *Notes: PANAS = Positive and Negative Affect Scale, SR = Sleep Restriction, ESR = Early Sleep Restriction, LSR = Late Sleep Restriction*

	Condition	**N**	**Mean**	**SD**	**Min**	**Max**	**Comparison Statistics**
High Positive Affect	Control	34	27.32	7.16	14	43	t = 8.11, df = 33, p < .001, 95% C.I. = 7.8, 12.9
	SR	34	16.97	5.18	10	27	
	ESR	17	15.53	4.36	10	24	t = -1.66, df = 32, p = .10, 95% CI = -6.41, 0.65
	LSR	17	18.41	5.66	10	27	
Low Positive Affect	Control	34	11.12	2.57	6	15	t = 3.52, df = 33, p <.001, 95% CI =1.04, 3.90
	SR	34	8.65	3.15	3	15	
	ESR	17	8.35	2.96	3	13	t = -0.54, df = 32, p = .59, 95% CI = -2.81, 1.64
	LSR	17	8.94	3.40	3	15	

There was a main effect of sleep night on high arousal positive affect, which significantly decreased following a night of sleep restriction compared to a normal night of sleep ($F(1, 32) = 55.6$, $p < .001$, $\eta^2_g = .44$). There was also a significant interaction between sleep restriction type

and sleep night ($F(1, 32) = 5.04$, $p < .01$, $\eta^2_g = .07$). There was not a main effect for type of sleep restriction ($F(1, 32) = .02$, $p = .88$, $\eta^2_g = .16$).

Pairwise comparisons showed that high arousal positive affect decreased following a night of sleep restriction compared to a normal night of sleep ($t = 8.11$, df = 33, $p < .001$, 95 % C.I. = 7.76, 12.95). High arousal positive affect was significantly lower for the ESR condition compared to their control ($t = 6.08$, df = 16, $p < .001$, 95 % CI = 8.77, 18.17) and when comparing the LSR condition to their control ($t = 2.85$, df = 16, $p = 0.01$, 95 % CI = 1.85, 12.62). ESR was trending towards a further reduction in high arousal positive affect than the LSR condition, however the difference did not reach statistical significance ($t = -1.66$, df = 32, $p = .10$, 95 % CI = -6.41, 0.65).

There was a significant main effect of sleep night in low arousal positive affect, which was decreased following a night of sleep restriction compared to a normal night of sleep ($F(1, 32) = 14.11$, $p < .01$, $\eta^2_g = .16$). There was no main effect for type of sleep restriction ($F(1, 32) = .05$, $p = .82$, $\eta^2_g = .001$) nor an interaction ($F(1, 32) = .39$, $p = .54$, $\eta^2_g = .01$)

Figure 8. Morning affect – high arousal positive affect. *Note: High arousal positive affect was measured using the PANAS-Positive Affect subscale. Responses to each item were scored 1 = "Very Slightly or Not at All" and 5 = "Extremely" and summed to create the high arousal positive affect score. Error bars represent standard error of the mean.*

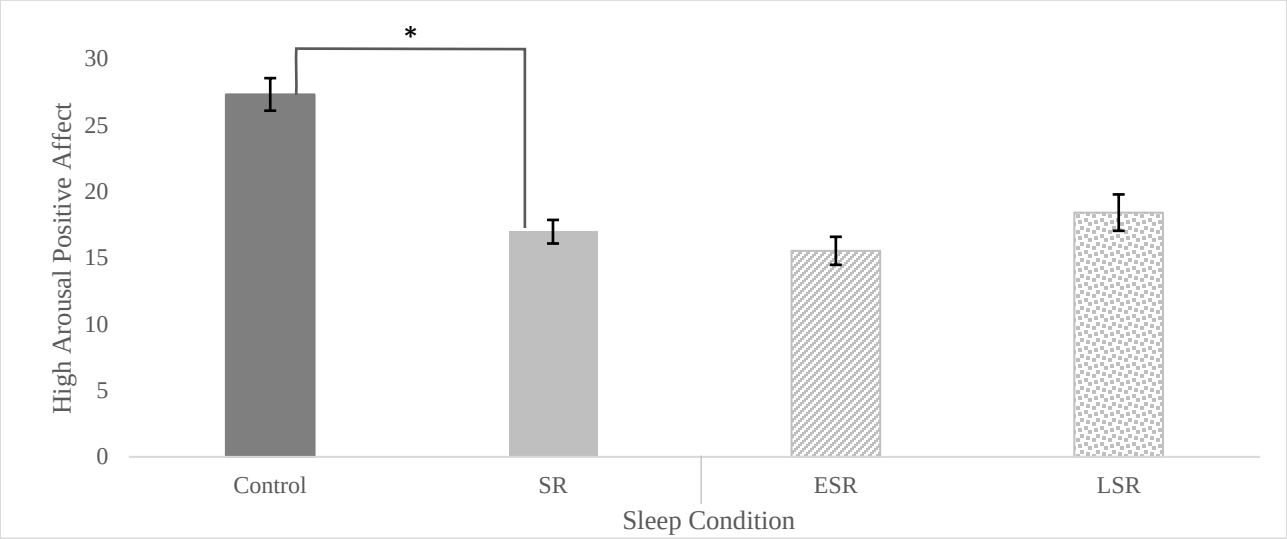
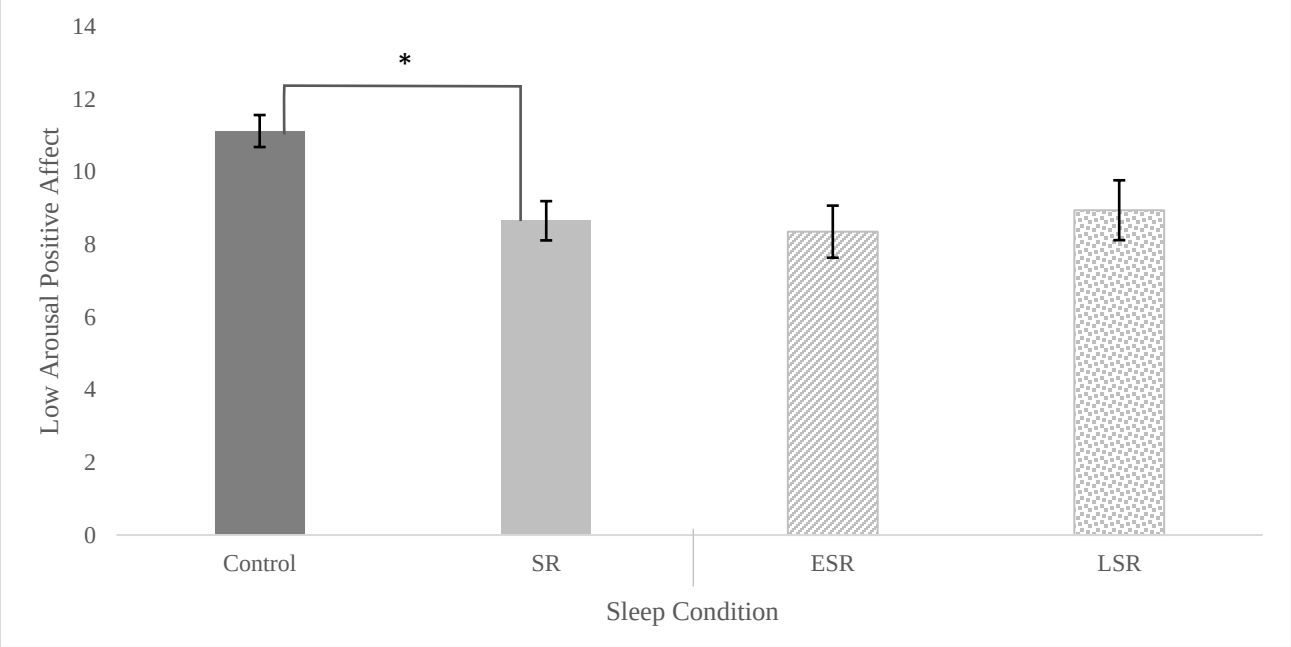


Figure 9. Morning affect – low arousal positive affect. *Note: Low arousal positive affect was measured using the PANAS-Serenity subscale. Responses to each item were scored 1 = "Very Slightly or Not at All" and 5 = "Extremely" and summed to create the low arousal positive affect score. Error bars represent standard error of the mean.*



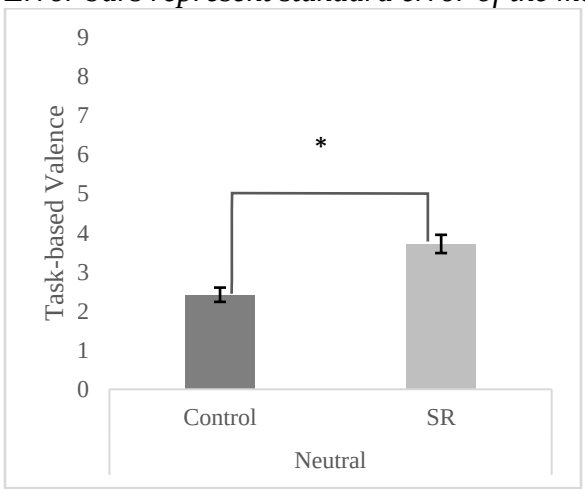
Aim 2

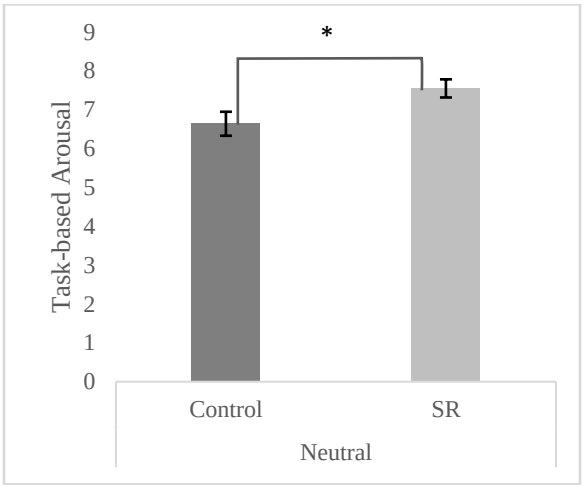
To address the second aim of the study, which was to examine positive emotional reactivity following sleep restriction compared to normal sleep, a series of 2 (SR type: ESR, LSR) x 2 (sleep condition: restriction, control) ANCOVAs were conducted for high arousal positive affect, low arousal positive affect, valence, and arousal in response to positive videos after the neutral condition (where participants were asked to simply react as usual). Total sleep time on the experimental night was included as a covariate for all models. Two additional participants were excluded from analyses due to missing data on the behavioral task.

For valence, there was a significant main effect of sleep night ($F(1,30) = 27.29$, $p < .001$, $\eta^2_g = .25$), which was more unpleasant following sleep restriction compared to a night of normal sleep. There was no main effect of restriction type ($F(1,30) = .006$, $p < .94$, $\eta^2_g < .001$) and no interaction for valence ($F(1,30) = .002$, $p = .97$, $\eta^2_g < .001$).

For arousal there was a significant main effect of sleep night ($F(1, 30) = 8.55$, $p < .01$, $\eta^2_g = .08$), with blunted arousal after a night of sleep restriction compared to control. There was no main effect for type of restriction ($F(1,30) = .27$, $p = .60$, $\eta^2_g = .006$) and no interaction between restriction type and sleep night ($F(1,30) = .16$, $p = .69$, $\eta^2_g = .002$) for arousal.

Figures 10 and 11. Task-based valence and arousal reactivity following neutral videos. *Note: Error bars represent standard error of the mean.*

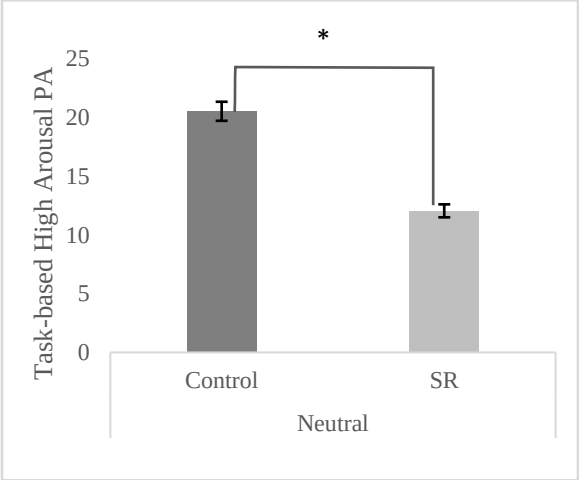


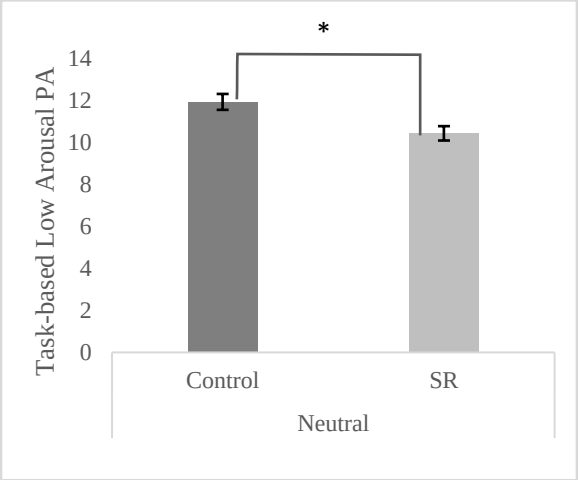


For high arousal positive affect there was a significant main effect of sleep night ($F(1,30) = 88.00$, $p < .001$, $\eta^2_g = .55$), high arousal positive affect was increased after the reactivity videos in the control compared to sleep restriction nights. There was no main effect of restriction type ($F(1,30) = .01$, $p = .98$, $\eta^2_g < .001$) or interaction for sleep night and restriction type ($F(1,30) = .08$, $p = .77$, $\eta^2_g = .001$).

There was a significant main effect of sleep night for low arousal positive affect ($F(1,30)= 15.77$, $p <.001$, $\eta^2_g = .12$), low arousal positive affect was higher following control compared to restriction after the reactivity videos. There was no main effect of restriction type ($F(1,30) = .61$, $p = .44$, $\eta^2_g = .01$) or interaction with sleep night ($F(1,30) = .24$, $p =.62$, $\eta^2_g = .002$).

Figures 12 and 13. Task-based high and low arousal positive affect following neutral videos.
Note: Error bars represent standard error of the mean.





Aim 3

The third and final aim was to investigate whether type of sleep restriction influenced the ability to upregulate positive emotions following the savoring task. A series of 2 (Restriction type: ESR, LSR) x 2 (Sleep night: restriction, control) x 2 (Task condition: reactivity, regulation) mixed ANCOVAs were conducted with valence, arousal, high arousal positive affect, and low arousal positive affect as outcome variables. Total sleep time on the experimental night was included as a covariate for all models due to the difference in sleep time between the two sleep restriction conditions.

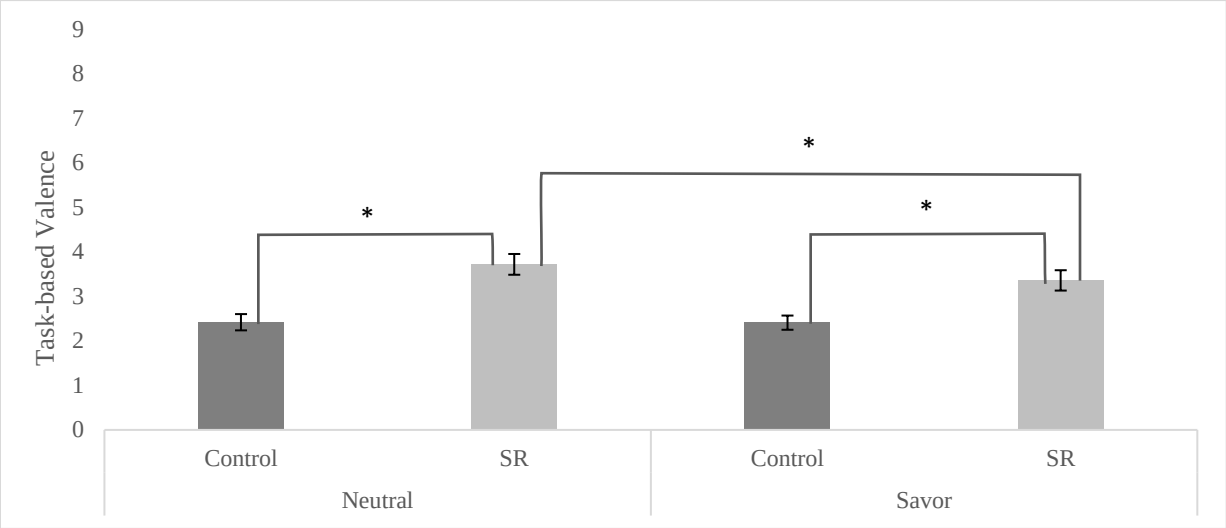
For valence, there was a significant main effect of sleep night ($F(1, 30) = 22.1$, $p < .001$, $\eta^2_g = .21$) and a significant main effect of task condition ($F(1, 30) = 4.54$, $p < .05$, $\eta^2_g = .01$). There was also significant interaction between sleep night and task condition ($F(1, 30) = 5.68$, $p < .01$, $\eta^2_g = .01$). Participants reported more pleasantness after being instructed to savor when sleep deprived when compared to the neutral/reactivity condition ($t = -2.47$, df = 31, $p = 0.02$, 95

% CI = -0.65, -0.06), but this difference between savoring and the neutral/reactivity videos did not appear when participants were well rested (t = -0.16, df = 31, p = 0.87, 95 % CI = -0.14, 0.12). There was no main effect for type of sleep restriction ($F(1, 30) = .001$, $p = .97$, $\eta^2_g < .001$) nor significant interactions with type of sleep restriction. The overall 3-way interaction was not significant ($F(1, 30) = .88$, $p < .36$, $\eta^2_g = .001$).

Table 4. Descriptive statistics for task-based valence. *Notes: Valence was measured using a self-assessment manakin (SAM) on a 1 – 9 scale. Lower valence values (1) represent feeling more pleasant and higher values represent unpleasant (9).*

		Sleep Night		Restriction Type	
Task Condition		Control	SR	ESR	LSR
Neutral	*N*	32	32	16	16
	Mean	2.42	3.72	3.58	3.85
	SD	1.03	1.32	1.4	1.27
	Min	1	1	1	2
	Max	5	5.67	5.67	5.67
Savor	*N*	32	32	16	16
	Mean	2.41	3.36	3.1	3.62
	SD	0.9	1.29	1.38	1.19
	Min	1	1	1	2
	Max	5	6	5.33	6

Figure 14. Task-based valence for savoring and neutral task conditions. *Note: Error bars represent standard error of the mean.*

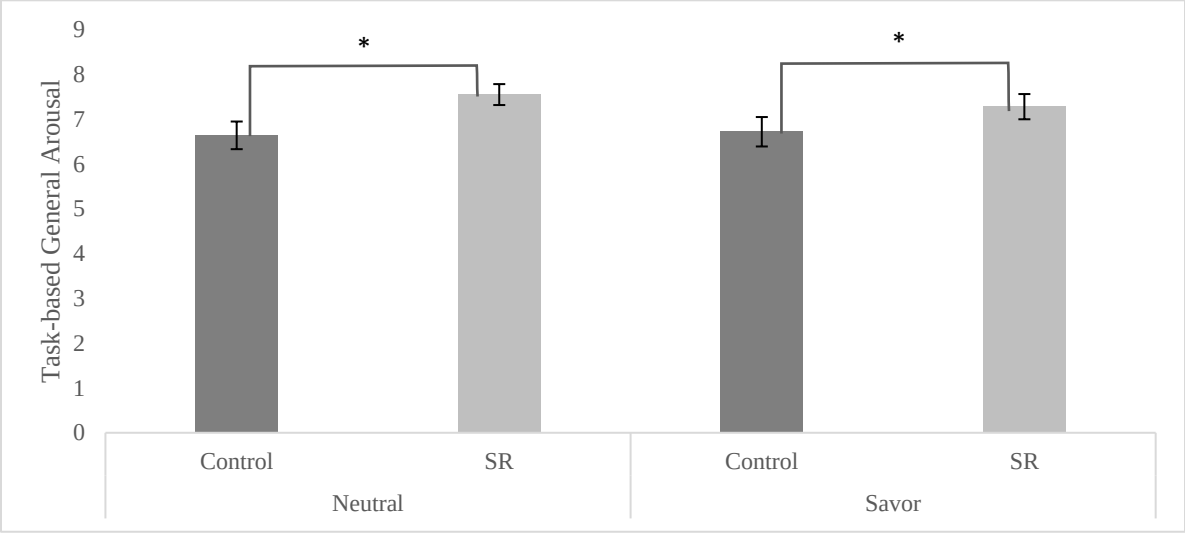


For arousal, there was a significant main effect of sleep night ($F(1, 30) = 5.19$, $p < .001$, $\eta^2_g = .05$), which was blunted following sleep restriction compared to control. There was no main effect of sleep restriction type ($F(1, 30) = 5.19$, $p < .001$, $\eta^2_g = .05$) nor task condition ($F(1, 30) = 5.19$, $p < .001$, $\eta^2_g = .05$). There were no significant interactions for general arousal.

Table 5. Descriptive statistics for ask-based general arousal. *Notes: General arousal was measured using a self-assessment manakin (SAM) on a 1 – 9 scale.. Lower arousal values (1) represent feeling more excited and higher values represent feeling more calm (9).*

		Sleep Night		Restriction Type	
Task Condition		Control	SR	ESR	LSR
Neutral	N	32	32	16	16
	Mean	6.64	7.55	7.38	7.73
	SD	1.75	1.32	1.49	1.16
	Min	2.67	4.33	4.33	5.33
	Max	9	9	9	9
Savor	N	32	32	16	16
	Mean	6.72	7.28	7.08	7.48
	SD	1.86	1.59	1.96	1.15
	Min	2.33	2.67	2.67	5
	Max	9	9	9	9

Figure 15. Task-based general arousal for savoring and neutral task conditions. *Note: Error bars represent standard error of the mean.*



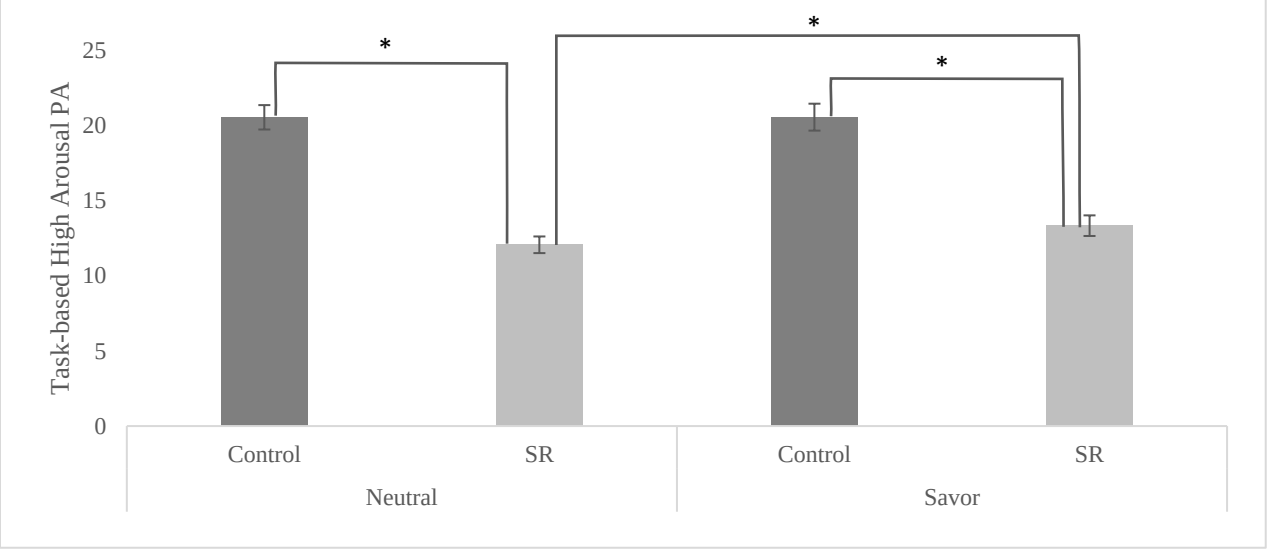
For high arousal positive affect, there was no main effect for type of sleep restriction ($F(1,30) = .08$, $p = .77$, $\eta^2_g = .001$), but there was a significant main effect of sleep night ($F(1,30) = 66.74$, $p < .001$, $\eta^2_g = .48$) and a significant main effect of task condition ($F(1,30) = 6.39$, $p < .01$, $\eta^2_g = .006$). There was also a significant interaction between sleep night and task condition ($F(1,30) = 6.67$, $p = .01$, $\eta^2_g = .005$). High arousal positive affect was increased following a normal night of sleep compared to sleep restriction following savoring videos ($t = -6.85$, df = 31, $p < .001$, 95 % CI = -9.37 -5.07). Moreover, there was no difference in high arousal positive affect when comparing savoring and neutral video reactivity following a night of normal sleep ($t = -0.04$, df = 31, $p = 0.97$, 95 % CI = -0.59, 0.58), but there was a significant difference in high arousal positive affect when comparing savoring and neutral videos following sleep restriction ($t = -3.16$, df = 31, $p = 0.003$, 95 % CI = -2.09, -0.45). When sleep restricted, high arousal positive affect was increased following savoring videos compared to neutral task conditions. There was not a significant

interaction between type of sleep restriction and task condition ($F(1,30) = .008$, $p = .93$, $\eta^2_g <$ .001), and the overall 3-way interaction was noy significant ($F(1,30) = .56$, $p = .46$, $\eta^2_g < .001$)

Table 6. Descriptive statistics for task-based high arousal positive affect. *Notes: High arousal positive affect was measured using the PANAS-Positive Affect subscale which consists of 10 items: attentive, active, alert, excited, enthusiastic, determined, inspired, proud, interested, strong Responses to each item were scored 1 = "Very Slightly or Not at All" and 5 = "Extremely" summed to create the high arousal positive affect score.*

		Sleep Night		Restriction Type	
Task Condition		Control	SR	ESR	LSR
Neutral	N	32	32	16	16
	Mean	20.54	12.06	12.35	11.77
	SD	4.59	3.13	2.67	3.6
	Min	12.67	7.33	8.67	7.33
	Max	32.33	18.67	18.67	18.33
Savor	N				
	Mean	20.55	13.33	13.56	13.1
	SD	5.07	1.71	4.31	3.52
	Min	11	7	7	7.67
	Max	31.67	28	22	19

Figure 16. Task-based high positive affect for savoring and neutral task conditions. *Note: Error bars represent standard error of the mean.*

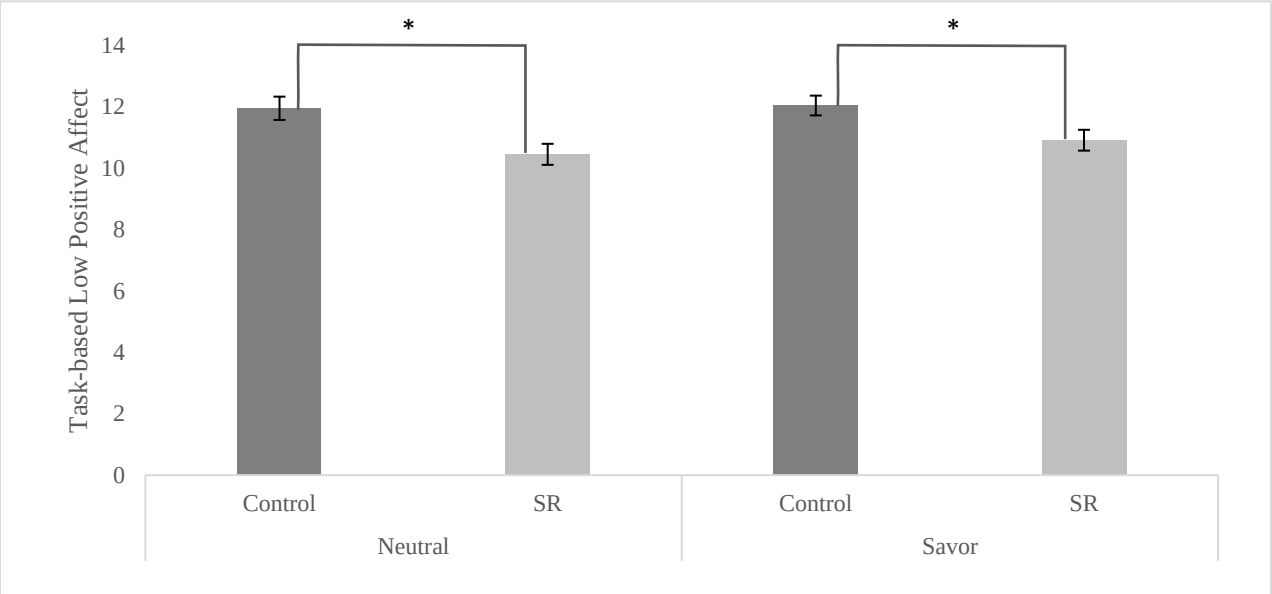


For low arousal positive affect, there was a significant main effect of sleep night ($F(1, 30) = 16.67$, $p < .001$, $\eta^2_g = .1$), low arousal positive affect was decreased following sleep restriction compared to control. There was no main effect for type of restriction ($F(1, 30) = .28$, $p = .60$, $\eta^2_g = .01$) or experimental task condition ($F(1, 30) = 2.77$, $p = .11$, $\eta^2_g = .05$). There were no interactions for low arousal positive affect.

Table 7. Descriptive Statistics for ask-based low arousal positive affect. *Notes: Low arousal positive affect was measured using the PANAS-Serenity subscale which consists of 3 items: calm, relaxed, and at ease. Responses to each item were scored 1 = "Very Slightly or Not at All" and 5 = "Extremely" summed to create the low arousal positive affect score.*

		Sleep Night		Restriction Type	
Task Condition		Control	SR	ESR	LSR
Neutral	N	32	32	16	16
	Mean	11.95	10.45	10.21	10.69
	SD	2.15	1.94	1.95	1.96
	Min	7	5.67	5.67	7
	Max	15	13.33	14	13.33
Savor	N	32	32	16	16
	Mean	12.04	10.91	10.81	11
	SD	1.82	0.98	2.11	1.78
	Min	8	6	6.33	7.76
	Max	15	15	13	14

Figure 17. Task-based low arousal positive affect for savoring and neutral task conditions. *Note: Error bars represent standard error of the mean.*



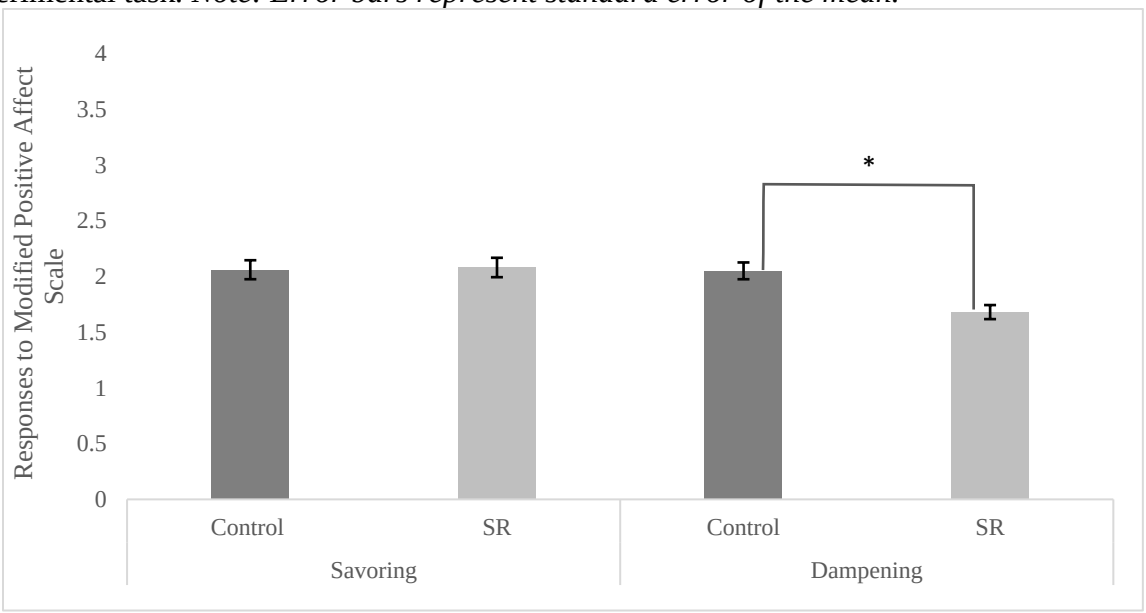
To address the final part of Aim 3, at the end of the savoring task participants reported on subjective savoring and dampening experiences. Two 2 (SR type: ESR versus LSR) x 2 (sleep condition: restriction versus control) mixed effects ANCOVAs were conducted, with self-reported savoring and dampening after the task as outcome variables and TST included as a covariate in both models. There was not a main effect of sleep night ($F(1, 30) = .02$, $p = .89$, $\eta^2_g < .001$) or sleep restriction type ($F(1, 30) = 2.72$ $p = .11$, $\eta^2_g = .07$), nor interactions ($F(1, 30) = 2.95$, $p = .10.$, $\eta^2_g = .02$) in subjective savoring. There was no significant difference in savoring following a normal night of sleep compared to a night of sleep restriction, when comparing savoring following ESR and LSR, nor when comparing dampening following ESR and LSR (see Table 8 for descriptive statistics). For subjective dampening, there was a significant main effect of sleep night ($F(1, 30) = 37.17$, $p < .001$, $\eta^2_g = .18$). Participants dampened more following a night of normal sleep compared to sleep restriction ($t = 6.42$, df = 32, $p < .001$, 95 % C.I = 0.25,

0.49). There was no main effect for sleep restriction type ($F(1, 30) = .69$, $p = .41$, $\eta^2_g = .02$) nor an interaction for dampening ($F(1, 30) = .46$, $p = .50$, $\eta^2_g = .003$).

Table 8. Savoring and dampening descriptive statistics. *Notes: Savoring and dampening were measured on a scale of 1 – 4 where 1 = Almost never and 4 = Almost always. Responses are summed to create a total score for savoring and dampening.*

	Sleep Condition	N	Mean	SD	Min	Max	t	df	p	95 % C.I.
Savoring	Control	33	2.06	0.49	1.33	3.33	.25	32	.80	-0.19, 0.14
	SR	33	2.08	0.50	1.00	3.00				
	ESR	17	1.96	0.39	1.33	2.67	-1.45	31	.16	-0.60, 0.10
	LSR	16	2.21	0.58	1.00	3.00				
Dampening	Control	33	2.05	0.43	1.43	3.00	6.42	32	< .001*	0.25, 0.49
	SR	33	1.68	0.36	1.00	2.71				
	ESR	17	1.64	0.37	1.14	2.71	-0.66	31	.51	-0.34, 0.17
	LSR	16	1.72	0.36	1.00	2.29				

Figure 18. Savoring and dampening positive emotion regulation strategies during the experimental task. *Note: Error bars represent standard error of the mean.*



DISCUSSION

The current study evaluated the influence of selective SWS and REM sleep restriction on positive affect, reactivity, and regulation the following day, and examined the influence of sleep loss on both high and low arousal positive emotional processes. Previous research has shown that selective REM sleep deprivation and selective SWS deprivation differentially influence next-day positive emotional processing compared to a night of healthy sleep (Finan et al., 2015; 2017). Consistent with hypotheses, participants reported decreased high and low arousal positive affect and more blunted reactivity to positive stimuli following sleep restriction compared to a night of normal sleep, but this occurred regardless of whether participants underwent a loss of primarily SWS or REM sleep. The SWS restriction condition reported significantly lower high arousal positive affect compared to control, but this was also true for the REM restriction condition. Consistent with prior research (Finan et al., 2017), following SWS restriction condition high arousal positive affect was trending lower compared to the REM restriction condition, but this difference was not significant. Further, there was no influence on type of sleep restriction on low arousal positive affect.

The second aim of the study was to examine positive reactivity. Participants reported less pleasant valence, lower general arousal, and decreased high and low arousal positive affective reactivity in response to positive videos when sleep restricted compared to well rested, which was in line with hypotheses. However, the type of sleep restriction did not have any influence on positive reactivity measures. Findings regarding the regulation of positive emotion were less clear cut. Participants reported less pleasant valence and a reduction in arousal, and high arousal positive affect when savoring after sleep restriction compared to a night of normal sleep.

However, when comparing emotion outcomes between neutral/reactivity clips and savoring clips, sleep restricted participants experienced better emotional outcomes when savoring compared to neutral videos. In contrast, participants did not experience emotional benefits when savoring when they were well-rested. Further, participants were more likely to report dampening when they were well-rested compared to a night of sleep restriction.

Sleep and Positive Affect

Participants were more likely to report a decrease in both high and low arousal positive affect, decreased pleasantness, and lowered arousal after a night of sleep restriction compared to a night of normal sleep. This is in line with a number of prior studies that suggest that sleep loss results in less positive affect (Finan et al., 2015; 2017; Kahn et al., 2013; Lo et al., 2016; Talbot et al., 2010; Schwarz et al., 2018). Importantly, this study extends prior literature and suggests that sleep loss influences different types of positive emotion, including both high and moderate types of emotions such as excitement and interest, but also low arousal states such as relaxed and at-ease. This is noteworthy because individuals experience low arousal positive states of emotion as frequently, if not more, than high and moderate arousal positive affect; the majority of daily experiences involve of moderate and low arousal (Diener et al., 1985; Scheibe et al., 2013; Zelenski & Larsen, 2000). Further, low arousal positive affect is positively related to life satisfaction, depression, mindfulness, anxiety, and stress independently of high arousal (McManus et al., 2019), so it is valuable to understand how sleep restriction influences low arousal states.

Type of sleep restriction did not have a statistically significant influence on affect, but selective SWS restriction lead to marginally less positive high arousal affect compared to REM restriction. This partially supports other empirical work that suggests the changes in REM sleep and SWS account for independent proportions of variation in positive affect. It is possible that adequate sleep duration by itself is important for positive affective experiences, but that SWS in particular may lead to lessened positive reactivity (Finan et al., 2015; Palmer et al., under review). Reductions in SWS have been shown to decrease positive affect and decrease attentional bias to positive affective stimuli (Finan et al. 2017), although very few studies have expanded on these findings. Even if marginal, when taken together with prior evidence, this has implications for how and when individuals experience sleep loss during their daily lives and stay up later than they are used to or in a way that is not in line with their typical sleep rhythm.

A growing body of evidence suggest that evening time preference is associated with worsened physical and mental health outcomes, such as anxiety and depression (Makarem et al., 2020; Merikanto et al., 2022; Norbury et al., 2022). Although not evaluated in this study, individuals who exhibit a diurnal preference for evening time, often referred to as evening types or “night owls”, likely experience sleep/circadian disturbances that change SWS and REM propensity, in turn altering the neural mechanisms involved in reward processing and emotion regulation, which heightens vulnerability to downstream mental health problems (Taylor & Hasler, 2018). Similarly in adolescents, evening chronotypes experience more emotional difficulties compared to adolescents with a morning chronotype (Dagys et al., 2012). Importantly, changes to positive affect may mediate the association between evening chronotype and symptom severity (Miller et al., 2016). Evening type individuals experience sleep restriction

for often than morning types due to the mismatch of their preferred diurnal rhythm and environmental factors such as early school or work start times (Tayler & Hasler, 2018). The current study mirrors sleep loss sometimes seen in night owls, further supporting the link between poor sleep and diminished positive affect and providing evidence that poor sleep quality likely precludes the onset of and increases vulnerability to mood disorders. Equally important, the timing of sleep loss and the effect on positive affect has implications for careers requiring regular shifts in the sleep-wake cycle, such as shift work in healthcare or commercial transportation, or long morning commutes or early school start times. The effects of curtailing certain phases of sleep over another may lead to differential outcomes and is worthy of further exploration to inform policy and organizational decision-making.

Sleep and Positive Emotional Reactivity

As expected, the current study also found that emotional reactivity was lower following sleep restriction. This is in line with several previous studies that have found reduced arousal and less pleasant emotions in response to positive affective stimuli after sleep loss (Cote et al., 2009; McMakin et al., 2016; Pilcher et al., 2015; Reddy et al., 2017; Zohar et al., 2005). Comparably, Tempesta et al. (2020) examined the impact of five nights of sleep restriction on emotional reactivity. After sleep restriction, participants rated pleasant and neutral images more negatively as compared to the rested condition, and there was no change to valence ratings of negative images following sleep restriction. Other studies which utilize the PANAS, instead of valence and general arousal, similarly find that positive affect is decreased following sleep restriction (Cote et al., 2009; Lo et al., 2016; Reddy et al., 2017).

One reason sleep loss may lead to blunted positive reactivity may be due to impaired top-down emotional processing. Functional connectivity between the prefrontal cortex and limbic system (e.g., amygdala) is diminished after sleep restriction, which may result in a disconnect between internal experiences and how emotions are appraised and displayed (Glosemeyer et al., 2020; Motomura et al., 2013; Yoo et al., 2007). Further, impaired top-down processing may lead to a negativity bias that heightens responses to negative experiences and dulls the experience of neutral and positive events (Gobin et al., 2015). Correspondingly, when individuals are sleep deprived and encounter a positive situation, energy levels may not be sufficient to increase experiences of positive affect (Zohar et al., 2005), and motivation to seek out potentially positive experiences may also be lessened for those experiencing sleep disturbances or reduced sleep (Palmer et al., 2020; Palmer et al., in press).

Low arousal positive reactivity (e.g., feelings of calm and content) declined following sleep restriction, which has been investigated less frequently. Importantly, the stimuli used in the current study were nature-related imagery, which may have prompted low arousal affective states specifically. Type of sleep restriction did not influence emotional reactivity during the experimental task, which was contrary to hypotheses. While prior research has implicated differing mechanisms in SWS and REM for mood and affect, how sleep architecture specifically contributes to positive emotional reactivity has been sparsely explored. What research does exist tends to utilize negative stimuli or experiences, and inconsistencies are common throughout the literature on sleep and emotional reactivity (Palmer et al., under review; Tempesta et al., 2018).

Sleep and Savoring

Instructions to savor did not uniformly increase positive affect. When participants were instructed to savor, they only had a meaningful change in positive reactivity (reflected in high arousal positive affect and pleasantness) following sleep loss, indicating that there was a benefit of intentionally engaging in savoring strategies when sleep restricted, but not when well rested. However, when participants were well rested, their positive emotional reactivity was heightened across all four reactivity measures regardless of whether or not they savored. Studies with healthy adults that attempt to up-regulate positive emotions or explicitly manipulate savoring consistently find increases in positive reactivity (Bryant & Veroff, 2017; Jose et al., 2012), so these results were unexpected. It is possible that there is a ceiling effect in the current study, which limits comparing savoring and neutral reactivity in the control condition. Regardless, the benefit of savoring instructions on positive reactivity following inadequate sleep did appear. Low arousal positive affect and general arousal were not significantly influenced by instructions to savor, however both reactivity measures were in the predicted direction for savoring compared to neutral reactivity.

Self-reported savoring strategies were not impacted by sleep loss, but participants reported that they dampened more following a normal night of sleep. Further, there was no influence of sleep restriction type for savoring or dampening. These results are contrary to predictions, but it is likely that dampening requires more cognitive resources. When instructed to savor when well rested, participants likely had the necessary cognitive capacity to monitor their emotional state, which may have resulted in heightened dampening strategies rather than increased savoring. This may reflect a “backfiring” effect observed in some happiness studies.

For example, Mauss et al. (2011) found that when individuals were experimentally induced to value happiness, they were less happy compared to control participants after watching a happy movie clip. Ford & Mauss (2013) describe these paradoxical outcomes of pursuing positive emotion. In the goal pursuit framework, the goal to increase happiness leads to paradoxical outcomes (i.e., less happy) through three mechanisms: setting unrealistically high standards for happiness, engaging in counterproductive action to attain happiness, and monitoring one's emotional state. It is possible that when participants were well rested during the experimental task, they were more likely to monitor their emotional states or set unrealistic expectations from the task. Monitoring emotional state may be more difficult when sleep deprived, and participants accordingly reported less dampening.

It is also notable that sleep restricted participants did not report savoring more following the savoring task instructions despite reporting an increase in high arousal positive reactivity. One possibility is that by only measuring some aspects of savoring and dampening, this study did not fully capture the strategies that participants utilized when instructed to upregulate their emotions during the experimental task, and the strategies used may more closely map onto the exact instructions provided versus the strategies assessed in the questions used (e.g., thinking about feeling strong or proud). Indeed, there are more cognitive strategies to up-regulate positive emotions than those included in the current study. The savoring and dampening responses were modified from a trait scale that may not accurately or fully reflect how participants attempted to up-regulate their emotions during the task. There is ample literature to support savoring as a cognitive strategy to maintain and extend positive emotion (Quoidbach et al., 2010). Other strategies aimed at increasing positive emotion include modifying behavior (e.g., smiling when

feeling sad), anticipation, and reminiscing (Bryant et al., 2005; Knutson et al., 2008; Messinger et al., 2001), but it is unlikely that participants engaged in these other forms of positive emotion regulation given the nature of the task and the instructions designed to elicit savoring. Furthermore, savoring was only measured at the end of the experimental task. It may be that asking participants to reflect on their savoring strategies after, rather than during, the task resulted in under or mis-reporting actual strategies utilized during the task in hindsight. In addition, it is important to note that participants were provided with instructions to savor, and thus it is unclear if they would be more or less likely to spontaneously savor when they are sleep restricted. These findings help to further understand how adaptive strategies that involve the intentional up-regulation of positive emotions, such as taking time to savor the moment, may improve positive emotional experiences following sleep loss. Because associations between sleep, the experience of positive emotions, and well-being are clear (Parsons et al., 2022; Simon et al., 2020; Vandekerckhove & Cluydts, 2010), targeting ways that individuals can alleviate, although not eliminate, the negative effect of sleep loss on positive affect is an important next-step in the literature.

The type of sleep restriction did not influence emotional experiences following savoring instructions during the experimental task. It is possible that REM and SWS only have differential effects for the experience of positive mood, rather than positive emotional reactivity and positive emotion regulation. Several studies (Finan et al., 2015, 2017) support that SWS loss impacts the experience of positive mood, but far fewer studies have examined REM (Palmer et al., under review) and sparse experimental evidence exists to support that differential mechanisms in REM and SWS contribute to positive emotion regulation. Some studies that increase SWS through

electrical stimulation or pharmacological manipulations report limited improvements in attention or executive function (Zhang & Gruber, 2019), so it may be that SWS may not directly impact processes that influence the regulation of emotional responses.

Limitations and Future Directions

The current study adds to the literature in several ways. First, findings extend the understanding that positive affect and positive emotional reactivity is lessened following sleep restriction using a rigorous, experimental design. This study also expanded knowledge regarding the influence of sleep loss and low arousal positive emotions, which have often been overlooked. This study is also novel in that it is the first to examine the role of sleep duration in the ability to savor using an experimental design. In addition, building on prior research, the current study used a split-night paradigm to examine the relative influence of SWS loss compared to REM sleep loss.

Despite these strengths, the current study also has a number of limitations. First, the sample was restricted to young adults between the ages of 18 – 25, so this study cannot be generalized to other periods of development. Prior studies have shown that adolescents may be more susceptible to the emotional effects of sleep loss compared to adults (Talbot et al., 2010), and the adolescent years are a time of rapid changes to both sleep and emotional experiences (Carskadon, 1990; Silk et al., 2003; Steinberg, 2005), which include changes to homeostatic sleep pressure that may influence SWS (Crowley et al., 2018). Therefore, future studies should explore the association between different types of sleep and savoring in younger ages. Additionally, participants were primarily white and were recruited using a convenience sample

of university students which also limits the generalizability of these findings. Although it has been clearly established that racial and ethnic disparities exist within sleep health (Adenekan et al., 2013; Carnethon et al., 2016; Grandner et al., 2016; Hale & Do, 2007). A disproportionate number of studies have examined differences in white and Black individuals compared to Hispanic, Asian, and other racial and ethnic groups, so it is important to focus on these populations in future work (Ahn et al., 2021). Further, because the sample consisted of individuals who were both healthy sleepers and did not have a history of diagnosed psychological or sleep disorders, these findings cannot be extended to clinical populations. This may be an important future direction, particularly in light of strong evidence suggesting that clinically depressed individuals respond to sleep loss compared differently than healthy individuals. Perhaps counterintuitively, individuals with depressive symptoms often show a beneficial effect of sleep restriction (Gillin et al., 2001). One night of total sleep deprivation has been shown to improve depression symptoms in up to 60% of treatments (Palagi et al., 2013). Partial sleep deprivation has shown similar effects, however there is evidence to suggest that total deprivation may have a stronger effect on symptom reduction (Giedke & Schazler, 2002). Unfortunately, the effect is not long lasting and a relapse into depression occurs after the next night of sleep (Reimann et al., 1993). One hypothesis is that the beneficial effect of sleep deprivation for mood is tied to altering an individuals disturbed circadian- and sleep-wake-dependent phase relationships and a concurrent increase of slow-wave-sleep pressure across the wake period (Giedke & Schazler, 2002; Wirz-Justice & Hoofdakker, 1999). However, depressed individuals regularly exhibit higher amounts of REM and enter into REM earlier in their sleep

cycle, which may lead to selective and disproportionate strengthening of negative memories, in turn increasing depressive symptoms (Tsuno et al., 2005; Armitage, 2007).

Another limitation is that participants were assigned to uniform sleep restriction windows, which may not have been in sync with their actual SWS/REM patterns or their typical sleep schedule. Participants were screened for bedtime that ranged between 10:00pm and 12:00am and waketime between 7 :00am – 9:00am so that sleep schedules aligned to the sleep restriction conditions as closely as possible. However, there is evidence that suggests participant sleep restriction studies should be tailored to each participant's sleep patterns (Rogers & Dinges, 2008), and this may be particularly true for the type of split-night protocol utilized in this study because it targets specific sleep stages. As noted, several studies provide evidence that this type of protocol differentially restricts SWS or REM (Casey et al., 2016; Gais et al., 2000; Menz et al., 2016; Parry et al., 2019; Tilley & Wilkinson, 1984; Wagner et al., 2001; Wu et al., 2008, 2010), however without the use of polysomnography, it is unclear how successful the split-night protocol was at selectively depriving these two sleep stages. It may be that the split-night protocol failed to fully discriminate SWS and REM. This study did not utilize polysomnography, so this cannot be resolved, but there is relatively robust indication that split-night protocols do indeed differentially restrict REM and SWS (Casey et al., 2016; Gais et al., 2000; Menz et al., 2016; Parry et al., 2019; Tilley & Wilkinson, 1984; Wagner et al., 2001; Wu et al., 2008, 2010). Further, the observation that positive mood following ESR was in the direction of hypotheses indicates that this may not be the case. Additionally, this study did not utilize a night of habituation in the lab to reduce any "first-night" effects on sleep quality (Lorenzo et al., 2002;

Tamaki et al., 2005), which may have led to poorer sleep quality during the in-lab experimental nights.

The use of only scenic nature related videos in the experimental savoring task may have also impacted the results. Most studies which aim up-regulate positive affect utilize a variety of video themes in their tasks that include categories such as scenery, humor, erotic, and compassion (Gross & Levenson, 1995; Gabert-Quillen et al., 2015; Gillman et al., 2017; Maffei & Angrilli, 2019; Samson et al., 2015). Videos from a validated set of similar scenic clips to elicit emotions were included in the initial video pool and utilized as a guideline for the remaining video selections, although they were not included in the final task (Maffei & Angrilli, 2019). The lack of distinction in the types of videos selected for the task may be reflected in the low variability observed in task-based emotional reactivity when participants were well rested, which may have been due to ceiling effects.

It has also been argued that emotion regulation paradigms, such as the one used in this study, should also investigate the decision to deploy emotion regulation strategies, rather than using paradigms that only investigate instructions to regulate (Bendall, 2017; Dore et al., 2017). This distinction is important because tendency and capacity to engage in emotion regulation may become separated if an individual has the capability to utilize numerous emotion regulation strategies but routinely uses one strategy. The result is an overall high capacity for emotion regulation strategies but low tendency for unused strategies (Silvers & Moreira, 2019). While participants were asked about savoring and dampening strategies following the experimental task, there may have been an effect of re-calling their strategies after the fact, rather than during the task. In addition, participants only reported on a small number of savoring and dampening

items which were adapted from trait measures, so it may be that this failed to fully capture what participants did when they were asked to up-regulate their emotional experience. The current study only truly speaks to emotional reactivity following task instructions, rather than the capacity to engage in emotional regulation or the utilization of strategies.

Future studies should also aim to address moderators of positive emotional reactivity and regulation, such as symptoms depression and anxiety. It is feasible that state savoring is influenced by trait levels of savoring, or an individual's tendency to savor. Similarly, trait levels of dampening may also moderate state dampening levels. The current study did not include analyses of specific types of savoring or dampening strategies. It will be important for future studies to evaluate each savoring and dampening response item to determine if they accurately reflect how participants up or down regulate positive affect.

Finally, due to the dearth of research on sleep and positive emotion regulation, prior effect sizes were unavailable to compute a priori power analyses for these models and these effects were estimated based on the large effect sizes found in prior research for the effect of sleep on affect/mood. Consequently, the effects found in the current study are interpreted with caution and should be replicated in future studies using larger samples to further clarify the relationship between sleep loss and positive affective outcomes such as mood, emotional reactivity, and emotion regulation.

The links between sleep loss and positive emotion processes are complex, and there is wide individual variability in vulnerability and susceptibility to the effects of sleep loss (Van Dongen & Belenky, 2009). For instance, Finan et al. (2019) recently found that the effects of sleep disruption on reward learning were dependent on an individual's positive affective

response to sleep disruption, and the effects were stronger for positive affect than negative affect. Critically, those with preserved positive affect responses following sleep restriction showed enhanced reward learning, which was in contrast to those who had decreased positive affect responses to sleep disruption and greater reward learning deficits (Finan et al., 2019). This is in line with other studies evaluating positive affect and the neural circuitry involved in reward valuation, which is linked to a variety of mood disorders (Gujar et al., 2001; Libedinsky et al., 2013). These findings indicate that it was an individual's positive affective response to sleep disruption that altered reward learning, further highlighting the need for studies which aim to identify who is resilient to the effects of sleep deprivation and whether resiliency to sleep loss varies within person. For instance, an individual may show resiliency in one functional domain, such as attention, but may be vulnerable to similar amounts sleep loss in other functional domains, such as mood (Frey et al., 2004).

Positive emotion regulation is key for effective coping and well-being and disrupted positive emotion regulation is observed in many psychiatric disorders. There are several evidence-based cognitive, behavioral, and self-systems treatment strategies and interventions that improve the ability to regulate positive emotions (see Carl et al., 2013 for review). Some approaches directly encourage savoring strategies, such as relaxation therapy and guided mediation, both of which have been shown to induce and extend the duration of positive affective experiences (Chesney et al., 2005; Tugade & Frederickson, 2007). Still, the relationship between sleep and treatment that bolsters the experience of positive life events remains unclear. Given that sleep disturbance is common among affective disorders and likely precludes the onset of emotional disorder, it is important to understand the relationships that exists between up-

regulating positive affect and sleep, and how these relationships influence vulnerability to psychological disorders. This information can be used to develop targeted mental health interventions aimed at improving positive affect, in part because savoring is a relatively simple cognitive approach to increasing positive affect.

Conclusion

In line with previous evidence, the current study found that both high and low arousal positive affect were reduced following sleep loss, and to a further extent following selective SWS restriction. Emotional reactivity was also blunted following sleep loss, however selective SWS and REM restriction did not affect positive emotional reactivity. Nonetheless, instructing participants to savor led to more pleasant valence and increased positive affect following sleep loss, which suggests that sleep deprived individuals can experience some affective benefits from explicit instructions to up-regulate positive emotion. Persistent sleep loss often occurs prior to the onset of various psychiatric disorders and subsequent changes to positive affect may be linked to the development of disorders such as anxiety and depression. Accordingly, adaptive emotion regulation strategies, such as savoring, may inform behavioral health interventions and improve outcomes for individuals who experience sleep problems. Further, the timing of sleep loss and its impact on positive affect has broader implications for policy and system-level practices that involve modified sleep-wake patterns, such as shift work (e.g., healthcare, commercial driving) and school start times.

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