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Journey into the night: unveiling the impact of sleep deprivation on mood and emotional processing

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Thesis

JOURNEY INTO THE NIGHT: UNVEILING THE IMPACT OF SLEEP DEPRIVATION ON MOOD AND EMOTIONAL PROCESSING

by

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JOURNEY INTO THE NIGHT: UNVEILING THE IMPACT OF SLEEP DEPRIVATION ON MOOD AND EMOTIONAL PROCESSING

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ABSTRACT

Introduction: Previous literature has demonstrated the imperative role of sleep in regulating various cognitive and emotional functions such as mood regulation and memory processing. Total sleep deprivation (SD) has been overwhelmingly shown to decrease positive affect (PA) and, less consistently, alter negative affect (NA) as well. In addition, SD has been shown to negatively impact overall memory, and may have differential impacts on neutral vs emotional memory content. This study aims to further clarify the effects of SD on mood and investigate if SD has similar or different impacts on emotional and neutral memory content. If SD impacts both mood and emotional memory processing, the exploratory aim of this research is to determine the relationship between mood and emotional memory processing following SD.

Methods: Sixty-nine participants were assigned to the sleep group (n = 21) and SD group (n = 48) as part of a larger investigation, where the SD group was further stratified for subsequent analyses. Participants completed the Positive and Negative Affect Scores (PANAS) assessment in the evening. Sleep group participants went home for the night to sleep and returned to the hospital in the morning, whereas SD group participants remained awake in the hospital overnight. In the morning, participants completed the PANAS test again and participants performed both the encoding and recognition portions of the Emotional Trade-Off (ETO) task to investigate differential effects on neutral and negative memory content. Repeated measures analysis of variance (ANOVA) was used to analyze PANAS and ETO scores with a significant threshold of $p <0.05$.

Results: No baseline (session 1) differences in PA and NA were found between the sleep and SD groups. At session 2 (morning), the SD group had significantly lower PA scores compared to the sleep group. Additionally, a significant decrease in PA in the SD group from evening to morning was observed, while NA remained stable. A significant condition effect on memory was also found, with the SD group performing worse on overall memory compared to the sleep group. A significant valence x scene component interaction was also found, and the emotional trade-off effect was successfully replicated in both rested and sleep-deprived conditions. Finally, a positive association was observed between PA and background scene components from the ETO.

Discussion: While NA did not change significantly from morning to evening testing sessions, PA was found to decrease significantly for the SD group. SD participants in this study exhibited significantly worse overall memory compared to those who slept, and all participants replicated the emotional trade-off effect. Exploratory analysis found a correlation between higher PA scores and better recollection of backgrounds, potentially explained by the broaden-and-build theory that suggests positive emotions enhance observance and memory formation. Future research should build upon these findings and further investigate the interaction between mood and emotional memory and their relationship with different features of sleep.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
BIDMC	Beth Israel Deaconess Medical Center
EEG	Electroencephalography
EMG	Electromyography
ETO	Emotional Trade-off Task
MCM	Mood-Congruent Memory
NA	Negative Affect
N1	Non-Rapid Eye Moment Stage 1
N2	Non-Rapid Eye Movement Stage 2
N3	Non-Rapid Eye Movement Stage 3
NREM	Non-Rapid Eye Movement
PA	Positive Affect
PANAS	Positive and Negative Affect Scores
REM	Rapid Eye Movement
SD	Sleep Deprivation
SPSS	Statistical Package for the Social Sciences
TSD	Total Sleep Deprivation

INTRODUCTION

Introduction to Sleep

As humans, we spend approximately one-third of our lives in the physiological state of sleep (Aminoff et al., 2011). With such a substantial amount of time dedicated to this state, it is without surprise that sleep is essential for countless regulatory and repair mechanisms that support both physiological and psychological health (Zielinski et al., 2016). Many of the various physiological contributions of sleep are summarized below in Table 1.

Table 1. Physiological Functions of Sleep (Ettinger & Kumari, 2015).

Functions
Brain Growth during Development
Energy Conservation
Brain Waste Clearance
Modulation of Immune Response
Improved Cognition, Performance, & Vigilance
Protection from Disease

Sleep primarily consists of two states: non-rapid eye movement sleep (NREM) and rapid eye moment sleep (REM) (Patel et al., 2024). Both NREM and REM sleep are found in all mammals and the majority of animals, including mice, rats, rabbits, dogs, cats, and other primates, a testament of the crucial role sleep plays in supporting life (Siegel, 2008). NREM sleep makes up approximately three-quarters of sleep per night and is further divided into three stages (N1, N2, N3), corresponding to the progressive deepening of sleep (Patel et al., 2024). NREM and REM sleep occur in a 90-minute cycle, 4-5 times throughout a single night of sleep (Dement & Kleitman, 1957; Zielinski et al., 2016). The duration of time spent in either NREM or REM sleep changes as the night progresses. REM sleep accounts for a larger proportion of the sleep cycle later in the night, whereas sleep is usually classified as deeper earlier in the night (Colten et al., 2006).

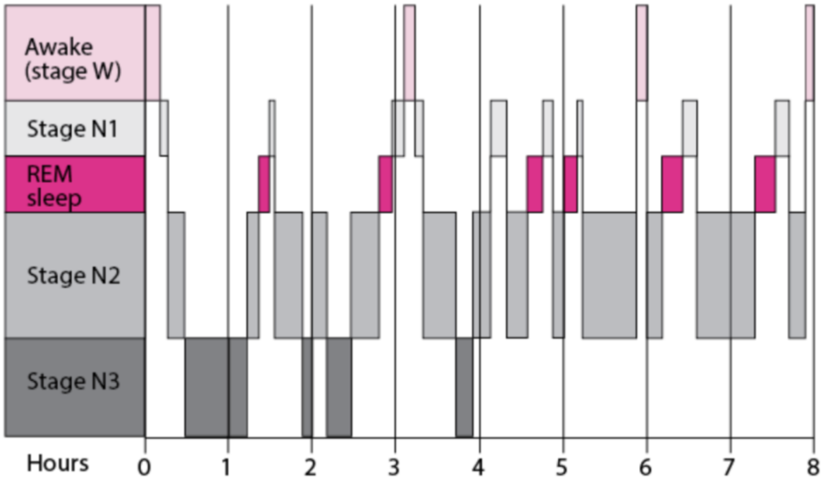

Figure 1. Stages of the Sleep Cycle. The cyclical phases of sleep are demonstrated below, with the least time spent in N1 and the largest time spent in N2. While N3 occurs mostly during the first half of the sleeping period, the amount of REM sleep increases throughout the duration of sleep (Schwab, 2022).

The unique physiological state of sleep is predominantly characterized by decreased movement of the body, a slower rate of breathing, decreased sensitivity to external stimuli, and closed eyes (Zielinski et al., 2016). However, it is important to note that these physiological characteristics do vary throughout a night of sleep, consistent with the classifications of NREM and REM sleep (Zielinski et al., 2016). These physiological differences are summarized in Table 2 and are compared to the physiological characteristics that are most often associated with the state of wakefulness.

Table 2. Physiological Characteristics of the three main Sleep Stages (Zielinski et al., 2016).

Wakefulness	**NREM**	**REM**
Enhanced movement activity	Reduced movement activity	Reduced movement activity (cataplasia)
Opened eyes	Closed eyes	Closed eyes (rapid-eye movements)
Enhanced responsiveness to external stimuli	Reduced responsiveness to external stimuli	Reduced responsiveness to external stimuli
Variable body position	Recumbent body position	Recumbent body position
Variable breathing rate	Regular breathing rate	Variable breathing rate

Abbreviations: NREM , Non-Rapid Eye Movement; REM , Rapid Eye Movement;

In addition, differences in brain waves, muscle activity, and eye movements, measured by electroencephalography (EEG), electromyography (EMG), and electrooculography (EOG), can also help to discern different stages of sleep. EEG’s are one of the most common tools for sleep research as they are able to harness multifaceted aspects of electrophysiological activity, namely temporal, spectral, and spatial, which aids in monitoring both NREM and REM sleep (Cox & Fell, 2020). While NREM sleep is usually signified by low frequency and high voltage EEG, REM sleep is represented by rapid low voltage EEG (Aserinsky & Kleitman, 1953; Zielinski et al., 2016). On EEG, different vigilance states are characterized by the following frequency bands: delta, theta, alpha, beta, and gamma (Zielinski et al., 2016). Table 3 describes the characteristics of each frequency band in further detail.

Table 3. Characteristics of Sleep Waves associated with various Sleep Stages (Zielinski et al., 2016).

Frequency Band	Frequency Range	Dominant Sleep Stage	Associated Function
Delta	0.5 – 4.0 Hz	NREM	Slow-wave sleep, memory consolidation, synaptic homeostasis, health
Theta	4.0 – 9.0 Hz	Wake and REM	Cognition, memory consolidation, movement activity, REM, development
Alpha	9.0 – 15.0 Hz	Wake	Visual activity and cognition
Beta	15.0– 30.0 Hz	Wake	Anxious thinking, alertness and critical reasoning
Gamma	>30.0 Hz	Wake and REM	Sensory processing, memory, cognition

Abbreviations: Hz, Hertz; NREM, Non-Rapid Eye Movement; REM, Rapid Eye Movement;

NREM sleep, across its three unique stages (N1, N2, N3), has been demonstrated to contribute to memory consolidation. N1 has been shown to be primarily responsible for the transition between wakefulness into a sleep state, and has not been shown to contribute to memory processing thus far (Wei et al., 2018). However, N2 sleep features sleep spindles and K-complexes which have both been shown to contribute to memory (Wei et al., 2018). Sleep spindles, on the other hand, have been implicated with the improved consolidation of emotional information (Cellini et al., 2016). Finally, N3, also referred to as slow wave sleep, is crucial for physiological repair, muscle strengthening, and immune system modulation (Zielinski et al., 2016). Its effects on emotional memory are also profound, with increasing proportions of slow wave sleep contributing to increased memory of unpleasant, or emotional, imagery (Cellini et al., 2016).

REM sleep, on the other hand, is the sleeping stage responsible for dreaming, enhancing many psychological functions including mood regulation and emotional memory (Perogamvros et al., 2013; Rasch & Born, 2013; Zielinski et al., 2016). While REM sleep has also been implicated in the consolidation of procedural memory, its contribution to emotional memory processing has been robustly demonstrated (Sara, 2017). Specifically, when REM sleep occurs after the encoding of emotionally arousing material, significant increases in learning have been reported. Two of the proposed processes by which this may occur are long-term potentiation and hippocampal-dependent memory processing (Sara, 2017). Since each individual stage of sleep contributes uniquely to physiological and psychological aspects of health, it is imperative that sleep is regulated appropriately.

Regulation of Sleep

There are two unique processes that work in tandem to regulate sleep in the human body: the circadian rhythm and the homeostatic sleep drive. The homeostatic drive regulates sleep by accumulating sleep pressure during time spent awake. From the first moment of wakefulness, the body undergoes wear and tear that stimulates the release of sleep-promoting hormones and neurotransmitters, thus increasing the drive for sleep as more time is spent awake (Cunningham et al., 2022). For example, adenosine accumulates in the brain during wakefulness and contributes to the sleep pressure build-up that drives the homeostatic regulatory process (Cunningham et al., 2022). This pressure build-up is resolved during periods of sleep, especially during deep sleep stages, thus allowing the body to maintain its sleep-wake-cycle. It is thus evident that the homeostatic drive for sleep would be extremely high following periods of sleep deprivation (SD).

By sending signals of both sleepiness and alertness within the body at different times, the circadian rhythm, also known as the “internal clock”, also plays a role in creating and regulating the sleep schedule over a period of 24-hours (Reddy et al., 2024). Interestingly, the circadian rhythm is set by external cues from the environment, namely light and darkness, which each promote alertness or sleepiness. With an impact on body temperature, appetite and diet, digestion, and hormone release, appropriate functioning of the circadian rhythm is essential in promoting positive health outcomes and overall well-being (Foster, 2020).

Considering the crucial impacts of the circadian rhythm, it is no surprise that disruption in sleep results in a misalignment between the internal clock of the body and external environmental cues. This misalignment may result in fewer hours slept during each 24-hour period, driven by issues with both falling asleep in the evening, as well as staying asleep throughout the night (Reddy et al., 2024). There are a number of factors that lead to disruptions in sleep, including blue light from screens at night, night shift work, and noise pollution, amongst numerous other factors.

The potential health consequences of sleep loss are both acute and chronic. Physiological diseases include obesity, diabetes, or cardiovascular issues, while psychological consequences involve depression, reduced cognition, memory and attention deficits, and potential mood-altering (Reddy et al., 2024).

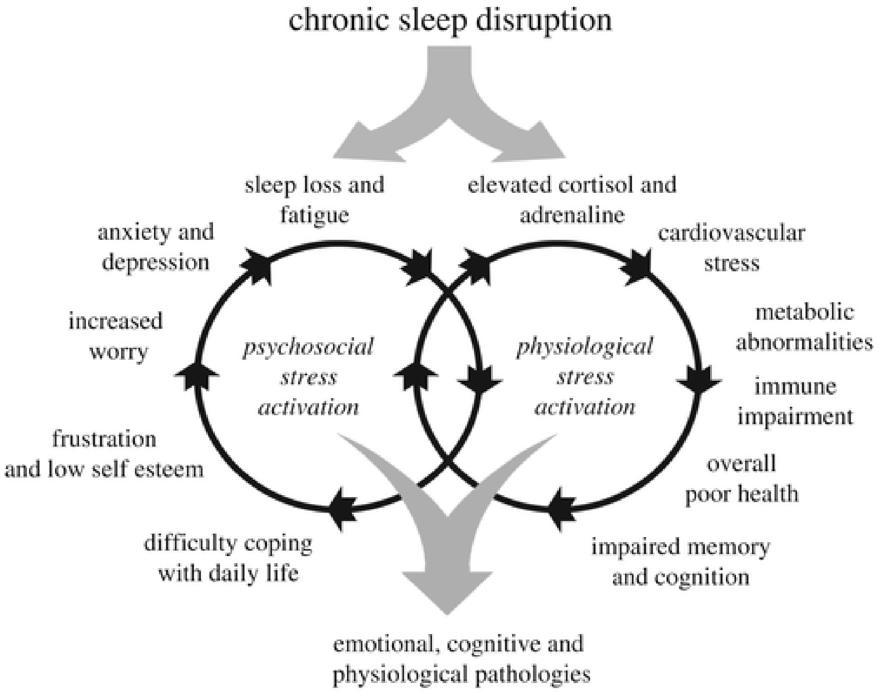

Figure 2. The Psychosocial and Physiological impacts of Chronic Sleep Disruption. Illustrated below are potential outcomes of chronic sleep deprivation that can ultimately cumulate to manifest as emotional, cognitive, and physiological pathologies (Foster, 2020).

In the United States, SD is not uncommon, with approximately 33% of adults sleeping under 7 hours per night, and less than 33% of high school students in the country acquiring the recommended 8 hours of sleep per night (Ettinger & Kumari, 2015). As a result of the widespread prevalence of SD in the population, significant impacts on mood and emotional memory have been noted in sleep deprived populations (Ettinger & Kumari, 2015).

Mood & Sleep

Mood is a component of psychological state that can be defined as either positive or negative, and is usually not brought on by a single specific stimulus, but instead is influenced by multiple factors (Lane et al., 2005; Watling et al., 2017). While it may be tempting to equate mood and emotion, it is important to distinguish them from each other as they represent different components of an individual's affective state. Most notably, emotions are the subjective experience of an individual with a specific stimulus, whether that be internal or external (Gross, 2015). Examples of stimuli include art and music, visual objects, words and speech, film, and many others (Altarriba, 2012). In this way, the presence of a stimulus is usually associated with changes in emotion, while changes in mood do not rely on a stimulus in order to occur. As such, emotions rely heavily on context and are thus experienced on a temporary basis, whereas mood states do not tend to fade as quickly (Ettinger & Kumari, 2015).

Table 4. Summary of Distinctions between Emotion and Mood (Beedie et al., 2003).

Criterion	**Emotion**	**Mood**
Anatomy	Related to the heart	Related to the mind
Awareness of cause	Aware of cause	Unaware of cause
Cause	Specific event or object	Less well defined
Consequences	Behavioral and expressive	Cognitive
Control	Not controllable	Controllable
Display	Displayed	Not displayed
Duration	Brief	Enduring
Intentionality	About something	Not something particular
Timing	Rises and dissipates quickly	Rises and dissipates slowly

When considering the association between sleep and mood, it is important to reference the sleep-mood cycle. This phenomenon states that a bidirectional relationship exists between sleep and mood, implying that not only do disruptions in sleep result in changes in mood, but changes in mood can also have an impact on sleep (Watling et al., 2017). The effects of sleep restriction and SD on mood have been studied numerous times with impacts reported on self-reported negative and positive mood states. Overwhelmingly, research studies have proposed that increases in negative mood states and decreases in positive mood states result from sleep restriction and deprivation (Cote et al., 2019; Kahn et al., 2013).

Previous research has gone on to show that the magnitude of the effect on self-reported mood states is dependent on whether positive or negative mood is being considered. According to a meta-analysis study, the decrease in self-reported positive mood states following insufficient sleep is of a larger magnitude than the increase in self-reported negative mood states, which was found to have a medium effect (Tomaso et al., 2021).

This analysis also investigated whether there were differences in mood effects depending on whether participants were sleep restricted or completely sleep deprived. Once again, it was found that the effects differed depending on whether self-reported positive mood or negative mood was being analyzed. Regarding positive mood, the authors reported a decrease in positive mood following both sleep restriction and total sleep deprivation (Tomaso et al., 2021). Moreover, the magnitude of effect did not depend on whether sleep was restricted or completely deprived; that is to say that restricting sleep to just a few hours at night and total sleep deprivation decreased self-reported positive mood to the same extent (Tomaso et al., 2021).

On the contrary, the increase in self-reported negative mood states resulting from sleep restriction compared to complete lack of sleep was more stunted; that is to say that an increased amount of sleep time lost generated a greater increase in self-reported negative mood states (Tomaso et al., 2021). The consistently large decrease in self-reported positive mood across the sleep restriction and complete SD groups strengthens the argument for the association between sleep loss and the onset of depression. Anhedonia, one of the major symptoms of depression, can be defined by a lack of feeling pleasure, thus being consistent with a decrease in self-reported positive mood state (Ettinger & Kumari, 2015). This highlights the potential importance of the bidirectional relationship between sleep and mood in psychiatric presentations and clinical outcomes. The mood deterioration associated with SD depicts an opportunity to consider sleep patterns in assessing and treating depressive disorders.

Self-reported mood can be measured by the Positive and Negative Affect Scale (PANAS), a broadly used tool in both clinical and research domains created by Watson et al. in 1988. Though this tool measures both positive and negative affect, it is important to note that these two parameters are measured discretely on their own independent scales (Flores-Kanter et al., 2021). In this way, the PANAS tool can be extremely useful for evaluating the potential impact of a research or therapeutic intervention on positive and negative affect as it can be easily measured pre- and post- intervention (Flores-Kanter et al., 2021). This tool can also prompt participants to report their associations with the positive and negative affect adjectives over the previous 7 days, which can be beneficial for evaluating longer-term fluctuations in mood (Mohn et al., 2018). Finally, the simple design of the PANAS, as a self-report tool, permits its use across various age groups and populations, thus bolstering its wide applicability and external validity in both clinical and research settings (Flores-Kanter et al., 2021).

Previous literature has shown that sleep contributes to the regulation of mood, with SD resulting in decreased PA and in some cases, increased NA. With these observations in mind, it is important to consider other psychological factors, such as memory, that might be reliant on sleep processes and thus be impacted by SD.

Emotional Memory & Sleep

Sleep has also been shown to be extremely important for memory consolidation in multiple contexts including learning, emotional-processing, and overall cognitive function. In particular, investigations have explored if sleep facilitates memory for information classified as emotional in nature above and beyond information that is considered neutral or non-arousing (Cunningham et al., 2022). An evolutionary role for heightened emotional memory has been identified, explaining that the recollection of negative memories may aid survivability in extenuating circumstances (Kaida et al., 2015).

One study evaluated the effects of sleep deprivation prior to the encoding phase, separating participants into a total sleep deprivation (TSD) group, a REM-sleep deprivation group, and a normal sleep group (Kaida et al., 2015). After encoding positive, negative, and neutral valence scenes, recognition tasks occurred after a short delay, as well as one week after encoding. Results from the short delay recognition task showed that the TSD group performed significantly worse for memory pertaining to all valences (Kaida et al., 2015). After one week, memory performance was still weaker for the TSD group, but this data point failed to reach significance (Kaida et al., 2015). The overall finding of this study suggested that while it is evident that TSD detrimentally impacts overall memory performance, its effects on negative memory were the least pronounced, suggesting a possible preferential selection of the emotionally arousing material (Davidson et al., 2021).

However, it is important to highlight other sleep and memory studies that have suggested other possible conclusions. In 2016, a study was conducted to determine whether a daytime nap impacted memory consolidation and retention for negative or neutral objects that were paired with images of neutral faces (Alger & Payne, 2016). All participants took part in the encoding phase, which was followed by a baseline memory task prior to sleep manipulation. The nap group was instructed to take a 90-minute day-time nap, while the wake group remained awake. Five hours later, both groups participated in another memory task. Compared to the baseline memory task, memory for the neutral objects was found to increase in the nap group, while no significant increase in memory of neutral objects was noted for the wake group (Alger & Payne, 2016). Further, negative object memory did not change significantly for either the nap or wake group between the two memory tasks. These results were explained by the potential of slow wave sleep in the consolidation of neutral memories, specifically, perhaps due to decreased emotional reactivity during this stage of sleep (Alger & Payne, 2016).

It is evident from the studies presented above that the field is reporting mixed results regarding the impact of sleep on emotional memory consolidation, and more research is needed in the field. The distinction between the phases of memory processing that have been manipulated in the studies outlined above is displayed on Figure 3. The nuances of these phases are important to consider when evaluating the effects of sleep and SD on emotional memory.

Figure 3. Five Stages of Long-Term Episodic Memory Processing. Sleep can be disrupted at any of the following five stages: 1. Prior to encoding emotional information, 2. Immediately following encoding during early consolidation, 3. During extended consolidation away from initial learning, 4. Just prior to retrieval of emotional memory, and 5. Post-retrieval as an emotional memory may be restructured and reconsolidated (Cunningham et al., 2022).

While the increased recollection of emotional memory has been associated with sleep, it is important to consider the emotional tone that co-exists with the memory, and whether the magnitude of this tone is also re-enforced by sleep. It has been found that emotional tone decreases over time and is not fortified by sleep in the same way that the memory itself is (Walker and van Der Helm, 2009; Goldstein and Walker, 2014). This has been hypothesized to allow for appropriate processing of negative emotional events that may be associated with significant trauma, potentially mitigating long-term emotional distress that may have resulted otherwise (Kaida et al., 2015).

Emotional Memory Trade-offs

It is also important to note that the memory of an emotional experience is not identical to the actual experience that occurred; there are key patterns in memory storage and retrieval that must be explored (Payne et al., 2008). In particular, when considering a complex memory with several details, a trade-off is usually observed since background information and peripheral details are often less well remembered in comparison to foreground details, especially when the foreground details are emotional in nature (Payne et al., 2004).

This trade-off effect was demonstrated by Stanny & Johnson in 2000 with the “Weapon-Focus Effect”. This study found that while victims were unable to recall the background scenes of their attack or even the faces of their attackers, they were able to remember details about the weapon used in the attack against them. As such, this could indicate that the emotional valence associated with the weapon led to preferential recall in comparison to the peripheral details (Payne et al., 2008). One hypothesis that has been offered suggests that central and peripheral elements of memory might be stored separately, meaning that one of the components might be inherently easier to recall. It was also proposed that the finding could have been the result of the existence of separate pathways for central object and peripheral background components of memory throughout the encoding, consolidation, or retrieval phases (Payne et al., 2008).

The emotional trade-off task (ETO) is a tool that has been used to determine whether inherent emotionality associated with different components of a scene goes on to impact the recollection of those particular scene components (Davidson et al., 2021). The task employs both negative and neutral objects and places them on neutral backgrounds. During the encoding phase, participants view all the images and sometimes perform a simple task such as rating the emotional intensity of the image. During the recall task, participants view the objects and backgrounds separately, and are asked to indicate whether they have previously seen the scene component, or whether it is new. Across the literature, it has been reported that generally, higher memory scores are reported for negative objects in comparison to neutral objects. Further, when neutral backgrounds are paired with negative objects, recollection for the neutral background is worse compared to when neutral backgrounds are paired with neutral objects (Davidson et al., 2021).

The first study to use the ETO examined memory specificity across two groups: older adults and younger adults (Kensinger et al., 2007a). The memory task tested a participant's ability to recall objects that had neutral, negative, or positive content. The results of the study displayed that negative objects had the highest memory specificity across both groups, suggesting that the negative emotional content may have been preferentially consolidated in comparison to the neutral and positive content (Kensinger et al., 2007a). Further research was needed to begin to understand the neural processes that may be responsible for this discrepancy, or trade-off, in memory consolidation.

The next study that harnessed the ETO to evaluate whether sleep may be a process that contributes to the emotional trade-off effect. The study compared the effects of nocturnal sleep compared to daytime wakefulness immediately after the encoding phase, allowing half the participants to sleep following encoding, and keeping the other half of the participants awake (Payne et al., 2008). Across all study participants, the results, as displayed on Figure 4, showed that objects causing negative arousal had a stronger recollection than objects that were classified as neutral (Payne et al., 2008). Backgrounds associated with these neutral objects, however, were better remembered than the backgrounds associated with the negative objects.

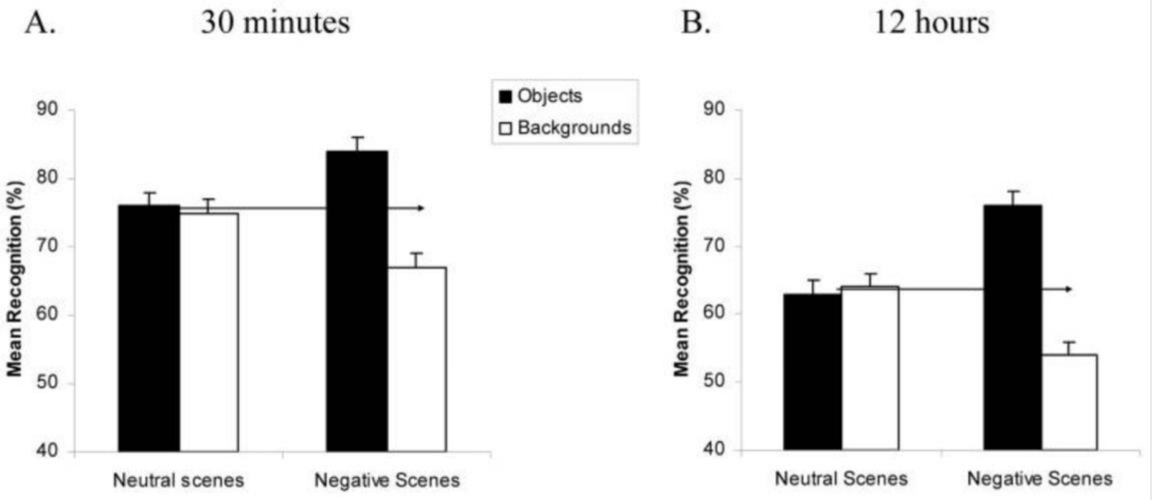

Figure 4. The emotional trade-off effect demonstrated across all study participants. (A) displays the recognition task completed after 30 minutes, while (B) represents the recognition task completed after 12 hours. Collapsed across sleep and sleep deprivation (SD) groups, it can be seen that negative objects have the highest mean recognition score during both recognition tasks. Further, it can be noted that negative backgrounds have a lower mean recognition score compared to neutral backgrounds across all study participants during both recognition tasks (Payne et al., 2008).

The effects of sleep were found to heighten the recollection of central negative objects, but did not have significant effects on neutral objects or background scene components (Payne et al., 2008). As such, following 12 hours of sleep after encoding, the magnitude of the difference in memory for negative objects and their paired backgrounds doubled for the sleep group in comparison to the wake group. This strengthens the argument that sleep preferentially consolidates emotional memories in comparison to neutral memories (Payne et al., 2008). It is important to note that while the negative object and neutral background were presented together, sleep may play a role in separating the individual scene components, thus fortifying the memory of the emotional piece without doing the same for its neutral counterpart. Overall, this study revealed the potential for emotional scene components to undergo different processing depending on whether sleep or wake follows initial encoding (Payne et al., 2008).

Previous studies have demonstrated the emotional trade-off effect, where emotional (ie. negative) elements of scenes showed increased recollection compared to neutral elements, and it has been hypothesized that neural processes during sleep may contribute to this trade-off (Vargas et al., 2019). The last study to date utilizing ETO investigated the effects of acute SD in the preferential consolidation of emotional memories, aiming to determine whether these results were indeed specific to the process of sleep. After randomly assigning study participants to sleep and SD groups, memory was assessed using the ETO. In this study, sleep was manipulated following the encoding phase, and prior to the recognition portion of the task. The results indicated that while negative objects were more successfully recalled compared to neutral objects, there was no significant difference in this recollection between the sleep and SD groups (Vargas et al., 2019). This finding postulates that the process of sleep may not be independently responsible for the effective consolidation of emotional memories. Instead, other factors such as circadian rhythms, stress, or mood-congruent effects, could also be contributing to the trade-off effect (Vargas et al., 2019).

Mood & Emotional Memory

Mood has been shown to impact numerous aspects of cognition including attention, executive control, and memory. This can be explained by a mood-state’s ability to impact neural processing, thus resulting in downstream effects on memory consolidation and decision-making (Faul & LaBar, 2023). Several clinical research endeavors have examined whether a substantive relationship exists between mood and emotional memory. The literature reports that the valence of the mood one is experiencing may aid in recalling memories that match that particular valence (Lewis et al., 2005). For example, if one is experiencing a positive mood, they may find it easier to recall memories that have been encoded as positive as well. The same trend has been shown for negative mood states and memories (Lewis et al., 2005).

One explanation for this phenomenon is referred to as mood-congruent memory (MCM) (Faul & LaBar, 2023). MCM describes how mood can influence the consolidation, storage, and retrieval of memories that match the particular mood that an individual is experiencing. In practice, MCM is often measured by inducing a certain mood-state onto a participant, and then testing the encoding and retrieval of information that is either congruent with that mood-state or opposite, in order to determine whether there is a measurable difference (Faul & LaBar, 2023).

The associative memory effect offers a potential explanation for the mechanism by which MCM functions. It states that storing a memory result in the formation of nodes, each corresponding to different components of the memory (ie. colors, shapes, smells, places, emotional valence, etc) (Lewis et al., 2005). The nodes capturing emotional valence can then be activated by other stimuli that share the same emotional valence. This activation then re-ignites all the other nodes that represented components of the initial memory, allowing for easier retrieval of the information (Lewis et al., 2005). This process is captured below in Figure 5.

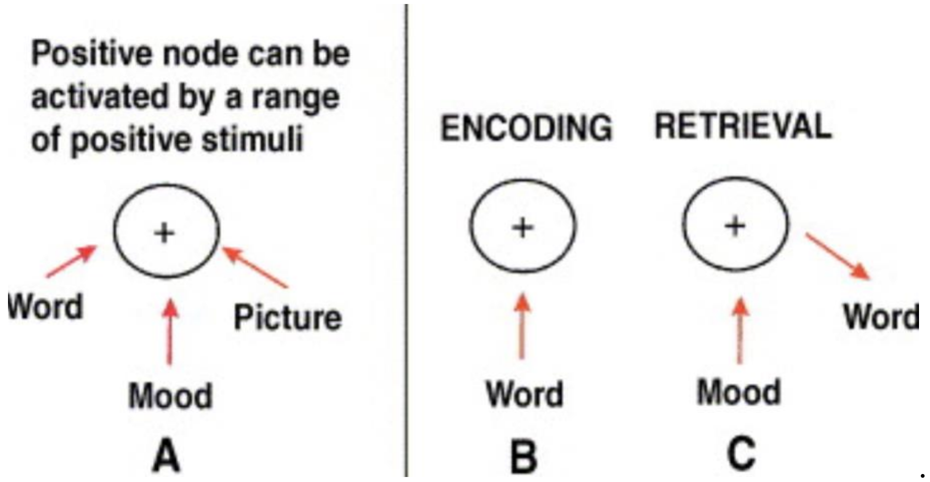

Figure 5. Mood Congruent Memory Facilitation can be explained using the Associative Model. The model proposes that stimuli belonging to a particular valence (positive or negative) can activate a node (A). During the encoding phase (B), the memory becomes associated with that particular valence. Thus, during retrieval (C), being in the mood-state corresponding to the correct valence can activate the node, aiding memory retrieval (Lewis et al., 2005).

Current Study

Based on the literature review of sleep and memory, it is evident that disagreement in the field persists over the preferential consolidation of emotional and neutral memories, and whether this process may be sleep-dependent (Alger & Payne, 2016; Davidson et al., 2021). The primary study that investigated the impacts of SD on emotional and neutral memories suggested that the preferential consolidation of emotional memories may be a sleep-independent process, since a significant difference in the emotional trade-off effect was not observed between the sleep and SD groups (Vargas et al., 2019). It is important to note, however, that this study only focused on SD after the encoding phase. It is possible that the placement of sleep manipulation within the memory processing framework could impact the results of the study (Cunningham et al., 2022). Expanding upon the previous literature, the current study will investigate the impact of SD prior to the encoding phase, resulting in a group of participants being sleep deprived during both the encoding and recognition phases of the ETO task.

Specific Aims

The first aim of this study was to determine the effect of one night of SD on mood. When examining the impact of SD on self-reported mood, I predicted that SD would result in both a decrease in PA and an increase in NA (Tomaso et al., 2021). The normal sleep group was not expected to report a significant change in either PA or NA.

The second aim of this study explored how normal sleep and SD participants performed on an emotional memory task, with SD occurring prior to encoding, and thus prior to consolidation and retrieval as well. It was expected that, in comparison to the SD group, normal sleep group participants would report a higher overall memory score (Kaida et al., 2015). Further, it was hypothesized that memory declines for the SD group would be most prominent for the neutral elements, both object and background, as well as for the neutral backgrounds paired with negative objects (Payne et al., 2008). However, it was expected that the deterioration in memory for the negative object component would be less pronounced compared to the other components (Kaida et al., 2015). As such, an increase in magnitude of the trade-off between the negative object and negative background was hypothesized for the SD group.

Pending a change in self-reported mood and emotional memory were found for the SD group, we planned an exploratory analysis of the correlation between the changes in mood and emotional memory. The investigation explored how mood at the time of the emotional memory task (encoding, consolidation, and recognition) was associated with performance on the emotional memory task.

METHODS

Participants

This clinical research study was approved by the institutional review board at the Beth Israel Deaconess Medical Center (BIDMC). Sixty-nine individuals participated in this study, with n=21 in the sleep group and n=48 in the SD group. This particular analysis was part of a larger study, which went on to further separate the SD group into a third condition. Four additional participants were successfully recruited and participated to varying extents in the study but were excluded from data analysis due to incomplete data collection. All participants were between the ages of 18-35 and were screened to ensure that they passed all inclusion and exclusion criteria. Participants currently taking medications that impacted neural functioning were excluded, as were participants taking antidepressant medications or sleeping aids. All participants were required to have normal or corrected vision, not report signs of color-blindness, and have normal or hearing-aid assisted hearing.

If participants reported the following medical conditions: seizures, high blood pressure, liver problems, kidney problems, thyroid problems, stroke, vascular disease, or heart arrythmias, they were excluded from the study. Participants were also excluded if they reported a previous diagnosis of a learning disorder, bipolar disorder, depression, or any other mental illness or emotional/psychiatric problem. Further, participants with medical complications such as undergoing electroconvulsive therapy, suffering major head trauma within the last two years, receiving a diagnosis of dementia, neurological or movement disorder, or having major surgery within the last one year, were also excluded from participating in the study.

Self-reported lifestyle factors were also evaluated through inclusion and exclusion criteria to determine appropriate participation in this study. Factors such as regularly going to sleep after 2:00 AM, regularly waking up after 12:00 PM, sleeping less than six hours per night, drinking more than four caffeinated beverages per day, or smoking more than one cigarette per day, all excluded participants from the study. Further, participants were asked to maintain a sleep log for the seven-days leading up to their participation date, keep a regular sleeping schedule for three nights before the study, refrain from napping on the day of the study, abstain from recreational drugs and alcohol for 24 hours before the study, and minimize caffeine intake for 24 hours before the study. If a participant could not commit to the above study criteria, they were also excluded from the study.

Evening Experiment Protocol (Session 1)

Patients arrived at BIDMC at 9:00 PM on their scheduled study participation day. After completing a brief check-in with an assigned research nurse, the research assistant communicated all experiment instructions and obtained informed consent from the participant. The participant was given a laptop and was settled in a quiet room where they could complete a variety of questionnaires and cognitive assessments. One such questionnaire was the PANAS assessment tool, which evaluated participant mood at the current timepoint.

The PANAS is a self-report tool that presents 20 unique adjectives, 10 from each of the positive and negative affect categories, and asks the participant to rate, on a Likert scale from 1-5, their agreement with how they feel that they embody each adjective at that particular moment in time (Mohn et al., 2018). Selecting a value of “1” indicated that the participant did not resonate with the adjective and a value of “5” indicated that the participant strongly resonated with the adjective. The PANAS tool ranks positive and negative affect discretely on individual scales, thus participants complete separate rankings for each adjective. The 20 adjectives are summarized in Table 5, separated by positive and negative affect.

Table 5. Positive and Negative Affect Scores (PANAS) Adjectives (Watson et al., 1988).

Positive Affect (PA)	**Negative Affect (NA)**
Interested	Distressed
Excited	Upset
Strong	Guilty
Enthusiastic	Scared
Proud	Hostile
Alert	Irritable
Inspired	Ashamed
Determined	Nervous
Attentive	Jittery
Active	Afraid

Abbreviations: PANAS, Positive and Negative Affect Scores; PA, Positive Affect; NA, Negative Affect;

By approximately 11:00 PM, participants had completed the various questionnaires and cognitive assessment tasks required of them in the evening session. Participants that were assigned to the sleep group were discharged by the research nurses and dismissed from BIDMC at this time to go sleep normally at home.. These participants were instructed to return to BIDMC by 8:30 AM the next morning in order to participate in the morning experimental protocol session.

SD Experimental Protocol

At this time, participants assigned to the SD group were escorted to a room where they would spend the rest of the night. They were given access to their cell phones, and were granted permission to access the internet, do homework, play games, watch low intensity television shows and movies, or take short walks. These activities were suggested in order to aid participants in staying awake throughout the night, and study staff were consistently monitoring these participants throughout the night. Participants were instructed that the following activities were prohibited: sleeping, eating chocolate (due to caffeine content), sweat inducing work outs, creating disruptive noise, and inducing significant stress upon themselves. Various questionnaires and cognitive assessments were performed by the SD participants at three intervals throughout the night.

Morning Experiment Protocol (Session 2)

At 8:30 AM the next morning, sleep condition participants arrived back at BIDMC and were admitted by the research nurse and instructed to fill out a sleep log pertaining to the previous night. Participants in both the sleep and SD conditions were provided with breakfast before beginning tasks for the morning session, Session 2. The first set of questionnaires began at approximately 8:45 AM. The PANAS assessment was collected once again, in addition to various other self-report and cognitive assessments. Following these questionnaires and assessments, the ETO portion of the experimental protocol began. After completion of the trade-off task, participants continued with the larger study protocol not of relevance to the current report.

Emotional Trade-off Task

In an ETO, participants go through both an encoding and a recognition phase. First, participants are presented with a series of images that consist of negative and neutral objects on neutral backgrounds, and are usually asked to perform a task, such as rate their level of emotional arousal to each image in order to maximize engagement with the stimuli and facilitate the encoding process. The recognition task begins after some time delay, with objects and backgrounds individually presented to the participant, instead of combined together as was the case in the encoding phase (see Figure 5). While "old" objects and backgrounds from the encoding phase are presented to the participants in this encoding phase, "new" objects and backgrounds that the participant has not yet encountered are also presented during recognition. Participants are tasked with identifying which scene components they have seen before, "old", and which scene components they have not seen before, "new".

At approximately 9:40 AM, the ETO encoding task began. Participants were presented with neutral and negative images, or scenes, on their laptop screen for approximately four seconds and were instructed to rate the emotional intensity of each scene on a scale from 1-5, with "1" representing "very low emotional intensity" and "5" representing "very high emotional intensity". Participants were encouraged to provide ratings according to their initial first impression of the scenes, reflecting personal experiences or other feelings that may come to mind immediately upon viewing the image for the first time.

The participants were given a brief practice round of ranking image emotional intensity before beginning the official encoding task. Fifty-two neutral object on neutral background scenes and 52 negative object on neutral background scenes were shown to participants during the encoding stage., for a total of 104 images at encoding. Approximately 20 minutes was allotted for each participant to complete the encoding task. At this point, participants were given a 10-minute break to stretch, use the restroom, and respond to a few additional questionnaires before continuing with the remainder of the ETO.

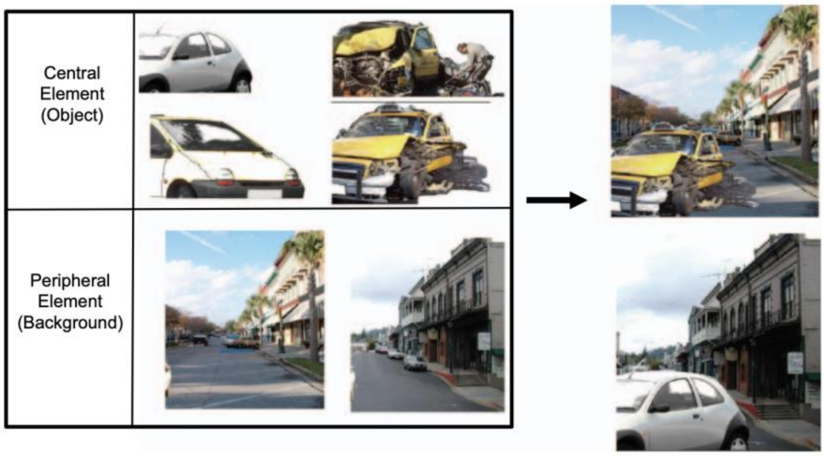

Figure 6. Example Scenes presented to Participants during the Emotional Trade-off Task (ETO). Below, two intact cars represented neutral objects, and two damaged cars represented negative objects. These objects were both placed on a neutral background, the street, to complete each scene (Payne et al., 2008).

The recognition task of the ETO took place next at approximately 10:10 AM. Participants were shown individual components of the neutral and negative scenes that they were shown previously in the encoding task, and were instructed to indicate if the image they were viewing was “old” by pressing “1”, they had seen it previously in the encoding task, or “new” by pressing “5”, they had not seen it previously during the encoding task. A total of 176 images were presented at recognition, with the following breakdown: 26 each of “old” neutral backgrounds, “old” negative backgrounds, “old” neutral objects, and “old” negative objects, 18 each of “new” neutral objects, and “new” negative objects, and 36 “new” neutral backgrounds. The scene components, presented as either object or background, were shown on the laptop screen for approximately three seconds, and participants were required to indicate their memory response within this allotted time. This recognition task took approximately 30 minutes for participants to complete.

After completing various other clinical and cognitive tasks throughout the late morning and afternoon, participants were required to complete an exit survey, and then received financial compensation and departed from BIDMC at approximately 3:00 PM after being discharged by the research nurse.

Statistical Analyses

All statistical analyses were performed in International Business Machines Statistical Package for the Social Sciences (SPSS) v29.0.1 (*SPSS Software | IBM*, 2024).

Group demographics were manually calculated and presented in percentage form. Demographic variables include age, biological sex, ethnicity, race, and highest level of education. The race categories included African American, American Indian/Alaskan Native, Asian, white, unknown, more than one race, and chose not to respond. T-tests were used to detect significant differences in the PANAS scores between the sleep and SD groups, and between session 1 and session 2 within the groups (significance threshold of $p < 0.05$). Composite PANAS PA and NA scores were calculated as instructed.

For the ETO task, corrected memory scores were calculated for analysis. If a participant correctly identifies an object or background previously presented in the encoding phase as “old”, this constitutes a “hit”. However, if a participant classifies an object or background as “old” but it had not been previously presented, this would be classified as a “false alarm”. The corrected memory score is calculated by subtracting a participants false alarm score from their hits score (Denis et al., 2022). Repeated measures analysis of variance (ANOVA) (2 x 2 x 2) was used to examine the effects of valence (negative vs. neutral), scene component (object vs. background) and condition (sleep vs. SD) on corrected memory scores for each valence and scene component type. This was followed up with a t-test and bivariate analysis to test the strength of results as well as the direction of the effects. A significance threshold of $p < 0.05$ was used. Memory retention of the objects was calculated separately for each valence (negative and neutral) as the number of items accurately remembered (i.e. hits) divided by the number of items originally viewed (Snodgrass & Corwin, 1988). Pearson correlations were used to explore associations between any changes in PANAS scores vs. corrected memory scores in both sleep and SD groups. Significant correlations were plotted using Microsoft Excel v16.77.1 (*Excel | Microsoft 365*, 2024).

RESULTS

Demographic Analysis

The demographic composition of participants in the study is presented in Table 6, categorized by the sleep group (n = 21) and the SD group (n = 48). The average age of participants in the sleep group was 23.29 years, while those in the SD group had a slightly lower average age of 21.50 years. In terms of biological sex, the sleep group consisted of 68.18% female and 31.82% male participants. The SD group had a higher proportion of female participants (77.08%) and a lower proportion of male participants (22.92%). As for ethnicity, 33.33% of the Sleep Group identified as Hispanic, which is roughly double the proportion in the SD Group (16.67%). The majority of participants in both groups were non-Hispanic, making up 66.67% of the Sleep Group and 83.33% of the SD Group. The research participants also showed racial diversity as in the sleep group, participants identified as African American (14.29%), Asian (28.57%), White (42.86%), and more than one race (14.29%). The SD group had similar racial representation, with African American (14.58%), Asian (35.42%), White (37.50%), and more than one race (2.08%). A small percentage identified as American Indian/Alaska Native (2.08%) or chose not to respond (6.25%). Regarding the highest level of education attained, the sleep group had 19.05% of participants with a graduate or professional degree and 42.86% with a Bachelor of Arts/Science. Some college was completed by 33.33% of participants, and 4.76% held a high school diploma. In the SD group, fewer participants had a graduate or professional degree (10.42%) and a Bachelor of

Arts/Science (25.00%), while a larger percentage had some college education (52.08%) or a high school diploma (12.50%).

Table 6. Demographic Analyses of Study Participants, stratified by Condition Group.

	Sleep Group (n=21)	**SD Group (n=48)**
Age (years)	23.29	21.50
Biological Sex		
Female	68.18%	77.08%
Male	31.82%	22.92%
Ethnicity		
Hispanic	33.33%	16.67%
Non-Hispanic	66.67%	83.33%
Race		
African American	14.29%	14.58%
American Indian / Alaska Native	0.00%	2.08%
Asian	28.57%	35.42%
White	42.86%	37.50%
Unknown	0.00%	2.08%
More than one race	14.29%	2.08%
Chose not to respond	0.00%	6.25%
Highest Education Level		
Graduate/professional degree	19.05%	10.42%
Bachelor of Arts/Science	42.86%	25.00%
Some college	33.33%	52.08%
High school diploma	4.76%	12.50%

Abbreviations: SD, Sleep Deprivation;

PANAS Results

Baseline (Session 1) PANAS scores were compared between the sleep and SD groups, and no significant difference was observed for either PA scores ($F_{1,69}$=0.759, p=0.276) or NA scores ($F_{1,69}$=3.652, p=0.491). At session 2, however, a significant difference between PA scores was found between the sleep group and the SD group ($F_{1,69}$=9.468, p=0.001). There was no significant difference in NA between the two condition groups ($F_{1,69}$=0.934, p=0.238). Further, within the sleep group, no significant changes were found for PA scores between session 1 and session 2 (t(20)=0.775, p=0.447), or for NA scores between session 1 and session 2 (t(20)=1.743, p=0.097). However, within the SD group, a significant difference was seen for PA scores between session 1 and session 2 (t(47)=12.828, p=0.001), with scores for PA at session 2 being significantly lower than scores at session 1. A numerical decrease was seen for NA scores within the SD group between session 1 and session 2 (t(47)=2.003, p=0.051), but it failed to reach significance.

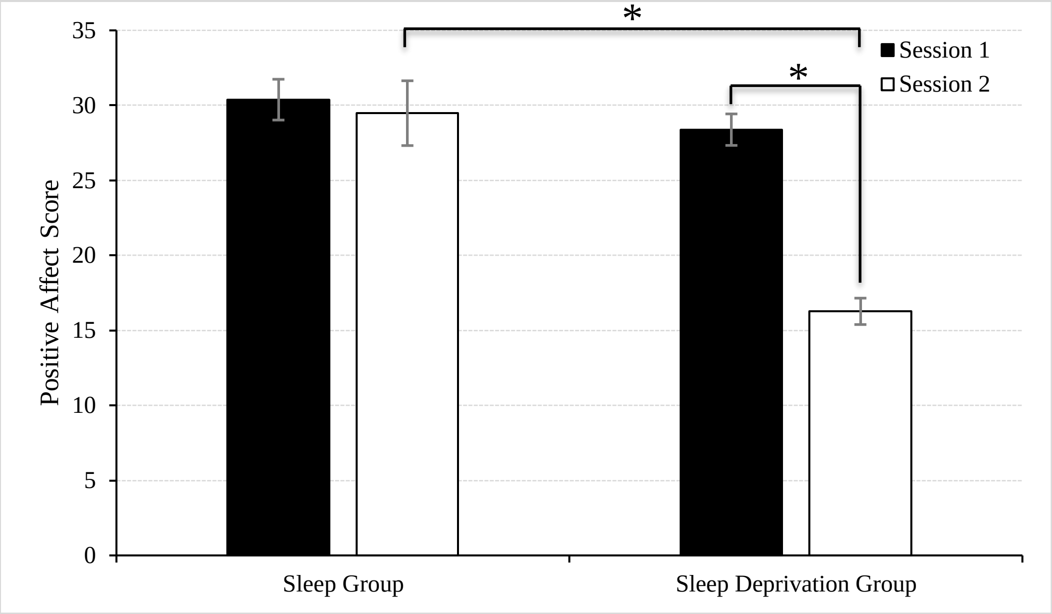

Figure 7. Positive Affect (PA) Score for Sleep and Sleep Deprivation (SD) Participants at Session 1 (Evening Session) and Session 2 (Morning Session). Baseline PA scores are represented by session 1 scores. No significant difference was found for PA scores between sleep and SD groups at baseline ($F_{1,69}$=0.759, p=0.276), however a significant difference was found for PA scores between sleep and SD groups at session 2 ($F_{1,69}$=9.468, *p=0.001). Within the groups, no significant difference in PA scores was found between session 1 and session 2 for the sleep group (t(20)=0.775, p=0.447), whereas a significant difference in PA scores was found between session 1 and session 2 for the SD group (t(47)=12.828, *p=0.001).

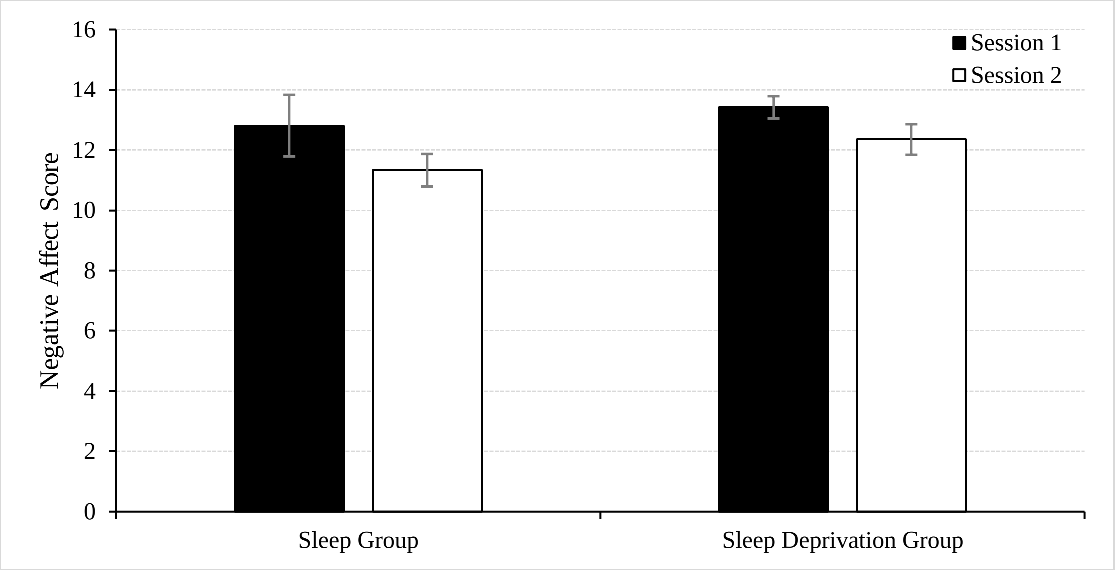

Figure 8. Negative Affect (NA) Score for Sleep and Sleep Deprivation (SD) Participants at Session 1 (Evening Session) and Session 2 (Morning Session). Baseline NA scores are represented by session 1 scores. No significant difference was found for NA scores between sleep and SD groups at baseline ($F_{1,69}$=3.652, p=0.491), or for NA scores between sleep and SD groups at session 2 ($F_{1,69}$=0.934, p=0.238). Within the groups, no significant difference in NA scores was found between session 1 and session 2 for the sleep group (t(20)=1.743, p=0.097), whereas a close to significant difference was found for the SD group (t(47)=2.003, p=0.051).

Emotional Trade-off Task Results

The main effect of condition was evaluated by calculating the corrected memory score for each condition group (sleep vs SD). The corrected memory score presented on Figure 9 was calculated by “hits – false alarms” from all the ETO categories into one corrected memory score (neutral object, neutral background, negative object, negative background), represented as a percentage. In Figure 8, corrected memory score for the sleep group was graphed against the corrected memory score for the SD group. The repeated measures ANOVA revealed a significant main effect of condition on memory scores ($F_{1,69}$=8.600, p=0.005), with the sleep group having a significantly higher corrected memory score in comparison to the SD group when collapsing across all valence and scene component types.

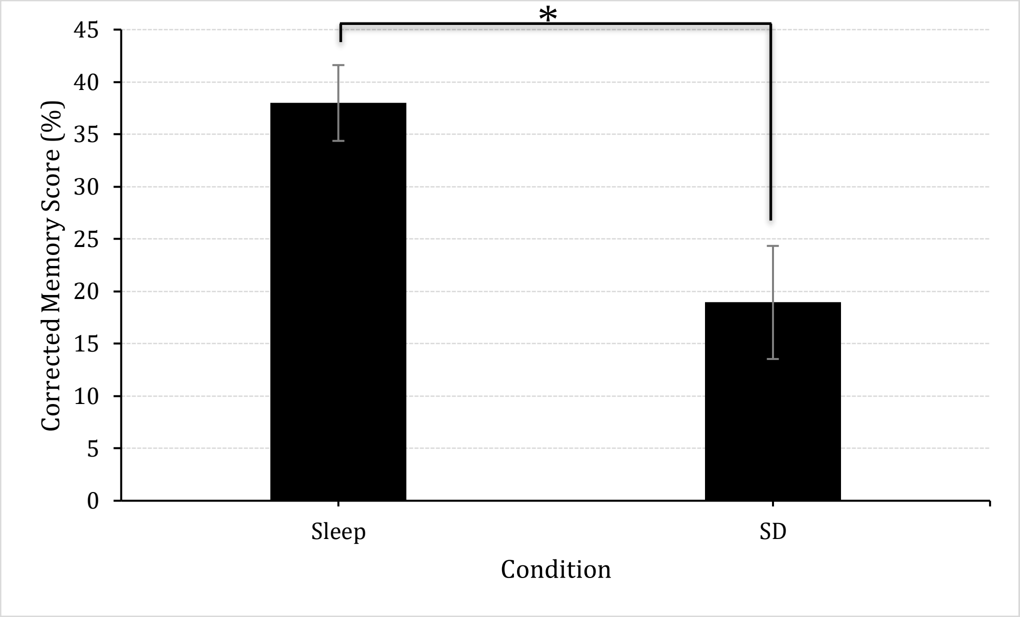

Figure 9. Main Effect of Condition on Corrected Memory Score. The sleep group is observed to have a significantly higher corrected memory score in comparison to the sleep deprivation (SD) group ($F_{1,69}$=8.600, *p=0.005).

The scene component and valence interaction across all participants is displayed on Figure 10. There was a statistically significant main effect of scene component (objects vs backgrounds) ($F_{1,69}$=46.049, p=0.001). Further, there was a significant interaction between scene component and valence (negative vs neutral), and that interaction is indicative of the emotional trade-off effect ($F_{1,69}$=63.999, p=0.001).

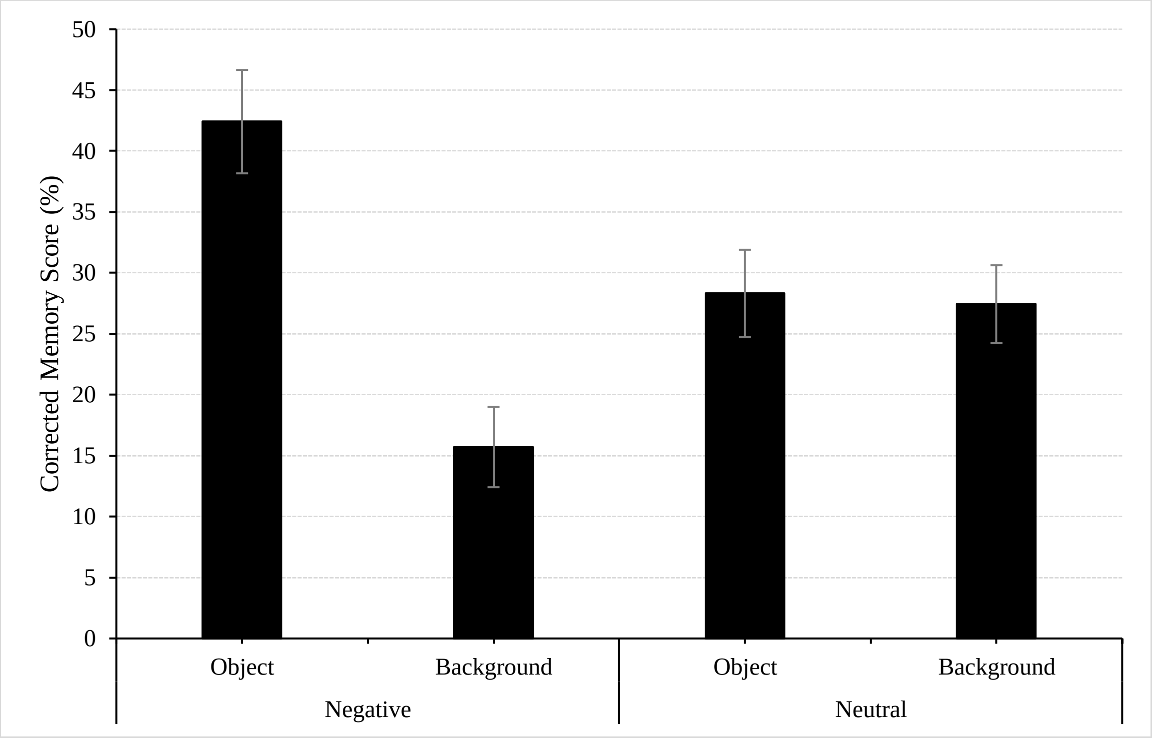

Figure 10. Scene Component and Valence interaction across all Participants. A main effect of scene component is present with statistical significance ($F_{1,69}$=46.049, p=0.001). Further, the emotional trade-off effect is present in the negative valence. The main effect of scene component and valence is demonstrated by the statistically significant difference in magnitude between the trade-offs for the two valences ($F_{1,69}$=63.999, p=0.001).

Figure 11 displays corrected memory scores, now stratified by condition as well. Not only did the emotional trade-off effect persists between the negative object and background for both the sleep and SD groups, but there was no significant difference between the magnitude of the trade-offs between negative objects and their paired backgrounds in each group (t(69)=0.204, p=0.839). Additionally, no significant difference was observed between the sleep and SD groups for the trade-off between the neutral object and background components (t(69)=-1.046, p=0.299). Importantly, it should be noted that while the pattern of the emotional trade-off effect was similar between conditions, the SD group had a lower corrected memory score in every component, regardless of valence, when compared to the sleep group.

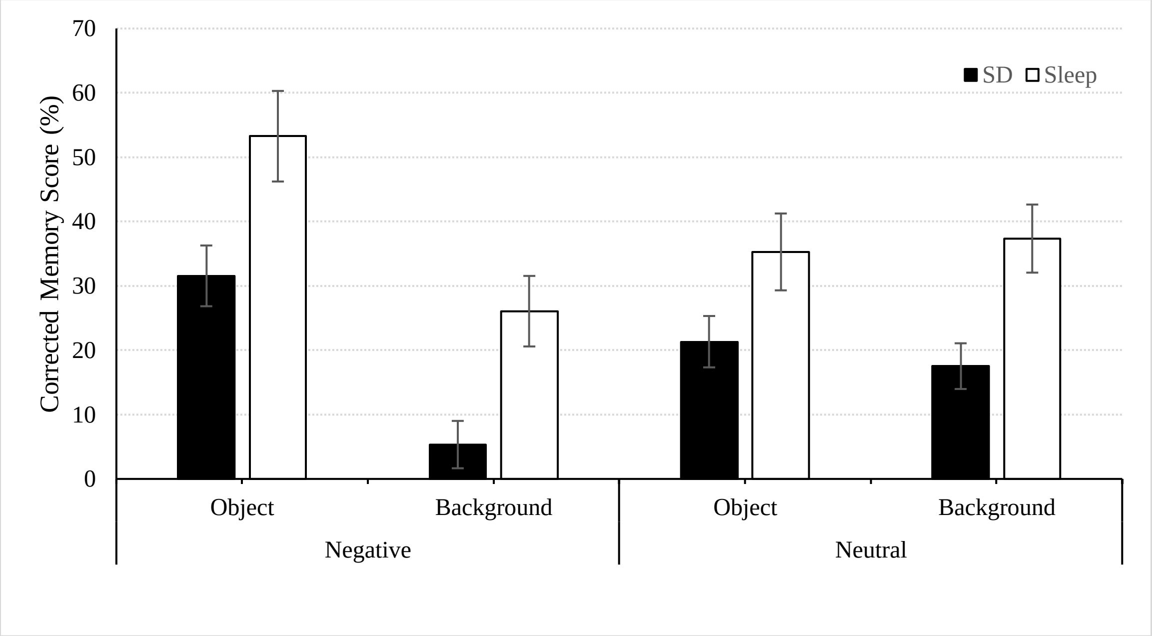

Figure 11. Trade-offs stratified by Sleep and Sleep Deprivation (SD) Groups. Across all scene components and both valences, it can be noted that the SD group obtained a lower corrected memory score than the sleep group. It can be observed that the emotional trade-off persists for the negative valence in both the sleep and SD groups. The magnitude of the emotional trade-off between the 2 conditions was not significantly different (t(69)=0.204, p=0.839). The trade-off for the neutral valence also was not found to have a significant difference in magnitude between the 2 conditions (t(69)=-1.046, p=0.299).

PANAS & Emotional Trade-off Task Correlation Results

Exploratory analyses revealed three statistically significant correlations between PANAS results and ETO results. All three of these reported correlations were obtained from grouping the entire participant pool, rather than differentiating between sleep and SD group in deriving the correlations. Figure 12 displays a weak positive correlation between PA scores at session 2 (morning session), and the percentage of negative background hits obtained from the ETO significant (r(69)=0.25, p=0.038), a proxy for emotional memory performance. The figure shows that with an increasing PA score at session 2, the percentage of negative background hits also increases. Figure 12 also depicts that participants in the SD group are clustered towards the lower end of the PA scores and therefore the lower end of the negative background hits, whereas the sleep group is clustered toward the higher end of the PA scores, and therefore the higher end of the negative background hits. As such, this may reflect that rested participants tended to have higher PA and memory abilities. Notably, this correlation did not persist when separated by condition.

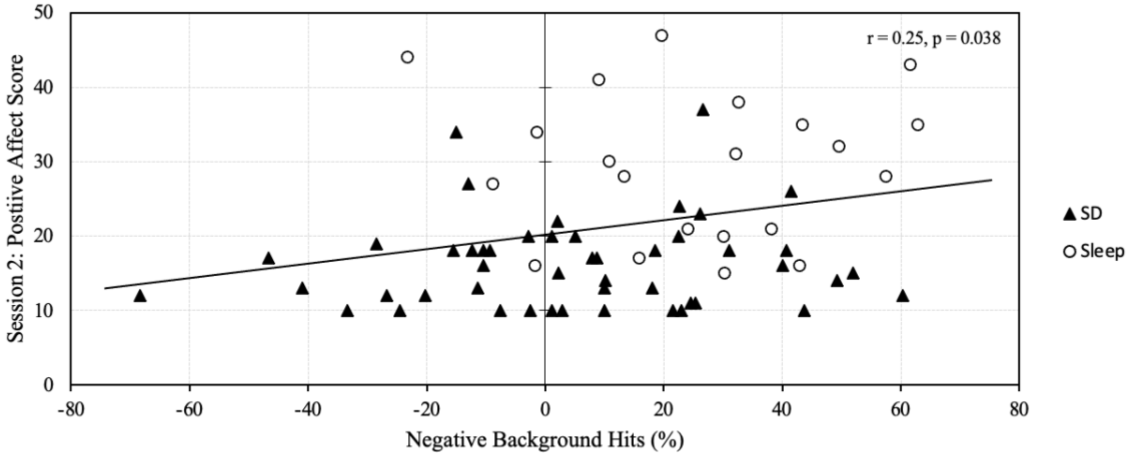

Figure 12. Scatterplot illustrating Pearson correlation coefficient between Positive Affect (PA) Score in Session 2, and percentage of Negative Background Hits. PA Scores were obtained from the Positive and Negative Affect Score tool, and percentage of Negative Background Hits were obtained from the Emotional Trade-off Task, performed at Session 2. A statistically significant weak positive correlation can be observed between the Session 2 PA Scores, and the percentage of Negative Background Hits (r(69)=0.25, p=0.038). *Abbreviations:* SD, Sleep Deprivation;

Figure 13 displays a weak positive correlation between the difference in PA scores between session 1 (evening session) and session 2 (morning session), and negative background hits obtained from the ETO. It can be seen that increases or minimal changes in PA were largely observed in the sleep group, whereas decreases in PA were largely observed for the SD group. The statistically significant weak correlation between difference in PA scores and negative background hits in Figure 13 depicts that decreases in PA between session 1 and session 2 are correlated with decreased emotional memory performance, while increases in PA between session 1 and session 2 are correlated with increased emotional memory performance (r(69)=0.27, p=0.023). This may reflect a smaller decrease in PA and higher memory abilities in rested participants compared to SD participants, and the correlation did not persist when separated by condition.

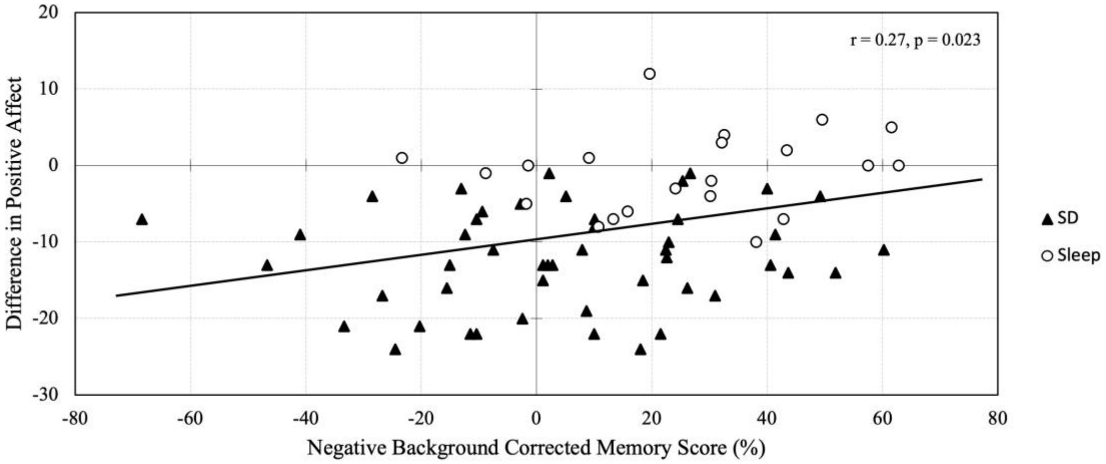

Figure 13. Scatterplot illustrating Pearson correlation coefficient between Difference in Positive Affect (PA) Scores between Session 1 and 2, and percentage of Negative Background Hits. PA Scores were obtained from the Positive and Negative Affect Score tool, and then the Session 1 PA Scores were subtracted from the Session 2 PA Scores to obtain PA Score Differences. The percentage of Negative Background Hits were obtained from the Emotional Trade-off Task, performed at Session 2. A statistically significant weak positive correlation can be observed between the Difference PA Scores, and the percentage of Negative Background Hits (r(69)=0.27, p=0.023). *Abbreviations:* SD, Sleep Deprivation;

Figure 14 displays the weak positive correlation between difference in PA scores between session 1 (evening) and session 2 (morning), and neutral background hits from the ETO (r(69)=0.34, p=0.005). It can be seen on the figure that the SD group is largely found to have reductions in PA scores with correlating weaker emotional memory performance, as indicated by lower neutral background hits. On the other hand, the sleep group is largely found to have increases or no change in PA scores, correlating with stronger emotional memory performance. Again, this may be more reflective of a smaller decrease in PA and higher memory abilities in rested participants compared to SD participants as the correlations did not survive when separated by condition.

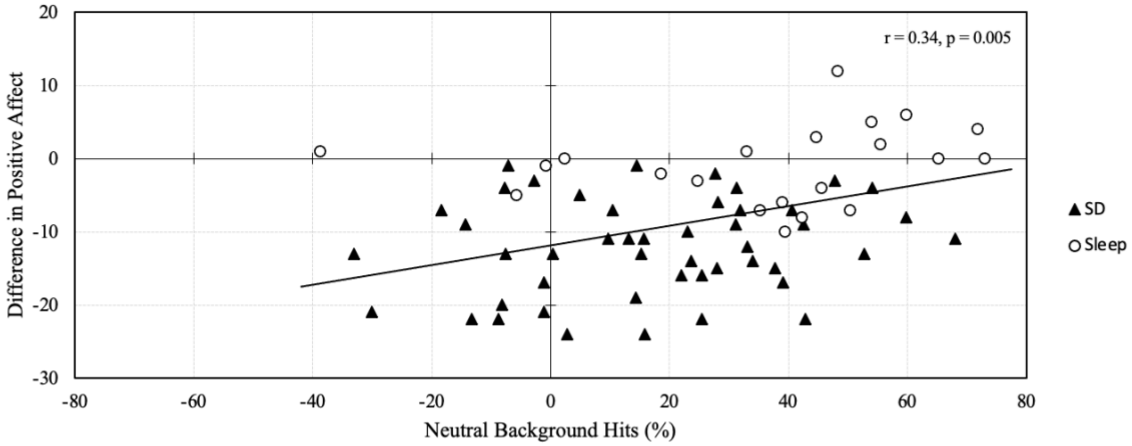

Figure 14. Scatterplot illustrating Pearson correlation coefficient between Difference in Positive Affect (PA) Scores between Session 1 and 2, and percentage of Neutral Background Hits. PA Scores were obtained from the Positive and Negative Affect Score tool, and then the Session 1 PA Scores were subtracted from the Session 2 PA Scores to obtain PA Score Differences. The percentage of Neutral Background Hits were obtained from the Emotional Trade-off Task, performed at Session 2. A statistically significant weak positive correlation can be observed between the Difference PA Scores, and the percentage of Neutral Background Hits (r(69)=0.34, p=0.005). *Abbreviations:* SD, Sleep Deprivation;

DISCUSSION

Goal of Study

The overall goal of this study was to determine the effects of SD on mood and emotional memory, when participants were sleep deprived prior to encoding, consolidation, and retrieval. Given the changes observed in both mood and emotional memory for the sleep and SD group, this study also investigated an exploratory aim evaluating whether a correlation exists between changes in mood across SD and emotional memory performance.

Mood & Sleep Analyses

The effects of SD on mood can be summarized by the significant difference in PA reported between session 1 (evening), and session 2 (morning). Importantly, this significant decrease in PA was only present for the SD group and did not occur for the sleep group. Importantly, no significant change in NA was noted between session 1 and session 2 for either the sleep or the SD group. These findings are in line with previous literature which has outlined that overwhelmingly, the largest impact of SD is a decrease in PA, with some evidence of SD resulting in minor changes in NA (Tomaso et al., 2021). One explanation for these findings is the sleep-mood cycle, which indicates that disruptions in sleep can have a resulting impact on mood (Watling et al., 2017). Further, a decrease in PA from SD is a finding that aligns well with the previously researched psychological consequences of SD, such as depression, anhedonia, and consistent alterations in mood (Reddy et al., 2024).

Emotional Memory & Sleep Analyses

The ETO revealed a significant condition effect, with the SD group reporting worse overall memory compared to the sleep group when both encoding and retrieval occurred in a sleep-deprived state. In addition to the worse overall memory score, the SD group also had poorer memory compared to the sleep group on every individual scene component and valence. Not only did we successfully replicate the emotional trade-off effect from literature, as indicated by a significant valence x scene component interaction, but intriguingly the trade-off persisted even after participants were separated out by condition. While overall memory performance was better in the sleep group, there was no difference in magnitude of the trade-offs when stratified by condition.

These findings are consistent with previous literature that employed similar ETO methods. Previous literature indicated that in order for a true trade-off effect to be shown, a significant valence x scene component interaction must be present (Kensinger et al., 2007b). Similar to the results of the "Weapon-Focus Effect", the negative central object demonstrated higher recollection than the neutral background, generating the emotional trade-off effect (Stanny & Johnson, 2000).

These results are also consistent with the findings of Payne et al., 2008, with the emotional trade-off effect being evident across all participants, with condition collapsed. When stratified by condition, the Payne study demonstrated that the trade-off effect doubled for the sleep group, with negative objects being recognized to an even larger extent than neutral objects when compared to the wake group (Payne et al., 2008). This was inconsistent with the findings of the current study, which did not demonstrate a significant difference between the magnitude of the emotional trade-off of the sleep and SD groups.

A potential explanation for this trade-off stems from the separate storage of central and peripheral components of memories. If different pathways exist for the encoding, consolidation, and retrieval of central vs peripheral components of memory, it is then possible for either of these separate components to be preferentially remembered over the other (Payne et al., 2008). If this process is in fact responsible for the emotional trade-off, it is important to note that it is still functional during periods of SD, since the emotional trade-off was still present in this group. As such, the separation of central and peripheral components of memory for storage may not be a sleep dependent process.

The findings of the current study, which manipulated sleep prior to the encoding phase, align well with Vargas et al., 2019, which manipulated sleep following the encoding phase of the ETO. This study concluded that the process of sleep may not be ultimately responsible for the preferential consolidation of emotional memories over neutral memories, due to the lack of a significant difference found between the emotional trade-off observed between the sleep and SD groups (Vargas et al., 2019). While overall memory was substantially worse following SD, the maintenance of the ETO effect in both groups is similar to the results of the current study. As such, it is important to consider whether the process of sleep itself allows for the heightened recognition of negative, and thus emotional, memories, or whether other factors, such as mood-congruent effects, may be responsible for these findings.

Mood & Emotional Memory Analyses

Finally, the exploratory investigation between mood and emotional memory revealed a correlation between PA scores and recollection of backgrounds, with higher PA scores from the PANAS test corresponding to better recollection of backgrounds presented in the ETO. It is worthwhile to note that this correlation did not persist when separated by condition, likely because sleep group participants had higher PA scores and higher memory scores, while the SD group displayed opposite results. Thus, the correlation that was drawn may in fact be better referred to as a group effect.

Regardless, further investigation into this proposed correlation is warranted. The broaden-and-build theory, which states that positive emotions play a role in expanding ones mindset in the moment, may explain a piece of this correlation (Fredrickson, 2004). If when experiencing heightened positive emotions, an individual is more observant and prone to inquiry, the theory posits that this individual is able to build stronger intellectual connections in that moment which can then be drawn on upon in the future (Fredrickson, 2004). Extrapolating this theory to PA and memory of backgrounds, it is possible that participants experiencing positive moods were more observant of the images they were presented, noticing additional details about the background, and forming intellectual connections during the encoding phase which they drew upon during the recognition phase of the ETO.

Limitations

This study emphasizes the cognitive and emotional implications of sleep by employing the PANAS test and ETO to describe differences between well-rested individuals and those subjected to sleep deprivation. The results of this study highlight the crucial role that sleep quality plays in healthy functioning and how it might be a key component in maintaining mental health, suggesting that proper sleep is not only integral to emotional well-being (mood) but also maintain cognitive functions. However, this study also presents several limitations that may impact the results of the study. First, the size of the SD group was larger in comparison to the sleep group, as the SD group was further divided in subsequent phases of the study. This discrepancy in group size could potentially impact the statistical power of the results as well as the generalizability of the findings.

Additionally, self-report methods were administered to assess mood in participants, which may inherently reflect their perceived emotions rather than their actual emotional state, thereby potentially introducing bias into the data. Such biases include social-desirability, where participants may tailor their responses to align with perceived social norms. Despite these limitations, we reported no significant differences in baseline mood between the groups prior to the sleep or sleep deprivation intervention to account for this bias. Another limitation arises from the fact that the quality and duration of sleep for the participants who slept at home was not monitored in a controlled environment, unlike the SD group. Participants provided a sleep log the following morning; however, without controlled conditions, variations in individual sleep patterns could influence the results, particularly the PANAS scores and performance on the ETO.

Future Directions

As research in this domain progresses, it would be crucial to investigate the effects of various sleep stages on mood and executive task performance. REM sleep, known for its role in emotional memory consolidation, could be examined more closely to better understand its potential therapeutic benefits in mood regulation and psychological resilience. Previous studies such as by Goldstein & Walker (2014) and van der Helm & Walker (2009) have suggested that REM sleep facilitates emotional processing, which could imply its importance in emotional adaptation and the management of stress-related disorders.

Another promising avenue for future research could involve restricting sleep selectively at various stages of the sleep cycle. This approach could help clarify the specific contributions of each sleep stage. Restricting sleep to certain stages and assessing the impact on ETO performance, particularly in SD groups, could provide insights into targeted interventions for cognitive enhancement. The work of Mander et al. (2013) and Ferrara & De Gennaro (2001) provides a foundation for exploring these relationships, highlighting the distinct roles of deep (N3) sleep and REM in memory consolidation and executive functioning.

Finally, exploring the interaction between mood, emotional memory, and sleep presents another critical future research direction. By utilizing neuroimaging techniques and physiological measures to understand cognitive implications of sleep patterns, researchers could gain deeper insights into how brain activity patterns are associated with mood regulation and memory processing during sleep, which could illuminate underlying mechanisms.

Conclusion

By demonstrating the cognitive impacts of sleep deprivation, this research highlights the importance of prioritizing sleep quality in mental health frameworks and public health policies. Given the links between sleep deprivation and social determinants of health, such as economic and social barriers that hinder access to quality sleep, targeted public health interventions should address these foundational issues. By promoting improved sleep hygiene, and consequently, cognitive functioning in the general population, we can significantly enhance the overall well-being of the population.

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