Memory Suppression under Sleep Deprivation: The Effects of Sleep Loss and Sleep Time on Suppressing Unwanted Memories

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Abstract

This study investigated the effect of acute partial sleep deprivation and long-term sleep patterns on performance on the Think/No-Think memory suppression task. The executive deficit hypothesis (Levy & Anderson, 2008) posited that individual differences in executive control can impact suppression task performance and hence, it was hypothesised that sleep differences, due to their influence on executive function, would cause deficits in inhibition. The Think/No-Think task involves learning a set of word pairs, then suppressing some of them by intentionally avoiding thinking of them. Participants were exposed to each word stimulus for a total of 12 repetitions during manipulation. Recall of suppressed and non-suppressed items were compared with both same probe and independent probe conditions to evaluate the effect of suppression. Suppressed No-Think items were recalled less frequently than Baseline items. Participants who underwent three hours of partial sleep deprivation the night before completing the task ($N = 19$) had their performance compared with fully rested controls ($N = 22$). Neither three hours of sleep deprivation nor average total sleep time influenced suppression task performance. This study has demonstrated that partial sleep deprivation of 3 hours does not adversely affect memory suppression.

Contents

Glossary of Terms

fMRI	Functional Magnetic Resonance Imaging device
IP	Independent Probe
NSD	No Sleep Deprivation
OCD	Obsessive compulsive disorder
PTSD	Post-traumatic stress disorder
SD	Sleep Deprivation
SP	Same Probe
SQS	Sleep Quality Scale
T/NT	Think/No-Think

1. Introduction

1.1 Overview

Suppression-induced forgetting is forgetting that occurs when content is intentionally forced out of the conscious mind or prevented from entering (Stramaccia et al., 2020; 2021). Modern understanding of this phenomenon is a recent addition to theories of forgetting and suggests that the ability to voluntarily suppress unwanted thoughts is an adaptive process that helps the human mind recall useful information without interference, and to reduce recall of unwanted intrusive thoughts (Anderson & Levy, 2009). Suppression-induced forgetting has been demonstrated to be cue-independent, meaning that a suppressed item remains forgotten regardless of what cue is used to attempt to cause it to be remembered (Anderson & Green, 2001).

1.2 Suppression-induced forgetting and unwanted thoughts

The suppression-induced forgetting mechanism is useful for helping understand to what degree humans can control their remembering and forgetting processes. Such research can aid understanding of what types of people are susceptible to the intrusion of unwanted thoughts, and which strategies are most successful at repelling these thoughts. Unwanted thoughts can often be traumatic and distressing, and better methods for suppressing these thoughts would hopefully aid individuals who frequently suffer from them. Developing further insight into suppression mechanisms may allow formulation of more accurately targeted clinical strategies to aid with suppressing unwanted thoughts. Research into memory suppression is most clinically critical to sufferers of conditions characterised in part by intrusive thoughts or compulsions, such as obsessive-compulsive disorder (OCD) or post-traumatic stress disorder (PTSD). The ‘obsessive’ element of OCD is characterised by repeated experiences of intrusive thoughts that are unwanted and distressing, and PTSD involves intrusion symptoms which can be experienced as unwanted, upsetting memories (DSM-5, American Psychiatric Association, 2013).

Individuals with OCD or PTSD have been demonstrated to struggle with success in suppression tasks (Janeck and Calamari, 1999). This study observed that when subjected to a suppression task, OCD participants experienced a ‘rebound effect’, characterised by an increase in intrusion of an item when attempting to not think about it (see Wenzlaff & Wegner, 2000, for a review), on a negative intrusive thought more frequently than control participants, demonstrating a susceptibility to these intrusive thoughts and a difficulty in suppressing them. The intrusive thought stimuli used for participants in this study were selected as items actually experienced as intrusive thoughts in day-to-day life by the participants. The rebound effect occurred only in the condition in which participants were explicitly instructed to actively suppress the unwanted thought, as opposed to being told that they are allowed to think about anything.

Catarino et al. (2015) observed a negative correlation between success on a suppression-induced forgetting task and PTSD symptom severity for suppression of emotionally weighted items, indicating that more severe PTSD symptoms appeared alongside the greatest difficulty in suppressing unwanted thoughts. PTSD patients have difficulty with intrusive thoughts in their day-to-day lives, and this study replicated this in a laboratory environment. It is unclear whether people who begin to suffer from PTSD then become more susceptible to intrusive thoughts, or if people with a predisposition to difficulties with suppression are more likely to suffer from more severe PTSD symptoms, or if the relationship is more complicated than these two variables alone. Nevertheless, this study demonstrated a key connection between PTSD and difficulty suppressing unwanted thoughts.

1.3 The executive deficit hypothesis

Levy and Anderson (2008) posited that differing performance in a memory suppression task such as the T/NT task can be explained by individual differences in executive function. They called this the executive deficit hypothesis. In the paper, they commented on the observation that there is often an occurrence of very large variations between participants on suppression tasks – while the average effect between participants is often only modest, some participants demonstrate suppression effects ten times the cohort average, and some experience a 'rebound effect', producing increased recall whereas suppression tends to induce forgetting and decrease recall. They suggested that an individual can control their memory much like they control the physical action of their body, using the conscious, active function of the brain. We have a natural response to catch a falling object, but we can inhibit that response in a situation where it is inappropriate, like when the falling object is a knife. The executive deficit hypothesis suggests that inhibition of thoughts and mental activities works much the same. Levy and Anderson used neurophysiological evidence to support this claim, by highlighting that suppressing an unwanted memory appears to be performed by the same executive control regions of the brain that are utilised to stop a motor action, such as halting the toss of a basketball (Anderson et al., 2004). Levy and Anderson were able to present further evidence for this position by connecting success in suppression tasks to many other individual differences closely related to executive control, including correlation with success rate on a working memory task, training in memory suppression, age of the individual, and suppression strategies employed.

Further research has provided support for the executive deficit hypothesis, such as that voluntary forgetting is less successful when attention is divided between multiple tasks (Román et al., 2009), or when participants receive a high load to occupy their working memory (Noreen

& de Fockert, 2017). Acute stress and trait anxiety, which impair executive control, have also been demonstrated to produce a reduction of successful suppression that was modulated by working memory capacity (Ashton et al., 2020, Waldhauser et al, 2011).

1.4 Executive function and intrusive thoughts

In further support of the executive deficit hypothesis, individuals with intrusive thought conditions such as OCD and PTSD have been demonstrated to have deficits in executive control. Isık Taner et al. (2011) found that children and adolescents aged 7 to 16 who had been diagnosed with OCD had difficulty with the executive-function-related measures of abstraction-fluency, mental set-shifting, visuospatial/construction ability, and verbal comprehension when controlling for IQ. Deficits in these measures indicate difficulties with concentrating, controlling responses, and resisting distraction. Additionally, deficits in executive function in individuals with OCD have been demonstrated to persist over time as a stable trait of individuals with the condition, rather than fluctuate with the deterioration or improvement of symptoms (Bannon et al., 2006). If it is true that executive control is responsible for the active manipulation of the human memory, then this is a potential connection in the relationship between the OCD brain and the inception of intrusive thoughts.

Olff et al. (2014) found PTSD patients, as opposed to trauma-exposed controls, demonstrated deficits in working memory, as well as other executive function domains such as set-shifting, planning, and flexibility. They made more errors in executive function tasks than control participants, had slower response times, and used less efficient strategies. The deficits in executive control of these two intrusive thought disorders may be potentially demonstrative of the key relationship between the development of the disorders and their susceptibility to intrusive thoughts.

1.5 Think/No-Think and sleep guidelines

The Think/No-Think (T/NT) paradigm originated from Anderson and Green (2001) as an experimental task designed to measure a participant's control over their retrieval processes. In the T/NT task, the participant learns a list of word pairs such that when presented with the Hint word they can recall the Response word. Then, pairs are split into Think, No-Think, and Baseline conditions. When a Hint word from a Think pair is presented, the participant aims to recall the Response word from the pair as learned. When a Hint word from a No-Think pair is presented, the participant aims consciously to suppress recall of the Response word. Baseline words are not presented and Think and No-Think contrasts are made in comparison to Baseline. How successfully the participant suppressed the No-Think words is measured by the degree to which they can still recall the Response words post-manipulation.

The original Think/No-Think experiment found that whenever participants were instructed to suppress a Response word, they later had difficulty recalling that Response word. This recall difficulty was found not only when probed by the Hint word (Same Probe) but also when probed by other hints trying to provoke recall of the suppressed item (Independent Probe). Same Probe recall trials are when the recollection for the target Response word is provoked by the same word it was learned with (e.g., JOY from the word pair PRIZE-JOY is probed by PRIZE). Independent Probe recall trials use associate hints (e.g., JOY from the word pair PRIZE-JOY is probed by associate hint 'EMOTION-J____'). This cue-independent suppression effect indicates that the suppression is not occurring at the level of the relationship between Hint and Response, but on the level of the concept itself. The suppressed item is being suppressed from multiple avenues of recall, suggesting that suppressing the item has caused it to be 'forgotten', or, at the very least, made more difficult to recall.

The T/NT paradigm has been useful for identifying groups or conditions under which an individual may have greater or lesser vulnerability to the intrusion of unwanted items, as well as identifying whether items that were suppressed were actually forgotten by the mechanism of suppression-induced forgetting. Simply demonstrating that an item does not intrude upon the psyche is not sufficient to prove that it has been suppressed into forgetting. Versions of the T/NT test that test recall of items before and after suppression demonstrate suppression-induced forgetting, whereas variants that assess rates of thinking about items that are supposed to be suppressed demonstrate only the occurrence of suppression. The meaningful difference between these two types of T/NT task are that an item could be successfully suppressed when required, but also recalled later when prompted in post-manipulation recall. A participant can both suppress an item with 100% success, and then show no evidence of suppression-induced forgetting when they recall it again later. Evidence of both types is useful as data on both successful suppression and successful suppression-induced forgetting are beneficial to comprehension of individual differences in strengths and vulnerabilities against intrusive thoughts.

Professor Michael Anderson, one of the original inventors of the task, has created a video which outlined the guidelines for correctly administering the T/NT task in an experimental setting. This video contains several guidelines to ensure that the task is run in accordance with its design. One such guideline is that all participants intending to complete the T/NT task must sleep a minimum of seven hours the night before they attend the task. After completing the task, each participant verifies the hours slept during the previous night on the short Post-experiment questionnaire (*Appendix D*), and any participants who sign off as not having slept the minimum of seven hours are excluded from the data pool.

1.6 Effects of sleep deprivation on cognition

Sleep deprivation (SD) has notable detrimental impacts on cognition. Failing to get the required amount of sleep is connected to impairments in cognitive and mental function (Killgore, 2010). Choshen-Hillel et al. (2021; 2020) observed that both acute and chronic SD impair cognitive functions such as attention control, cautious behaviour, and executive function. They also observed that some effects caused by chronic SD were exacerbated by acute SD. Acute SD is more commonly studied in psychological research because it is more easily controlled, but chronic SD is more common in typical populations (Alhola & Polo-Kantola, 2007). As such, the adverse effects of chronic SD have been less established but are likely to be more prevalent in the real world (i.e., outside of a laboratory). Total sleep time has been indicated to influence cognitive performance on working memory and verbal fluency in young adults (Wilckens et al., 2014). Additionally, people experience more intrusions on the T/NT task when trials are longer or more difficult, indicating that elements such as fatigue are detrimental to successful suppression (van Schie et al., 2017).

Sleepiness reported by participants in a study by Rossa et al. (2014) was associated with loss of function in participants who had suffered an average acute loss of 3.7 h of sleep the night before. These participants were also habitual late sleepers who would have habitually short sleep times even when not disrupted by experimental sleep deprivation. Interestingly, these deficits in function did not include difficulty in inhibiting responses in an emotional Go/No-Go task. In this case their results did not support their hypothesis that acute partial SD would impair inhibition of emotional stimuli, which was found in full 36 h SD participants in Anderson and Platten (2011) (this is research by C. Anderson, no known relation to Professor Michael Anderson). The authors of the Rossa et al. study suggest that possible causes of these results are that the negative emotional stimuli have different effects between word stimuli and image stimuli, or that this particular version of the task operated in a different section of the brain, compared to the response inhibition system, thus circumventing the effects of the sleep reduction manipulation. One other possibility, addressed in the study's limitations, is the consideration that the habitual short sleepers that comprised the participant group were not significantly deviated enough from the typical amount of sleep they get, and being habitual short sleepers, they may be more comfortable in functioning on an amount of sleep below the recommended average. Sleep habits vary widely between individuals (Aeschbach et al., 2001), as most adults fall within 7 to 9 h of sleep per night (Kripke et al., 1979). Habitual short sleepers express similar deficits in cognitive function akin to partial sleep deprivation (Kronholm et al., 2009). It is possible that since the participants in the Rossa et al. study live as short sleepers under a state akin to partial sleep deprivation, the application of further partial sleep deprivation was insufficient to generate impairment of inhibitory processes in their study.

Insomnia and disrupted sleep are also prevalent in the intrusive thought conditions highlighted in this review. Sleep disturbance is not a diagnostic criterion for OCD, but sleep disturbance is relatively common in OCD patients. Moreover, a meta-analysis performed by Paterson et al. (2012; 2013) identified that severity of OCD symptoms had a positive correlative relationship with severity of sleep disturbances, although it is likely these sleep disruptions are mediated by comorbidity with depression (Díaz-Román et al., 2015). Nonetheless, OCD is still comorbid with depression at the high rate of 50-60% (Heyman et al., 2006), meaning that sleep disturbances are still highly prevalent in OCD regardless of whether OCD is the sole cause. PTSD, on the other hand, is directly defined by trauma-related arousal in the form of difficulty with sleeping in the DSM-5 (DSM-5, American Psychiatric Association, 2013).

1.7 Sleep deprivation and suppression

Sleep deprivation has been demonstrated to impact suppression ability. Zhao et al., (2018; 2019) reported that being deprived of sleep negatively impacts performance on a button-pressing response inhibition task. The fMRI recordings of sleep-deprived participants in this experiment observed reduced activation in the core regions of the response inhibition system of the brain, indicating that sleep deprivation reduces an individual's ability to inhibit automatic responses. After loss of sleep, individuals fail more at inhibiting responses when prompted by negative emotional stimuli (Anderson & Platten, 2011). This is highly relevant to research pertaining to inhibiting unwanted thoughts, as these thoughts often contain traumatic content or are associated with traumatic experiences. If sleep deprived individuals struggle with inhibition prompted by negative stimuli, one might anticipate that they would be more susceptible to traumatic intrusive thoughts.

A particularly relevant study by Harrington et al. (2021) used a variant of the T/NT task which used neutral faces as Hints and either neutral or negative emotionally weighted scenes as Responses. In this study, participants completed the learning phase in the evening, during which they practiced associating the Response with the appropriate Hint. After, they either got a full night's sleep or got zero hours of sleep before attempting to perform the suppression element of the Think/No-Think task in the morning. Participants were instructed to rate whether the Response thought intruded into their mind 'never', 'briefly', or 'often'. Harrington et al. identified that fully sleep-deprived individuals did indeed suffer more intrusions when attempting to suppress unwanted thoughts of both the negative emotional and neutral emotional varieties in comparison to well-rested participants. Sleep-deprived participants also suffered from increased relapses in failed suppression, demonstrating that even if they succeeded in suppressing an unwanted thought the first time, they were more likely to lapse in concentration later and accidentally allow the thought to resurface. These results indicate that acute total sleep deprivation interferes with the brain's inhibitory functions, impairing the sleep-deprived individual's executive ability to suppress unwanted thoughts when presented with reminders. This study also provides a precedent that this effect can be expected specifically when working with the T/NT paradigm.

1.8 Sleep deprivation and the executive deficit hypothesis

Kronholm et al. (2009) performed analyses on the results of a Finnish national interview and health survey and noted that a short amount of sleep was associated with both feelings of fatigue and tiredness, as well as decreases in cognitive performance, supporting the notion that partial sleep deprivation is chronically apparent in short sleepers. Considering that the executive deficit hypothesis (Levy & Anderson, 2008) posited that difficulties in suppressing unwanted thoughts are mediated by various individual differences in executive function, there is therefore a possibility that time asleep is an individual difference that influences susceptibility to thought intrusions. Whereas acute sleep deprivation or chronic sleep deprivation due to extraneous circumstances (e.g., working a highly demanding job such as resident physician (Choshen-Hillel et al., 2021;2020)) would be more appropriately considered state-like phenomena, being a habitual short sleeper is more accurately described as an individual trait (Tucker et al., 2007). Since sleep deprivation is predictive of deficits in executive function (Liu et al., 2015), being a habitually short sleeper may be an individual difference that contributes to the deficits in executive function theorised by Levy and Anderson (2008).

The aggregate of previous research indicates relationships between OCD or PTSD occurrence coinciding with increased susceptibility to intrusive thoughts, frequent sleep disturbances, and poor performance on tasks requiring executive function. The directions of relationships between these coinciding elements us unclear. Such a question is beyond the scope of this thesis and is a question that psychology as a discipline is not yet fully equipped to answer. Indeed, there is little evidence beyond the theoretical that there are even causative or linked relationships between these elements. However, there are theoretical precedents for these relationships that have been highlighted in *Sections 1.3* through *1.8*.

1.9 Habitual sleep time and sleep quality

Differences in habitual time asleep may have no influential effect on suppression task performance because of how variations in usual sleep time are considered natural. Without participants with low-sleep time (i.e., sleeping fewer than 6 h each night (Aeschbach et al., 2001)), the natural variation in sleep patterns prevalent between individuals may mitigate the effects of ‘losing’ sleep. To a person who sleeps 9 h most nights, being made to sleep only 6 h will be a significant deviation from their typical sleep. For others, sleeping only 6 h a night is typical and is an amount of sleep that they can fully function on. There is a large variability in the standard sleep parameters for healthy young adults (Tucker et al., 2007). As such, it is possible that this large variability accounts for any minor differences in time asleep and as such they may have no effect on suppression. An individual is expected to display no noticeable difference in health or in waking performance regardless of where their natural amount of habitual sleep falls in the range of 6 to 9 h (Hor & Tafti, 2009).

However, such natural variations between sleep times may still be sufficient to cause cognitive deficits. A consensus statement released by the American Academy of Sleep Medicine and Sleep Research Society outlined that cognitive performance (which, in this case, included cognitive processing speed, vigilant attention, and working memory) was vulnerable to deficits when sleep duration was below 7 h (Consensus Conference Panel, 2015). This indicates that natural variations in sleep time may be sufficient to exhibit deficits in a cognitive capability task such as the T/NT task, since some people naturally sleep fewer than 7 h most nights.

Wilckens et al. (2014) tested the effect of total sleep time on cognitive performance measures and found that total sleep time influences cognitive performance in young adults. Very high and very low sleep times were predictive of deficits in working memory and verbal fluency, but these abnormal total sleep times were not predictors of deficits in performance in the Flanker Stroop task, an inhibition-based task. While total sleep time influences cognitive ability, this suggests it is not a universal deficit to all areas of executive function. Consequently, suppression in the T/NT task may not be influenced by total sleep times, as it may be one of the domains of cognitive capability not influenced by total sleep time as indicated by Wilckens et al. (2014).

1.10 Motivation and rationale for the present study

If acute partial sleep deprivation or differences in an individual's sleep habits could be demonstrated to influence No-Think suppression task performance, then partial sleep on the night before or habitual time asleep could be considered an element of the executive deficit hypothesis. To my knowledge, only complete sleep deprivation (zero hours of sleep) has been used to test memory suppression task performance using T/NT. Since loss of inhibition control has been demonstrated by Anderson and Platten (2011) to occur after total sleep deprivation but was not after 3.7 h of sleep deprivation (Rossa et al., 2014), it appears that partial sleep deprivation has a much weaker effect on inhibition control. However, the direct effect of partial sleep deprivation and habitual time asleep, if any, on performance on a memory suppression task such as T/NT has not been thoroughly examined. Natural variations in total sleep time are not influential to many health differences (Hor & Tafti, 2009), but cognitive measures may be affected, although some are not (Consensus Conference Panel, 2015; Wilckens et al., 2014). Examination of how a cognitive measure related to inhibition such as the T/NT memory suppression task is affected by partial sleep deprivation and habitual sleep time may help to better understand the relationship between sleep loss and cognitive deficits. Getting a short amount of sleep causes fatigue and tiredness (Kronholm et al., 2009) so tiredness may be a moderating variable for the effect of low sleep time on T/NT task performance. As such, a subjective measure of tiredness was acquired through the Sleep Quality Scale (*Appendix B*)

The effect of partial sleep loss on suppression is an important factor to consider in T/NT design, because the T/NT guidelines posed by Michael Anderson disallow the inclusion of data from anyone who self-reported as having slept fewer than seven hours the night before performing the task. If Rossa et al.'s (2014) results are not aberrant and partial sleep deprivation has no significant effect on control over inhibition, this would indicate that the relationship between sleep loss and inhibition is less pronounced than has been claimed. This would also indicate a possibility that the 7 h slept restriction suggested by Michael Anderson is unnecessary since partial sleep deficits would have precedent for not influencing T/NT suppression task performance.

The present study aimed to address these questions. Using the T/NT paradigm, the current study investigated the effects of both acute partial sleep deprivation and long-term sleep trends on suppression performance. The clinical relevance of the present study has been demonstrated by the prevalence of intrusive thoughts in many psychiatric conditions including

PTSD and OCD, and a possible link between the attenuation of intrusive thoughts and memory suppression ability as assessed by the T/NT task.

1.11 Aims, objectives and hypotheses

The aims of the present study were to investigate whether acute partial sleep deprivation and individual habitual sleep time affect T/NT suppression task performance.

The objectives of the study were as follows:

Objective 1: Determine whether three hours sleep deprivation alters the recall of either Think or No-Think items after the T/NT suppression task.

Objective 2: Determine whether self-reported long-term sleep quality is a predictor of either Think or No-Think item recall after the T/NT suppression task.

Objective 3: Determine whether mean hours slept over one week is a predictor of either Think or No-Think item recall after the T/NT suppression task.

The hypotheses of the study were as follows:

Hypothesis 1: The Think enhancement effect will occur in this study, such that Think items will be recalled more than Baseline items.

Hypothesis 2: The No-Think suppression effect will occur in this study, such that No-Think items will be recalled less than Baseline items.

Hypothesis 3: Three-hour sleep deprivation participants will have increased recall of No-Think items due to experiencing difficulties with suppression.

Hypothesis 4: Participants who self-rate their sleep quality as poorer will show increased recall rates of No-Think items, as poor sleep quality will increase susceptibility to intrusions.

Hypothesis 5: Participants who sleep fewer hours over seven days before completing the Think/No-Think task will show increased recall rates of No-Think items, as lower sleep time will increase susceptibility to intrusions.

2. Method

2.1 Participants

Forty-one participants (16 male, 25 female) completed participation in this experiment and are included in the final dataset. They were all students at the University of Canterbury aged 18-25. Each participant completed all in-person experimental sessions on dates between 16/08/2021 and 08/02/2022. Participants were required to be able to commute to the University campus without driving or cycling. This was to ensure that if they were in the Sleep Deprivation (SD) subgroup, they could safely attend in-person without the danger of driving or cycling while sleep deprived. Participants were required to have good English reading ability, as the memory component of the T/NT task requires reading, understanding, and recalling English words. Participants were not permitted to participate if they had diagnosed attention deficit hyperactivity disorder (ADHD) due to the attention-focused nature of the suppression task, and were also not permitted if they were colour-blind, due to the importance of distinguishing red words from green words in the T/NT task. Participants were not screened for abnormal sleep patterns during recruitment, nor were they excluded on the basis of sleep disorder prevalence.

Participants were recruited through several avenues used to advertise to students at the University of Canterbury, including the Student's Association Facebook page and multiple departments' mailing lists. Individuals interested in participating sent an email to the primary researcher, who provided them with the study's information sheet (*Appendix E*).

Ethical approval for this study was provided by the University of Canterbury Human Research Ethics Committee (HEC 2021/92).

2.2 Materials

Smart-watches were provided to participants to track their seven nights of sleep; these were the AdorHealth H30 Unisex Health Monitoring Smart Watch. Some participants reported inaccuracies with watch sleep recordings. If an error was detected, participants were instructed to also self-report the most accurate estimation they could make of their hours slept, in case the watches produced clearly inaccurate results. Ideally, this experiment would have used specialist equipment to track overnight sleep, but this was not possible due to budgetary restraints.

The Think/No-Think task was run on a desktop computer on the University of Canterbury campus. Two alternate rooms were used for data collection, and both were selected for minimum distractions to allow participants to focus fully on the suppression task. Neither room had external windows, nor was used by anyone else during data collection. Both rooms had very little in the form of visual or auditory distraction.

The digital Think/No-Think task consists of software programmed in MatLab, provided by the MRC Cognition and Brain Sciences Unit of the University of Cambridge. The Think/No-Think software controls counterbalancing and word list presentation.

2.3 Design

The experiment used a mixed design. The experimental group was the Sleep Deprivation (SD) group, and the control group was the No Sleep Deprivation (NSD) group. The independent variables of the experiment were as follows: (i) whether a participant was in the SD or NSD group, (ii) how many hours each participant slept for the first six nights of the week, (iii) how many hours each participant slept on night seven, and (iv) each participant's Sleep Quality Scale score. The dependent variable was % recall. The main comparisons of interest for the different sleep conditions were: (i) change in recall of Think items from before and after T/NT memory suppression was performed compared to Baseline for both Same Probe (SP) and Independent Probe (IP) recall, (ii) change in recall of No-Think items from before and after T/NT memory suppression was performed compared to Baseline for both SP and IP recall.

2.4 Procedure

Once a participant identified to the researcher that they were interested in participating, having read the information sheet (*Appendix E*), they were sorted randomly into the SD condition or the NSD condition. Random sorting was achieved by alternating which group each participant was sorted into when they signed up (the first participant was NSD, the second was SD, the third NSD, and so on. SP first or IP first, and counterbalances were also assigned randomly in the same manner).

Once a participant selected a date and time for their in-person T/NT task participation, they were required to use a smart-watch to track seven nights of their sleep, recording their results in a cloud-stored Google Sheet visible only to them and the researcher. NSD participants needed only to track seven nights of their sleep as normal and attend the scheduled in-person T/NT task participation the day after night seven. SD participants would receive a differently formatted Google Sheet from NSD participants. Once the first six nights of sleep were filled into the SD Sheet, the Sheet would calculate their mean hours slept, subtract three hours from the average, and present this number to participants as their hours required to be slept for night seven. This meant that SD participants had a sleep goal for night seven of their mean hours slept over the previous six nights minus three hours. Upon completing the seventh night of sleep, this would then also be entered into the Sheet.

To control for effects of time of day on tiredness from sleep deprivation, participants were asked to complete their in-person T/NT task participation at the same time of day. The majority of participants conducted their participation in the afternoon, between 12pm and 4pm. Due to the practicalities of scheduling, some were slightly earlier or later. In-person T/NT task participation would typically take just under 90 min for any given participant.

Upon arrival for the in-person T/NT task participation, participants were required to fill out the Sleep Quality Scale, a 28-item 4-point Likert scale questionnaire about the participant's self-reported quality of sleep over the last month (*Appendix B*). Upon completion, the participant was seated in front of the computer running the T/NT software and was instructed on the first section of the task.

In the first section, each participant was presented with 66 word pairs (*Appendix A*) one at a time on the computer screen for 4 s each. Participants were instructed to study each word pair for 4 s and form a connection between the two words so that when they are later presented with the left-hand word (the Hint word) they can successfully recall the right-hand word (the Response word). Of these 66 word pairs, there were 18 non-critical word pairs which were either discarded after the first section of the task, or used in later practice rounds to allow the participants to practice the tasks before being tested on them. The remaining 48 items were critical items which they would be assessed on. Immediately after seeing all 66 word pairs, each participant was tested on their ability to recall the Response words when presented with the Hint words, saying their answers out loud. Directly after each Hint word was presented, the participant would then see the correct Response word in blue font, providing them confirmation of their answer if they recalled it correctly, or another chance to learn the word if they failed to recall it. If the participant successfully recalled 24 or more of the 48 critical items, they would advance to the next section. Otherwise, they would repeat the exact same phase again with the words in a new order, giving them a second opportunity to reach 24 of 48 critical items. Upon failure to recall 24 or more critical items on the second attempt, a participant would be informed that the experiment was completed and would thus be unable to move to the next phase, excluding them from the dataset due to failure to demonstrate a robust memory of the critical items. After successfully recalling at least 24 items, each participant would repeat the same testing phase as the previous phase, except without the reminders of the correct Response word. Performance in this phase would be used to measure how much each participant could successfully recall, pre-T/NT suppression.

In the second section of the experiment, each participant practiced and completed the T/NT suppression task. The T/NT suppression task works as follows: Each participant was presented with the Hint words from the first section alone on the computer for 4 s each, except the word now appeared in either green text or red text. If the word appeared in green text, this was a Think item, and the participant was required to recall the Response word associated with this particular Hint word, but to keep in in mind the entire time the Hint word is on the screen, instead of vocalising the answer. If the Hint word appeared in red, this was a No-Think item, and the participant was required to avoid, to the best of their ability, thinking of the Response word associated with this Hint word. If a Hint word was presented in either red or green once, it remained the same colour in subsequent presentations throughout the entire experiment – a word never appeared as both red and green at separate instances. Participants received detailed instructions on precisely how to perform the suppression of the No-Think items, and which strategies were unacceptable to use in this task. Participants were instructed to always look at, comprehend, recognise, and pay full attention to each red Hint word until it disappeared from the screen. They were instructed to not think about the Response words for red Hint words, including after the Hint word was no longer on the screen. Participants were also instructed not to block the Response word by thinking of another word, image, or idea to replace it with. It was made clear to them that while blocking the Response word to a particular Hint word, the only thing they were permitted to think about was that Hint word.

Before performing the T/NT suppression task proper that would be assessed for analysis, each participant practiced the task twice. After each practice section (lasting about one minute), the participant answered questions on a brief questionnaire to validate that the participant was following instructions (since much of the T/NT suppression task was performed in the participant's head and was difficult to verify.) If a participant misunderstood any instructions or used any unwanted strategies to suppress No-Think Response words, the T/NT diagnostic questionnaire (*Appendix C*) highlighted this and the instructions were made clear to the participant to ensure the task was being performed in a satisfactory manner.

After two instances of practising the T/NT task and answering the questionnaire immediately afterward, each participant began the T/NT task proper. This featured four blocks of T/NT task performance identical to the practice rounds, except containing the critical word pairs used in the primary analysis. Counterbalancing between groups for participants determines which pairs become Think, No-Think, and Baseline items. Each block lasted about 7½ min, and between each block was an opportunity for the participant to rest their mind for 30-40 s and regain their mental composure, since the task can be mentally fatiguing. Between blocks 2 and 3, the T/NT diagnostic questionnaire was repeated from the practice phases to ensure the participant was following instructions as desired.

In the third and final section of the experiment, each participant's recall for the critical items was tested again, to determine what effect the T/NT suppression had on their ability to recall the words. At this stage, participants saw this section in a different order, depending on whether they were counterbalanced to perform SP recall first or IP recall first. The mechanics of SP and IP recall are explained in *Section 2.5a*.

All participants first performed an 8-item practice round of SP recall to ensure that they understood the instructions and were once again recalling items out loud. The 8 items used were non-critical. SP recall was identical to the first phase, in which they saw the Hint word and produced the associated Response word. After this, each participant was instructed on how the IP recall task works. After the rules for the IP recall task were explained, and each participant had practiced both SP recall and IP recall on the same 8 non-critical items, participants were split into either SP recall for all critical items, then IP recall for all critical items, or vice versa. This split was performed to alleviate the effects of order on the recall of the items.

After completing both SP and IP recall, the participant had completed their participation in the experiment and were asked to fill out the Post-experiment questionnaire (*Appendix D*), which asked each participant to explain the strategies they used for suppressing the unwanted Response words. This questionnaire also asked each participant to rate how frequently they used three of the unwanted strategies on a scale from 0 (Never) to 4 (Very Frequently). If a participant scored 4 or higher on this section, their data would be excluded due to demonstrating a failure to comply with crucial experimental instructions.

2.5 Data analysis

2.5.1 Same Probe and Independent Probe

Same Probe (SP) recall uses the Hint words that were used in training as probes to prompt the recall of the Response words. For example, participants would learn to respond with JOY on seeing the hint word PRIZE from the example pair PRIZE-JOY. In SP recall, the word PRIZE was used as the probe to test if the participant could remember the response word JOY.

In Independent Probe (IP) recall, participants were tested to see if they could recall the critical Response words they had learned when presented with a probe other than the Hint word they learned it with. For example, instead of seeing the Hint word PRIZE from the example pair PRIZE-JOY, the participant would see an associate hint 'EMOTION' alongside the first letter of the Response word associated with that hint. When presented with 'EMOTION – J____', the participant is required to recall the familiar Response word JOY despite previously only recalling it when presented with the Hint word PRIZE.

2.5.2 Conditionalised and Unconditionalised recall.

Of the 48 items, each participant would have a group of 16 words assigned to the Think condition which were presented to the participant in green font during the memory suppression task, a second group of 16 assigned to the No-Think condition which were presented to each participant in red font during the memory suppression task, and a third group of the remaining 16 words assigned to Baseline. Baseline items were not presented at all during the memory suppression task, but their recall was assessed before and after. The data on how many words were successfully recalled post-manipulation is codified in two ways in this experimental analysis - Unconditionalised and Conditionalised. Unconditionalised recall is expressed as a percentage out of the possible total of 16 items of how many items were successfully recalled post-manipulation by the participant. Conditionalised recall is expressed as a percentage out of the number of items the participant recalled pre-manipulation of how many items they successfully recalled post-manipulation. For example, a participant who recalled 10 of 16 items pre-manipulation and 12 of 16 items post-manipulation would have an unconditionalised recall of 75% (12 out of 16) and a conditionalised recall of 120% (12 out of 10). Variables of both types were used in this analysis to assess whether post-manipulation recall changed in relation to pre-manipulation recall based on either total words recalled (unconditionalised) or in direct relation to how much their recall rates improved or deteriorated over suppression (conditionalised). Unless specified, data for the different recall rates were analysed as an aggregate of both conditionalised and unconditionalised data. As such, percentage recall rates do not necessarily correspond to exactly what percentage of possible items were recalled.

3. Results

3.1 Descriptive statistics

Forty-one participants were included in the analysis. While the study's original goal was 48 participants, 24 in each of the No Sleep Deprivation (NSD) and Sleep Deprivation (SD) conditions, data collection was cut short due to time restraints caused by COVID-19. Of the 41 participants, 22 (53.7%) were in the NSD group and 19 (46.7%) were in the SD group. Three participants were excused from completing the latter half of their in-person participation due to failure to reach the criterion in the memory test. These participants were excluded from the final dataset. Zero participants were excluded due to misunderstanding the task and using unwanted strategies, as surveyed after their task performance by the Post-experiment questionnaire (*Appendix D*).

3.1.1 Hours slept

Each participant used a smart-watch to track how many hours of sleep they got each night for seven nights before their in-person task participation. On their seventh and final night of sleep, SD group participants were required to sleep three hours less than the mean of their first six nights slept. For the complete dataset (N = 41), the mean hours slept across the six non-sleep deprivation nights was M = 7.5 h (*st.dev.* = 0.8). The minimum mean hours slept by a single participant was 4.7 h and the maximum was 9.1. The participant who slept an average of 4.7 h each night before performing three hours sleep deprivation was a noted outlier (the second lowest mean sleep across the first six nights was 6.2 h). This participant reported chronic insomnia which caused her to get one hour of sleep on one of the non-sleep deprivation nights, resulting in a very low mean. This participant slept four to seven hours for the other five non-SD nights. For NSD participants (N = 22), the minimum mean hours slept by a single participant across all seven nights of tracking was 6.6 h and the maximum was 8.9 h. The NSD participants slept a mean of 7.4 h each night, with a standard deviation of 0.7 h. Three hours sleep deprivation was achieved by the SD group. Mean hours slept for the first six nights by SD participants (*N* = 19) was 7.4 h. Mean hours slept for night seven by SD participants was 4.4 h. Each SD participant did a good job of obeying SD instructions and there were no outliers for participants who failed to achieve 3 h sleep deprivation by either overshooting or undershooting their sleep goal for night seven.

For hours slept on night seven by SD participants, the minimum was 1.7 by the above-mentioned outlying insomniac participant. The maximum hours slept by a SD participant on night seven was 5.7 h by a participant who slept a mean of 8.3 h across the six nights prior, and the minimum sleep on night seven by a NSD participant was 5.6 h by a participant who slept a mean of 7.1 h across the six nights prior. Apart from these two participants, all SD participants slept less than all NSD participants on night seven. The mean hours slept by NSD participants on night seven was 7.5 h, while the mean for SD participants was 4.4 h.

3.1.2 Sleep Quality Scale

All participants (*N* = 41) filled out the Sleep Quality Scale (SQS, *Appendix B*) on the day of their in-person participation. The SQS is a Likert-style questionnaire with 28 items, each scored Rarely, Sometimes, Often, or Almost Always. Each possible answer adds 0, 1, 2, or 3 points to the participant's score depending on the answer given. Typically, 'Rarely' is worth 0 points, up to 'Almost Always' being worth 3 points, although seven items are reverse-coded and are the opposite, with 'Rarely' worth 3 points and 'Almost Always' worth 0. Possible total scores for the SQS range from 0 to 84, with a higher number indicating a worse self-reported quality of sleep over the past month. The overall mean SQS score by all participants was *M* = 34.6, *st.dev.* = 9.9. The minimum score was 16, reported by a SD participant, and the maximum score was 59, also reported by a SD participant (this was the subject with chronic insomnia). One-way ANOVA demonstrated no significant difference between SD and NSD groups on reported SQS score F (1,39) = 0.11, p =.74.

3.2 Parametric assumptions

Levene's test for homogeneity of variance indicated that data for post-manipulation recall rates did not violate the assumption of homogeneity of variance. For the variables that showed the largest F value, Unconditionalised-SP recall, Levene's test indicated that variances across these variables were equal, F (2,120) = 2.15, p =.12. All other Levene's tests on other variables also produced nonsignificant results. However, the Shapiro-Wilk test for normality of distribution indicated that the data for post-manipulation recall rates violated the assumption of normality and was not normally distributed. All twelve post-manipulation recall variables (all permutations of either Think or No-Think or Baseline, and either unconditionalised or conditionalised, and either SP or IP) showed significant departure from normality, e.g., Unconditionalised-Think-SP recall W (41) = 0.91, p <.01. As such, non- parametric test results will be reported in *Section 3.3*.

3.3 Think/No-Think effect

The differences in recall between Baseline items and Think or No-Think items was examined to determine if Think or No-Think items were recalled differently from Baseline items. Conditionalised and unconditionalised recall were combined to create an aggregate score that reflects a combination of raw recall and recall change. As such, the following recall percentages do not represent exactly how many items total were recalled, but instead account for individual improvement or detriment from pre-manipulation. After manipulation, Baseline (unmanipulated) items had a mean recall of 92.3%, with a standard deviation of

8.8%. Think items had a mean recall of 93.7%, with a standard deviation of 10.4%. No-Think items had a mean recall of 87.3%. with a standard deviation of 15.7%. Thus, Think items were recalled 1.4% more frequently than Baseline items, and No-Think items were recalled 5.0% less frequently than Baseline items.

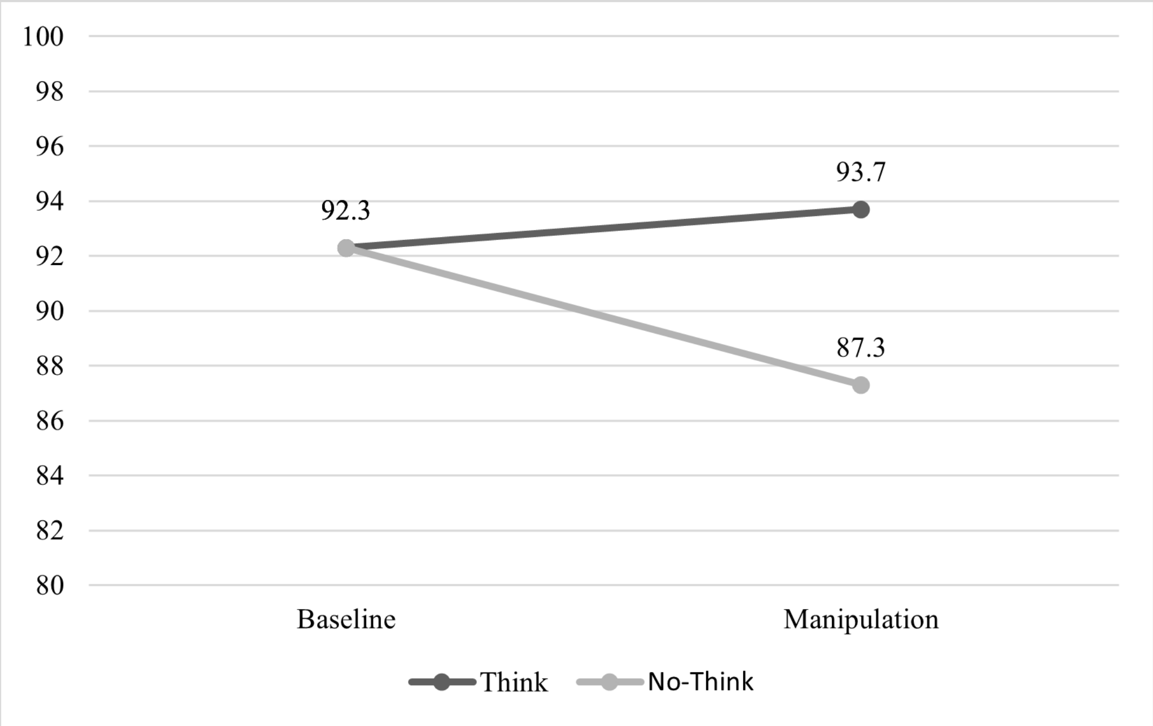

Figure 1. Difference in mean recall scores from Think and No-Think compared to Baseline. (*N* = 41)

Non-parametric tests were used for these analyses because the data violated the assumption of normality. Shapiro-Wilk tests indicated that the difference between Think and Baseline was not normally distributed *W* (40) = 0.92, *p* <.01, and nor was the difference between No-Think and Baseline *W* (40) = 0.76, *p* <.01.

3.3.1 Think Effect

There was a 1.4% increase in recall for Think items when compared with Baseline. Wilcoxon signed rank analysis indicates the Think effect did not occur overall as Think items were not recalled more frequently than Baseline items *W* (40) = 437, *p* =.52, two-tailed. The

Think effect also did not occur in only NSD participants *W* (21) = 122, *p* =.84, two-tailed. or in only SD participants *W* (18) = 104, *p* =.43, two-tailed. This indicates that the 1.4% increase in recall was not significant.

For each participant, increase or decrease from percentage Baseline score to percentage No-Think score was calculated. This variable represents each participant's change in recall resulting from enhancement of Think items. However, there was no significant enhancement effect in the dataset. Figure 2 demonstrates participant variation between Think-to-Baseline recall. For Think-to-Baseline recall percentage difference, the participant mean was 1.3% with a median of 0.2% and a standard deviation of 10.7%. The minimum score was -19.8% and the maximum score was 43.8%.

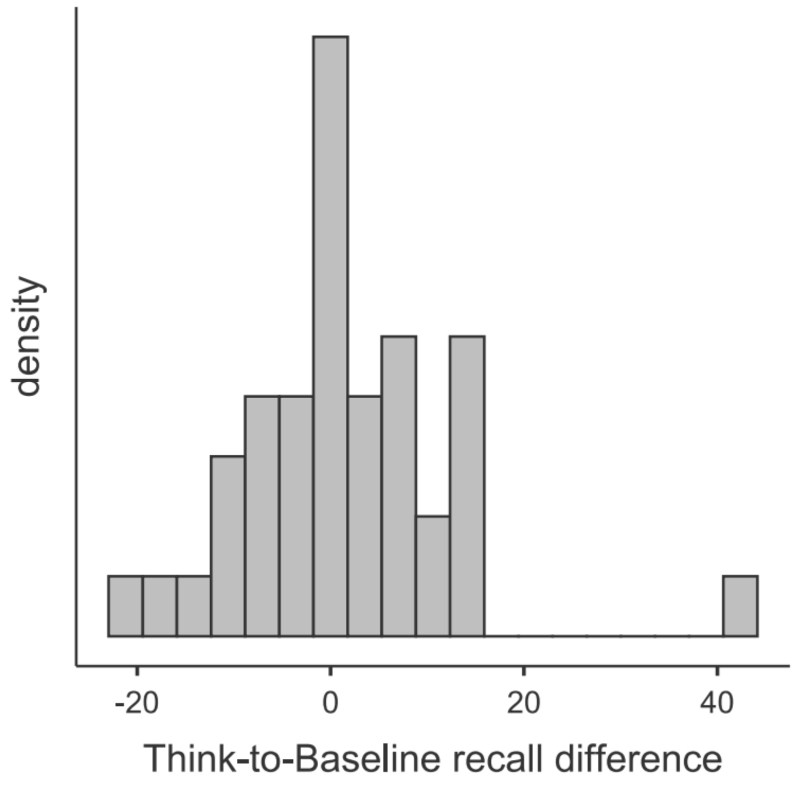

Figure 2. Think-to-Baseline recall difference for post-manipulation recall tasks for each participant (*N* = 41)

3.3.2 No-Think Effect

There was a 5.0% decrease in recall for No-Think items when compared with Baseline. Wilcoxon signed rank analysis indicates the No-Think effect occurred overall as No-Think items were recalled less frequently than Baseline items W (40) = 564, p =.04, two-tailed. This indicates that the 5.0% decrease in recall was significant. The No-Think effect was not found in only NSD participants W (21) = 178, p =.10, two-tailed, or in only SD participants W (18) = 113, p =.24, two-tailed. Significance of the No-Think effect in the whole cohort but not in either NSD or SD condition indicates that the smaller groups have insufficient power to produce the effect.

For each participant, increase or decrease from percentage Baseline score to percentage No-Think score was calculated. This variable represents each participant's change in recall resulting from suppression of No-Think items. Figure 3 demonstrates participant variation between No-Think-to-Baseline recall. The participant mean was -5.4% with a median of -3.6% and a standard deviation of 15.1%. The minimum score was -77.7% and the maximum score was 13.9%.

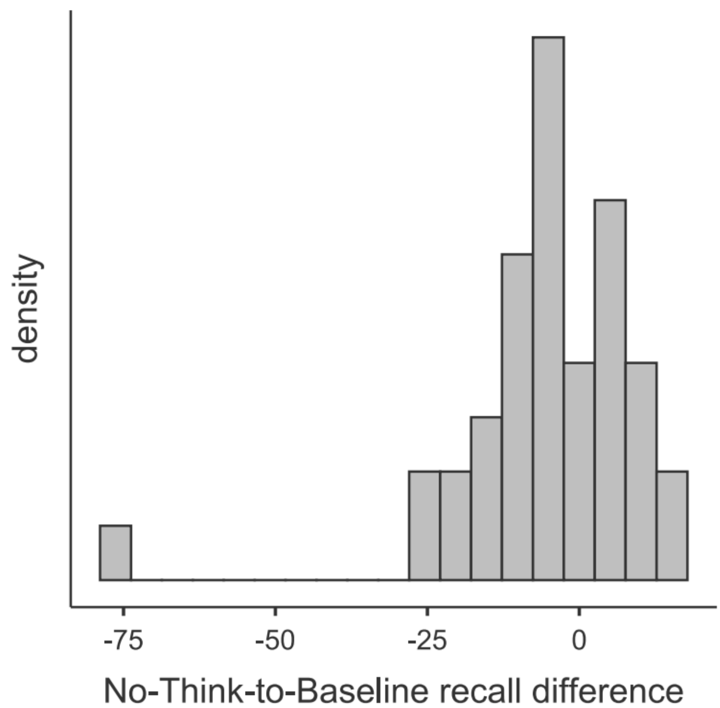

Figure 3. No-Think-to-Baseline recall difference for post-manipulation recall tasks for each participant (*N* = 41)

3.4 Sleep deprivation effect on Think/No-Think performance

3.4.1 Effect of sleep deprivation manipulation

Mann-Whitney U tests were run to determine whether SD influenced percentage difference between Think-to-Baseline recall or percentage difference between No-Think-to-Baseline recall. Figures 4 and 5 below display the variables graphed in Figures 2 and 3 separated by SD or NSD participants. Descriptive statistics for these variables separated by NSD and SD are included in Table 1.

	N	Median	IQR	Mean	Std. Deviation
Think-NSD	22	0.1%	-6.7% – 5.6%	1.0%	12.9%
Think-SD	19	0.4%	-2.4% – 7.0%	1.7%	7.8%
NoThink-NSD	22	-6.2%	-9.8% – 2.5%	-7.4%	18.1%
NoThink-SD	19	-2.1%	-8.1% – 4.0%	-3.2%	10.8%

Table 1. Median, interquartile range, mean and standard deviation for Mean percentage changes in recall.

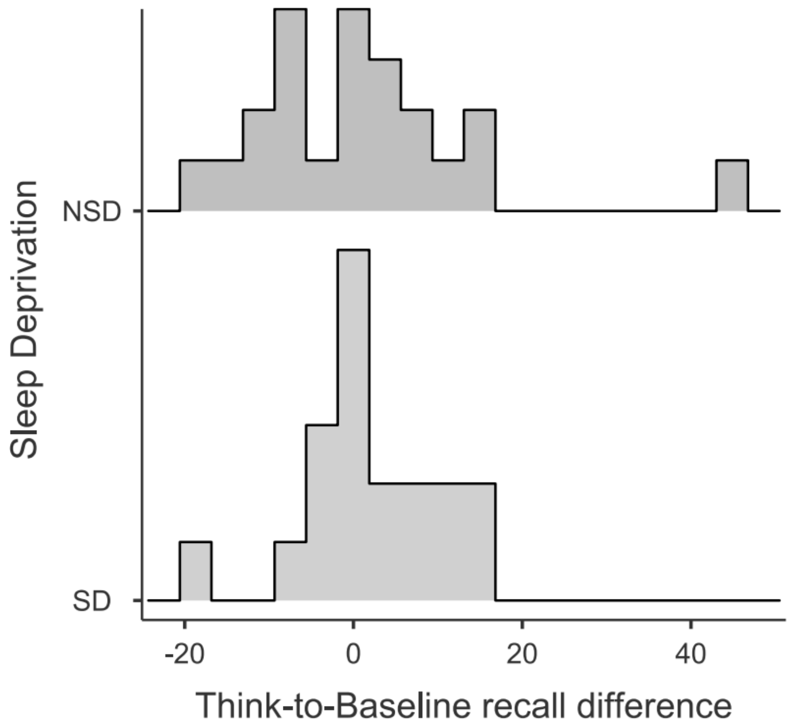

Figure 4. Think-to-Baseline recall difference for post-manipulation recall tasks separated by No Sleep Deprivation or Sleep Deprivation (*N* = 41)

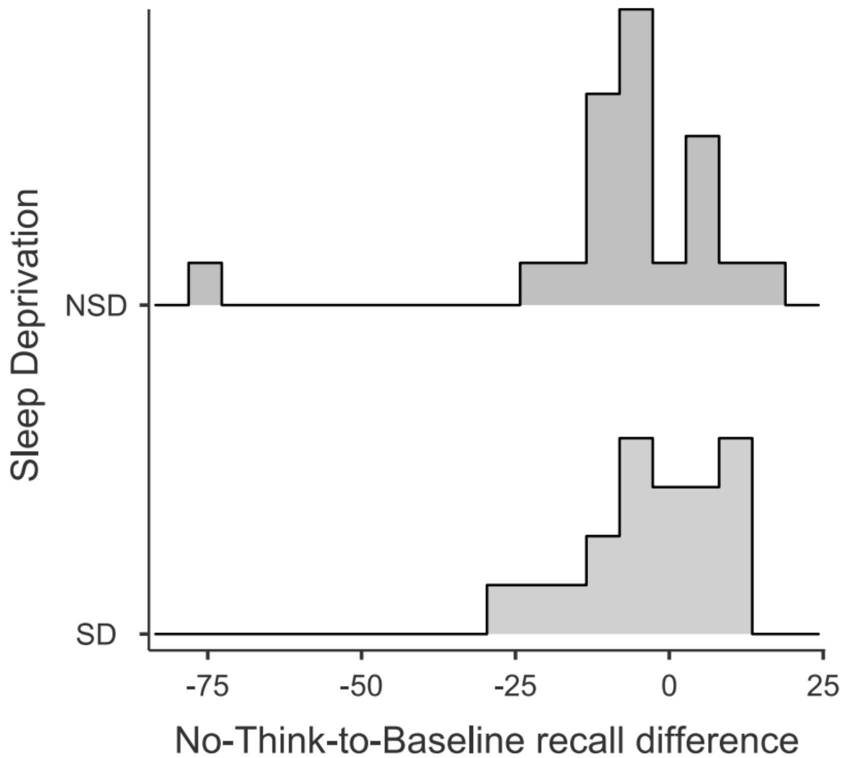

Figure 5. No-Think-to-Baseline recall difference for post-manipulation recall tasks separated by No Sleep Deprivation or Sleep Deprivation (*N* = 41)

Mann-Whitney U tests revealed that whether a participant was NSD (*Mdn = 0.1%*) or SD (*Mdn = 0.4%*) had no effect on Think-to-Baseline recall difference (*U* = 185, *p* =.54), and that whether a participant was NSD (*Mdn = -6.2%*) or SD (*Mdn = -2.1%*) also had no effect on No-Think-to-Baseline recall difference (*U* = 180, *p* =.46). Separating unconditionalised and conditionalised results did not produce significant results, and neither did separating data into SP and IP.

While SD manipulation did not have a significant effect on recall, the raw numbers indicate a trend that sleep may have an effect. The mean No-Think-to-Baseline recall difference for the whole dataset was *M* = -5.4%. Separating the participants into NSD and SD, the mean for NSD participants was *M* = -7.4% and the mean for SD participants was *M* = -3.2%, which indicates that NSD participants were more able to suppress No-Think items than SD participants, though not to a statistically significant degree. This suggests that there may be an effect of sleep on recall that cannot be detected by the present study due to low number of T/NT repetitions (12 only, when 16 is typical (Anderson & Green, 2001)) or low statistical power.

3.4.2 Interaction between sleep deprivation and No-Think effect

Mixed ANOVAs were performed to determine whether a participant being SD or NSD interacted with any other No-Think variables, to examine whether there was an interaction effect between whether a participant was SD or NSD and the significant No-Think effect. For this analysis, recall type was split into conditionalised and unconditionalised recall. While the data violates normality, ANOVA is robust to such violations, and is the ideal test for examining interaction effects.

For unconditionalised recall, the No-Think effect was still observed F (1,39) = 4.80, p =.03. There was no significant interaction observed between the difference in recall from Baseline to No-Think and whether a participant was SD or NSD F (1,39) = 1.61, p =.21. There was no significant interaction with SP or IP recall type. For conditionalised recall, the No-Think effect was no longer observed F (1,39) = 2.85, p =.10. There was no significant interaction observed between the difference in recall from Baseline to No-Think and whether a participant was SD or NSD F (1,39) = .11, p =.74. There was no significant interaction with SP or IP recall type.

Since neither a main effect nor an interaction effect for SD or NSD group can be observed, this indicates that whether a participant was deprived of 3 h of sleep or not had no bearing on their T/NT task performance.

3.4.3 Effect of sleep time on the seventh night

Each participant tracked their sleep for seven nights before completing their in-person suppression task participation. Each participant's time slept for night seven was included in linear regression to examine whether it produced a significant correlation with either rates of recall for Think items or No-Think items, or for mean percentage change in recall from Think-to-Baseline or No-Think-to-Baseline. Night seven sleep hours was not a significant predictor of Think recall (r = 0.01, p =.94), No-Think recall (r = 0.15, p =.36), Think-to-Baseline difference (r = 0.04, p =.83) or No-Think-to-Baseline difference (r = 0.17, p =.29), outlier removed (r = 0.09, p =.57). These results indicate that hours slept on the seventh night, when SD participants did their sleep deprivation and NSD slept normally, produced no change in post-manipulation recall variables, or in percentage difference in recall from Think- or No-Think-to-Baseline.

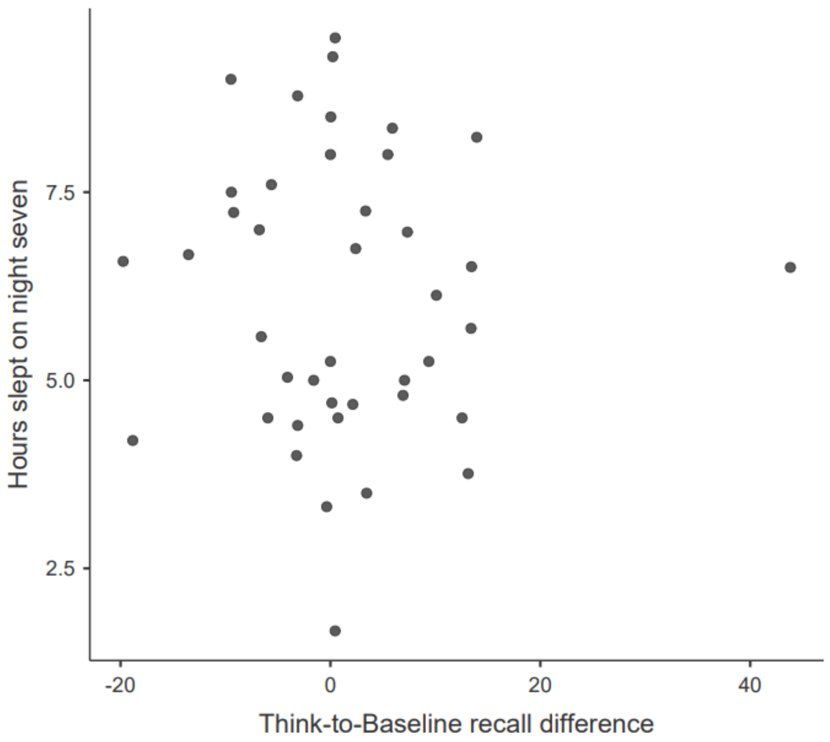

Figure 6. Scatterplot relationship between Think-to-Baseline recall difference compared to hours slept on night seven (r = 0.04)

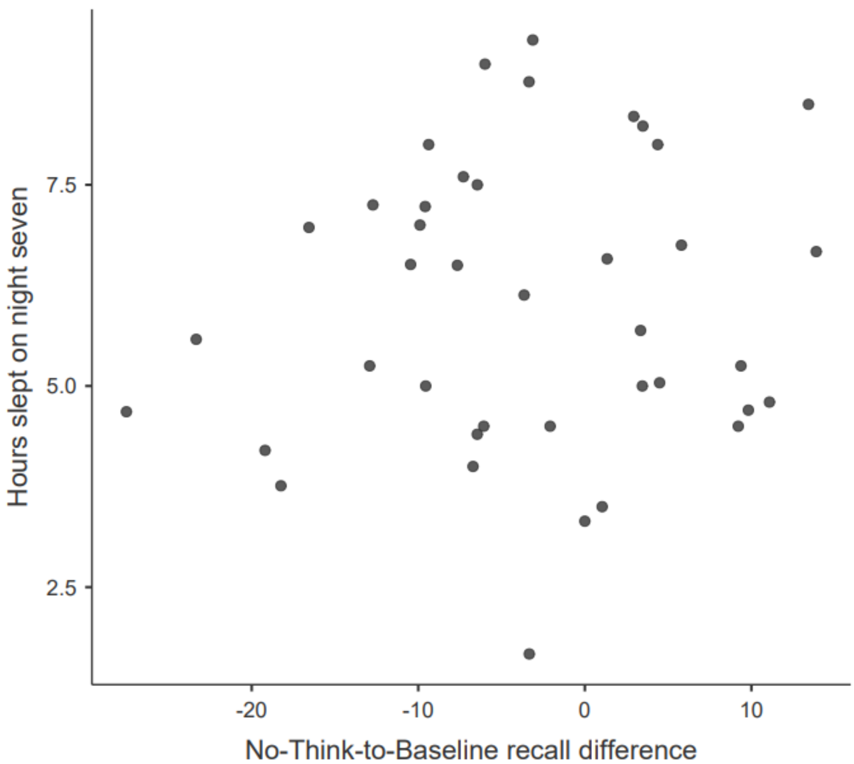

Figure 7. Scatterplot relationship between No-Think-to-Baseline recall difference compared to hours slept on night seven (outlier removed, r = 0.09)

For No-Think-to-Baseline difference, an outlier with a score of -77.68% difference heavily influences the regression outcomes. For comparison, the regression results without this outlier are included, and scatterplots using No-Think-to-Baseline recall difference as a variable exclude this participant to give a clearer idea of the distribution of the general cohort.

In summary, the above results for between-groups analyses suggest that loss of three hours of sleep relative to an individual's usual total sleep time had no influence on the suppression or enhancement effects in the Think/No-Think task. Additionally, since hours slept for night seven had no correlative relationship with any post-manipulation recall variable, this indicates that low hours slept, regardless of whether the low hours are typical or atypical for a given individual, had no effect on Think/No-Think suppression.

3.5 Sleep Quality Scale

Participant responses to the Sleep Quality Scale (SQS, *Appendix B*) were indicative of how positive or negative each participant felt about the quality of their last month of sleep. Linear regressions were performed to determine whether SQS score had a correlative relationship with either rates of recall for Think items or No-Think items, or for mean percentage change in recall from Think-to-Baseline and from No-Think-to-Baseline. SQS score was not a significant predictor of Think recall (r = 0.08, p =.62), No-Think recall (r < 0.01, p =.97), Think-to-Baseline difference (r = 0.14, p =.38) or No-Think-to-Baseline difference (r = 0.03, p =.84), outlier removed (r = 0.02, p =.92). Thus, it was found that SQS score produced no significant correlations with recall variables, indicating that self-rated sleep quality has no influence on the suppression effect in the Think/No-Think task.

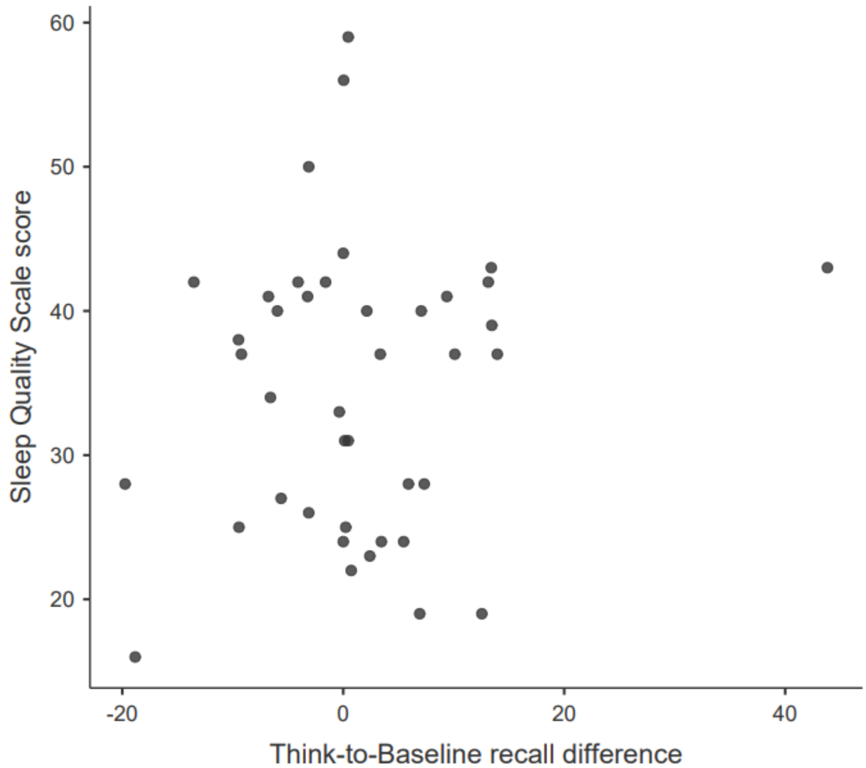

Figure 8. Scatterplot relationship between Think-to-Baseline recall difference compared to sleep quality scale score (*r* = 0.14)

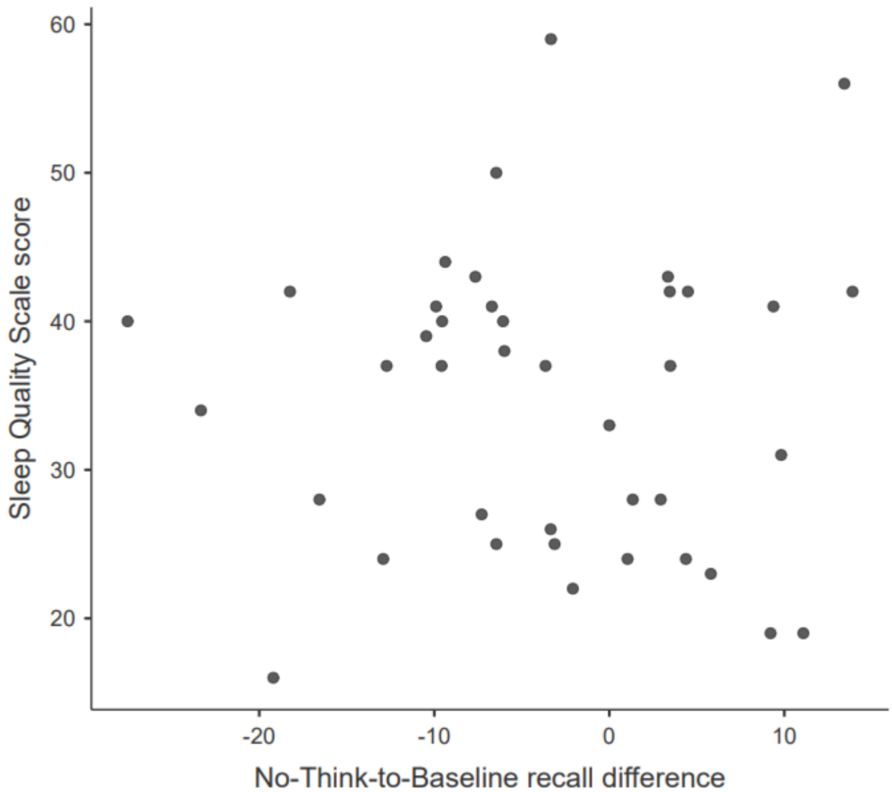

Figure 9. Scatterplot relationship between No-Think-to-Baseline recall difference compared to sleep quality scale score (outlier removed, *r* = 0.02)

3.6 Six- and seven-night sleep time

Each participant recorded one week's sleep with a smart-watch. Mean hours slept for the first six nights (before SD manipulation was applied) and on all seven nights (including the SD manipulation night) were examined using linear regressions to determine whether six- or seven- night sleep time score had a correlative relationship with either rates of recall for Think items or No-Think items, or for mean percentage change in recall from Think-to-Baseline and from No-Think-to-Baseline. Six-night hours slept was not a significant predictor of Think recall (r = 0.03, p =.87), No-Think recall (r = 0.16, p =.31), Think-to-Baseline difference (r = 0.02, p =.90) or No-Think-to-Baseline difference (r = 0.15, p =.34), outlier removed (r = 0.09, p =.60). Seven-night hours slept was not a significant predictor of Think recall (r = 0.03, p =.87), No-Think recall (r = 0.20, p =.21), Think-to-Baseline difference (r = 0.03, p =.84), or No-Think-to-Baseline difference (r < 0.18, p =.27), outlier removed (r = 0.13, p =.43). These results indicate that each participant's prior week of sleep was not a predictor of the suppression effect in the Think/No-Think task.

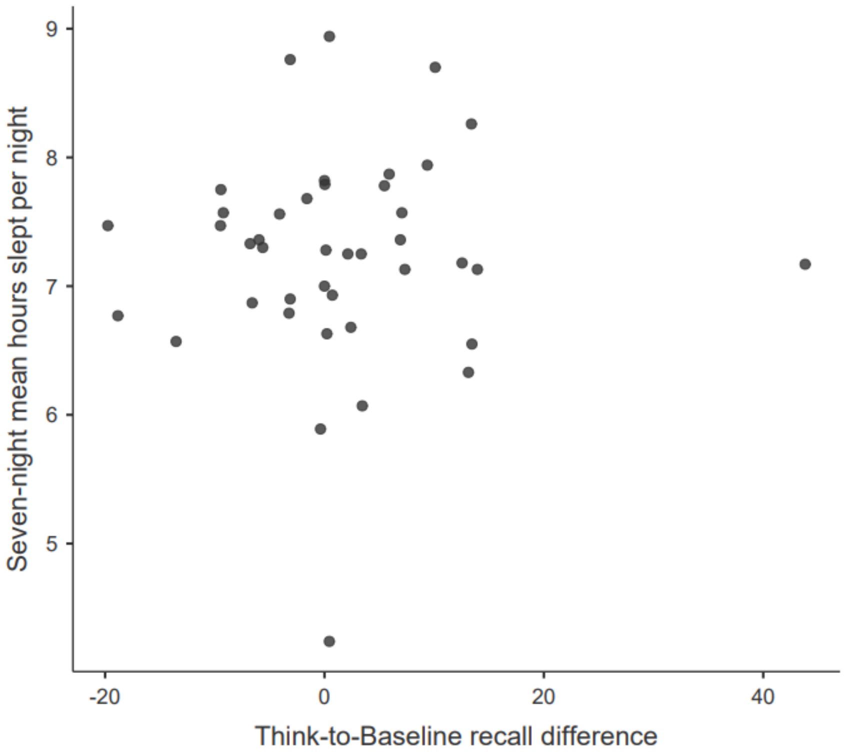

Figure 10. Scatterplot relationship between Think-to-Baseline recall difference compared to seven-night mean hours slept per night (r = 0.03).

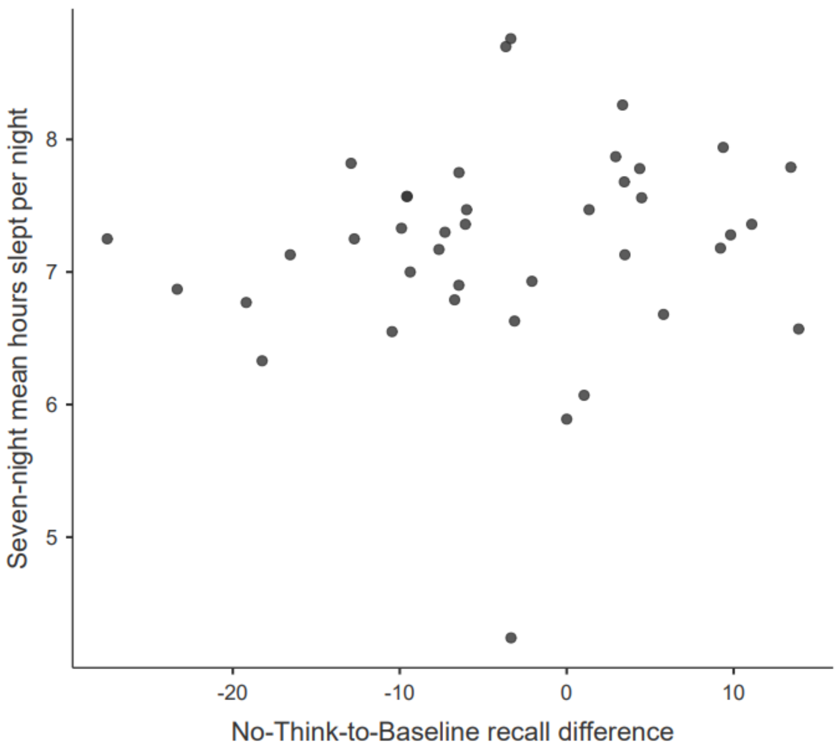

Figure 11. Scatterplot relationship between No-Think-to-Baseline recall difference compared to seven-night mean hours slept per night (outlier removed, r = 0.13).

4. Discussion

4.1 Summary of key results

The results from this study demonstrated that neither acute partial sleep deprivation (3h) nor shorter usual sleep times have a moderating effect on Think/No-Think task performance. Thus, these results do not support the study's hypotheses that sleep manipulation and sleep trends would affect the rates at which Think and No-Think items were recalled post-manipulation, at least for up to 3 h of SD. These results are compatible with some prior research but conflict with other previous results.

The Think effect did not occur in the present study. While there was an observable increase in recall of 1.4% between Think and Baseline items, meaning Think items were recalled more frequently than Baseline items, this difference was not significant. However, the No-Think effect did occur in this study. No-Think items were recalled 5.0% less frequently than Baseline items. While the typical strength of the No-Think suppression effect is around 6-8% (Levy & Anderson, 2008, Stramaccia et, al., 2020; 2021), the 5% less recall observed in this study was statistically significant. Thus, the No-Think effect originally observed in Anderson & Green (2001) was successfully replicated in this experiment. Anderson & Green used 16 repetitions of exposure to the No-Think item during the suppression manipulation to produce the effect, but this experiment replicated it with 12 repetitions. Since there was no interaction of recall type for No-Think suppression, the No-Think effect was observed at a statistically similar level for both SP and IP recall, which indicates that the nature of the probe was irrelevant to the rates of No-Think recall. These results suggest that No-Think items were occasionally forgotten through the method of suppression-induced forgetting, such that they had been suppressed to a degree that meant they could no longer be recalled when prompted by both familiar and unfamiliar probes.

Experimental manipulation of 3 h sleep deprivation had no influence on rates of post-manipulation recall for either Think or No-Think items. Whether the probe was SP or IP had no bearing on this effect. Effect of time asleep was examined in both the SD manipulation and through the number of hours slept by each participant on night seven, regardless of whether they were in the SD manipulation group. Neither had any significant effect on T/NT task performance. However, NSD participants had a 7.4% mean difference between No-Think recall and Baseline recall, whereas SD participants had a mean difference of only 3.2%. This non-significant difference may indicate the prevalence of a sleep deprivation effect on T/NT recall that was not detected by the present study.

Hours slept over the week prior to task participation by participants in this study did not have significant predictive relationships with their Think or No-Think recall or Think- or No-Think-to-Baseline difference. The present study can make this inference only for when an individuals' sleep falls within typical boundaries as the present study comprised mostly of individuals with sleeping patterns within typical variation (Hor & Tafti, 2009). While there were some participants with somewhat atypical sleeping patterns, they were not intentionally recruited and instead occurred naturally in the dataset's variation. Additionally, self-rated sleep quality over the past month as represented by the Sleep Quality Scale (SQS) had no relationship with any T/NT task recall. This suggests that self-rated long-term sleep quality is not a predictor nor confounder of performance on the suppression task. The combination of these results indicate that long-term sleep times do not influence performance on the T/NT suppression task.

4.2 Comparisons with previous research into effect of sleep on suppression

Previous research into the influence of sleep on suppression indicated that sleep deprivation reduced inhibition and increased the prevalence of intrusion of suppressed items.

Harrington et al. (2021) found that after 36 h of sleep deprivation, participants were 50% more likely to experience intrusions of unwanted thoughts. Anderson and Platten (2011) found that after 36 h of sleep deprivation, participants were 31.3% more likely to exhibit poor impulse control (lower reaction time but higher error rate) on a Go/No-Go task. The present study did not replicate possible implications of this effect using a T/NT task with partial sleep deprivation participants. There are several differences between these studies that could possibly account for the difference. Firstly, the present study used only partial sleep deprivation (3 h less sleep than normal) whereas the previous studies used total sleep deprivation resulting in no sleep for 24 or more hours. Rossa et al. (2014) found that <4 h partial SD was insufficient to produce a change in memory inhibition when compared with fully rested participants. The second primary difference between the two previous studies and the present study is that they used emotionally weighted stimuli, whereas the present study used emotionally neutral word pairs as stimuli. Since negative emotional memories are more likely to be recalled in detail (Kensinger, 2007) the usage of neutral stimuli in the present study may have influenced the effect that SD had on post-manipulation recall. Either of these main differences, or any of the present study’s limitations are possible explanations for the difference in results.

4.3 Sleep, sleep quality, and the executive deficit hypothesis

The non-significant relationships between sleep variables and T/NT task recall indicate that, unless extreme, total sleep time is not an influencing variable on memory suppression. This implies that only total SD or states that induce a powerful fatigue are sufficient to alter memory suppression. States such as being an individual who sleeps lower than the average for their cohort, or being deprived only 3 h of sleep, do not appear to have the same influence on memory suppression as states such as being under 36 h SD or being severely sleep deprived.

This study observed a lack of effect of long-term sleep amount or sleep quality on post-manipulation recall, suggesting that variations in total sleep time are not predictors of suppression ability. These results suggest variations within natural sleep for long-term sleep habits should not be considered amongst contributors to individual differences in executive function. Levy and Anderson (2008) indicated that there may be many different variables which determine capabilities in executive function that differ between humans, the sum of which would determine how capable a given individual is at suppressing unwanted thoughts. The current results are indicative that healthy variation of total sleep time is not amongst these variables. Prolonged sleep loss does however appear to be impactful on suppression performance (Choshen-Hillel et al., 2021; 2020, Harrington et al., 2021).

4.4 Implications for the Think/No-Think task

There was no difference in the effect of minor sleep variations from either three-hour acute partial SD or longer-term sleep trends on recall rates. This indicates that while larger losses of sleep may be sufficient to alter post-manipulation recall, small losses of sleep do not impair memory inhibition to the degree that post-manipulation recall rates in the T/NT task are changed. Specifically, while No-Think suppression was observed, it was not made any stronger or weaker by the participant's last night of sleep. Though no Think item recall enhancement was observed, sleep had no mediating effect on recall of Think items. This leads to the novel conclusion that the effect of minor sleep deprivation is insufficient to alter the outcome of a participant's T/NT task performance. If this is indeed the case, then Michael Anderson's guidelines for the T/NT task that require a participant to complete a minimum of 7 h of sleep are unnecessarily restrictive. Participants that typically sleep fewer hours had no difference in performance on the task, and neither did participants who had lost 3 h of sleep. While some requirement for sufficient sleep should probably be in place, 7 h as the lower bound cut-off may be too restrictive, considering the present study observed no difference between NSD participants who slept a mean of 7.5 h the night before participation and SD participants who slept a mean of 4.4 h on the same night.

While partial sleep deprivation did not influence recall rates for T/NT, there is a possibility that it influenced the time taken to successfully recall a suppressed word. While this is purely anecdotal, and based on unmeasured observations from data collection, it was noticed that there were multiple times in which a SD participant would take a few seconds of exertion to recall a suppressed item, although they would ultimately successfully recall their target. This was not noticed when NSD participants were being assessed. As only accuracy was measured, a possible difference in reaction times is unrepresented in the data of the present study. There is precedent for SD having a detrimental impact on reaction time, but not accuracy, for inhibition trials: Song et al (2019) observed that this difference was also mediated by chronotype (morning-type person or evening-type person). It is possible that while partial SD was insufficient to affect post-manipulation recall rates of success, it may be strong enough to influence response time for suppressed items. This would make sense as items that have been actively pushed out of the mind may take more time and effort to be retrieved, and this would indicate that an item has been partially forgotten. There is also evidence for increased reaction time to recall intentionally forgotten items (Fawcett & Taylor, 2008). Further investigation should be undertaken to determine if partial sleep deprivation is powerful enough to influence reaction times. If this were the case, there would be a more compelling reason to add a requirement for minimum hours slept before attempting the T/NT task.

4.5 Review of hypotheses

'*Hypothesis 1:* The Think enhancement effect will occur in this study, such that Think items will be recalled more than Baseline items.' This hypothesis was not supported, as Think items were recalled only 1.4% more frequently than Baseline items, which was a non-significant difference.

'*Hypothesis 2:* The No-Think suppression effect will occur in this study, such that No-Think items will be recalled less than Baseline items.' This hypothesis was supported, as No-Think items were recalled 5.0% less frequently than Baseline items, which was a significant difference.

'*Hypothesis 3*: Three-hour sleep deprivation participants will have increased recall of No-Think items due to experiencing difficulties with suppression.' This hypothesis was not supported. Differences in SD versus NSD participants were not visible in post-manipulation recall success rates. When sorting instead for hours slept on night seven, regardless of whether the participant was under SD or not, there was still no effect.

'*Hypothesis 4*: Participants who self-rate their sleep quality as poorer will show increased recall rates of No-Think items, as poor sleep quality will increase susceptibility to intrusions.' As there was no significant correlation between SQS score and post-manipulation recall rates, this hypothesis is not supported. No connection between self-reported sleep quality and T/NT task performance could be identified.

'*Hypothesis 5*: Participants who sleep fewer hours over seven days before completing the Think/No-Think task will show increased recall rates of No-Think items, as lower sleep time will increase susceptibility to intrusions.' Neither six-day nor seven-day mean sleep hours had a correlative relationship with post-manipulation recall rates. For natural variation between healthy sleepers, there was no effect identified, and thus, this hypothesis is not supported.

4.6 Limitations of the present study

The first limitation of the present study is that specialist polysomnography equipment was not available to track participant sleep. The AdorHealth H30 Unisex Health Monitoring Smart Watches were selected primarily for fitting within budgetary restrictions. Specialist actigraphy equipment may have improved the accuracy of the sleep data of the study. However, usage of the budget Smart Watches was probably still more accurate than using self-report to have each participant report their own sleep without technological aid.

The cohort for this study comprised only of university students. Students at universities or colleges have been demonstrated to sleep fewer hours compared to a typical population (Taylor & Bramoweth, 2010). As such, sleep times in this study may not represent a typical population of all ages.

Participants were not selected for having extreme values within their sleep trends. If a version of this study was conducted using individuals with normal sleep as the control group and individuals with extreme sleep (i.e., sleeping fewer than 6 h or greater than 10 h most nights) then effects of sleep trends may become more apparent. As it stands, this study used a participant group that was not designed to have extreme sleep values in it, and as such investigated only the effects of variation within a typical cohort. While it is still useful to demonstrate the effect of such a cohort, this study did not examine the best cohort for investigating the possible effect. Further research using participants with extreme sleep values may provide valuable insight into how sleep trends affect suppression when extreme high hour or extreme low hour sleepers are tested.

4.7 Further research

Differences in No-Think-to-Baseline group means between the NSD cohort and the SD cohort, though non-significant, are indicative of a relationship between sleep loss and T/NT task performance. The present study's results indicate that repetitions with increased power and/or increased T/NT repetitions may possibly have success in producing significant sleep effects. Further research examining the influence of sleep loss on the T/NT task would aid our presently limited understanding of sleep's influence on T/NT suppression.

As discussed in *Section 4.4*, there is a possibility of the effect of partial sleep loss on reaction times for recalling suppressed items versus non-suppressed items. Increased reaction time to recall a forgotten item is evidence that the item required further effort to be recalled (Fawcett & Taylor, 2008). Research into the effect of acute sleep deprivation and long-term sleep habits should consider investigating the effects of these sleep variables on reaction time to respond to suppressed versus non-suppressed items.

The primary body of existing research focused on the influence of sleep on suppression tasks (Anderson & Platten, 2011, Harrington et al., 2021) used emotionally weighted stimuli. The present study used only neutral stimuli. Loss of sleep can cause disinhibition of emotional regulation alongside other associated cognitive deficits (Marin & Lopera, 2009), and sleep deprivation results in a specific vulnerability to reacting to emotionally negative stimuli (Franzen et al., 2009). Perhaps the vulnerability to responses to emotional stimuli is a key element of the effect of sleep deprivation on inhibition. This is not included in the scope of the present study. As such, further research comparing the inhibition of both emotional and neutral stimuli is ideal for best understanding which specific mechanisms are responsible for variations in suppression ability. Research in the influence of emotionally weighted stimuli is key in aiding individuals with psychiatric conditions such as OCD and PTSD, since the associated intrusive thoughts often have a negative emotional weight.

Additional research into the relationship between sleep loss, executive function, and memory suppression is advised. As demonstrated in *Sections 1.3* through *1.8*, there are multiple pieces of information highlighting an existing network of potential connections between these cognitive elements. While the exact nature of these connections is presently not apparent, further research should explore the influences shared between these variables. The present study has demonstrated the theoretical precedents, but the present study has failed to elucidate the nature of the relationship. As such, further research should explore this relationship with different novel strategies, such as collecting reaction times.

4.8 Conclusion

To conclude, the present experiment found no effect of acute partial sleep deprivation or of usual long-term sleep time on performance on the Think/No-Think suppression task. This result is consistent with previous research which indicated that partial sleep deprivation does not negatively influence inhibition but was still surprising considering that sleep deprivation has been demonstrated to negatively affect suppression task performance. This experiment was designed to demonstrate a facet of the relationship between sleep loss and memory suppression, and the results failed to support this claim, at least for partial (3 h) sleep deprivation. There remains a large, unproven step between suppression of No-Think items and the persistent intrusive thoughts that affect individuals with conditions such as OCD and PTSD. Nevertheless, the present research contributes to a growing body of research designed to better understand the mechanisms of suppression-induced forgetting, and the many individual differences that influence one’s ability to ward off unwanted thoughts.

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6. Appendices

Appendix A: Think/No-Think word list

Cue	Response	Alternate Cue	Use of Pair
ERRAND	HOUR	TIME-H	Test Pair
TATTOO	UNCLE	RELATIVE-U	Test Pair
CRUMB	TOASTER	APPLIANCE-T	Test Pair
STUMBLE	CLOWN	CIRCUS-C	Test Pair
HAVEN	FALCON	BIRD-F	Test Pair
SLANDER	ROACH	INSECT-R	Test Pair
POSITION	CHAIR	FURNITURE-C	Test Pair
ORPHAN	LAMB	ANIMAL-L	Test Pair
DECAY	CARBON	ELEMENT-C	Test Pair
BRAID	DOLL	TOY-D	Test Pair
JARGON	PHYSICS	SCIENCE-P	Test Pair
ACCIDENT	SNOW	WEATHER-S	Test Pair
REFLEX	BICYCLE	VEHICLE-B	Test Pair
TRIBE	VALLEY	LAND-FORM-V	Test Pair
VICE	CIGAR	TOBACCO-C	Test Pair
VITAMIN	LEMON	FRUIT-L	Test Pair
GATE	DAISY	FLOWER-D	Test Pair
PASTE	TOMATO	VEGETABLE-T	Test Pair
FAULT	SADNESS	EMOTION-S	Test Pair
PLANET	BLUE	COLOR-B	Test Pair
POLLUTION	SULFUR	CHEMICAL-S	Test Pair
CLUSTER	NECKLACE	JEWELRY-N	Test Pair
WEDGE	CHEDDAR	CHEESE-C	Test Pair
BELT	SHIRT	CLOTHING-S	Test Pair
MIXTURE	JAR	CONTAINER-J	Test Pair

Cue	Response	Alternate Cue	Use of Pair
KILN	HAMMER	TOOL-H	Test Pair
GREED	PENNY	MONEY-P	Test Pair
AMBITION	BALLET	DANCE-B	Test Pair
FUSS	POODLE	DOG-P	Test Pair
BROOM	HOUSE	BUILDING-H	Test Pair
RELIEF	BOURBON	ALCOHOL-B	Test Pair
SNAG	COTTON	FABRIC-C	Test Pair
ARCH	SANDAL	FOOTWEAR-S	Test Pair
CUSTOM	TOMB	BURIAL-T	Test Pair
FLAG	SWORD	WEAPON-S	Test Pair
TICKET	FLUTE	INSTRUMENT-F	Test Pair
SPINE	LOBSTER	SEAFOOD-L	Test Pair
ALARM	COBRA	SNAKE-C	Test Pair
LEVER	STEEL	METAL-S	Test Pair
APRON	NUTMEG	SPICE-N	Test Pair
THUD	FOOTBALL	SPORT-F	Test Pair
MOSS	NORTH	DIRECTION-N	Test Pair
PEG	OAK	TREE-O	Test Pair
RIM	GRANITE	ROCK-G	Test Pair
GLOW	PHANTOM	SUPERNATURAL-P	Test Pair
NAIL	PICTURE	ART-P	Test Pair
MOB	ROBBERY	CRIME-R	Test Pair
PITY	GOLDFISH	FISH-G	Test Pair
AVENUE	MILE	DISTANCE-M	Filler Pair
BEACH	AFRICA	CONTINENT-A	Filler Pair
REALITY	ILLUSION	DREAM-I	Filler Pair
JAW	GUM	CANDY-G	Filler Pair
WARRIOR	HERO	CARTOON-H	Filler Pair

Cue	Response	Alternate Cue	Use of Pair
POLISH	DIAMOND	GEM-D	Filler Pair
BOOTH	DIAL	RINGTONE-D	Filler Pair
NEEDLE	DOCTOR	PROFESSION-D	Filler Pair
TAPE	RADIO	MEDIA-R	Filler Pair
ENERGY	AMP	–	Filler Pair
LINT	CURTAIN	–	Filler Pair
REMOVE	CANCER	–	Filler Pair
BOND	WEDDING	–	Filler Pair
LOAN	POVERTY	–	Filler Pair
TYPE	FILE	–	Filler Pair
PAPER	PACKAGE	–	Filler Pair
GARAGE	BENCHPRESS	–	Filler Pair
STRAW	WICKER	–	Filler Pair

Some filler words were not repeated beyond the pre-manipulation phase and, as such, have no associate hint. Therefore, their *Alternate Cue* column is empty.

Appendix B: Sleep Quality Scale

Using a four-point, Likert-type scale, respondents indicate how frequently they exhibit certain sleep behaviours (0 = "rarely," 1 = "sometimes," 2 = "often," and 3 = "almost always"). Scores on items belonging to factors related to restoration after sleep and satisfaction with sleep are reversed before being tallied. Total scores can range from 0 to 84, with higher scores demoting more acute sleep problems.

The following is a survey to know the quality of sleep you had for the last one month. Read the questions and check the closest answer.

Examples: Rarely: None or 1-3 times a month. Sometimes: 1-2 times a week. Often: 3-5 times a week. Almost always: 6-7 times a week.

Items: (an [R] denotes a reverse coded item)

1. I have difficulty falling asleep.
2. I fall into a deep sleep. [R]
3. I wake up while sleeping.
4. I have difficulty getting back to sleep once I wake up in the middle of the night.
5. I wake up easily because of noise.
6. I toss and turn.
7. I never go back to sleep after awakening during sleep.
8. I feel refreshed after sleep. [R]
9. I feel unlikely to sleep after sleep.
10. Poor sleep gives me headaches.
11. Poor sleep makes me irritated.
12. I would like to sleep more after waking up.
13. My sleep hours are enough. [R]
14. Poor sleep makes me lose my appetite.
15. Poor sleep makes it hard for me to think.
16. I feel vigorous after sleep. [R]
17. Poor sleep makes me lose interest in work or others.
18. My fatigue is relieved after sleep. [R]
19. Poor sleep causes me to make mistakes at work.
20. I am satisfied with my sleep. [R]
21. Poor sleep makes me forget things more easily.
22. Poor sleep makes it hard to concentrate at work.
23. Sleepiness interferes with my daily life.
24. Poor sleep makes me lose desire in all things.
25. I have difficulty getting out of bed.
26. Poor sleep makes me easily tired at work.
27. I have a clear head after sleep. [R]
28. Poor sleep makes my life painful.

Appendix C: Think/No-Think diagnostic questionnaire

GREEN TRIALS

1. For the Hint words presented in Green, how often did you try to think of the associated RESPONSE word as fast as possible?

Never		Half of the time		Always
0	1	2	3	4

RED TRIALS

1. When Hint words appeared in Red, how much time did you spend looking the Hint word, without shifting your eyes OR attention to something else?

Didn’t look at them		Half of the time		The entire time
0	1	2	3	4

2. For Red trials, how often did you read and understand the Hint word?

Never		Half of the time		Always
0	1	2	3	4

3. How often were you able to avoid thinking about the Response word that went with it?

Never		Half of the time		Always
0	1	2	3	4

4. How often did you replace the original Response word with another word or thought?

Never		Half of the time		Always
0	1	2	3	4

5. How often did you actively push the Response word out of mind if it did come to mind?

Never		Half of the time		Always
0	1	2	3	4

6. Did you ever intentionally think about the Response word “just for a second” to see if you still knew it?

Never		Half of the time		Always
0	1	2	3	4

7. How often did you think about the Response word after the Hint word went off the screen?

Never		Half of the time		Always
0	1	2	3	4

Appendix D: Think/No-Think Post-experiment questionnaire

1. Please rate the extent to which you used each of the following strategies in order to keep the response word from coming to mind when presented with Hints in Red rectangles.

a. I simply moved my eyes away from the HINT word so I didn't have to look at it.

Never	Rarely	Sometimes	Often	Always
0	1	2	3	4

b. Although I kept my eyes on the HINT word, I covertly shifted my attention to a different spot on the screen/elsewhere in the room, so I could avoid looking at the HINT word.

Never	Rarely	Sometimes	Often	Always
0	1	2	3	4

c. I shifted my attention to something else in my mind, such as another word, idea, sound, image, or memory. In other words, I came up with an alternative thought in order to prevent the Response word from coming to mind.

Never	Rarely	Sometimes	Often	Always
0	1	2	3	4

d. I played word games with the HINT word on the screen, repeated the HINT over and over, or simply focused on the visual properties of the word.

Never	Rarely	Sometimes	Often	Always
0	1	2	3	4

e. I simply focused on blocking/pushing out thoughts of Response word, without replacing it with any other thought.

Never	Rarely	Sometimes	Often	Always
0	1	2	3	4

f. Other, please describe your strategy below, after rating how often you employed it.

Never	Rarely	Sometimes	Often	Always
0	1	2	3	4

____

____

2. Sometimes people suspect that their memory will be tested on response words for HINT words presented in Red rectangles later on, even though they have been asked to not think about these RESPONSE words. Each of the following three statements is intended to measure whether you ever INTENTIONALLY made an effort to think about the responses for the HINT words presented in Red rectangles (so please only consider those instances in which you purposefully thought of a response, not those in which a response automatically came to mind). Please make a rating for each statement and be as honest as possible with your ratings.

a. I simply moved my eyes away from the HINT word so I didn't have to look at it.

Never	Rarely	Sometimes	Often	Always
0	1	2	3	4

b. *After* a HINT word in a Red box went off the screen, I checked to see if I still remembered the response word

Never	Rarely	Sometimes	Often	Always
0	1	2	3	4

c. When I saw a HINT word in a Red box, I thought about the response that went with it to improve my memory for that word pair.

Never	Rarely	Sometimes	Often	Always
0	1	2	3	4

3. Last night, how many hours of sleep did you get? (estimate as accurately as possible)

≤2 3 4 5 6 7 8 9 10 ≥11

Appendix E: Information Sheet

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26/07/2021
HREC Ref: HEC 2021/92

Sleep and Control over Attention
Information Sheet for participants

Kia ora,

You are invited to participate in a research study which seeks to examine a 'control over attention' task presented on computer. This study is being conducted by Duncan Matchett from the University of Canterbury | Te Whare Wānanga o Waitaha (UC). Other research team members include Associate Professor Ewald Neumann, PhD candidate Usman Afzali, and Prof Richard Jones. The study is being carried out as a requirement for Duncan's Master's thesis.

Please be advised that you should be at least 18 years old to participate. Furthermore, you will not be able to finish your participation if you have a history of ADHD or difficulty distinguishing colours.

What is the purpose of this research?
This research aims to determine the effects of total sleep time over one week on an individual's performance in the 'control over attention' computer task. We are interested in finding out about the inner workings of human attention, and how sleep time can influence them. The information from this study will help to construct a body of knowledge on this task.

Why have you received this invitation?
You are invited to participate in this research because you responded to a request for participants.
Your participation is voluntary (your choice). If you decide not to participate, there are no consequences. Your decision will not affect your relationship with me, the University of Canterbury or any member of the research team.

What is involved in participating?
If you choose to take part in this research, you will be provided a smart watch to track your sleep over seven consecutive days prior to coming to the University of Canterbury campus to complete the task. For example, if you were scheduled to complete the task on a Monday, you would need to use your smart watch to track your sleep each night for one week, starting the Monday prior and ending the Sunday night before you participate in the computer task. The computer task will be run in the afternoon. We will copy the data on the smart watch

from those seven nights of sleep into a spreadsheet manually, without downloading any data stored on the watch.

For the purposes of this study, a smart-watch is any device that can be used to provide accurate data on the wearer's sleep cycles, and can record the total hours slept each night.

During this computer task, you will first be asked to study pairs of neutral words on the computer screen. Following that, we want to see how well you have learnt the pairs in a test-feedback phase. In a second part, you will then be asked to pay close attention to some of the words while trying to ignore others. Finally, we will ask you to describe how well you were able to ignore some of the words and to focus on others.

The set of questionnaires is a pen and paper measure about the computer task. You will be asked a series of multiple-choice questions about your experiences during the task. We estimate that your participation will take around 70 to 90 minutes on the day, plus one week's worth of sleep tracking.

Are there any potential benefits from taking part in this research?
We do not expect any direct benefits to you personally from participating in this interview. However, the information gathered will potentially benefit.

At the conclusion of the study, we will provide you with receive $40 in Countdown vouchers. You will get this inducement even if you withdraw from the study.

Are there any potential risks involved in this research?
We are not aware of any risks to participants in the research.

What if you change your mind during or after the study?
You are free to withdraw at any time. To do this, please let me know either during the study or after you have finished. We will remove any information you have provided up to that point from the data set if it is still possible. Excluding your data will become increasingly difficult from 22nd October onwards. You will be able to keep your Countdown voucher if you have already received it.

What will happen to the information you provide?
You are assured of the complete confidentiality of data gathered in this investigation: your identity will not be made public at all. All data will be collected by the primary researcher, Duncan Matchett. To ensure anonymity and confidentiality, your name and email address will be recorded on a separate sheet and you will be assigned an alphanumeric code. That code will be used on the experiment software for participation. Therefore, the collected data will not have your name on it. Once you have completed your participation, the sheet - which has your name and email address– will be deleted. My supervisor, my two co-supervisors and I will be able to see the raw anonymous data after it is collected. Furthermore, the raw anonymous data will be made publicly available on an online research repository known as OSF (Open Science Framework https://osf.io/).

We will store all study data in password-protected files on the University of Canterbury computer network or in lockable cabinets in lockable offices. The computer will be electronically locked when not attended by the researcher and no one except the principle researcher and the supervisory team will have access to the data. The data will not be transferred to any other personal or university computers.

I will be responsible for making sure that only members of the research team use your data for the purposes mentioned in this information sheet.

Will the results of the study be published?
The results of this research will be published in a Master's thesis. This thesis will be available to the general public through the UC library. Results may be published in peer-reviewed, academic journals. Results will also be presented during conferences or seminars to wider professional and academic communities. You will not be identifiable in any publication. A summary of results will be sent to all participants who request a copy of these.

Who can you contact if you have any questions or concerns?
If you have any questions about the research, please contact: Duncan Matchett (dma186@uclive.ac.nz) Ewald Neumann at (ewald.neumann@canterbury.ac.nz), Usman Afzali (usman.afzali@pg.canterbury.ac.nz) or Richard Jones (richard.jones@canterbury.ac.nz)

This study has been reviewed and approved by the University of Canterbury Human Research Ethics Committee (HREC). If you have concerns or complaints about this research, please contact the Chair of the HREC at human-ethics@canterbury.ac.nz).

What happens next?
Please let me know within 48 hours if you want to participate in this study. If you agree to participate, you will be asked to read a consent form, which you will be asked to complete when you meet the researcher.

Appendix F: Sleep Deprivation Information Sheet

School of Psychology, Speech and Hearing.
Phone: +64 3 369 3777
Email: dma186@uclive.ac.nz
26/07/2021
HREC Ref: HEC 2021/92

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Sleep and Control over attention
Information Sheet for participants
Sleep deprivation group

You have been randomly selected to be a part of the study group that receives three hours of sleep deprivation as part of the study. As mentioned in the information sheet to all participants, this study is examining the effects of sleep time on performance in the 'control over attention' task. We are also looking at the effect of three hours sleep deprivation on task performance.

In addition to using the smart watch to track seven nights of your sleep patterns, you will be required to sleep three hours less than you normally do on the night before you come into UC to complete the computer task. This means going to bed three hours later, or getting up three hours earlier, or something in between such as going to bed an hour and a half later, then also getting up an hour and a half earlier.

All participants receive access to a Google Sheet with which to track their sleep, as noted in the information sheet to all participants. Yours will also feature a calculator that determines the average sleep you got each night for the first six nights of sleep tracking, and uses this number to calculate how many hours you should aim to sleep for the seventh night. It is important that you fill this out prior to going to bed for the seventh night, so that you know how many hours you need to sleep to fulfil the '3 hours sleep deprivation' required of your participation.

Sleep deprivation has short-term effects. The most important to consider is the increased risk of causing a car accident. As a result, you will be required to attend the computer task at UC without driving or cycling. Sleep deprivation can also cause difficulties with memory, focus and judgement, as well as mood changes and irritability. We advise that following your participation in this experiment, you get a good night's sleep to catch up with lost sleep.

We understand that as a UC student, you will often be required to complete tests and assignments that require your full focus and capabilities. As a result, please work with us to arrange a time for your completion of the computer task that does not conflict with any assignments or other important dates. If you organise a date for your participation, then need to change it, do not hesitate to contact the researcher, Duncan Matchett (dma186@uclive.ac.nz) and reschedule.

If you have any questions or concerns about the sleep deprivation element of the experiment, contact Duncan Matchett (dma186@uclive.ac.nz), primary supervisor Associate Professor Ewald Neumann, or co-supervisors PhD candidate Usman Afzali or Prof Richard Jones, who can be contacted at (ewald.neumann@canterbury.ac.nz), (usman.afzali@pg.canterbury.ac.nz) and (richard.jones@canterbury.ac.nz). They will be pleased to discuss any concerns you may have about participation in the project.

Appendix G: Consent Form

School of Psychology, Speech and Hearing.
Phone: +64 3 369 3777
Email: dma186@uclive.ac.nz
26/07/2021
HREC Ref: HEC 2021/92

UC UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Sleep and Control over Attention
Consent Form for Participants

☐ I have been given a full explanation of this project and have had the opportunity to ask questions.

☐ I understand what is required of me if I agree to take part in the research.

☐ I understand that participation is voluntary and I may withdraw at any time without consequences. Withdrawal of participation will also include the withdrawal of any information I have provided should this remain possible.

☐ I understand that any information or opinions I provide will be kept confidential to the researcher and the researcher's supervisors. I understand that any published or reported results will not identify me.

☐ I understand that a thesis is a public document and will be available through the UC Library.

☐ I understand that all data collected for the study will be kept in locked and secure facilities and/or in password protected electronic form. I understand the data will be stored indefinitely in the publicly available online research repository Open Science Framework.

☐ I understand the risks associated with taking part and how they will be managed.

☐ I understand that I can contact the researcher Duncan Matchett at dma186@uclive.ac.nz or supervisors Ewald Neumann at (ewald.neumann@canterbury.ac.nz), Usman Afzali (usman.afzali@pg.canterbury.ac.nz) or Richard Jones (richard.jones@canterbury.ac.nz) for further information. If I have any complaints, I can contact the Chair of the University of Canterbury Human Research Ethics Committee, Private Bag 4800, Christchurch, (email: human-ethics@canterbury.ac.nz).

☐ I would like a summary of the results of the project.

☐ By signing below, I agree to participate in this research project.

Name:__________________________Signed:________________________Date: ______________________________

Email address *(for report of findings, if applicable)*:
____

Appendix H: Deception Debrief Sheet

Basic Experiment Summary and Procedure:
Thank you for participating in this experiment. This research is exploring the basic mechanisms underlying human memory and attention. In particular, this project focuses on the ability to intentionally suppress specific memories. In this experiment we initially had you study arbitrary pairings of words. Then after you learned these pairs, we asked you to not think of (suppress) some of those response words and to recall (practice) others. Near the end of the experiment, we tested you on all the words to determine what effect the effort of suppression had on your memory for the items. In other words, does repeatedly avoiding thinking about a word make it harder to remember later?

Our study was also looking at the effects of sleep and sleep deprivation on performance in this task. Participants were randomly assigned ‘normal sleep' or ’3 hours sleep deprivation', and comparisons between these groups on task performance is the focus of our study, learning how sleep deprivation can affect memory suppression performance. If you were part of the sleep deprivation group, we strongly advise that following your participation in this experiment, you get a good night's sleep to catch up with lost sleep.

The true nature of this experiment was obscured to you because performance on the memory suppression task is different if you are expecting to have your memory tested. Because of this, we introduce it as an exclusively attention-based task.
You can decide to withdraw and have your data removed now that you know the true nature of the experiment/research. If you do so, you will be allowed to keep your $20 Countdown voucher.

Experiment Details: Do people really forget words they are asked to suppress?
In general, repeatedly encountering a reminder of a word will improve one's memory for that word. However, despite repeated reminders for suppression items, people display poorer memories for the items they previously ignored (suppressed). This indicates that people are able to successfully prevent these memories from coming to mind, and that the effort of suppressing these words has a lasting effect on one's later memory for these items. Interestingly, if you test memory for these same response words with a new unrelated cue (the new categories that you were tested on at the end of the experiment) performance is still worse. This indicates that the response word itself, rather than just the arbitrary word pair that was studied, has been inhibited.

Everyday examples of suppression:
This ability to intentionally keep unwanted memories from coming to mind is a very important ability in everyday life. When trying to remember where you parked earlier in the morning it is often necessary to effortfully keep the place you parked yesterday out of mind. When you have just moved you initially have to avoid thinking about your old phone number in order to remember your new phone number. If people have this ability to intentionally cause long-lasting suppression of their memories, this ability could be what allows people to repress unpleasant memories. Repression has always been difficult to discuss analytically because the mechanism that caused repression has never been understood. This research could potentially open a window into how people repress memories.

As a reminder, your confidential data will be stored for archival purposes and later reanalyses. You are free to withdraw your consent and discontinue participation at any time without penalty.
If you have any questions, you may ask your experimenter Duncan Matchett (dma186@uclive.ac.nz) or feel free to contact Ewald Neumann (ewald.neumann@canterbury.ac.nz) or Usman Afzali (usman.afzali.@pg.canterbury.ac.nz)