Title: Pre-Experimental Sleep Effects on Directed Forgetting

Authors: Victoria A. J. Kavanagh, Kathleen L. Hourihan

Affiliation: Psychology Department
Memorial University of Newfoundland
232 Elizabeth Ave
St. John's, NL
CANADA
A1B 3X9

Corresponding Author: Victoria Kavanagh, vajk87@mun.ca, 709-864-8876
Psychology Department
Memorial University of Newfoundland
232 Elizabeth Ave
St. John's, NL
CANADA
A1B 3X9

Abstract

A directed forgetting (DF) paradigm was used to compare the remembering and forgetting of participants with good sleep quality to those with poor sleep quality and the presence of insomnia symptoms. This study implemented a point system in place of remember and forget instructions in a DF task with the goal of computing DF costs and benefits. Relations among memory, sleep, and working memory capacity (WMC) were also examined. DF benefits were observed in both groups, with negative costs found for participants without the presence of insomnia symptoms. WMC was found to be related to memory for positive point items only, and did not differ based on sleep quality. These results suggest that the presence of self-reported insomnia symptoms does not affect performance on a DF task.

Keywords: Directed Forgetting; Working Memory Capacity; Sleep Quality; Insomnia

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1. Introduction

Forgetting is often seen as a flaw. When we cannot store information, process it, or retrieve it when wanted, we consider this to be a failure of our memory (e.g., Schacter, 2001). What is usually overlooked, however, is how beneficial forgetting can be; many everyday occurrences rely on us forgetting information in favour of other information. For example, if we park in a different parking spot every day, then we need to forget where we parked yesterday so that we are not wandering aimlessly in an attempt to find our car (Bjork, 1989). Without the ability to forget some things, we would be in a constant state of having to sort out one memory from the next.

While it may seem like forgetting is easy, it is actually a complicated, multifaceted process. Some forgetting is incidental and happens without effort (or intention), but other forms of forgetting are intentional and may require effortful inhibition of memories (e.g., Wylie, Foxe, & Taylor, 2008). In studies involving *directed forgetting* (DF), participants are instructed to remember or forget specific information. This paradigm shows that intentional forgetting can be quite successful, as participants reliably recall or recognize fewer items they are asked to forget compared to items they are asked to remember, even when asked or paid at test to ignore previous instructions to forget (MacLeod, 1998).

Over the years since DF was first used in experimental settings (e.g., Brown, 1954), the limits of the phenomenon have been examined by including numerous additional manipulations and individual difference measures. Two such individual difference measures include sleep and working memory (WM). Sleep has been incorporated into DF studies to examine whether sleep can limit the effects of forgetting and facilitate the remembering of all information (Abel & Bäuml, 2013). WM has been examined in order to determine whether the amount of information someone can hold in their limited WM capacity affects forgetting as a whole (Aslan, Zellner, & Bäuml, 2010). Limits to such studies to date, however, include that the role that sleep prior to the experiment has on forgetting has not been examined and that previous results involving DF and WM are not conclusive. The goal of this paper was to address these limits.

1.1. Directed Forgetting (DF)

In the item method of DF, participants are given a cue to either remember (R) or forget (F) each item presented in the study list (as opposed to the list method, in which participants in the experimental condition are presented with one list to forget and one list to remember and participants in the control condition are given two lists to remember). At test, participants are asked to disregard the initial cues, and to recall or recognize all studied items. With the item method, the DF effect is considered to be the advantage in memory for R cued over F cued items. In the list method, the DF effect occurs as *benefits* in memory to the second (remember) list for the experimental condition over the second (remember) list of the control condition, and/or as *costs* in memory for the first (forget) list of the experimental condition in comparison to the first (remember) list of the control condition. The most accepted explanation for why DF effects occur with the item method is selective rehearsal (Bjork, 1970). Although shallow rehearsal can maintain information, more elaborative rehearsal is required to improve long term memory (e.g., Craik & Watkins, 1973). In item method DF, because participants are aware that they may receive an F cue, items are rehearsed only shallowly until the cue is presented. After a cue is given, however, rehearsal of the item will either continue for the R cued items or stop for the F cued items (Woodward, Bjork, & Jongeward, 1973); essentially, an F cue renders the item irrelevant information that is to be discarded in favour of the R cued items.

It was originally thought that F cued items were passively dropped from the rehearsal set, not to be thought of again (Elmes 1969; Fawcett & Taylor, 2008). More recently, however, some researchers believe that an important part of selective rehearsal is the deliberate inhibition of the F cued items (e.g., Zacks, Radvansky, & Hasher, 1996). Instead of passively ignoring any item associated with an F cue in favour of those associated with an R cue, participants try to actively forget, or inhibit (though this term is debated amongst researchers; for discussion, see Carr, 2007) the F cued items. For example, Fawcett and Taylor (2008) examined how long it took participants to detect visual probes after being presented with a memory cue and found that it took longer to detect the probes after an F cue was given than after an R cue, showing that participants were more preoccupied cognitively when processing the F cue. Other support for this includes Fawcett and Taylor (2011) who had participants respond to probe words following a cue in an item method DF paradigm, and Taylor and Hamm (2016) who had participants locate words on a screen following a cue; both found that all tasks took longer following F cued items than R cued items.

The process of selective rehearsal is heavily reliant on WM, which deals with the immediate processing and encoding, maintenance and manipulation, decision making, and response outputs based on the information (Sweller, 2011; Whitney & Rosen, 2013). Because WM has a limited capacity (Miller, 1956), irrelevant information is discarded in favour of relevant information (Baddeley, 1986; Ecker, Oberauer, & Lewandowsky, 2014). It was originally thought that the irrelevant information passively decayed on its own (Baddeley, 2000) but now it is believed by some researchers that the irrelevant information is purposefully removed from WM (Berman, Jonides, & Lewis, 2009; Ecker, Lewandowsky, & Oberauer, 2014; Ecker, Lewandowsky, Oberauer, & Chee, 2010), an ability that varies depending on an individual’s WM. Thus, there is a clear role for WM in the selective rehearsal involved in item method DF: Items are initially held in active WM, but then may be actively removed upon receiving an F cue, in favour of rehearsing more relevant R items.

As an alternative to the standard R and F cues used in item method DF, Friedman and Castel (2011) used a value-directed remembering paradigm, pairing each item with a point value; participants were instructed that scores at test would fluctuate depending on the recall or recognition of the items associated with each point value. For example, in Experiment 3, Friedman and Castel used four point values: +10, +5, -5, or -10. Participants were told that if they recalled an item worth +10 points at test their score would go up by 10 points but, if they recalled an item worth -10 points, their score would go down by 10 points. In this instance, points that will increase the score should act as an R cue and points that decrease the score should act as an F cue (see also Golding, Roper, & Hauselt, 1996). At test, however, participants were encouraged to recall any item they studied and were told that the scores did not matter. Friedman and Castel found that, while recall was highest for words worth +10 points, there was no difference between the other point values. As explained by Castel, Benjamin, Craik, and Watkins (2005), people choose to encode items associated with higher points, but put little value on lower point values. So, participants may have treated the +10 as an R cue, as it would maximize their score at test, but did not treat the +5 as an R cue or the negative values as an F cue, as they would not maximize their score at test. This would result in the participants ignoring the other point values rather than trying to actively remember the +5 point value or actively trying to suppress the negative point values, leading to recall being equal for all three.

1.2. Working Memory Capacity and Directed Forgetting

Working Memory Capacity (WMC) is an estimate of how much information a person can hold and work with in WM at one time (Anderson, 1990). WMC tasks take a wide range of forms including having a participant count backwards while responding to cues on a screen (Aslan et al., 2010; Lee & Lee, 2011), recalling a specified item in a series of items (Noreen & De Fockert, 2017), and alternating between solving mathematics problems and recalling letters (Unsworth, Heitz, Schrock, & Engle, 2005). With increasing support for the role of WM in DF (e.g., Macmillan, 2000), especially in item method DF, some experimenters have chosen to use WMC tasks to further observe this role, but overall, the evidence for a relation between the two is mixed.

While some support has been found for a relation between WM and DF using both the item and the list method (e.g., Aslan et al., 2010), some research actually shows that this relation is not as strong as it may seem (e.g., Lee, 2012). Even among the studies that have found a relation between WM and DF in the past, the nature of the relation and the explanations for why there is a relation have varied. For example, both Aslan et al. (2010) and Soriano and Bajo (2007; Experiments 2 and 3) presented participants with a WMC task and a list method DF task and found that participants with higher WMC showed greater levels of forgetting, meaning that participants recalled fewer items from the F cued list. The explanation for both of these results was that inhibition, which is the purposeful discarding or suppressing of irrelevant information (Baddeley, 1986; Ecker et al., 2014), played a significant role. Essentially, it is thought that people with high WMC have greater control over their ability to inhibit information (Brewin & Beaton, 2002). For both Aslan et al. and Soriano and Bajo, this meant that the participants were better able to inhibit the F cued list which caused them to have lower recall at test because this list was less readily available. The participants with low WMC, however, were less able to inhibit information. Consequently, when they were presented with an F cue, they were less able to actively inhibit that list, and the list was more readily available at test.

In contrast to Aslan et al., (2010) and Soriano and Bajo (2007), Delaney and Sahakyan (2007) proposed that context is actually the reason for the connection between WMC and DF. Using a list method DF task, Delaney and Sahakyan also found that participants who had a higher WMC recalled fewer F cued list items than those with lower. They did not, however, find any differences in R cued list recall related to WMC. Instead of proposing that this was due to differences in inhibitory control, Delaney and Sahakyan proposed that the participants with high WMC were more context dependent and suffered to a greater extent when the context changed from the F cued to the R cued list, compared to those with lower WMC. This greater context change led to increased forgetting.

Marevic, Arnold, and Rummel (2018) also found results indicating that the relation between WMC and DF may not be due to difference in inhibitory control. Using an item method DF task, Marevic et al. examined whether there was a correlation between WMC and DF. In contrast to Delaney and Sahakyan's list method study, Marevic et al. found that participants with higher WMC actually recalled significantly more R cued items than the participants with lower WMC and that there was no difference between the two groups in the recall of F cued items. They concluded that, while higher WMC led to greater memory, it did not affect the inhibition of items at all. It should be noted, however, that Marevic et al. used word pairs and cued recall in their study as opposed to single words and free recall (or recognition), which are more typically used.

To further complicate the picture, some studies have found either no relation between WMC and DF or have found opposing results to the studies mentioned above. For example, Lee (2012) increased the cognitive load of participants with the intention of equating reduced available WM resources to having low WMC. Then, using an item method DF task, they showed that these participants recalled fewer F cued items, resulting in greater DF effects compared to those who did not have their cognitive load increased. This finding was similar to that of Lee and Lee (2011) who also used an item method DF task and manipulated cognitive load. Unlike the studies mentioned previously which would suggest a positive correlation between WMC and high levels of either forgetting or remembering, the Lee and colleagues' results would suggest a negative correlation between WMC and high levels of forgetting. Overall, there is yet to be a conclusive answer to whether there is a relation between WMC and DF, especially for the item method. When DF effects and WMC are related, it is not consistent whether WMC is related to increased remembering or increased forgetting abilities.

1.3. Sleep, Sleep Quality, and its Effect on Cognition

Sleep is an important aspect of everyday life, without which normal functioning would be affected in numerous ways. Without sufficient sleep or good quality sleep, people can suffer physically (e.g., they can have increased blood pressure; Tockikubo, Ikeda, Miyajima, & Ishii, 1996; and a heightened activation of the sympathetic nervous system; Kato et al., 2000), psychologically (e.g., they can be diagnosed with a *Diagnostic and Statistical Manual of Mental Disorders* (DSM-V; American Psychiatric Association, 2013) disorder such as insomnia, which is characterized by difficulties in getting to sleep, staying asleep, or waking up early) or cognitively (e.g., they can have decreased alertness and trouble remembering new information; Diekelmann & Born, 2010; Killgore & Weber, 2014).

Although it may seem like sleep is something that just effortlessly occurs every night, it is actually a complicated process that gets more complicated when considering all of the different ways insufficient sleep or poor sleep quality can be defined. For example, one definition of sleep quality includes at least six different sub-definitions (Buysse, Reynolds, Monk, Berman, & Kupfer, 1989; Moon, Phelan, Lauver, Bratzke, 2015). In this definition, sleep quality can be determined by the general quality of the sleep, the duration (how long the sleep is), the sleep latency (how long it takes to get to sleep), how efficient the sleep is (how long sleep is relative to the amount of time spent in bed), whether sleep is disrupted throughout the night, and whether medication is required to aid in getting to sleep. In comparison, the Patient-Reported Outcomes Measurement Information System- Short Form (PROMIS-SF; Yu et. al, 2012), which is a scale that measures sleep disturbance and impairment due to problems with sleep, measures disturbance in terms of sleep quality itself, individual aspects of the six sub-definitions, and other things not listed by Buysse and colleagues. For example, the sleep disturbance scale asks about sleep quality, falling asleep, staying asleep, and getting enough sleep, all independent of one another, among other things. Given how varied these definitions can be both within and between who is defining it, it is easy to see just how complicated it is to define "problems with sleep."

1.3.1. What Does Sleep Affect?

Without proper sleep, individuals suffer in a wide range of cognitive areas compared to those who experience sufficient sleep and good quality sleep (Maquet, 2001; Pilcher & Huffcut, 1996; Stickgold, 2005). Deterioration has been seen both in studies in which participants undergo total sleep deprivation, which is a prolonged continuous period of wakefulness (e.g., staying awake all night; Babkoff, Mikulincer, Caspy, Kempinski, & Sing, 1988), and in studies in which participants undergo repeated partial sleep deprivation, which is repeated periods of not getting enough sleep (Belenky et al., 2003). Both total and repeated partial sleep deprivation have been found to have similar effects on cognition (Frenda & Fenn, 2016). Some of the areas that suffer include alertness and attention, which is severely lowered after 24 hours of total sleep deprivation (Durmer & Dinges, 2005; Joo, Yoon, Koo, Kim, & Hong, 2012); control over language and verbal memory, which is poor when sleep quality is poor (Lo, Groeger, Cheng, Dijk, & Chee, 2016; Tsapanou et al., 2017); inhibitory control, which decreases during sleep deprivation (Killgore & Weber, 2014; Lim & Dinges, 2008); and response time, which increases when tired (Alhola & Polo-Kantola, 2007). General executive functioning is also found to suffer after short sleep duration (Tsapanou et al., 2017) and longer sleep latency (Nebes, Buysse, Halligan, Houck, & Monk, 2009).

Poor sleep also affects the encoding and storing of information into long term memory. Essentially, good overall sleep is necessary for the learning of new information and subsequent remembering of that information (Killgore & Weber, 2014). If sleep is insufficient in some way (whether it be quality or quantity) before learning information, then the brain is less equipped to acquire new information (Walker & Stickgold, 2006). Support for this comes from the finding that both forms of sleep deprivation lead to a decrease in activity in the posterior hippocampus, which affects subsequent remembering (Alberca-Raina, Canteru, & Atienza, 2015; Drummond et al., 2000; Van Der Werf et al., 2009; Yoo, Hu, Gujar, & Jolesz, 2007). This is also supported by Harrison and Horne (2000b) who found that participants showed poor source recognition if they were sleep deprived before learning during the experiment. If sleep is insufficient in some way after learning but before retrieval however, then the consolidation of that information is hindered (Diekelmann & Born, 2010); this consolidation is usually found to be affected by the overall amount of sleep obtained (Lahl, Wispel, Willigens, & Pietrowsky, 2008). After learning information, any interference can degrade how well that information is stored, but, if learning is followed by an interference-free period, then that information is stored more closely to its original form (Della Sala, Cowan, Beschin, & Perini, 2005); sleep provides this interference-free period, and, without proper sleep overall, this period is compromised.

Although study results are not conclusive, WM is also thought to be affected by poor sleep (Ballesio, Cerolini, Ferlazzo, Cellini, & Lombardo, 2018; Lim & Dinges, 2010). One finding in support of this is that areas of the brain that are impacted by sleep loss are also important to WM, specifically the pre-frontal cortex which shows decreased levels of activation following sleep deprivation (Chee & Choo, 2004; Harrison & Horne, 2000a; Horne, 1993; Thomas et al., 2009, Whitney & Rosen, 2013; Wu et al., 1991). Petrov, Lichstein, and Baldwin (2014) also found a trend towards a correlation between occurrences of sleep disorders and lower WMC. Despite these findings, other studies have not found any correlation between WM or WMC and poor sleep (Drummond et al., 2012; Feld, Weis, & Born, 2016). One explanation for why it is hard to specify whether WM is affected by poor sleep is that studies examining sleep influences on WM tend to use ‘working memory’ as a general term, despite its variety of components and methods of measurement (Whitney & Rosen, 2013). As previously stated, WM involves processing, maintenance, decision making, and response outputs; studies measuring one component of WM may confound this aspect with WM as a whole. It is possible, then, that results regarding WM and poor sleep are inconsistent due to the inconsistencies in measuring and labelling WM. Additionally, the same might also be true for the use of terms ‘sleep’ and ‘poor sleep,’ which are also complex and made up of a variety of components, leading to further inconsistences in the results due to the inconsistencies in the labelling and measuring of the terms.

1.4. Sleep and Directed Forgetting

Unintentional forgetting can be caused by a number of different things, including interference with accessing information at retrieval (Brown, Neath, & Chater, 2007) and interference during the storing and consolidation of information (Wixted, 2010), which, as stated previously, can be prevented by proper sleep (Atherton et al., 2016; Diekelmann & Born, 2010). Intentional forgetting is commonly studied using DF, and thus far, researchers have only examined how sleeping can influence DF effects using the list method, focusing on whether the consolidation benefits of sleep can prevent the forgetting of information. For example, Abel and Bäuml (2013) had four groups of participants study at either 9:00 am or 9:00 pm and then test twelve hours later at either 9:00 pm or 9:00 am, respectively. Half of the participants experienced twelve hours of wakefulness in between study and test (am-pm) while the other half experienced sleep during their twelve hour retention interval (pm-am), allowing for them to benefit from interference-free time to consolidate the studied information. While the participants who stayed awake for the full twelve hours showed significant DF costs (with the group who were given the F cue recalling significantly fewer list items than those who were given the R cue), the participants who slept did not show any differences in memory regardless of what cue they received. This showed that the period of sleep protected the critical list items from being forgotten. This result was replicated by Saletin, Goldstein, and Walker (2011) who had participants study and test at the same times but allowed one group to nap for up to 100 minutes during the retention interval and had the other group stay awake for the duration. Reduced intentional forgetting when sleep follows learning has also been observed in a Think/No-Think experiment (Fischer, Diekelmann, & Born, 2011), and an experiment using paired association (Wilhelm et al., 2011).

1.5. Limitations and Theoretical Motivations

A limitation to the previous studies that have examined the effect of sleep on forgetting using DF is that they do not examine the whole picture. First, these studies have examined the effect that sleep has on forgetting after learning has already occurred (e.g., Abel & Bäuml, 2013; Rauchs et al., 2011; Saletin et al., 2011); no study has examined the effect of how sleep quality prior to the experiment affects learning and subsequent forgetting. While it is important to know that sleep after learning can protect against forgetting (Abel & Bäuml, 2013), it is also important to know whether prior self-reported sleep quality will affect forgetting, especially for those who can benefit from forgetting (e.g., those who experience a trauma or jurors who are instructed to forget testimony in court). Second, these studies have manipulated sleep between participants (e.g. Hupbach, 2017; Wilhelm et al., 2011). Participants are randomly assigned to whether they will experience a period of wakefulness or a period of sleep; none of the past studies have tested participants based on natural sleep quality as opposed to manipulated sleep quality. It is important to examine participants without manipulating sleep quality because this manipulation is unrepresentative of how learning normally occurs (Hershner & Chervin, 2014). Finally, all of the known DF experiments that deal with sleep use the list method as opposed to the item method, so the effect of sleep on factors specifically related to the item method (e.g., selective rehearsal; Bjork, 1970) is unknown. While the list method of DF focuses on how participants attempt to forget recently learned information, the item method of DF focuses on the ability to selectively control whether information is learned in the first place, and thus the item method can inform on how pre-experimental sleep quality influences this process.

1.6. The Present Study

The current study examined how naturally occurring self-reported sleep quality influences item method DF by focusing on sleep prior to the experiment, as opposed sleep after learning occurred, in order to examine whether non-manipulated prior sleep quality (in the form of sleep disturbance and impairment due to problems with sleep, and the presence of insomnia symptoms) affects subsequent forgetting. To clearly examine this, however, this study used a point system variant of the item method DF paradigm (Friedman & Castel, 2011), modifying it by adding in a value of 0 points, to allow for a baseline condition in an item method DF experiment (see also Foster & Sahakyan, 2012, who used all positive point values as a baseline condition). We expected that including both negative and zero point value items would provide a greater contrast of importance to participants, and thus lead to active rehearsal of positive point value items, active suppression of negative point value items, and no additional active processing of zero point value items. By having three point values (a negative point value, a positive point value, and a neutral point value), costs, that are typically associated with list method DF, can be measured in item method DF by comparing the negative point value to the neutral point value and benefits, also typically associated with list method DF, can be measured by comparing the positive point value to the neutral point value. Sleep measures (Sleep Condition Indicator, Espie et al., 2014; Patient Reported Outcomes Measurement Information System, Yu et al., 2012) were used to determine how the effect of sleep quality and problems with sleep before the experiment influences DF costs and benefits. The DF paradigm was reported first below in order to lay the framework for how the sleep measures were incorporated into the analysis. In addition, the relation between self-reported sleep and WMC and the relation between WMC and DF was examined.

For the DF task, we predicted that both costs and benefits would be found. Specifically, it was thought that recognition for the positive point value would be higher than the other two point values (with the difference between this value and the neutral point value considered a DF benefit), and that recognition for the negative point value would be lower than the other two point values (with the difference between this value and the neutral point value considered a DF cost). This result was expected because it was thought that the neutral point value would act as a cue for the participant to neither actively rehearse nor actively inhibit the items associated with that point value. The items associated with the positive point value, however, would be actively rehearsed and encoded, and recognition would therefore be higher for these items. Similarly, the items worth the negative point value would be actively inhibited and the recognition for the items would suffer compared to the neutral items.

For the data reflecting the sleep quality and the presence of insomnia symptoms (which were collected using self-report questionnaires), it was expected that each would affect the DF results in one or two ways. Specifically, it was believed that, for those with the worst sleep disturbance and impairment in daytime functioning due to problems with sleep or with the presence of insomnia symptoms, there would be lowered benefits and/or reduced costs in comparison to those who do not exhibit problems with sleep based on our measures. First, since problems with sleep are believed to affect the ability to encode information (Walker & Stickgold, 2006), participants who exhibit problems on either of the used sleep questionnaires would recognize fewer of the items associated with the positive point values and have lowered, if any, DF benefits. This could be caused by the participants' reduced ability to encode these items, caused by ineffective rehearsal. Second, since problems with sleep impair the ability to inhibit information (Killgore & Weber, 2014; Lim & Dinges, 2008), and selective rehearsal relies on the ability to inhibit information (Fawcett & Taylor, 2008; Zacks, Radvansky, & Hasher, 1996), those who have problems with their sleep may show reduced or negligible costs. If participants cannot actively inhibit the encoding of these items, then there would be higher recognition of these items at test and the costs for these items should be reduced.

For the role of WMC in the current study, there were a number of possible relations to be found. First, to the extent that WMC plays a role in selective rehearsal, there may be a positive correlation found between WMC and both DF costs and benefits (Aslan et al., 2010; Macmillan, 2000), regardless of sleep quality or presence of insomnia. Second, to the extent that WMC was affected by sleep, there would be a negative correlation found between WMC and the sleep measures (i.e., higher scores related to greater problems with sleep being associated with reduced WMC). Last, WMC might not have been found to be correlated with either DF or sleep confirming studies that have found similar results (e.g., Drummond et al., 2012; Lee, 2012).

2. Method

2.1. Participants

A group of 94 undergraduate students from Memorial University of Newfoundland were used. Two additional participants were tested but were excluded due to computer errors. Of the 94 participants used, 71 identified as female while 23 identified as male. All participants identified with the sex to which they were born except for two, who declined to disclose; these participants were excluded from analyses involving sex. The average age of the participants was 20.67 years old ($SD = 3.46$). The first language of the participants was not recorded. For relevant analyses, participants were split into two groups based on how they scored on the SCI. In line with Espie et al. (2014), participants scoring 16 or less were considered as having insomnia symptoms (31 participants) and those scoring higher than 16 were considered to not have insomnia symptoms (63 participants).

Total sample size was determined based on the between-subjects factor of whether participants have insomnia (yes or no). Since no previous study involving sleep and DF has examined naturally occurring problems with sleep, minimum sample size was based on the average number of participants per group in several similar studies that have manipulated sleep (Abel & Bäuml, 2011; Cairney, Durrant, Musgrove, & Lewis, 2011; Hupbach, 2017; Rauchs et al., 2011; Saletin, Goldstein, & Walker, 2011; Wilhelm et al., 2011). The average number of participants per group was calculated to be 29, which was confirmed using a G*Power (Erdfelder, Faul, & Buchner, 1996) A-priori, Analysis of Variance (ANOVA) analysis. Using an effect size f of 0.4, calculated from the main effects of the previous studies, and setting power to be .95, the minimum total sample size was calculated to be 58 (29 per group). Actual sample size exceeded this minimum and led to unequal sample sizes due to the experimenters having no control over whether the participants entering the lab had naturally occurring problems with sleep or not; testing continued until each group had at least 29 participants.

2.2. Tasks and Materials

2.2.1. Cognitive Tasks

For the DF task, 180 English words, obtained from the Medical Research Council Psycholinguistic Database (Coltheart, 1981), were used and ranged in length from four to seven letters (M = 4.70, SD = 0.77). The frequency of the words ranged from 50 to 80 occurrences per million words in the English language (M = 62.46, SD = 8.49; Kučera & Francis, 1967) and were equated based on familiarity, imageability, concreteness, and meaningfulness. Words were vetted and were excluded from use if they were proper nouns or were too similar to other words used either semantically or phonetically. E-Prime software version 3.0 (Psychology Software Tools, Pittsburgh, PA) was used to present stimuli and record responses in the DF task.

The DF task used a within-subject design. Participants were told that each word was worth either +10 points, 0 points, or -10 points for an upcoming test with the intent that participants would try to remember the words valued at +10 points, forget the words worth -10 points, and that the words worth 0 points would act as a control. Recognition hit rates were used to compute DF costs and DF benefits. Costs were calculated by subtracting the hit rate for words worth -10 points from the hit rate for words worth 0 points. Benefits were calculated by subtracting the hit rates for words worth 0 points from the hit rates for words worth 10 points. For each participant, a random half (90) of the word pool was selected to serve as study items while the other half served as new items at test. Of the study items, one third were randomly assigned to each point value condition (30 each).

The WMC task in this experiment was an automated working memory capacity task called the Automated Operation Span Task (AOSPAN; Unsworth et al., 2005). This experiment used the partial WMC score given by the task as recommended by Unsworth et al.

Three questionnaires were also used in the experiment, as described below.

2.2.2. Demographics questionnaire

This questionnaire consisted of six questions that asked, in order, the participant's age, gender, sex, whether they were taking medications that could affect cognitive functioning, whether they were taking any substances (over-the-counter or prescribed) to help them sleep, and whether they were taking any substances (e.g., caffeine) to help them stay awake. The first three questions had open-ended responses while the last three were *yes/no* responses. All responses were coded numerically so that they could be used in correlational analyses. For gender and sex, female was coded as 1 while male was coded as 2; no response was coded as 0. For the medication use, taking the medication was coded as 1 while not taking the medication was coded as 2.

2.2.3. Sleep Condition Indicator (SCI; Espie et. al, 2014)

The SCI is a subjective measure of insomnia that was developed based on the DSM-V (American Psychiatric Association, 2013) criteria for insomnia. It asks questions regarding problems with sleep in the last month. While it is a subjective measure, the SCI has been found to have moderate correlations with objective measures of insomnia such as actigraphy and the Consensus Sleep Diary (Wong et al., 2017). A total score of 16 or less is indicative of possible insomnia (and can be used as such as a categorical variable), though scores can also be used continuously with lower scores indicating a greater presence of insomnia symptoms (both were used in this study).

2.2.4. PROMIS-SF (Yu et. al, 2012)

The PROMIS-SF uses subjective measures of both sleep disturbance (SD) and sleep-related impairment (SRI). It asks questions regarding sleep in the last week. For scoring, all points are added up and transformed into a T-Score; higher scores are indicative of greater levels of sleep disturbance or sleep related impairment. T-scores for both the SD and the SRI can be used continuously or can fall into one of four categories. This study used the scores continuously.

2.3. Procedure

Participants first completed an informed consent form upon entering the lab. The experimenter then provided a brief verbal overview of the experiment and showed the participant to the computer to begin the first task. All participants completed the tasks in the same order: 1) AOSPAN; 2) DF; and, 3) Questionnaires (demographics, SCI, and PROMIS-SF)[1].

The Automated Operation Span (AOSPAN) task consisted of three practice sessions and 15 main trials. The practice sessions had participants recall letters, verify simple math equations, and then alternate between the two. The main trials had participants also alternating between the two.

The AOSPAN task was then followed by the DF task. Participants were presented with a series of words, one at a time, to study for an upcoming test. The words were assigned to one of three point values and participants were told that they would have a score at test that would either increase, decrease, or stay the same based on the point value assigned to the words they recognize. All 90 words in this session were presented in the centre of the screen in black, 22-point *Courier New* font for two seconds. The presentation of each word was followed by a point value in the centre of the screen for two seconds: +10, which was shown in green, 0, which was shown in black, or -10, which was shown in red. Words and associated point values were presented in random order. After the presentation of the words, participants were given one minute to work on a connect-the-dot distraction task. This task was then followed by a recognition test in which participants were presented with all 180 words (i.e., 90 studied and 90 new), one at a time, in random order. Participants were instructed to press the “z” key if they were shown a word that had not been studied previously and to press the “m” key if they were shown a word that had been studied previously. They were also instructed to disregard the earlier information that there was a score for the test and to respond to words that were associated with 0 points and -10 points as being previously studied as they would not be penalized for it.

After participants were finished with the DF task they completed paper copies of the demographics questionnaire, and the SCI and PROMIS-SF questionnaires. Completion of these

[1] In addition to the questionnaires listed above, the Kessler Psychological Distress Scale (Kessler et al., 2003) was also administered. Analyses involving this scale, however, did not show any significant correlations involving the main measures of the study and are therefore not reported below.

questionnaires was followed by a quick debriefing period and additional verbal consent for use of data where deception was used during the DF task.

2.4. Analytic Strategy

First, we analyzed the data related to DF using Analyses of Variance (ANOVAs). We began by examining the DF performance for the three point values separately using an ANOVA, and then an additional ANOVA examined the computed benefits and costs. Next, we split the participants into two groups (whether or not they had the presence of insomnia symptoms) based on the SCI measure and compared how the groups performed on the DF task. Third, we looked at the relation between the DF measures and WMC using correlations. Finally, we analyzed the sleep measure data, again, by using correlations. We looked at the relation between the SCI and the PROMIS measures and then the relation between these measures and WMC. For the main analyses of the results, an alpha level of .05 was used.

3. Results

3.1. Directed Forgetting

Figure 1 shows the recognition hit rate for the different point values. Hit rates were analyzed using a one-way repeated measures ANOVA, with the point value (10 vs. 0 vs. -10) as the within-subject factor. The main effect of point value was significant, $F(2, 186) = 110.207$, $MSE = 0.013$, $p < .001$, $\eta^2_p = .542$. Follow up paired sample t-tests conducted on point value found that all three values differed significantly from one another. Point value +10 differed from both point value -10 (t (93) = 10.791, $p < .001$, Cohen's $d = 1.113$), and point value 0, (t(93) = 12.968, $p < .001$, Cohen's $d = 1.338$), with hit rates being higher for the +10 point value. Point value -10 also differed from point value 0, (t(93) = 2.487, $p = .015$, Cohen's $d = 0.257$), with hit rates being higher for the -10 point value. The mean false alarm rate was .275 (SE = .016).

3.1.1. Directed Forgetting and Sleep Measures

The correlations between the DF measures and the SCI can be found in Table 1; none of these correlations were significant. Before examining how sleep, as defined by our sleep measures, affected performance on the DF task, participants were split into two groups based on the SCI, as stated previously; see Table 2 for descriptive statistics. Participants' memory for the study words depending on point value based on this split is shown in Figure 1. Hit rates were analyzed using a 2 (insomnia: yes vs. no) x 3 (point value: +10 vs. 0 vs. -10) mixed factors ANOVA, with point value again as the within-subject factor and insomnia as a between-subjects factor. The main effect of point value was again significant, $F(2, 184) = 95.270$, $MSE = 0.013$, $p < .001$, $\eta^2_p = .509$. However, neither the main effect of insomnia, $F(1, 92) = 0.300$, $MSE = 0.069$, $p = .585$, $\eta^2_p = .003$, nor the interaction, $F(2, 186) = 1.686$, $MSE = 0.013$, $p = .188$, $\eta^2_p = .018$, were significant.

Figure 2 also shows benefits and costs split between participants with insomnia symptoms and those without. Means were analyzed using a 2 (insomnia: yes vs. no) x 2 (DF Measure: benefits vs. costs) mixed factors ANOVA. DF Measure was the within-subject factor and insomnia was the between-subjects factor. Again, there was a main effect of DF Measure, *F*(1, 92) = 79.979, *MSE* = 0.032, $p < .001$, $\eta^2_p = .465$, but no main effect of insomnia, *F*(1, 92) = 0.004, *MSE* = 0.016, $p = .615$. There was also a trend towards a significant interaction, *F*(1, 92) = 3.798, *MSE* = 0.032, $p = .054$, $\eta^2_p = .040$. Follow up independent samples t-tests on the interaction showed no differences between those with and without insomnia symptoms for benefits (*t* (92) = -1.167, *p* = .246 Cohen's *d* = -0.256), but did show significant differences between those with and without insomnia symptoms for costs (*t* (92) = 2.179, *p* = .032, Cohen's *d* = 0.478); those without the presence of insomnia symptoms showed significantly smaller costs (indeed, a negative cost) relative to those with the presence of insomnia symptoms.

Lastly, differences in false alarms for participants with and without the presence of insomnia symptoms were analyzed using an Independent Samples t-test. This analysis showed that false alarms for participants without the presence of insomnia symptoms (*M* = .284) did not differ from false alarms for participants with insomnia symptoms (*M* = .257); t(92) = .787, *p* = .433, Cohen's *d* = 0.173.

3.1.2. Directed Forgetting and WMC

Table 1 also presents the correlations between the WMC measure and the DF measures. The descriptive statistics for the WMC measure can be found in Table 2. Table 1 shows that WMC was significantly positively correlated with the +10 point value and benefits, with a higher WMC related to higher hit rates and larger benefits. WMC was not, however correlated with the -10 point value, the 0 point value, or costs.

Table 1

Correlations Among the DF Measures and WMC

	+10	-10	0	Benefit	Cost	WMC	SCI
+10	1.00						
-10	.492**	1.00					
0	.520**	.726**	1.00				
Benefit	.406**	-.303**	-.507**	1.00			
Cost	.047	-.355**	.386**	-.368**	1.00		
WMC	.467**	.055	.065	.379*	.014	1.00	
SCI	-.145	-.076	-.196	.071	-.164	.055	1.00

Note: * denotes $p < .05$; ** denotes $p < .01$

3.1.3. Directed Forgetting, WMC, and Sleep

Table 2 presents the correlations between the WMC measure and the DF measures for participants with and without insomnia symptoms, respectively. The SCI was again used as a categorical variable. The separate groups show the same overall pattern of correlations as in the entire sample: the WMC measure was significantly positively correlated with the +10 point value and benefits, but not, however, significantly correlated with the -10 point value, the 0 point value, or costs.

Table 2

Correlations Among and Descriptive Statistics for WMC and the DF Measures For Participants With and Without Insomnia Symptoms

	WMC	+10	-10	0	Benefit	Cost	M	SD
WMC	-	.382**	.045	.034	.332**	-.018	56.921	13.586
+10	.644**	-	.443**	.506**	.433**	.038	.764	.162
-10	.074	.600**	-	.715**	-.320*	-.457**	.574	.189
0	.161	.546**	.792**	-	-.558**	.296*	.518	.176
Benefit	.453*	.377*	-.287	-.570**	-	-.273*	.246	.168
Cost	.158	.050	-.109	.521**	-.527**	-	-.056	.138
M	54.452	.774	.564	.572	.202	.008		
SD	13.401	.178	.172	.201	.182	.123		

Note: * denotes $p < .05$; ** denotes $p < .001$; Correlations for participants with the presence of insomnia symptoms (n=31) are presented below the diagonal, and correlations for participants without the presence of insomnia symptoms (n=63) are presented above the diagonal. Means and standard deviation for participants with the presence of insomnia symptoms are presented in the horizontal rows, and means and standard deviations for the participants with the presence of insomnia symptoms are presented in the vertical columns.

3.2. Sleep Measures

Table 3 presents the correlations between the SCI score (as a continuous measure) and both components of the PROMIS measure. This table shows that the SCI measure is significantly negatively correlated with the disturbance component of the PROMIS, and the impairment component of the PROMIS, with greater presence of insomnia symptoms related to worse levels of sleep disturbance and overall impairment due to problems with sleep. The disturbance component of the PROMIS was significantly positively correlated with the impairment component of the PROMIS, with worse levels of sleep disturbance related to overall impairment due to problems with sleep.

Table 3 also shows that WMC is not correlated with any of the sleep measures.

Table 3

Correlations Among and Descriptive Statistics for the Sleep Measures and WMC

	SCI	Dist.	Imp.	WMC	M	SD
SCI	1.00				19.10	6.81
Dist.	-.763**	1.00			51.50	6.95
Imp.	-.668**	.656**	1.00		58.10	8.07
WMC	.055	-.100	-.078	1.00	56.10	13.50

Note: * denotes $p < .05$; ** denotes $p < .01$; Dist = Disturbance Component of PROMIS, Imp = Impairment Component of PROMIS; t-scores were used for the Disturbance and Impairment measures; see coding for demographic measures above.

4. Discussion

The primary goal of this study was to observe the effects of naturally occurring sleep problems (as opposed to manipulating sleep deprivation) on intentional forgetting. In addition, the relations among WMC, sleep, and DF were further explored. It was hypothesized that using a point value system instead of R and F cues would allow us to compute both DF costs and DF benefits in the item method, expecting that participants with worse levels of problems with sleep would show reductions in both measures. We also predicted that WMC would be related to problems with sleep and, subsequently, DF as well.

Overall, a DF effect was found due to the presence of benefits, though no costs occurred, with memory being better for the words associated with the +10 point value than the 0 or -10 point values. It was also found that problems with sleep had no impact on remembering (or forgetting) with overall recognition being similar between groups. Finally, it was found that WMC was not related to problems with sleep but was related to the remembering aspect of DF. These findings, in relation to the other measures, and their implications will be discussed in more detail below.

4.1. Directed Forgetting Costs and Benefits

As hypothesized, DF benefits were found with participants recognizing more of the words associated with the +10 point value than the 0 point value. This result is similar to that of Friedman and Castel (2011), who also found memory to be highest for the highest point value (+10) used in their study. Unexpected, however, was the presence of negative costs with participants recognizing slightly more of the words associated with the -10 point value than the 0 point value, primarily in participants without insomnia. This result was neither the desired outcome in this study, nor does it align with Friedman and Castel. As stated previously, Friedman and Castel found that, while memory was highest for the +10 point value, memory for all other point values was similar to one another. This study, on the other hand, found a difference among all three point values.

Among the possible reasons for why this study found negative costs when using a point value of 0 is that a point value of -10 carried some participant meaning, leading to it being encoded, but a point value of 0 did not. It is possible that participants chose to encode the words associated with the +10 point value as it would help their score the most at test but also to encode the words associated with the -10 point value in the study phase so that they knew to not respond to those words at test in order to also better their score. Since the 0 point value would neither benefit nor harm them at test, little encoding was done for the words associated with that point value. Especially considering that Friedman and Castel (2011) used free recall (whereas the current study used recognition), however, it would not have been an effective strategy to attempt to encode the words that would harm their score as the items would not have been represented at test for a recognition judgement. It would have been a more reasonable strategy for the participants in the current study to attempt to encode two-thirds of the study words as opposed to the participants in Friedman and Castel's study to attempt to encode all of the study words. This explanation, however, cannot explain why the participants in Friedman and Castel's study also chose not to encode the lower positive point value (+5) and only focused on the highest positive point value. It is also important to point out that the negative costs observed were associated with a very small numerical difference and effect size; there was a relatively large sample size for the within-subject analysis conducted on the DF costs and benefits. Especially when compared to the effect sizes found for the other DF results, this small effect size is unlikely to be especially meaningful.

Regardless of what explanation is behind the negative costs found in this study, it does not appear that the use of a point system in item method DF, as currently implemented, is an effective way to be able to analyze both costs and benefits similar to that of list method DF. However, several studies have shown item method costs and benefits using a between-subjects design with one group being given the standard R or F cues following each individual item and the control group getting only R cues following each individual item (e.g., Sahakyan & Foster, 2009; Taylor, Quinlan, & Vullings, 2018). Performance for forget-half groups was compared to remember-all groups with costs occurring if memory was lower for the forget items in the forget-half group compared to memory in the remember-all group and benefits occurring if memory was higher for the remember items in the forget-half group compared to memory in the remember-all group. In contrast to the current study, Taylor et al. (2018) found costs but no benefits. Participants in their forget-half group remembered fewer forget items compared to the remember-all group but performed similarly when responding to their remember items. Sahakyan and Foster (2009), on the other hand, found both costs and benefits when the participants read action phrases but found neither when participants acted out phrases. These results show that it possible to observe both costs and benefits, or at least costs, when applying a control variable to an item method task, so, given the right manipulation, the same results might be able to be replicated using a point system design.

4.2. Naturally Occurring Problems with Sleep and Forgetting

In order to explore how forgetting in this study was impacted by naturally occurring problems with sleep, SCI scores were used to compare DF costs and benefits between those with and without insomnia symptoms. First, unexpectedly, these results showed that the participants with the presence of insomnia symptoms did not have lower levels of remembering overall. Those with the presence of insomnia symptoms were just as able to remember the studied words as were the participants without the presence of insomnia symptoms. Despite this being unexpected, however, there is past research that could explain this finding (Schmidt, Richter, Gendolla, & Van Der Linden, 2010). Schmidt et al. found in their study that young poor sleepers were able to focus their cognitive resources to the memory task at hand for short periods of time. So, while these young adults scored with at least threshold levels of insomnia on the measure given, they were able to perform similarly to young adults with no sleep problems when the resources were present to do so. It is possible that the participants in this study were able to do the same thing: They were able to divert their cognitive resources to the memory task at hand and were able to perform similarly to their counterparts with no presence of insomnia symptoms.

A second, and expected, result was that the participants with the presence of insomnia symptoms were unable to inhibit the words associated with the -10 point value compared to the 0 point value, as memory for both was similar as can be seen from the cost analysis (Figure 2). Unexpected, however, was that the participants without the presence of insomnia symptoms not only did not inhibit memory for the words associated with the -10 point value, but also showed significant negative costs with memory in fact being better for the words associated with the -10 point value than the 0 point value. This (larger) group’s performance is likely the driving factor behind that result in the full sample.

One explanation for why the participants with insomnia symptoms showed no costs while the participants without symptoms showed negative costs (Figure 2) follows the logic behind the explanation presented previously for the difference between the -10 and 0 point values and the logic laid out by Schmidt et al. (2010). If the participants were attempting to encode the words associated with the -10 point value in order to successfully reject them at test, this would again explain why the participants without insomnia symptoms showed negative costs, recognizing more of the words associated with the -10 point value once instructed to disregard the point values at test. If then also taking into account that the participants with the presence of insomnia symptoms were diverting their cognitive resources towards remembering what they could, resulting in the similar DF benefits overall, it would make sense that they had no resources left to put towards remembering information in order to avoid it later, resulting in no negative costs.

4.3. The Role of WMC

The last hypothesis made was in regard to the effect of problems with sleep on WMC and how that related to DF. While it was thought that having the presence of insomnia symptoms would lead to a decrease in WMC, there was unexpectedly no relation between the sleep measures used and WMC. It was expected that a relation would be found because previous research would suggest there to be one (e.g., Ballesio et al., 2018; Lim & Dinges, 2010), but, as pointed out by Whitney and Rosen (2013), and discussed above, the past literature tends to use WM as a global term without fully defining which part of WM is being measured. It is possible that WMC is not generally found to be affected by poor sleep and that it should not have been expected to in this study either.

Additionally, WMC was related to DF independent of sleep. High WMC was related to higher recognition of the words associated with the +10 point value and the calculated benefits. This finding is important because it is in line with the findings of Marevic et al. (2018), who, as mentioned previously, also found WMC to only be related to the ‘remember’ items in their item method design. It should be noted that the importance of this finding is further highlighted by the fact that this is one of few studies to actually examine the role of WMC using an item method design and it replicated the previous findings. In terms of what the relation between WMC and DF would suggest to the overall literature, it is plausible that WMC is related to the active rehearsal of information and not the attempted inhibition or suppression of that information. Alternatively, there may be little role for active inhibition in the form of selective rehearsal implemented in item method DF. This would explain why WMC was correlated with recognition of the +10 point value words and not the -10 point value words.

4.5. Limitations

Several limitations to the current study should be noted. First, in regard to the DF data, the analyses were conducted with the assumption that the participants treated the +10 point value and the -10 point value as direct remember and forget instructions, respectively. While these point values were treated analytically as direct cues, as that was their intended purpose, it is possible that the participant did not treat them as such. If the participants did not treat the point values as intended, then this could be a reason behind why the manipulation involving the -10 point value did not work (Figure 1). Further work on these point values is required to address this issue. Second, since there was a small number of participants with the presence insomnia symptoms compared to those without, analyses based on this group could have been limited in power. This limit could be supported by the small effect size exhibited.

A third limit is that the sleep measures used asked participants questions based on wide time frames (e.g., seven weeks, one month, or no time limit at all). It is possible that the average responses given by participants were less reflective of how they were actually affected by their sleep in the moment. Similar to this point, a last limit to the current study is the use of self-reported sleep measures themselves. Indeed, self-reported measures can be problematic with regard to issues such as the reporter having faulty memory or under/over-reporting. It is possible that some of the participants in this study over- or under- estimated their sleep problems and rated themselves higher or lower on the SCI than was true to their actual sleep problems. If objective measures, such as actigraphy (which monitors physiological functions during sleep and can be as unobtrusive as wearing a watch-like device; Vallieres & Morin, 2003), were used as opposed to self-report measures, the distribution of participants to the presence of insomnia symptoms/no presence of symptoms groups could have been more refined and the differences between the two groups in relation to the performance on the DF task could have been more apparent. It should be noted, however, that both measures used were successfully validated against other objective sleep measures, as mentioned above (Espie et al., 2014; Yu et al., 2012), so it is possible that the distribution of the participants to the two groups would not have changed substantially had objective measures been used.

4.6. Future Directions

Based on the limitations listed above and other observations, there are several things that should be explored further given this study. First, since it is possible that the participants did not treat the point values as remember/forget cues, the use of a 0 point value in order to compute costs and benefits in an item method DF experiment should be replicated, but by either questioning the participant on what their strategies were given the cues or by using more salient instructions involving the other point values (e.g., explicitly instructing participants to try to forget items associated with negative point values). If it is assured that the participants are treating the other point values as remember/forget cues then it is possible that memory might be found to be worse for the negative point value compared to the neutral point value, as intended. Second, the effect of naturally occurring sleep on forgetting should be observed once more using more refined measures of sleep. Differences in the relation between sleep and forgetting might be found if measures used in the diagnosing of sleep problems are used. This suggestion is limited, however, by the accessibility of those sleep measures. Third, given the general use of the term ‘WM’ in the sleep literature, the exact effect of sleep on each part of WM should be separated out for easier clarification in the future as to what should be expected when testing the effect of sleep on WMC.

Last, given Schmidt et al.’s (2014) finding that poor sleepers tend to divert resources in order to cope with the effects of poor sleep on memory, another direction that should be considered is examining the effect of the capacity of available resources in poor sleepers in relation to the current study. This would be done in order to see if the null finding of the effect of sleep on overall memory is caused by the participants with the presence of insomnia symptoms actually using all of their resources in order to match the performance of their counterparts. This could be explored further using response time tasks following the logic of Fawcett and Taylor (2008; 2011), who examined the attentional aftereffects of remember and forget instructions.

Their studies measured response times to visual probes presented after memory cues, and showed slower times following F than R cues, indicating that forgetting is effortful. Other researchers have shown that the more available attentional resources one has, the more likely attention is to be captured by irrelevant information during a given task (e.g., Lavie, Hirst, De Fockert, & Viding, 2004). So, if participants with the presence of insomnia symptoms have fewer attentional resources, they would be less distracted by irrelevant probes, leading to faster reaction times on a primary task. Those without the presence of insomnia symptoms, on the other hand, should have slower reaction times on the task as they are more likely to be distracted. If this were the case, it would support the resource diversion explanation for the current null finding.

4.7. Conclusions

The current study showed that the use of point values in an item method DF experiment could produce benefits but not costs. This finding suggests that, with further modifications, the use of a control variable in an item method DF experiment might be a plausible method for separating costs and benefits within-subjects. It was also shown that the participants with naturally occurring insomnia symptoms were just as able to remember information as were the participants without insomnia symptoms and neither group showed evidence of inhibiting information. With further support for this finding, this could mean that people who exhibit insomnia symptoms do not find their sleep problems to be as problematic in relation to memory and rehearsal as one would expect. Finally, it was shown that WMC was related to remembering in the DF task and not the sleep measures used. This would suggest that WMC in general is not affected by the presence of insomnia symptoms, nor does it have an affect on one’s ability to intentionally forget information.

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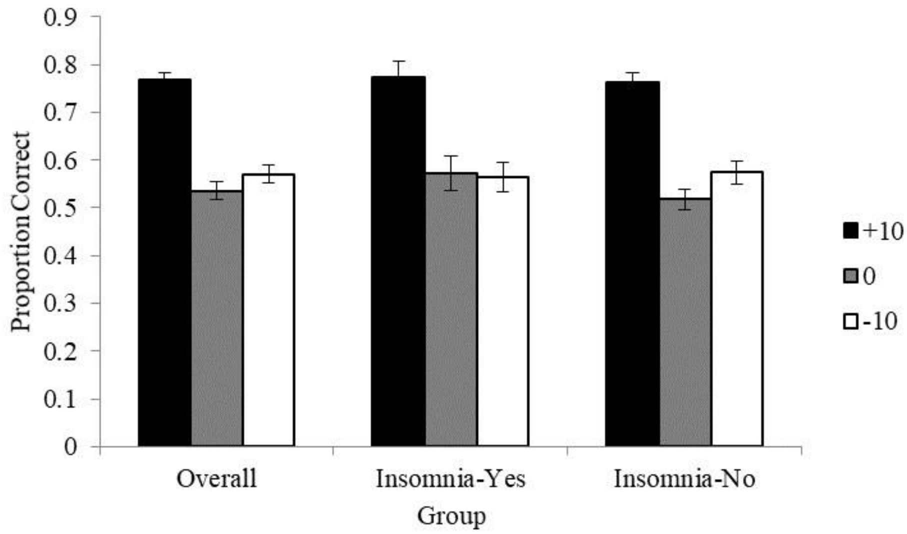

Figure 1. Mean proportion correct for the three point values overall and split between participants with insomnia symptoms and those without. Error bars represent standard error of the mean.

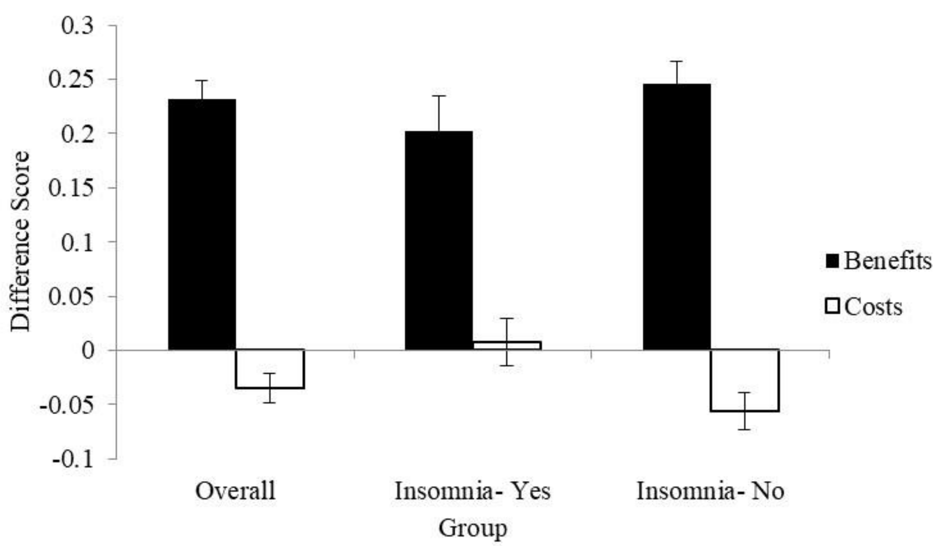

Figure 2. Mean difference scores showing DF benefits and costs overall and split between participants with insomnia symptoms and those without. Error bars represent standard error of the mean.