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Associative Memory Performance Following Periods of Wakeful Rest and Technological Distraction

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ASSOCIATIVE MEMORY PERFORMANCE FOLLOWING PERIODS OF WAKEFUL REST AND TECHNOLOGICAL DISTRACTION

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ASSOCIATIVE MEMORY PERFORMANCE FOLLOWING PERIODS OF WAKEFUL REST AND TECHNOLOGICAL DISTRACTIONS

by

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ABSTRACT

ASSOCIATIVE MEMORY PERFORMANCE FOLLOWING PERIODS OF WAKEFUL REST AND DISTRACTION

by Chalise Carlson

We often spend breaks in our day by engaging with technological devices. However, literature across several species indicates that resting quietly without engaging in other activities, termed wakeful rest, can be beneficial to memory consolidation, a period following encoding which serves to stabilize memories. Prior research demonstrates that wakeful rest benefits memory for single items. However, the effects of wakeful rest on associative memory, (i.e. memory for associations between stimuli), remain unclear. To elucidate the effects of wakeful rest on associative memory, a study was designed to examine differences in associative memory performance following periods of wakeful rest and game play during the consolidation phase. Using a within-subjects design, 41 young adult participants, aged 18-27 years, (a) encoded a list of word pairs, (b) engaged in one of the consolidation phase tasks, and (c) underwent an associative memory test. The consolidation phase included a digital breathing task which represented the wakeful rest condition and a find-the-difference digital game which represented the distraction condition. Both tasks were presented on a tablet. The entire process was then repeated by encoding a new set of stimuli and engaging in the second consolidation phase task, followed by a final memory test. It was hypothesized that associative memory would be better following wakeful rest than game play. Contrary to this hypothesis however, no differences were found between the two conditions. Further research should be done to clarify the relationship between wakeful rest and consolidation of associative memories.

ACKNOWLEDGMENTS

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could pursue this dream. I hope that they will forgive this selfish act and understand how important education can be. Lastly and mostly, I'd like to thank my husband Jeremy. I literally could not have done this without him, his support, and understanding. Although our life has not been easy, it has been an adventure and I love him and admire his dedication to our family and happiness.

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Introduction

Mobile devices provide entertainment, social connection, and escape from work, school, or even family situations. The Pew Research Center recently found that 77% of US adults report using a smartphone and 90% of those owners report having it available for frequent use (Rainie & Zickuhr, 2015; Smith, A., 2017). Recent studies which monitored participants' actual smartphone usage found that the average smartphone user swipes, touches, and clicks his or her phone 2,617 times per day (Winnick, 2016) and that college aged students yield a mean time of 300 minutes per day of use (Lepp, Barkley, & Karpinski, 2015). Even though smartphone ownership is becoming more popular among all age groups, adults aged 18-29 boast the highest percentage rate of smartphone users at 92% (Smith, A., 2017). Furthermore, 78% of young adults report that smartphone use yields the experience of productivity, but 73% admit that smartphone use is distracting (Smith, A., & Page, 2015). Indeed, the mere presence of a cell phone, even without notification activity or use, has been shown to decrease performance on complex cognitive tasks such as digit cancellation tasks and trail making tests (Thornton, Faires, Robbins, & Rollins, 2014). Additionally, distractions of cell phone calls received by an experimenter or by texts sent directly to the participant have been shown to lead to deficits in simple item recognition tasks (Smith, T., Isaak, Senette, & Abadie, 2011).

Some researchers claim that mobile device distraction is made worse by media multitasking, or quickly switching attention from one source of information to another. Frequently transferring focus from one source to another has been negatively correlated with the ability to sustain attention for longer periods (Van der Schuur, Baumgartner, Sumter, & Valkenburg, 2015). It is assumed that when tasks are performed simultaneously, such as driving and talking on the phone, a deficit in attentional resources is created. Watson et al. (2016) found that cognitive tasks (representing cognitive distraction) introduced while participants drove a simulated vehicle resulted in poorer driving performance as well as decreased recognition memory. In another study, participants deemed to be high media multitaskers, due to frequent use of more than one stream of media, were found to demonstrate deficits in working memory tasks requiring filtering of unimportant information (Uncapher, Thieu, & Wagner, 2016). Additionally, Cain, Leonard, Gabrieli, & Finn (2016) found that standardized academic test scores were negatively correlated with media multitasking in teens and that these same teens tended to have poorer performance in executive functioning including working memory tasks requiring frequent switching of attention from one source to another. It bears noting that some of these findings have been recently challenged by a replication study and meta-analysis by Wiradhany & Nieuwentstein (2017). However, results did indicate an association between high media multitasking and a tendency to be easily distracted.

In addition to being distracting, some researchers claim that frequent mobile media use is related to increased life stress, especially for university students who tend to use mobile media for brief periods of time via games and entertainment apps. Increased stress from interpersonal relationships, families, and career worries predicts higher levels of smartphone overuse, or addiction (Kuang-Tsan & Fu-Yuan, 2017). Overusing smartphones can lead to anxiety and decreased efficiency of the brain's executive functioning for accomplishing tasks involving attention-switching, inhibitory control, and working memory (Hartanto & Yang, 2016). Furthermore, smartphone addiction has become a pertinent concern especially among the young adult population. Emotional dependence upon smartphones can alter a user's daily routines, amount of exercise achieved, stress and anxiety levels, sleep, emotional awareness, ability to concentrate, and ability to keep or form interpersonal relationships (Hawi & Samaha, 2016).

An exploratory study of smartphone use and college GPA showed that, even after controlling for a number of variables, frequency of smartphone use was predictive of lower GPA (Lepp et al., 2015). Furthermore, researchers have found that academically struggling university students may be especially drawn to the addictive qualities of smartphones, thus augmenting the academic strain (Hawi & Samaha, 2016). Although the precise relationship between media use and academic performance remains underspecified, two hypotheses for the negative effects of media use on performance have emerged: 1) time spent using technological media replaces time spent on academic activities such as homework or attending to lecture, and 2) media use decreases the ability to process and consolidate previously learned information (Van der Schuur et al., 2015). With respect to the latter, Tossell, Kortum, Shepard, Rahmati, and Zhong (2015) suggested that time previously used for quiet contemplation or review has been replaced by the distracting and entertaining qualities of the smartphone. As such, the constant barrage of information from mobile devices in place of periods of rest may be contributing to changes in academic performance. Although the research to date suggests a negative effect of media use on academic performance (Van der Schuur et al., 2015), it remains unclear whether and how media use affects specific cognitive abilities, such as memory, which contribute to academic performance.

Rest, Consolidation, and Memory

Wakeful rest (WR), a designated time of distraction free rest while awake, is often referred to as mind wandering, daydreaming, or introspection. Although a seemingly unproductive activity, recent exploration into the phenomenon indicates that WR may be more beneficial to cognition, specifically episodic memory, than previously understood (Brokaw et al., 2016; Staresina, Alink, Kriegeskorte, & Henson, 2013). Episodic memory is a form of long-term memory for events and episodes that is critically dependent on the hippocampus, a brain region in the medial temporal lobe (Scoville & Milner, 1957). As an example of an episodic memory, imagine that you and your friends attend a movie one evening. Your episodic memory for this event would include associations between who you were with, where you were, and details of the movie plot: associations that are represented by synaptic connections between hippocampal neurons. Importantly, these connections can be subsequently strengthened or weakened by various factors, including the process of consolidation.

Memory consolidation or the stabilization and strengthening of memories, takes place following initial memory formation. Successful consolidation is thought to produce durable memories that are more resistant to change and less likely to be forgotten or distorted. Consolidation can occur on different time scales, with synaptic consolidation occurring minutes to hours after a memory is encoded and systems consolidation occurring over months to years (Diekelmann & Born, 2010). The synaptic consolidation process is thought to stabilize memory representations by increasing resistance to interference caused by novel information (Inostroza & Born, 2013). Consolidation is believed to involve multiple reactivations of a memory's neural representations after it has been encoded (Carr, M., Jadhav, & Frank, 2011), which is to say, the same neuronal network that was active during initial encoding becomes reactivated post-encoding. Proof of reactivation in humans is evidenced by functional magnetic resonance imaging (fMRI) studies which demonstrate reactivation patterns similar to those made during encoding (Deuker et al., 2013; Tambini & Davachi, 2013). Behaviorally, consolidation is thought to lead to increased memory retention, even without effortful rehearsal during the consolidation period (Staresina et al., 2013). However, presentation of a highly similar stimulus during the consolidation period can cause retroactive interference and reduce the vitality of the memory (Dewar, Cowan, & Della Sala, 2007). For example, seeing the first Avengers movie on Saturday afternoon followed by its sequel that evening may cause you to forget details of the first movie, given the overlapping plot elements.

Conversely, when we sleep, we experience a complete lack of interfering information, which may be one reason why sleep has proven to be beneficial for memory consolidation. Diekelmann and Born (2010) offer the theory that sleep enhances memories partially due to the disengagement of the memory system. When no new memories are being encoded during sleep, the system is free to consolidate existing memory representations. Sleep is divided into several stages which cycle throughout the night, including rapid eye movement (REM) sleep and four stages of non-rapid eye movement (NREM) sleep. NREM sleep consists of light sleep (stages 1 and 2) and deep or slow wave sleep (SWS; stages 3 and 4). Each stage is characterized by different patterns of coordinated oscillations. Sharp wave ripples (SWR) and spindles are characteristic during SWS. The active system consolidation hypothesis states that after encoding, SWS initiates a synchrony between multiple brain areas using cortical oscillations, hippocampal SWR, and thalamocortical spindles. This synchronized activation is associated with alterations in gene expression and strengthened synaptic connections between the neurons representing a given memory and thus, is associated with strengthening and stabilizing a memory representation.

Within the hippocampus, SWRs are posited to coordinate reactivations of memory components (Bergmann & Staresina, 2017). For example, a subset of neurons representing your memory for watching *The Avengers* would be reactivated during SWRs and this reactivation is thought to promote consolidation. Critically, not only are SWRs present during SWS, but rodent data suggest that they are also seen during WR (Carr, M. et al., 2011; Jadhav, Kemere, German, & Frank, 2012). Given that these activations also occur in humans, WR could also have a consolidating influence on human episodic memory.

Episodic Memory

Episodic memory is inherently associative in nature, such that co-occurring elements of an event (e.g., eating popcorn and feeling the overly cold air conditioning while watching *The Avengers*) are bound together into a single, cohesive memory. The association between concomitant elements of a memory are thought to be represented by synaptic connections between neurons in the hippocampal and parahippocampal areas of the brain (Yonelinas, Hopfinger, Buonocore, Kroll, & Baynes, 2001). Subsequently, when any one element of the memory is recalled, such as the smell of the popcorn, the memory is triggered in its entirety, a process known as pattern completion (Moscovitch, Cabeza, Winocur & Nadel, 2016). This phenomenon is seen in the reactivation patterns of rat hippocampal place cells. Place cells are so named because they selectively fire action potentials when the animal is in a very specific location, usually identified during maze exploration. Interestingly, however, scientists have also observed reactivations of place cells representing the maze when the animal is outside of the maze. Such reactivations often occur in conjunction with SWRs and are thought to enhance consolidation for the rat's memory of the maze. Place cell reactivations in conjunction with SWRs are seen both during SWS (Inostroza & Born, 2013) as well as while the animal is awake and resting, feeding, or grooming (Carr, M. et al., 2011). Jadhav et al. (2012) found that interruption of awake SWR activity impaired the rat's ability to navigate through previously learned environments. These findings in rodents indicating that the disruption of WR may impair memory imply that human episodic memory may be similarly influenced by disruption of WR through regular media use. The replacement of distraction free time with consumption of highly stimulating media may be negatively impacting memory consolidation and thus episodic memory.

Wakeful Rest Experimentation

Typically, behavioral WR experiments utilize a paradigm comparing memory performance following WR to memory performance following a distractor task. Current WR literature has utilized distractor tasks such as spot-the-difference games or visuospatial puzzles: Whereas the WR condition typically involves spending time with eyes closed but awake and resting. Most findings to date indicate that WR is beneficial for later memory retrieval compared to time spent in the distractor condition (Brokaw et al., 2016; Craig & Dewar, 2018; Craig, Wolbers, et al., 2016; Dewar, Alber, Butler, Cowan, & Della Sala, 2012). However, one experiment found that memory for face name pairs did not significantly differ between the WR and distractor conditions, although the false alarm rate was lower following WR than distraction (Dewar, Alber, Cowan, & Della Sala, 2014).

Stimuli used in WR experiments typically include single items such as words and pictures of objects (Craig, Della Sala & Dewar, 2014; Craig & Dewar, 2018). The use of retrieval tests involving single items is surprising considering the numerous neuroimaging and lesion studies conducted to date which indicate that the hippocampus plays a larger role in supporting associative memory than item memory. For example, associative memory increases activation in the hippocampus and neighboring areas compared to item memory (Yonelinas et al., 2001). Such evidence suggests that associative memory tasks may be better suited for studying the effects of WR on hippocampal synaptic consolidation than item memory tasks. To date, however, few studies have investigated this relationship. Two exceptions are listed here. As mentioned above, Dewar et al. (2014) used face name pairs but did not find a significant difference in associative memory between the WR and distraction conditions. Additionally, Craig, Dewar, Della Sala, and Wolbers (2015) examined route direction information in relation to landmarks and found that successful association of the direction with the landmark was increased following WR. To my knowledge, no studies to date have explored the influence of technology distraction versus WR on nonspatial associative memory.

To date, studies of WR have exclusively instructed participants to spend time alone in a darkened room with no distractions (Brokaw et al., 2016; Craig, Dewar, Harris, Della Sala, & Wolbers, 2016; Dewar et al., 2014). Confounds that arise from comparing this type of WR to distraction include a lack of control for both visual stimulation and device use. As such, it is difficult to know whether differences in memory performance across conditions are attributable specifically to differences in memory consolidation. Furthermore, the type of WR used in these studies is likely not realistic for young adults' busy schedules or their attachment to their phones. Thus, it is important to study WR experiences which better control for visual stimulation and device use and also more closely match periods of downtime in a young adult's life.

Statement of Purpose

The current study aimed to extend prior findings in three key ways: (1) focusing on associative memory rather than single item memory, while (2) better controlling for differences across WR and distraction conditions, and (3) using a more naturalistic WR condition for a young adult population. With respect to the latter two points, rather than simply asking participants to sit quietly in a darkened room during WR, they were provided with a breathing app on a mobile device. As such, both tasks involved visual stimulation and device use. However, the WR condition was designed to elicit low levels of cognitive engagement, whereas the distractor condition was meant to elicit higher levels of cognitive engagement and distraction. A within-subjects design was used in which participants studied a list of word pairs, performed one of two consolidation phase tasks (WR or distractor), and then underwent a test of associative recognition. This process was then repeated using a new list of word pairs, followed by the second consolidation phase task and a final associative memory test. Condition order was counterbalanced across participants. Critically, verbal stimuli were used for the associative memory task, whereas visuospatial stimuli were used in both consolidation phase tasks to minimize retroactive interference. It was hypothesized that associative memory performance following the WR condition would be significantly better than that following the distractor condition. Confirmation of this hypothesis would suggest that young adults who spend much of their downtime engaged with mobile devices may experience ineffective memory consolidation, which could in turn negatively impact grades or work performance.

Method

Participants

A statistical power analysis was performed for sample size estimation using a matched pairs means difference test in G*Power (Faul, Erdfelder, Buchner, & Lang, (2009). Using a medium effect size of .50, with $\alpha = .05$ and power = .90, the analysis indicated that a sample size of $N = 36$ was needed. Figuring in a 15% attrition rate, 41 younger adults (18-27 years of age, $M = 18.97 \pm 1.97$) were recruited and made up a convenience sample taken from the San José State University (SJSU) student population via the Sona online recruiting system. Participants earned credit or extra credit as detailed by their instructors. Participation was limited to adults who spoke English fluently given that all the study materials were presented in English. Additionally, recruitment materials included an explanation that individuals with a history of neurological or psychiatric conditions that could influence cognitive functioning did not qualify for the study. Of the 41 participants enrolled in the study, data were excluded from three who gave indications that they fell asleep during the WR condition. Further, two participants' data were corrupted due to technology malfunction. Thus, the total sample size used for statistical analyses was 36 participants.

Research Design

A within-subjects' crossover design with 1 factor (WR vs. distractor) was applied. Experimental procedures were performed at the Carr Lab Investigating Memory and the Brain (CLIMB) on the SJSU campus. The experiment included two rounds of each of the following; encoding, consolidation, and retrieval. The order of experienced consolidation conditions during the consolidation phase was counterbalanced across participants.

Materials

Sleep survey. Along with filling out a standard demographic survey, participants were asked to input the time they had fallen asleep the previous night and awoken the present morning, thus giving a measure of the amount of time slept. Additionally, they were asked to fill out the Stanford Sleepiness Scale, which indicated their current level of sleepiness/alertness (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973). Thorley (2013) found that associative memories for details are positively affected by increased quality and duration of sleep and negatively affected by a person's current level of sleepiness.

Memory task. The associative memory task utilized pairs of unrelated, neutral concrete nouns. In total, 240 nouns were used to create 120 word pairs for use over the entire experiment. Sixty pairs were used for the first round of the associative memory test, and another 60 pairs were used for the second round test. Stimuli were presented and responses were collected on a MacBook (Apple, Cupertino, CA) using PsychoPy software (Peirce, 2009).

Consolidation tasks. The WR condition utilized a breathing app, Breathe+ (Dynamic App Design, 2017), and the distraction condition utilized a puzzle game app, Find Differences (Bilash, 2015), both of which were performed using an iPad (Apple, Cupertino, CA). See Figure 1 for examples. Breathe+ provides breath guidance visualized as wavy lines of color. These lines move from the bottom of the screen to the top, indicating inhalation, and then from the top of the screen to the bottom, indicating exhalation. An interactive spot-the-difference video game, Find Differences, served as the distraction condition. During game play, the player attempts to find the differences between the two images. Once a difference is found, the player touches the screen and the difference is marked digitally with a circle. Several images were provided, and instructions encouraged participants to move to the next scene if they could no longer find any differences.

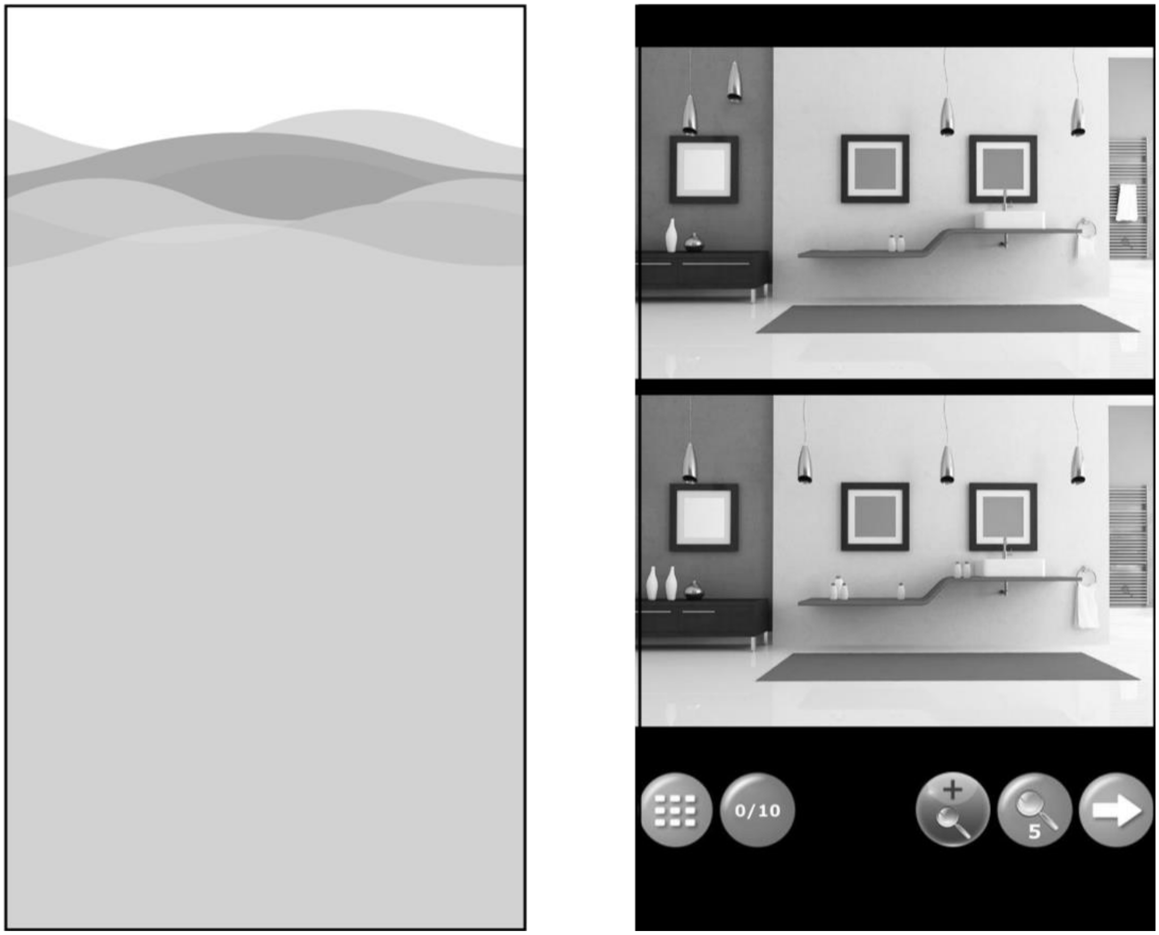

Figure 1. Screen shots of the consolidation tasks apps. Breathe+ (left) for the wakeful rest condition, Find Differences (right) for the distraction condition.

Posttest. Following each retrieval test phase, participants were asked if they had fallen asleep during the consolidation task. Three participants indicated that they had fallen asleep during the WR task and were excluded from analysis to control for memory consolidation improvements gained through sleep instead of WR. Furthermore, an additional survey was included to better understand the state of mind of participants during each of the consolidation phase tasks. The participants indicated the percentage of time they spent thinking about each of the following; “Mind was blank,” “Thinking of memorized words,” “Thinking about the future,” “Thinking about the past,” “Thinking about what I am doing," "Meditating," and "Other". A two-way repeated measures analysis of variance (ANOVA) was used to find mean differences.

Procedure

The within-subjects design meant that each participant performed two rounds of encoding, consolidation, and retrieval, with separate sets of words which were counterbalanced across participants. Participants performed both rounds in a single, one hour session (Figure 2). After signing the consent form, participants were asked to fill out the demographic and sleep surveys. Afterward, participants were trained on the associative memory task. During encoding (Figure 3), participants viewed a list of word

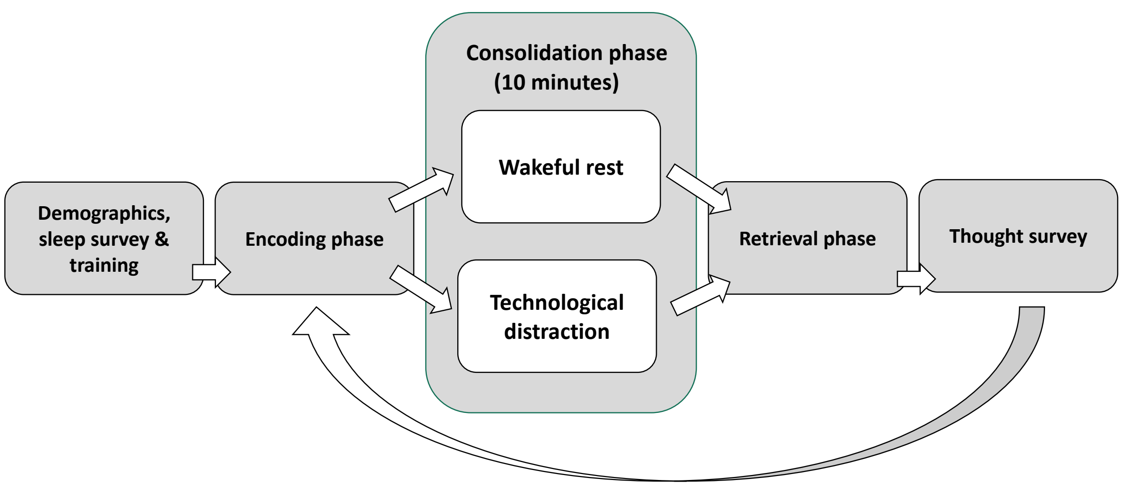

Figure 2. Experiment flow. Participants first completed demographic, sleep surveys, and training on the memory and consolidation tasks, followed by the encoding phase of the memory task. They then completed one of the two consolidation phase tasks followed by a retrieval phase of the memory task and finally, a thought survey. Afterward, participants repeated the encoding phase with a new set of word pairs, followed by the other consolidation task, a second retrieval phase, and another thought survey.

pairs (n = 40), which consisted of unrelated, neutral concrete nouns. Participants were instructed to form a mental image of the two items interacting, a strategy designed to augment associative encoding. They were told that their memory for the word pairs would later be tested. Word pairs were displayed for 4 s interspersed with a brief fixation cross (duration: 0.5 s).

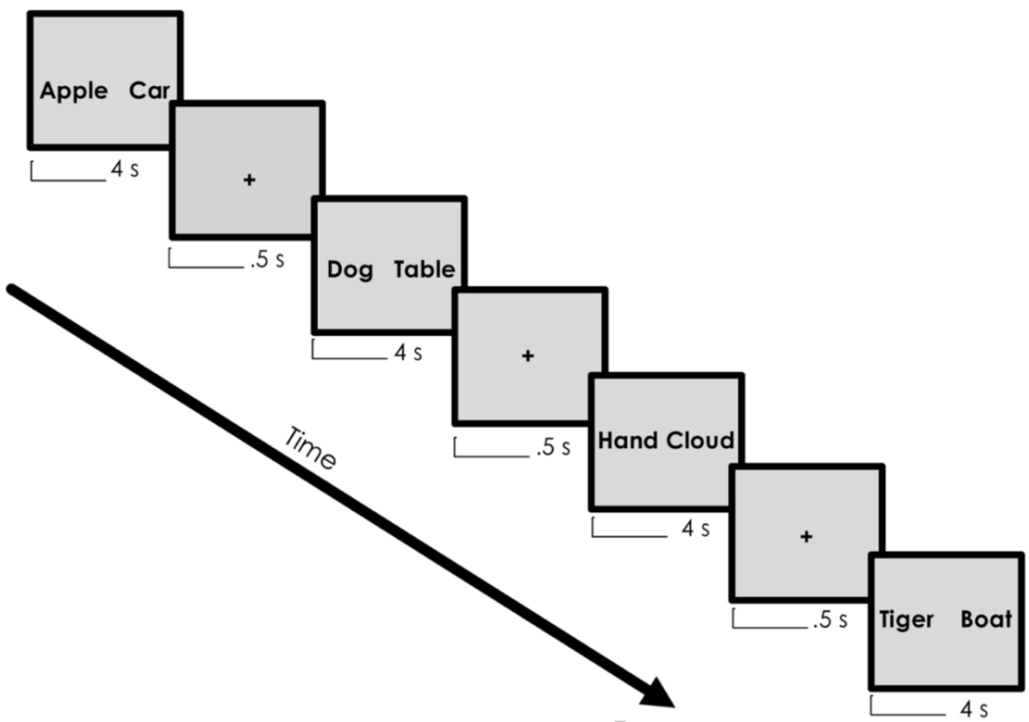

Figure 3. Encoding phase of the memory task. Word pairs were presented for 4 s with a fixation cross presented for 0.5 s between pairs.

Following encoding, participants then performed one of the two consolidation phase tasks for a ten minute period. During the WR condition, participants were given the Breathe+ app via iPad and instructed to perform the breathing activity. Participants were asked to sit quietly using the app and perform the breathing task until the program ended.

During the distractor condition, participants played the Find Differences game via iPad. Game scores were not tabulated: Rather, instructions to participants were to simply to do their best to find differences without becoming frustrated.

Following the consolidation phase, participants were asked to complete the associative memory task on the laptop (Figure 4). Participants were presented with three word pair types: intact (n = 20), recombined (n = 20), and new (n = 20). They were then asked to make one of three responses via the keyboard: “intact”, “recombined”, or “new.”

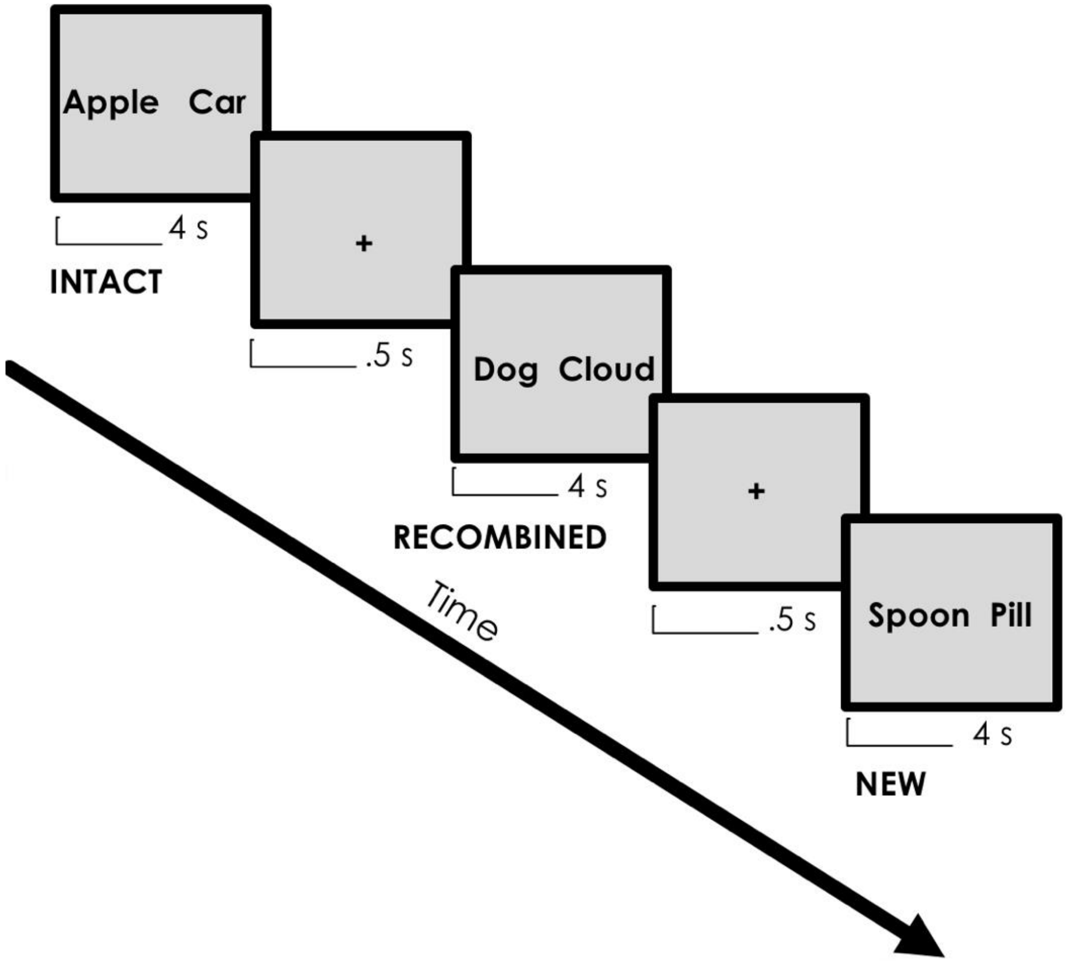

Figure 4. Retrieval phase of the memory task. Word pairs were again presented for 4 s with an interstimulus interval of 0.5 s. Three types of pairs were used: Intact = same pairing as during the encoding phase, recombined = words seen during encoding but recombined into novel pairings, and new = entirely new words not seen during the encoding phase.

Word pairs were again presented for 4 s with fixation trials interspersed (duration: 0.5 s). Trial order for both encoding and retrieval was randomized. Recognition test results were used to classify retrieval trials into nine conditions (3 pair types x 3 responses; see Table 1). Trial types are abbreviated with two letters such that the first letter refers to the pair type and the second letter to the response. IR, for example, would serve as the abbreviation for an intact pair (I) incorrectly identified as recombined (R).

Table 1

Retrieval Response Abbreviations

Abbreviation	Stimulus type	Participant response
II	Intact stimulus called	"intact"
IR	Intact stimulus called	"recombined"
IN	Intact stimulus called	"novel"
RI	Recombined stimulus called	"intact"
RR	Recombined stimulus called	"recombined"
RN	Recombined stimulus called	"novel"
I	Novel stimulus called	"intact"
R	Novel stimulus called	"recombined"
N	Novel stimulus called	"novel"

The sensitivity index, associative d-prime (*d'*), was used as the overall metric of memory performance (as seen in Carr, V., et al., 2017). *D'* is a sensitivity measure originating from signal detection theory (SDT). SDT provides a template for describing decisions regarding whether a stimulus was previously studied or is new. In typical item recognition memory tasks, there are two stimulus types, old (i.e., previously studied) and new. For each item viewed during the recognition task, participants are asked to decide whether the item is old or new. The combination of two stimulus types and two response types gives a total of four conditions (Figure 5). From these conditions, *d'* can be calculated as follows; *d'* = z ("old" | old) - z ("old" | new). In the current associative memory study, however, there were three stimulus types (intact, recombined, and new) and participants are asked to decide whether each pair was intact, recombined, or new: This provided a total of nine conditions (Figure 6). As such, a modified version of *d'* was used that took into account associative hits and associative false alarms to focus solely on the participant's ability to correctly or incorrectly recognize associations between previously studied words. Therefore, the equation used was as follows; associative *d'* = z ("intact"| intact) - z ("intact" | recombined). Analyses comparing associative *d'* for the two conditions of interest were run using a paired samples, two-tailed t-test. Alpha was set at $\alpha = .05$.

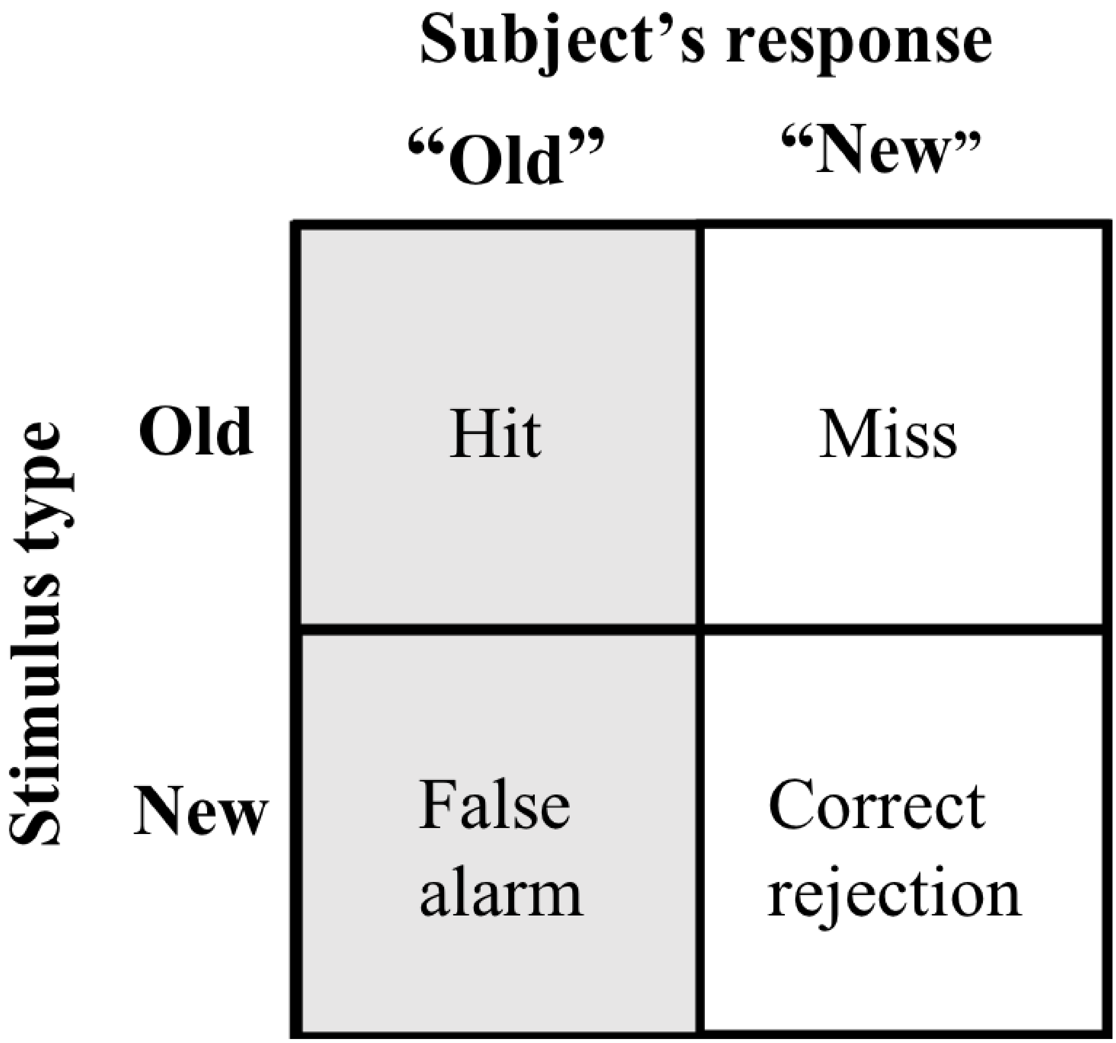

Figure 5. Terminology arising from signal detection theory as applied to an item recognition task. Highlighted in gray are the two conditions used to calculate *d'*.

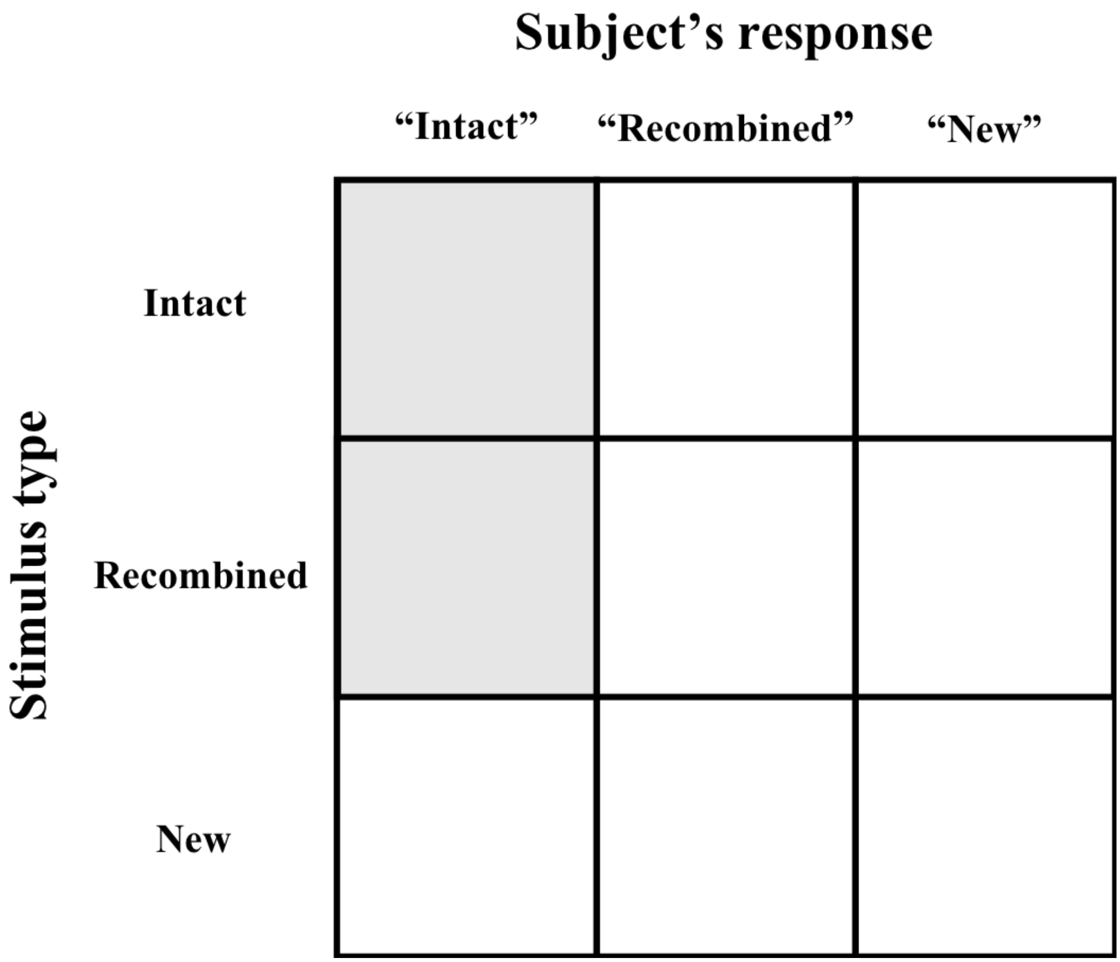

Figure 6. Nine possible conditions arising from an associative memory task. Highlighted in gray are the two conditions used to calculate associative *d'*: associative hits and associative misses.

Following each retrieval test, participants completed the posttest survey described above, inquiring about whether or not they had fallen asleep during the consolidation task and what type of thoughts they had experienced during this task. Following the survey, participants were given a break and then a new set of word pairs to memorize. They then completed the entire process once again, using the other consolidation task the second time around.

Results

Memory Performance

Memory performance following each of the two consolidation tasks is shown in Figure 7. As described above, these results were used to compute an overall measure of memory performance for each condition, associative *d'* (Figure 8), which takes into account how frequently participants respond "intact" to intact vs. recombined stimuli. The impact of the two consolidation tasks on associative *d'* was evaluated using a paired-samples t-test. No difference was found between conditions, such that the *d'* values for the technological distraction condition (*d'* = 1.97, *SD* = 1.23) and the WR condition (*d'* = 1.94, *SD* = 1.22), were not significantly different, t (35) = 0.25, p = .80. Similarly, there was no significant difference in criterion levels for the two tasks: technological distraction condition (c = 0.22, *SD* = 0.37), WR condition (c = .21, *SD* = 0.41), t (35) = 0.06, p = .95.

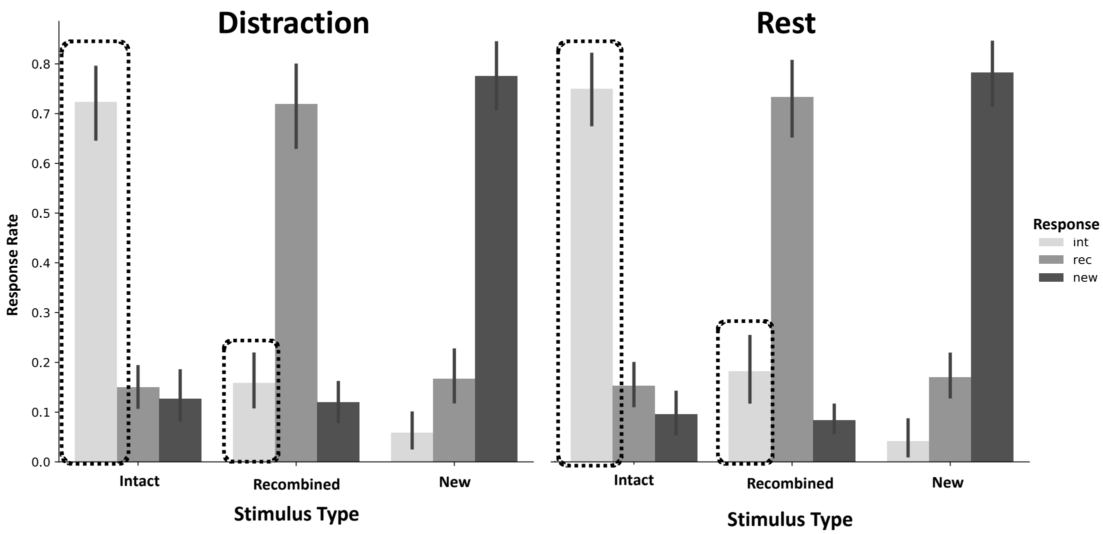

Figure 7. Response rates from the associative memory test following each consolidation task. Three types of stimuli were presented (intact, recombined, and new pairs), and participants responded “int” (intact), “rec” (recombined), or “new”. Dotted lines indicate data used in the associative *d'* calculation: *d'* = z (“intact ” | intact) - z (“recombined ” | intact).

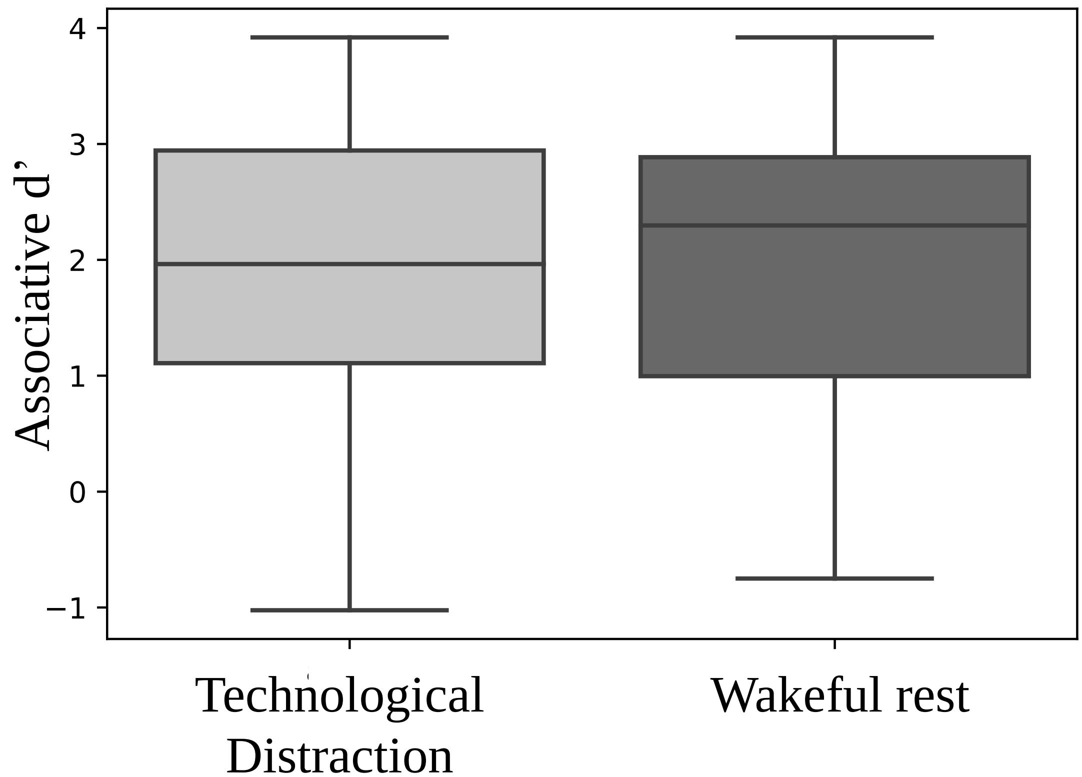

Figure 8. Overall performance on the consolidation task as measured by associative *d'*. Associative *d'* = z ("intact" | intact) - z ("recombined" | intact). No statistical difference was found between the two conditions.

Complementary Analyses

In addition to the main analysis investigating task differences in associative *d'*, the differences in item memory were examined by calculating item *d'*. The calculation was performed using the following equation, which includes all hits and false alarms regardless of whether the participant's associative memory was correct; item *d'* = z (II + IR + RI + RR) - z (NI + NR). Results yielded no significant differences in item *d'* between the distraction condition (*d'* = 2.32, *SD* = 1.15) and the WR condition (*d'* = 2.49, *SD* = 0.92), $t\,(35) = -1.22$, $p = .23$.

Posttest

As described above, three participants noted on the posttest that they fell asleep: Thus, their data were excluded from all analyses. For the questions regarding thoughts experienced during the consolidation tasks, participants assigned percentage values based on their experience (see Table 2). A two-way repeated measures ANOVA was performed to determine whether there were differences in percentage values according to task (WR, distraction), or cognitive process (mind blank, word rehearsal, etc.), and whether there was an interaction between the two.

Results of the ANOVA indicated no significant main effect of task, $\lambda = 0.96$, $F(1, 35) = 1.32$, $p = .26$. However, results did show a significant main effect of cognitive process, $\lambda = 0.03$, $F(6, 30) = 167.56$, $p < .001$, such that collapsed across groups, participants spent more time engaging in subsets of activities than others, as revealed by a series of pairwise comparisons of time spent engaged in each cognitive process. Only those results that survived Bonferonni correction are listed below. Analyses revealed that participants spent more time Doing than engaging in Memorizing ($t(35) = 5.74$, $p < .001$), Mind blank ($t(35) = 7.54$, $p < .001$), Future ($t(35) = 7.94$, $p < .001$), Past ($t(35) = 9.51$, $p < .001$), Meditating ($t(35) = 9.63$, $p < .001$) and Other ($t(35) = 12.85$, $p < .001$). Participants also reported more time spent doing each of the following than engaging in Other thoughts: Memorizing ($t(35) = 5.12$, $p < .001$), Mind Blank ($t(35) = 7.13$, $p < .001$), Future ($t(35) = 3.96$, $p < .001$), Past ($t(35) = 3.24$, $p < .001$), and Meditating ($t(35) = 3.29$, $p < .001$). No other pairwise comparisons of thought processes were statistically significant once corrected for multiple comparisons (p's $> .05$).

Finally, analyses revealed a significant interaction effect between task and cognitive processes, $\lambda = .28$, $F(6, 30) = 12.83$, $p < .001$. A simple main effects analysis was then conducted to evaluate time spent engaged in each cognitive process according to consolidation task (Table 2). A statistically significant difference was found between tasks for the following cognitive processes; Mind blank, ($t(35) = -3.40$, $p = .002$), Future ($t(35) = -3.37$, $p = .002$), Past ($t(35) = -2.27$, $p = .03$), Doing ($t(35) = 8.60$, $p < .001$) and Meditating, ($t(35) = -3.50$, $p = .001$). When a Bonferroni correction was used to account for multiple comparisons, time spent thinking about the past was no longer significantly different across consolidation tasks. Importantly, no differences between consolidation tasks were found regarding conscious efforts to memorize the associated words from the memory task ($t(35) = -1.39$, $p = .17$). Overall, these findings indicate that the WR condition encouraged introspection relative to the distraction condition and that participants were more engaged with the task during the distraction condition relative to the WR condition.

Table 2

Averaged Percentage of Activity during Consolidation Task

Cognitive Process	Distraction	Rest	*p*
Mind Blank	8.98%	20.24%	< .001
Memorized words	13.74%	16.86%	.17
Future	5.13%	13.54%	< .001
Past	5.38%	8.80%	.03
Doing	68.93%	26.61%	< .001
Meditating	0.28%	13.03%	< .001
Other	0.72%	0.78%	.97

Sleep

To examine whether self-reported hours of sleep were correlated with associative *d'* memory performance, each of the two conditions were separately calculated. There were no significant correlations found for the distraction condition, r (34) = 0.04, p = .81, or for the WR condition, r (34) = -0.03, p = .87. Next, the correlations of the associative *d*' scores of each condition were calculated with the sleepiness scores. Again, no significant correlations were found for either the distraction condition, r (34) = 0.08, p = .64 or the WR condition, r (34) = -0.15, p = .38. As such, neither sleep duration nor sleepiness levels were used as control variables in the preceding analyses of memory performance.

Discussion

Despite prior evidence that WR is beneficial for consolidating memories for single items relative to distraction, the current experiment did not find a difference in associative memory performance following the WR and technological distraction conditions. Specifically, there was no significant difference in associative *d'*, a measure of overall performance on the associative memory recognition task. Therefore, the findings did not support the hypothesis that associative memory performance following periods of WR would be better than performance following periods of technological distraction. Below, potential reasons for why the findings of the current study may differ from those of prior studies are discussed.

The two activities presented on the iPad were intended to promote differences in memory consolidation, one encouraging restful breathing and introspection (Breathe+) and the other representing a more interactive and distracting game playing scenario (Find Differences). Given the lack of difference in memory performance following the two consolidation tasks, it is possible that the tasks were not sufficiently different from one another with respect to the degree to which participants engaged in WR. However, analysis of the thought survey data demonstrated a significant interaction between consolidation task and cognitive process, with more introspective thoughts happening during the WR task and more stimulus oriented thoughts occurring during the distraction task. These results indicate that the tasks significantly differed from one another in their ability to evoke different kinds of thinking, and as such, the lack of memory differences across the two tasks does not appear to be attributable to high similarity between tasks.

In the current study, participants were not explicitly instructed to engage in any one type of thought process during the WR condition. Prior studies (e.g., Dewar et al., 2014) have compared the utility of autobiographical memory prompts (i.e. "think about a time when…") to time spent in WR with no cued thought processes and found that cued autobiographical memories or future visualizations were not as conducive to memory consolidation as allowing participants to think freely. The authors suggest that autobiographical memories and visualizations could be interfering with the hippocampal consolidation process. Given that a large percentage of the participants reported thinking about the future and/or past, this may have dampened consolidation for the word pairs during the WR period. Strategies for minimizing autobiographical thought during the consolidation phase should be considered in future studies.

One major methodological difference between the current study and prior studies that report improved memory following WR is the use of technology during the WR condition. Whereas prior studies have encouraged WR by resting quietly in a dark room, often with eyes closed and minimal auditory stimulation (Brokaw et al., 2016; Craig et al., 2014; Craig & Dewar, 2018; Craig, Wolbers, et al., 2016; Dewar, Alber, Butler, et al., 2012), in the current study participants were asked to use the Breathe+ app on the iPad to encourage WR. Although participants reported less time spent engaging with this task than the distractor task, it is possible that the visual display of the breathing task, and/or monitoring one's breath, was too stimulating to allow for increased memory consolidation. This experiment was the first to explore WR with participants leaving their eyes open and being visually stimulated. For the beneficial effects of WR to be significant, participants may need to experience WR with eyes closed or without monitoring one's breath. Future studies could consider, for example, using auditory stimuli to guide breathing, or using a dynamic visual stimulus without instructions to monitor breathing.

A second methodological difference between the current study and past studies of WR is examining associative memory rather than memory for single items (i.e. singly presented words or pictures of objects). Here, word pairs were utilized to more closely match the associative nature of stimuli used in rat studies of hippocampal consolidation. However, future studies should look at both single item and associative memory to see if WR differentially affects each type of memory.

Another possible deficiency is that the memory task used in the current study was not challenging enough to produce the desired effect. Although participants' scores were in the expected range with no ceiling effects, it is possible that increasing the difficulty could have made the effect more apparent. One future avenue of exploration would be to increase the delay between encoding and retrieval (e.g., one hour), thereby making the task more difficult and potentially more sensitive to consolidation effects. Another option for increasing difficulty of the memory task would be to alter the test from a recognition to a cued recall test. For instance, researchers could present one of the words from the pair as a cue and ask the participant to type in the paired word. Another simple technique to enhance task difficulty would be to increase the number of word pairs to be memorized, creating more stimuli to be remembered and requiring more effort during retrieval. Any one or combination of these memory task changes would produce a more effortful task, which may be more sensitive to detecting consolidation effects and providing further insight into factors relating to memory consolidation.

Finally, the relatively short consolidation period used (10 minutes) may not have been sufficient to encourage different amounts of synaptic consolidation. Although previous research has successfully utilized a 10 minute consolidation period (Craig, Wolbers et. al, 2016; Craig & Dewar 2018; Dewar et al., 2012), perhaps a longer interval is required when processing visual imagery and monitoring breath. As such, future studies could consider testing a variety of different consolidation times.

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Appendix A: Stanford Sleepiness Scale/Sleep survey

Using the scale below pick what best represents how you are feeling right now:

- ○ Feeling active, vital, alert or wide awake
- ○ Functioning at high levels, but not fully alert
- ○ Awake, but relaxed; responsive but not fully alert
- ○ Somewhat foggy, let down
- ○ Foggy; losing interest in remaining awake; slowed down
- ○ Sleepy, woozy, fighting sleep; prefer to lie down
- ○ No longer fighting sleep, sleep onset soon; having dream-like thoughts
- ○ Asleep

About what time did you go to bed last night? (include "AM", "PM")

About what time did you wake up this morning? (include "AM", "PM")

On the following scale, please indicate the quality of sleep you experienced last night:
(0 = restful, 7 = wakeful)

Restful — Wakeful

0 1 2 3 4 5 6 7

The quality of sleep experienced last night

Appendix B: Thought Survey

Did you fall asleep during the iPad task?

- ○ Yes
- ○ Maybe
- ○ No

Approximately how long did you sleep?

Minutes

0 1 2 3 4 5 6 7 8 9 10

Number of minutes slept during task

Please enter the proportion of time you spent on the following activities during the task: (must equal 100)

Mind was blank	0
Thinking about memorized words	0
Thinking about the future	0
Thinking about the past	0
Thinking about what I am doing	0
Meditating	0
Other:	0
Total	0