

Remembering to Execute a Goal: Sleep on It!

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Abstract

Remembering to execute deferred goals (prospective memory) is a ubiquitous memory challenge, and one that is often not successfully accomplished. Could sleeping after goal encoding promote later execution? We evaluated this possibility by instructing participants to execute a prospective memory goal after a short delay (20 min), a 12-hr wake delay, or a 12-hr sleep delay. Goal execution declined after the 12-hr wake delay relative to the short delay. In contrast, goal execution was relatively preserved after the 12-hr sleep delay relative to the short delay. The sleep-enhanced goal execution was not accompanied by a decline in performance of an ongoing task in which the prospective memory goal was embedded, which suggests that the effect was not a consequence of attentional resources being reallocated from the ongoing task to the prospective memory goal. Our results suggest that consolidation processes active during sleep increase the probability that a goal will be spontaneously retrieved and executed.

Keywords

sleep, memory, prospective memory, intentions, consolidation, binding, interference

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Prospective memory refers to the ability to remember to execute goals in the future. Examples of real-world prospective memory goals include remembering to take one's medication with breakfast and calling one's mother on her birthday. Prospective memory is critical in many contexts, such as avoiding embarrassing blunders in the workplace (e.g., remembering to turn off one's cell phone before a lecture), fulfilling social obligations (e.g., delivering a message to a friend), maintaining physical health (e.g., remembering to go to the gym after work), and adhering to a clinician's advice (e.g., remembering to use a recommended coping strategy during a panic attack). Given the fundamental importance of prospective memory to everyday life, a prominent question concerns the factors that might enhance prospective remembering. A provocative possibility, suggested by work on retrospective memory (i.e., memory for past events), is that sleep might enhance people's memory to execute a goal at the appropriate moment.

Several studies suggest that sleep helps improve retrospective memory. In his seminal study, Ebbinghaus (1885/1964) observed a reduction in the rate of forgetting from 9 hr to 24 hr after learning (2.1%), relative to the rates of forgetting from 1 to 9 hr (8.4%) and from 24 to 48 hr (6.1%) after learning. That is, less forgetting occurred during the interval that included the first night of sleep following learning than during the other two intervals. Jenkins and Dallenbach (1924) manipulated

sleep and wake retention intervals and confirmed that syllable recall was greater following a sleep delay than following a wake delay. Contemporary studies have further documented the benefits of sleep for remembering information from the past (e.g., Payne, Stickgold, Swanberg, & Kensinger, 2008; Rasch, Buchel, Gais, & Born, 2007). Given these findings, one might conjecture that sleep would generally benefit memory, including prospective memory (more theoretical development for this expectation is provided later in this introduction).

Alternatively, some prospective memory research suggests that wake, not sleep, should benefit goal execution. Kvavilashvili and Fisher (2007) reported that individuals often encounter cues (e.g., a telephone) related to a goal (e.g., call the experimenter on Sunday), and these cues spontaneously remind them of their goal. These authors suggested that conscious retrieval strengthens the goal representation (cf. the testing effect: Roediger & Karpicke, 2006; see also Marsh, Cook, & Hicks, 2006, with regard to prospective remembering). In a study consistent with this suggestion, Hicks, Marsh, and Russell (2000) found that prospective memory improved

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over delay intervals from 3 to 15 min. One interpretation of this counterintuitive effect is that with longer delays, participants retrieve the goal more often (thereby strengthening its representation; Marsh, Cook, & Hicks, 2006). According to this idea, assuming that conscious retrieval is precluded during sleep, sleep could reduce prospective remembering relative to wake intervals of a similar length.

In the present investigation, we used a laboratory prospective memory task to explore whether sleep enhances people's memory to execute a goal at the appropriate moment. In laboratory prospective memory tasks (Einstein & McDaniel, 1990), participants are instructed to form a specific prospective memory goal and then perform some ongoing task (e.g., rating words). During performance of the ongoing task, participants must execute the prospective memory goal (e.g., press the "F1" key on a keyboard) upon presentation of a target cue (e.g., a specific word). The following experiment included short-delay conditions, in which the first target cue appeared approximately 20 min after the prospective memory goal was encoded, and long-delay conditions, in which the delay was approximately 12 hr. Participants were tested in the morning, in the evening, or both, so that the retention interval included nighttime sleep or daytime wake (and to control for circadian influences). To demonstrate that our paradigm could reliably produce standard retrospective memory sleep effects, we included syllable recall (following Jenkins & Dallenbach, 1924) and working memory (reading and symmetry spans) measures. We predicted that sleep would benefit recall, but not working memory.

An additional important aspect of the design concerns associations between the prospective memory goal and the context. Instructions for prospective memory tasks typically emphasize a target cue and associated goal, and therefore lead participants to form a relatively strong associative encoding between the target cues—in the present case, word cues—and the goal (intended action; McDaniel, Howard, & Butler, 2008). Additionally, however, associations between the ongoing task (the context) and the prospective memory goal may be formed (e.g., an association between the goal to take medication and seeing the medicine box while getting ready for bed). Not surprisingly, these context-goal associations seem to be especially robust and influential in prospective remembering when the prospective memory instruction is provided directly during practice of the ongoing task (Nowinski & Dismukes, 2005) or when the experimenter explicitly informs the participant as to the context in which the target cue will appear (Marsh, Hicks, & Cook, 2006).

In the present study, we intended to illuminate the degree to which sleep might strengthen context-goal associations. Given this particular purpose, participants were told that the target cues could occur at any time during the experiment, and the cues did occur in three separate contexts (i.e., three ongoing tasks: living/nonliving decision, lexical decision, and semantic categorization). During the first experimental session (which included prospective memory encoding), the description and practice of the semantic categorization task was temporally

paired with encoding of the prospective memory goal. We thought that the temporal pairing would potentially link the semantic categorization task to the goal. To the extent that sleep were to strengthen this link, prospective memory would improve primarily for the semantic categorization context following the sleep-filled delay.

The idea that sleep might strengthen the context-goal link raises the interesting issue of how a strengthened link would benefit prospective memory. One possibility is that once the context is encountered, the context would explicitly remind the person of the goal; the person would then recruit cognitive resources to maintain the goal until the target cue was encountered (Marsh, Hicks, & Cook, 2006). This formulation suggests that sleep-related benefits to goal execution would be a consequence of allocating resources to the goal during the appropriate context (which would be indexed by decline in performance of the ongoing task).

A second possibility is that the presence of the relevant context could automatically increase the level of resting activation of the representation of the goal (see ACT-R model, described in Anderson & Lebiere, 1998), thereby priming the goal to be retrieved (Nowinski & Dismukes, 2005). This idea implies that sleep-related facilitation could be supported without changes in resource allocation; instead, an increased resting activation of the goal representation (prompted by an associated context) could increase the likelihood that the target cue would spontaneously trigger retrieval of the goal (Goschke & Kuhl, 1993; Yaniv & Meyer, 1987). This possibility would be consistent with theoretical (McDaniel & Einstein, 2000, 2007) and empirical (Scullin, Einstein, & McDaniel, 2009; Scullin, McDaniel, & Einstein, 2010) work suggesting that individuals may spontaneously retrieve prospective memory goals without having to devote attentional resources toward maintaining those goals. To help inform debate concerning these possibilities, we included a control condition in which participants never encoded the prospective memory goal, so that we could assess whether any sleep-related benefits in prospective memory were accompanied by a decline in performance of the ongoing task (which would implicate allocation of resources toward the memory goal).

Finally, if sleep did improve goal execution, the context manipulation might allow us to illuminate the possible (sleep-related) mechanism. Jenkins and Dallenbach (1924) argued that sleep protects against "the interference, inhibition, or obliteration of the old by the new" (p. 612). According to this interference view, across all contexts a sleep delay should produce better prospective remembering than an equally long wake delay by protecting the goal (and the cue-goal associations) from interference. By contrast, according to the consolidation account of sleep-related memory benefits, these benefits are due not only to (passive) protection against interference, but also to (active) reactivation and restructuring that occurs during sleep (Ellenbogen, Hu, Payne, Titone, & Walker, 2007; Rasch et al., 2007; Walker, 2009). Of particular relevance to execution of prospective memory goals across contexts is

research suggesting that sleep might benefit associative memory by strengthening associative links (for brief reviews, see Diekelmann, Wilhelm, & Born, 2009; Walker, 2009).

To the degree that sleep promotes the strengthening of associative links (the *binding* view; Ellenbogen et al., 2007; Mograss, Guillem, & Godbout, 2008), sleep might benefit prospective memory primarily through strengthening the relevant context-goal associations. Given that the semantic categorization context was temporally paired with the prospective memory goal during encoding, the binding view suggests that sleep would most benefit prospective memory during the semantic categorization context (relative to the other contexts; see Drosopoulos, Windau, Wagner, & Born, 2007, for evidence that sleep strengthens temporal associations).

Method

Participants and design

Washington University undergraduates ($N = 121$) participated in experimental sessions that began at 9:00 a.m. or 9:00 p.m. The design for the experimental conditions was a 2×2 factorial in which encoding time (morning or evening) and delay (short or long) were between-subjects variables ($n = 24$ in each of the four conditions). There were no significant main effects or interactive effects of encoding time and delay on hours slept the night before the memory tests (largest $F = 1.97$, for the interaction; $M = 6.82$ hr), Symptom Checklist-90 (Derogatis, 1977) score (largest $F = 1.29$, for the main effect of encoding time), or Morningness-Eveningness Questionnaire (MEQ; Horne & Ostberg, 1976) score (largest $F = 3.91$, $p > .05$, for the main effect of encoding time). A control group ($n = 25$) that did not receive the prospective memory instructions was also tested specifically so that we could compare their performance on the ongoing task with that of participants in the sleep-delay condition.

Task overview

Figure 1 summarizes the task procedure for the first and second experimental sessions. In the short-delay conditions, between Session 1 and Session 2, participants stretched, rested, drank water, used the restroom, and so forth. This break typically lasted a few minutes. In the long-delay conditions, after completing the first experimental session, participants were instructed to return to the laboratory at 9:00 a.m. or 9:00 p.m. for the second session.

Session 1 procedure. The first session began with a reading span task. This was an automated working memory task that required participants to maintain letters in mind (for intermittent serial recognition tests) while determining whether sentences made sense (see Unsworth, Redick, Heitz, Broadway, & Engle, 2009, for full details).¹

After performing the reading span task, participants performed three ongoing tasks (in the following order): living/nonliving

decision, lexical decision, and semantic categorization. All three of these ongoing tasks had the same structure in that participants first learned the task instructions, then practiced the task, and finally performed a 150-trial experimental block (to ensure familiarity with the task for Session 2). In the living/nonliving decision task, participants were to determine whether a presented noun represented a living (e.g., “dog”) or nonliving (e.g., “chair”) object. In the lexical decision task, participants were instructed to determine whether a string of letters formed a word (e.g., “kite”) or a nonword (e.g., “itek”). In the semantic categorization task, a word in uppercase letters appeared to the right of a word in lowercase letters (e.g., “hockey SPORT”), and participants were instructed to determine whether the referent of the word in lowercase was a member of the category designated by the word in uppercase. Participants reported their decisions on the ongoing tasks by pressing keys marked “Y” (“yes”) and “N” (“no”; the “1” and “2” keys, respectively, on the number pad of a computer keyboard).

Immediately following the semantic categorization block, participants encoded the prospective memory goal. They were told that in addition to performing the ongoing tasks, they would need to remember to perform an action in the future. Specifically, they were instructed to press the “Q” key if they ever saw the word *table* or *horse* during any point in the experimental session (or the next session). The experimenter required them to write down the instructions, to ensure that the prospective memory goal was encoded.

After filling out a few demographics questionnaires (and Symptom Checklist-90; Derogatis, 1977), participants studied a list of syllables (e.g., “cen”), which they were told to remember for a later test (following Jenkins & Dallenbach, 1924). During the study phase, the 10 syllables each appeared for 4 s. The study phase was followed by an immediate request to recall all the syllables on a notepad. Participants were required to repeat the study phase until they could recall at least 8 syllables, before ending Session 1.

Session 2 procedure. Participants began the second session by filling out the MEQ (Horne & Ostberg, 1976), which assesses subjective optimal time of day, and answering sleep-related questions (e.g., estimated asleep and wake times). Following these questionnaires, participants were given 3 min to recall the syllables they had previously studied. They then performed the reading span task, which was followed by the ongoing tasks (in the following order): living/nonliving decision, lexical decision, and semantic categorization. During each 150-trial experimental block, each prospective memory target (*horse* and *table*) appeared once (for a total of six targets in Session 2). The frequency with which the target words were presented was consistent with the frequency used in other prospective memory tasks, which typically include targets on fewer than 5% of trials (see Loft, Kearney, & Remington, 2008).

The final task performed was an automated symmetry span task. This working memory task required participants to report whether patterns were symmetrical while maintaining the

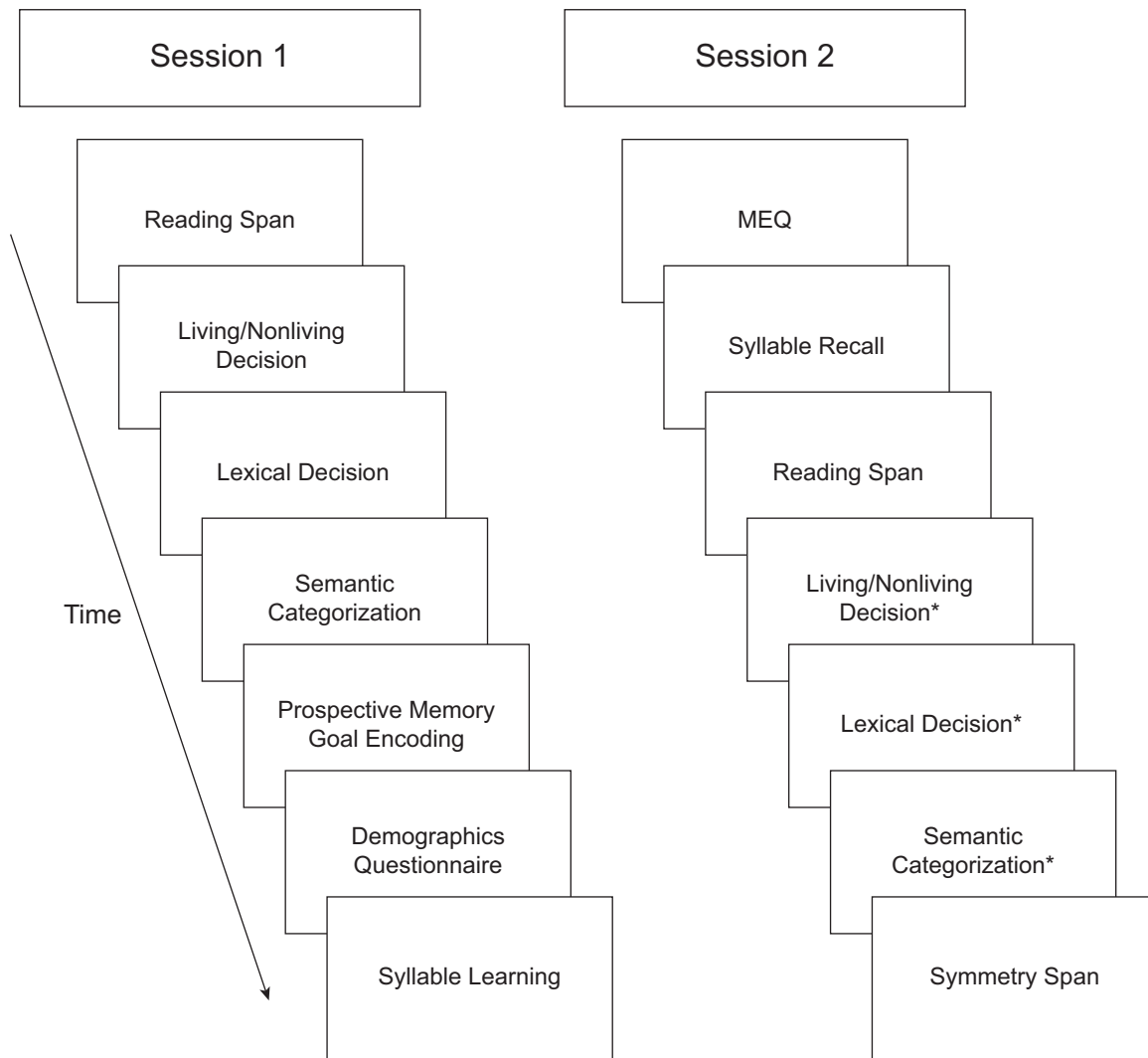


Fig. 1. Tasks included in the first and second experimental sessions. An asterisk indicates that prospective memory targets (horse and table) appeared during the task. MEQ = Morningness-Eveningness Questionnaire (Horne & Ostberg, 1976).

location and serial order of matrix cells in mind (see Unsworth et al., 2009, for elaboration).

Results

An alpha level of .05 was used for inferring statistical significance.

Prospective memory

Goal execution was assessed as the proportion of targets to which participants responded by pressing the “Q” key (see Fig. 2). We were particularly interested in levels of performance during the semantic categorization task, which was temporally paired with the goal during encoding. We conducted a $3 \times 2 \times 2$ mixed analysis of variance (ANOVA) that included the within-subjects variable of ongoing task (living/nonliving decision, lexical decision, or semantic categorization) and the

between-subjects variables of encoding time (morning or evening) and delay (short or long). The three-way interaction was significant, $F(2, 184) = 4.46$, $MSE = 0.05$. Simple-effects tests demonstrated a main effect of the ongoing task only in the sleep-delay condition, $F(2, 46) = 5.55$, $MSE = 0.05$ ($F = 2.03$, $F < 1$, and $F = 1.43$, in the short-morning-delay, short-evening-delay, and wake-delay conditions, respectively); in this condition, goal execution was greater during semantic categorization than during the living/nonliving decision task, $t(23) = 3.16$, and the lexical decision task, $t(23) = 2.56$ (goal execution did not differ between the latter two ongoing tasks, $t < 1$).

To directly gauge the effects of sleep, we conducted a 3 (ongoing task) $\times 2$ (sleep- or wake-delay condition) mixed ANOVA, which revealed a significant interaction, $F(2, 92) = 3.64$, $MSE = 0.037$. Inspection of Figure 2 suggests that this interaction reflects an advantage in the sleep-delay condition (relative to the wake-delay condition) for the semantic categorization task, but not the lexical decision task or the

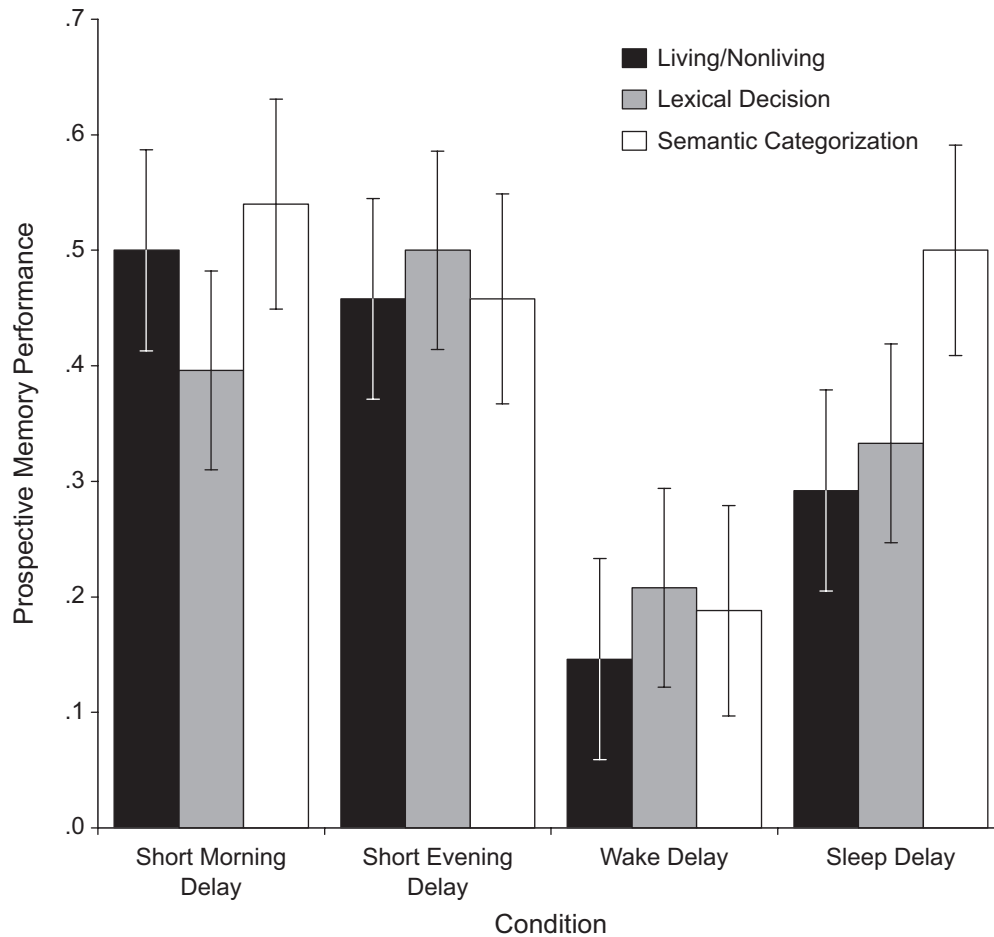


Fig. 2. Prospective memory performance (mean proportion of targets to which participants responded by pressing the “Q” key) as a function of condition and ongoing task. In the short-morning-delay and short-evening-delay conditions, participants performed the prospective memory task approximately 20 min after encoding the goal. In the wake-delay condition, participants encoded the goal in the morning and performed the task on the evening of the same day. In the sleep-delay condition, participants encoded the goal in the evening and performed the task on the morning of the next day. Error bars represent standard errors.

living/nonliving decision task. To gain direct evidence for this interpretation, we conducted a follow-up 2 (encoding time) \times 2 (delay) ANOVA for each ongoing task. In the lexical decision and living/nonliving decision tasks, the only significant effect was that prospective memory declined with delay, $F(1, 92) = 8.99$, $MSE = 0.18$, and $F(1, 92) = 4.25$, $MSE = 0.18$, respectively. Performance did not differ between the sleep-delay and wake-delay conditions for these two ongoing tasks—lexical decision: $t(46) = 1.05$; living/nonliving decision: $t(46) = 1.32$. By contrast, the ANOVA for the semantic categorization task revealed a significant Encoding Time \times Delay interaction, $F(1, 92) = 4.72$, $MSE = 0.20$; prospective memory performance was lower in the wake-delay condition than in both the sleep-delay condition, $t(46) = 2.53$, $d = 0.75$, and the short-delay conditions combined, $t(70) = 2.86$, $d = 0.68$. There was not even a numerical difference between performance in the sleep-delay and short-delay conditions (both $M_s = .50$). Thus, sleep augmented goal execution during the context that was temporally paired with the prospective memory goal during encoding.

Retrieval processes

Was the sleep-related benefit to prospective memory due to differential resource allocation or to spontaneous retrieval? To answer this question, we examined mean reaction times in the ongoing tasks (Einstein et al., 2005). A $3 \times 2 \times 2$ mixed ANOVA that included ongoing task (living/nonliving decision, lexical decision, or semantic categorization) as a within-subjects variable and encoding time (morning or evening) and delay (short or long) as between-subjects variables produced a main effect of ongoing task, $F(2, 184) = 788.68$, $MSE = 7,530.82$; responding during the semantic categorization task ($M = 1,126$ ms) was slower than responding during the living/nonliving decision task ($M = 824$ ms), $t(95) = 22.88$, which was slower than responding during the lexical decision task ($M = 664$ ms), $t(95) = 17.87$. Ongoing task did not interact with the other variables (all $F_s < 1$), which indicated that the speed of responding on the ongoing task did not vary in synchrony with prospective memory changes. Furthermore, to

determine whether the prospective memory task impaired performance on the ongoing tasks, we compared performance on the ongoing tasks (Session 2) in the sleep-delay condition with performance on the same tasks by the control group (which was given no prospective memory goal). This critical test revealed no group difference in reaction times for these tasks ($M_{\text{difference}} = 23$ ms, all t s < 1; cf. the larger difference scores obtained by Marsh, Hicks, & Cook, 2006).

Sleep manipulation checks

To examine premanipulation and postmanipulation retrospective memory, we determined the number of syllables recalled in the final study trial and the Session 2 recall test and then analyzed these data in 2 (encoding time: morning or evening) \times 2 (delay: short or long) between-subjects ANOVAs. There were no significant effects on recall during the study phase (largest $F = 1.28$, for the main effect of delay), but the analysis of performance on the final recall test revealed a significant interaction, $F(1, 92) = 10.58$, $MSE = 2.56$ (Table 1). Syllable recall was similar in the morning- and evening-short-delay conditions ($t < 1$). Recall was greater in the short-delay conditions combined than in the wake-delay condition, $t(70) = 8.43$, $d = 2.02$, and the sleep-delay condition, $t(70) = 2.92$, $d = 0.70$. Syllable recall was also greater in the sleep-delay condition than in the wake-delay condition, $t(46) = 3.75$, $d = 1.11$. Thus, the results replicated Jenkins and Dallenbach's (1924) finding that sleep-filled retention intervals buffered against syllable forgetting.

Performance on the first and second reading span tasks, as well as the symmetry span task, was calculated as the total number of items (i.e., letters or cells) recalled in the correct serial position. To investigate whether working memory performance depends on quality of delay (as suggested by Kuriyama, Mishima, Suzuki, Aritake, & Uchiyama, 2008, but not predicted by the binding or interference views), we conducted a 2 (encoding time: morning or evening) \times 2 (delay: short or long) between-subjects ANOVA on each working memory measure. There were no significant effects for Session 1 reading span performance (largest $F = 1.51$, for the main effect of delay), which indicates that there were no preexperimental between-group differences (see Table 2 for means). In addition, there were no significant effects for Session 2 reading span (all F s < 1) or symmetry span (largest $F = 1.74$, for the interaction). Thus, in contrast to the retrospective and

Table 1. Performance on the Syllable Recall Task: Mean Number of Syllables Recalled on the Final Study Trial and in the Final Recall Test

| Condition | Final study trial | Final test |
|---------------------|-------------------|-------------|
| Short morning delay | 8.50 (0.78) | 7.58 (1.41) |
| Short evening delay | 8.50 (0.83) | 7.50 (1.06) |
| Sleep delay | 8.46 (0.78) | 6.46 (1.89) |
| Wake delay | 8.21 (0.42) | 4.42 (1.89) |

Note: Standard deviations are given in parentheses.

Table 2. Mean Working Memory Performance

| Condition | Reading span: Session 1 | Reading span: Session 2 | Symmetry span |
|---------------------|----------------------------|----------------------------|------------------|
| Short morning delay | 58.21 (10.58) | 62.21 (11.77) | 30.79 (7.95) |
| Short evening delay | 55.54 (14.20) | 60.38 (11.03) | 29.88 (7.79) |
| Sleep delay | 60.58 (9.93) | 64.00 (8.94) | 32.23 (7.10) |
| Wake delay | 59.04 (11.68) | 61.67 (8.83) | 28.79 (8.98) |

Note: Standard deviations are given in parentheses. The maximum score was 75 for the reading span task and 42 for the symmetry span task.

prospective memory results, but as predicted by most views of the effects of sleep on cognition (e.g., hippocampus-dependent consolidation theories; Brankack, Platt, & Riedel, 2009), the results for working memory showed no benefits of sleep.

Discussion

This experiment examined the effect of sleep on execution of prospective memory goals. The observed effects were clear-cut. Not only were participants more likely to remember to execute the prospective memory goal after a sleep delay than after an equally long wake delay, but goal execution was similar following a 20-min delay and a 12-hr sleep-filled delay (during the semantic categorization task). This finding is inconsistent with the idea that sleep might undermine prospective remembering by precluding goal rehearsal (cf. Hicks et al., 2000) or by reducing the processing of cues related to the goal that would otherwise occur during waking periods (cf. Kvavilashvili & Fisher, 2007). However, the results are consistent with the finding that sleep benefits retrospective memory (e.g., Jenkins & Dallenbach, 1924; also compare our prospective memory results with the working memory results of Kuriyama et al., 2008). The practical implication is that goals, such as remembering to call your mother on her birthday or to exercise the next day, are more likely to be remembered if encoded in the evening for execution following a full night's sleep.

The binding view of sleep-induced memory improvements, which is a variant of consolidation theory, suggests that sleep increases associative binding. According to this view, "consolidation consists of restructuring or reorganizing weak associations in order to strengthen associative links" (Mogras et al., 2008, p. 431). The idea that weak associations may be selectively strengthened by sleep (Drosopoulos, Schulze, Fischer, & Born, 2007; Stickgold, Scott, Rittenhouse, & Hobson, 1999) nicely accounts for our finding that in the sleep-delay condition, prospective memory was amplified in the semantic categorization context. It is plausible that the initial link between the goal and the semantic categorization context was relatively weak because the pairing between context and goal was temporal, rather than explicit. Also in line with the conjecture that the context-goal link was weak is the fact that goal execution during semantic categorization was not augmented relative to the other contexts (living/nonliving decision, lexical decision) in the short-delay conditions. When

more explicit or stronger links between the context and goal are encoded, the presence of the context does benefit prospective memory in the case of short delays (Marsh, Hicks, & Cook, 2006; Nowinski & Dismukes, 2005). It seems likely that the goal-context association was weak at encoding and that sleep consolidated this link.

The classic theory of sleep-related memory improvement is that sleep improves memory by protecting it against interference (Jenkins & Dallenbach, 1924). In this view, sleep should enhance prospective memory across all contexts. This interference-related explanation is inconsistent with our finding that sleep did not significantly benefit prospective memory during the living/nonliving or lexical decision tasks; in contrast, following sleep, prospective remembering during the semantic categorization task was so well preserved that there was no decline in performance relative to the short-delay conditions. Thus, the pattern of goal execution across contexts appears to be most consistent with the idea that sleep benefits memory through a binding process that strengthens weak temporal, contextual, or other associations (Drosopoulos, Windau, et al., 2007; Ellenbogen et al., 2007; Mograss et al., 2008). In a sense, sleep reinforced in memory a context in which the goal was to be executed (presumably through consolidation processes).

The results of our study have further implications for how individuals remember to execute prospective memory goals, especially over long delays. Even though there were large group differences in prospective memory performance, the groups did not differ in performance of the ongoing tasks. Furthermore, performance of these tasks did not differ between the sleep-delay condition and the control condition. These results are inconsistent with a resource-allocation account (e.g., Marsh, Hicks, & Cook, 2006), which predicted that the goal-context association would lead to a greater amount of resources being allocated toward maintaining the goal during the semantic categorization task. However, the results are generally consistent with the idea that a goal may be retrieved spontaneously (McDaniel & Einstein, 2007; Scullin et al., 2010). One possibility is that the semantic categorization task increased the resting activation of the cue-goal representation in the sleep-delay condition, which subsequently facilitated goal execution via spontaneous memory-activation processes (Goschke & Kuhl, 1993; Nowinski & Dismukes, 2005).

Our finding that sleep benefits the execution of a prospective memory goal converges well with Diekelmann, Wilhelm, Wagner, and Born's (2010) recent demonstration that intentions are consolidated during the slow-wave sleep stage (relative to the rapid eye movement, or REM, stage); this sleep stage involves rapid, synchronized firing in hippocampal cells, which is a presumed neural underpinning of memory consolidation during sleep (for a review, see Sejnowski & Destexhe, 2000; Walker, 2009). That slow-wave sleep should enhance the retrieval and execution of intentions is consistent with the idea that the spontaneous-retrieval mechanism is hippocampus dependent (McDaniel & Einstein, 2007; Scullin et al.,

2009), and converges with the present study's finding that sleep augments the probability of spontaneous goal retrieval.

In conclusion, the present study provides additional support for the idea that sleep promotes memory consolidation (e.g., Brankack et al., 2009; Rasch et al., 2007; Walker, 2009), and perhaps the binding of weak associations. Most important is the finding that sleep helps, rather than hinders, goal execution. Such a result has both theoretical and practical importance: To enhance prospective remembering over long intervals (e.g., on the order of a day), one might form the goal before sleeping, rather than at the outset of a busy day. Indeed, our findings produce a counterpoint to McDaniel, Einstein, Stout, and Morgan's (2003) original admonition (with regard to executing goals) to "do it or lose it"; after forming a goal that cannot be executed immediately, one might do well to "sleep on it."

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Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

Note

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