*****ARTICLE IN PRESS AT PSYCHONOMIC BULLETIN & REVIEW********

Effects of Pre-study and Post-study Rest on Memory: Support for Temporal Interference Accounts of Forgetting

Ullrich K. H. Ecker[1], Jia-Xin Tay[1], & Gordon D. A. Brown[2]

[1]University of Western Australia, University of Warwick[2]

Word Count: 4,077 (Brief Report; count includes main text and references)

Acknowledgments: This research was facilitated by Discovery Grant DP110101266 and an Australian Postdoctoral Fellowship from the Australian Research Council (ARC) to the first author. We thank Charles Hanich, Stewart Craig, Devon Spaapen, and Ee Pin Chang for research assistance and Stephan Lewandowsky for his guidance. The lab web address is www.cogsciwa.com.

Contact: Ullrich Ecker, School of Psychology (M304), University of Western Australia, Perth 6009, Australia; Phone: +618 6488 3257; Fax: +618 6488 1006; E-mail: ullrich.ecker@uwa.edu.au

Abstract

According to interference-based theories of memory, including temporal distinctiveness theory, both *pre-study* and *post-study rest* should have a beneficial impact on memory performance. Specifically, higher temporal isolation of a memorandum should reduce proactive and/or retroactive interference and should thus result in better recall. The present study investigated the effects of pre-study rest and post-study rest in a free recall paradigm. Participants studied three lists of words, separated by either a short or long period of low mental activity (a tone-detection task). Recall targeted the second list; this list was studied in one of four conditions, defined by the fully crossed factors of pre-study and post-study rest duration. Two experiments found a beneficial effect of pre-study rest (and to a lesser extent post-study rest) on list recall. This result is in line with interference-based theories of memory. By contrast, a beneficial effect of pre-study rest is not predicted by consolidation accounts of memory and forgetting; our results thus require additional assumptions and/or a better specification of the consolidation process and its time course to be reconciled with consolidation theory.

Keywords: Interference; Temporal distinctiveness; Consolidation; Episodic memory; Free recall

Effects of Pre-study and Post-study Rest on Memory: Support for Temporal Interference Accounts of Forgetting

Interference theory (Underwood, 1957) states that cognitive processing of information either before or after encoding of a memorandum can impair its subsequent retrieval from memory. Interference is thus a disturbance of memory, resulting from material encoded before (proactive interference) or after (retroactive interference) learning of a memorandum. Many cognitive models of memory see interference as the main reason why people forget (e.g.., Botvinick & Plaut, 2006; Brown, Neath, & Chater, 2007; Farrell & Lewandowsky, 2002; Mensink & Raaijmakers, 1988; Oberauer & Kliegl, 2006; Oberauer, 2009). In particular, in Brown et al.'s (2007) temporal-distinctiveness account, interference effects are determined by temporal proximity; interfering material is thought to compete with the memorandum during retrieval depending on their proximity in temporal space—the smaller the temporal distance between the distractor and the memorandum, the more interference there will be. Support for this account comes *inter alia* from free recall and recognition memory studies manipulating the inter-stimulus interval of study-list presentation (Brown, Morin, & Lewandowsky, 2006; Morin, Brown, & Lewandowsky, 2010; Rönnberg, 1980). These studies have found that recall of individual items is a function of their temporal isolation at study. Interference theory hence predicts that item memory should improve as the item's temporal isolation grows. In particular, it makes the prediction that periods of pre-study and post-study rest should both improve memory.

The prediction of interference theory regarding *post-study rest* is shared by other theoretical accounts of memory, in particular consolidation theory. According to consolidation theory (Wang & Morris, 2010; Wixted, 2004), newly formed memories are labile and require time to stabilize to avoid forgetting; consolidation is the process of progressive post-acquisition stabilization (Dudai, 2004) of memory representations. Consolidation is thought to be particularly active during sleep and periods of low mental activity, in particular when no new memories are formed (Born, 2010; Wixted, 2004). Forgetting results when consolidation is interrupted, be it by disruptive brain stimulation or injection of amnestic agents, or by a taxing mental activity that takes cognitive resources away from the consolidation process, in particular new learning (Dudai, 2004; Wixted, 2004). Accordingly, studies comparing memory for newly encoded materials after a period of rest or sleep with memory for the materials after a period of wakeful activity typically find that memory benefits if encoding is followed by a period of low-mental activity (Dewar, Alber, Butler, Cowan, & Della Sala, 2012; Dewar, Cowan, & Della Sala, 2010; Gais, Lucas, & Born, 2006).

The prediction of a beneficial effect of *pre-study rest*, however, is unique to temporal distinctiveness theory (or any implementation of interference theory that makes assumptions about temporal proximity). Retrieval of a memorized item should be facilitated by its temporal isolation on both sides of the temporal dimension. It follows that pre-study rest should have similar benefits to post-study rest (see Morin et al., 2010, for supporting evidence). While interference theory makes a specific prediction regarding the effects of pre-study rest on memory, consolidation theory is much less specific in predicting the effects of pre-study rest, mainly because consolidation can be disrupted by subsequent events but not by previous events (however, we discuss some possible ways in which consolidation theory could address the issue in the Discussion of Experiment 1).

The aim of the current study was to test the predictions made by interference theories pertaining to the effects of pre- and post-study rest. To this end, we employed a word recall task involving three study lists, with recall targeting the second list. Lists were separated by rest intervals that were either short or long. These intervals were filled with low mental activity (an easy tone-detection task) designed to control cognitive processing and prevent articulatory rehearsal, while not providing any substantial interference or disruption of consolidation[1]. The present study thus aimed to extend the finding that temporal isolation benefits recall of individual items (Brown et al., 2006) to entire item lists. Specifically, recall performance should be affected by both post- and pre-study rest: performance should be best in the condition with maximal temporal isolation of the memoranda (i.e., with long pre- and post-study rests), and worst in the condition with minimal temporal isolation (i.e., with short pre- and post-study rests).

Experiment 1

Method

Participants. Power analysis suggested a minimum sample size of 28 to find a medium-sized effect (f = .25) with α = .05, 1-β = .80, and a moderate correlation between repeated measures of r = .40. We tested 36 undergraduate students from the University of Western Australia (23 females, 13 males; mean age M = 20.13 [SD = 4.79] years), who received course credit.

Apparatus. The experimental program was designed with MATLAB. Headphone sets with integrated microphones were used to administer audio stimuli and to record vocal responses.

Design. This experiment employed a 2 × 2 within-subjects design with factors pre-study rest (short vs. long) and post-study rest (short vs. long), resulting in four conditions short/short (SS), short/long (SL), long/short (LS), and long/long (LL).

[1] We argue that the tone task itself is unlikely to cause forgetting because it is known that repeated encoding of the same distractor stimuli does not lead to forgetting (most likely due to novelty-gated encoding; cf. Lewandowsky, Geiger, & Oberauer, 2008). We acknowledge that some more implicit memory trace of having performed the task will be formed, but under complete rest participants are also likely to engage in cognitive activities that will produce such traces.

Materials. The study task involved the learning of three 8-word lists. Words were drawn from a pool of 192 words selected from the MRC Psycholinguistic Database (http://websites.psychology.uwa.edu.au/school/MRCDatabase/mrc2.html). Selected words (a) were monosyllabic nouns, (b) had three to six letters, (c) had a Kucera-Francis frequency > 28, (d) had familiarity and concreteness ratings > 400, and (e) were not confusable with other words on the list. Words were presented centrally on the screen, one at a time, for 500 ms, with an inter-stimulus interval of 400 ms.

Tone-detection task. Rest intervals contained a tone-detection task, identical to that used by Ecker, Brown, and Lewandowsky (2014). Participants were presented with an ongoing sequence of two different tones—80% low-pitched tones (440 Hz) and 20% high-pitched tones (523 Hz), presented for 150 ms per tone with an inter-tone interval of 600 ms. The sequence of tones was random, except that the first tone was always a standard low tone. Participants were instructed to press the “h” key on the keyboard upon hearing a high tone, and had 600 ms from the onset of a high tone to respond. The word “MISS” was presented in red for 150 ms if participants failed to respond. Conversely, if participants pressed the “h” key upon presentation of a low tone, the words “FALSE ALARM” were presented instead. The duration of the task was 15 s for short intervals, and 120 s for long intervals.

Procedure. Participants first completed a practice trial, which familiarized them with the tasks and procedures. Participants then underwent a total of eight experimental trials (two per condition) in a randomized order. The sequence of tasks across the different conditions is illustrated in the top panel of Figure 1.

Each trial began with a buffer, filled with quiet ambient music. A doorbell chime and the text “Prepare for word list” on-screen announced the first study list. After study of list 1, participants proceeded on to the tone-detection task for the pre-study rest interval. This was followed by study of list 2 (i.e., the main list of interest), the post-study rest interval (filled with the tone-detection task), and study of list 3. An additional interval filled with the tone-detection task ensured that the retention interval between study and test of list 2 was constant across conditions. Participants then proceeded to the memory test; the text “Please recall words from the second list” prompted participants to perform the free recall by speaking into the microphone. Once the participants were done, the program prompted them to additionally recall either words from the first or the third list (list selection was counterbalanced). Participants had a maximum of 30 s to recall a list but also had the option to abort after 15 s if they could not remember any more words. Each trial ended with a 30 s buffer interval before the next trial. Each trial took approximately 6.5 min; the entire experiment took approximately 60 min to complete.

Results

Performance in the tone-detection task was high and equivalent across conditions (mean correct response rate ranged from $M = .971$ to $M = .977$ across conditions). Data were also screened for poor performance in overall recall of list 2. Four sets of data were removed according to *a priori* recall performance criteria (overall recall performance < 12.5%, i.e., an average of less than one word recalled per trial, $n = 2$, or a recall score of zero on 37.5 % of the trials, i.e., 3 or more trials, $n = 2$). The final sample size was $N = 32$.

List-2 recall performance. Recall performance across conditions is presented in Figure 2. Performance was best in the LL condition and worst in the two short pre-study rest conditions SS and SL. A 2 × 2 repeated measures ANOVA found a main effect of pre-study rest, $F(1, 31) = 4.54$, $p = .04$, $MSE = .02$, $\eta_p^2 = .13$. The main effect of post-study rest and the interaction were non-significant, $F < 1$.

Intrusion-corrected list-2 recall performance. It is possible that the observed pattern of recall was overlaid by a non-uniform distribution of intrusion errors. Intrusions of extra-list items could reflect a noisier list representation and could thus be a marker of the quality of list memory. Intrusion-corrected scores were hence calculated by subtracting the number of intrusions from the number of words recalled, divided by the number of words presented to facilitate comparisons with the raw recall performance presented earlier (note that intrusion-corrected scores can become negative). The intrusion-corrected recall performance was taken to provide a clearer indication of how “cleanly” the studied items were represented in and retrieved from memory.

Intrusion-corrected recall performance is presented in Figure 3; numerically, performance was best in the LL condition and worst in the SS condition. A 2 × 2 repeated measures ANOVA confirmed the main effect of pre-study rest, $F(1, 31) = 5.02$, $p = .03$, $MSE = .04$, $\eta_p^2 = .14$. The main effect of post-study rest approached significance, $F(1, 31) = 3.49$, $p = .07$, $MSE = .04$, $\eta_p^2 = .10$; the interaction was non-significant, $F(1, 31) = 1.41$, $p = .24$.

List-1 recall performance. Predictions regarding list-1 performance were complicated by the facts that list 1 was presented at different times across conditions (unlike list 2; cf. Figure 1) and that differential ease of recalling list 2 in different conditions might have influenced results of list-1 recall. Nonetheless, there was a theoretical reason to look at list-1 recall: Consolidation theory could explain a beneficial pre-study rest effect on list-2 recall performance by assuming that lists compete for consolidation resources: Specifically, list 1 should be more fully consolidated when the list-2 pre-study rest interval (i.e., the list-1 post-study interval) is long rather than short, leaving more resources for list-2 consolidation after its study. By contrast, temporal distinctiveness theory would predict roughly equivalent performance in both long and short list-1 post-study rest conditions because the first list was consistently isolated on one side of the temporal dimension (cf. Figure 1). Two one-way repeated measures ANOVAs of list-1 recall and intrusion-corrected list-1 recall performance found no effect of post-study rest, $F < 1$.

Discussion

Experiment 1 found a significant beneficial effect of pre-study rest on free recall, along a near-significant beneficial effect of post-study rest on intrusion-corrected free recall performance. This result is in line with the predictions of temporal distinctiveness theory: the more temporally isolated a list, the better its recall. In other words, the more distant a neighboring list, the less interference it conveyed.

While consolidation theory makes no specific assumptions regarding the pre-study interval, it was worth considering potential alternative explanations derived from consolidation theory. A possible explanation of how pre-study rest might affect memory could be formulated based on the suggestion that previously learned material competes with the memorandum at retrieval. The impact of this material might then depend on the duration of pre-study rest (cf. Dewar, Cowan, & Della Sala, 2007): a longer duration would allow more consolidation of the material, and it might hence contend more strongly with the memorandum at recall. However, this view would predict that longer pre-study rest intervals might lead to *poorer* recall of the memorandum and can thus not explain the current results.

On the other hand, to the extent that consolidation of previously encoded information has been completed when the memorandum is presented, there might be more resources available for the consolidation of the memorandum. It follows that recall of the memorandum might *improve* with longer pre-study rest intervals. Therefore, at first glance, the beneficial effect of pre-study rest could be explained by consolidation theory with help of the additional assumption that lists compete for consolidation resources; that is, the list-2 pre-study rest benefit might actually reflect a list-1 post-study rest effect in that list 2 might benefit from resources available for consolidation after list 1 was more fully consolidated during the rest period between lists 1 and 2. However, more thorough consolidation of list 1 should arguably be reflected in list-1 recall performance, which was unaffected by the duration of the list-1 post-study rest interval. We also note that it is difficult to derive predictions from consolidation theory given the fact that the time course of consolidation processes has not been well-specified (cf. Brown & Lewandowsky, 2010; Ecker & Lewandowsky, 2012; Ecker et al., 2014; Lewandowsky, Ecker, Farrell, & Brown, 2012).

To conclude, a beneficial effect of pre-study rest sits comfortably with interference theory but it would require additional assumptions to align pre-study rest effects with consolidation theory. We thus take the results of Experiment 1 as support for temporal distinctiveness theory. To corroborate our findings, we ran Experiment 2.

Experiment 2

Experiment 2 was an almost identical replication of Experiment 1, with shorter "long" intervals (cf. bottom panel of Figure 1). There were several reasons for this change. On a theoretical level, a shortening of the long intervals implied a more stringent test of temporal distinctiveness theory, as it reduced the between-condition differences in temporal isolation. On a methodological level, it allowed participants to complete three instead of two trials per condition, increasing reliability of our measures. Some participants in Experiment 1 had also commented on the tediousness of the task, so on a pragmatic level, the change made the task less tiring and arguably reduced potential fatigue effects.

Method

Participants. We tested 36 undergraduate students from the University of Western Australia (22 females, 14 males; mean age *M* = 20.50 [*SD* = 4.66] years), who received course credit.

Apparatus, Design, Materials, and Procedure. Experiment 2 was identical to Experiment 1, with the exception of the long interval durations, which were shortened from 120 s to 60 s. Also, each participant completed three (instead of two) trials per condition.

Results

Performance in the tone-detection task was high and equivalent across conditions (mean correct response rate ranged from *M* = .975 to *M* = .980 across conditions). Data were screened for poor performance in list-2 recall. Four sets of data were removed based on the *a priori* performance criteria of Experiment 1. The final sample size was *N* = 32.

List-2 recall performance. Recall performance across conditions is presented in Figure 4. Numerically, performance was best in the LL condition and worst in the SS condition. A 2 × 2 repeated measures ANOVA found a main effect of pre-study rest, $F(1, 31) = 7.37$, $p = .01$, $MSE = .01$, $\eta_p^2 = .19$, and a main effect of post-study rest, $F(1, 31) = 4.72$, $p = .04$, $MSE = .01$, $\eta_p^2 = .13$. The interaction was non-significant, $F < 1$.

Intrusion-corrected list-2 recall performance. Intrusion-corrected recall performance is presented in Figure 5; numerically, performance was again best in the LL condition and worst in the SS condition. A 2 × 2 repeated measures ANOVA confirmed the main effect of pre-study rest, $F(1, 31) = 11.48$, $p = .002$, $MSE = .02$, $\eta_p^2 = .27$. The main effect of post-study rest was marginally significant, $F(1, 31) = 4.00$, $p = .054$, $MSE = .02$, $\eta_p^2 = .11$. The interaction was non-significant, $F < 1$.

List-1 recall performance. A one-way repeated measures ANOVA of list-1 recall performance found a marginally significant effect of post-study rest, $F(1, 31) = 3.82$, $p = .06$, $MSE = .01$, $\eta_p^2 = .11$. List-1 recall tended to be superior after short list-1 post-study rest. Analysis of intrusion-corrected list-1 recall scores yielded no significant result, $F < 1$.

Discussion

Experiment 2 replicated the results obtained in Experiment 1: Recall of list 2 benefited from both a long pre-study and a long post-study interval—in other words, the higher the list's temporal isolation, the better recall. Additionally, the analysis of list-1 recall—that is, slightly better recall of list 1 after *short* post-study rest—suggested that the beneficial effect of list-2 pre-study rest cannot be understood as an effect of the more thorough consolidation of list 1.

General Discussion

The aim of this study was to investigate the effects of pre-study and post-study rest on free recall to test specific predictions of interference theory. We found that list recall benefited from both pre-study and post-study rest (at least in intrusion-corrected recall) across two experiments. The present study thus extends findings of temporal isolation benefiting the recall of individual items and demonstrates a beneficial effect of the temporal isolation of entire lists of items. Hence there is now strong evidence for temporal isolation effects on the free recall of both individual items (e.g., Brown et al., 2006; Rönnberg, 1980) and entire lists, in addition to some evidence for temporal isolation effects on recognition and serial recall (Morin et al., 2010).

The fact that temporal isolation effects occur most clearly in free recall is easily explained by a fundamental assumption of temporal distinctiveness theory, namely that items are encoded into a multi-dimensional memory space, where the temporal dimension is only one among potentially many dimensions. The temporal dimension will be most important for free recall of recent events (cf. Brown & Lewandowsky, 2010); it will be less useful in serial recall, where the position of items in a list (i.e., a positional dimension) is crucial, or in recognition, which can partially rely on item familiarity rather than a recall-like recollection process that may be more sensitive to temporal context (cf. Yonelinas, 2002).

Regarding the effects of *post-study rest*, interference theory assumes that they occur because they reduce retroactive interference (Ecker et al., 2014; Mercer, 2014; also see Souza & Oberauer, 2014). However, we note that effects of post-study rest are also predicted by consolidation theory. In fact, recent publications have used post-study rest effects in support of consolidation theory (cf. Dewar et al., 2010, 2012).

By contrast, beneficial effects of *pre-study rest* are not predicted by consolidation theory, and require additional assumptions to be explained: Consolidation theory would have to assume that the pre-study rest effect is governed by the completion of the first distractor list's consolidation within the long (120 s) but not the short (15 s) rest interval, freeing up resources for the consolidation of target list 2 in the former but not the latter case. To the extent that the active mechanism of consolidation is reactivation of memory traces (cf. Oudiette & Paller, 2013), this would imply that the long pre-study rest interval could serve to reduce competition for reactivation between the distractor and target lists. However, due to the lack of specification of consolidation theory—in particular the lack of temporal parameter specification (cf. Brown & Lewandowsky, 2010; Ecker & Lewandowsky, 2012; Ecker et al., 2014; Lewandowsky et al., 2012), this remains a speculative post-hoc explanation.

We conclude that the overall pattern of results we obtained confirmed the predictions of an interference-based temporal distinctiveness framework: item lists were recalled worst when least temporally isolated, and best when most temporally isolated. In particular, the observed effect of pre-study rest was uniquely predicted by temporal interference theory (cf. Brown et al., 2007; Ecker et al., 2014; Mercer, 2014). We do stress that the present results should not be taken as evidence against the general relevance of consolidation (for which there are other lines of evidence; cf. Born, 2010; Dudai, 2004; Wixted, 2004). However, our results should encourage consolidation theorists to specify the time course of consolidation to allow more precise predictions regarding the effects of pre-study rest, and to consider factors such as interference and temporal distinctiveness in their modeling and theorizing.

References

Born, J. (2010). Slow-wave sleep and the consolidation of long-term memory. *The World Journal of Biological Psychiatry*, *11*, 16-21. doi:10.3109/15622971003637637

Botvinick, M. M., & Plaut, D. C. (2006). Short-term memory for serial order: A recurrent neural network model. *Psychological Review*, *113*, 201-233. doi:10.1037/0033-295X.113.2.201

Brown, G. D. A., & Lewandowsky, S. (2010). Forgetting in memory models: Arguments against trace decay and consolidation failure. In S. Della Sala (Ed.), *Forgetting* (pp.49-75). Hove: Psychology Press.

Brown, G. D. A., Morin, C., & Lewandowsky, S. (2006). Evidence for time-based models of free recall. *Psychonomic Bulletin & Review*, *13*, 717-723. doi:10.3758/BF03193986

Brown, G. D. A., Neath, I., & Chater, N. (2007). A temporal ratio model of memory. *Psychological Review*, *114*, 539-576. doi:10.1037/0033-295X.114.3.539

Dewar, M. T., Alber, J., Butler, C., Cowan, N., & Della Sala, S. (2012). Brief wakeful resting boosts new memories over the long term. *Psychological Science*, *23*, 955-960. doi:10.1177/0956797612441220

Dewar, M. T., Cowan, N., & Della Sala, S. (2007). Forgetting due to retroactive interference: A fusion of Müller and Pilzecker's (1900) early insights into everyday forgetting and recent research on anterograde amnesia. *Cortex*, *43*, 616-634. doi:10.1016/S0010-9452(08)70492-1

Dewar, M. T., Cowan, N., & Della Sala, S. (2010). Forgetting due to retroactive interference in amnesia: Findings and implications. In S. Della Sala (Ed.), *Forgetting* (pp. 185-208). Hove: Psychology Press.

Dudai, Y. (2004). The neurobiology of consolidations, or, how stable is the engram? *Annual Review of Psychology*, *55*, 51-86. doi:10.1146/annurev.psych.55.090902.142050

Ecker, U. K. H., & Lewandowsky, S. (2012). Computational constraints in cognitive theories of forgetting. *Frontiers in Psychology*, *3*(400), 1-5. doi:10.3389/fpsyg.2012.00400

Ecker, U. K. H., Brown, G. D. A., & Lewandowsky, S. (2014). *Memory without consolidation: Temporal distinctiveness explains retroactive interference.* Manuscript submitted for publication.

Farrell, S., & Lewandowsky, S. (2002). An endogenous distributed model of ordering in serial recall. *Psychonomic Bulletin & Review*, *9*, 59-79. doi:10.3758/BF03196257

Gais, S., Lucas, B., & Born, J. (2006). Sleep after learning aids memory recall. *Learning & Memory*, *13*, 259-262. doi:10.1101/lm.132106

Lewandowsky, S., Ecker, U. K. H., Farrell, S., & Brown, G. D. A. (2012). Models of cognition and constraints from neuroscience: A case study involving consolidation. *Australian Journal of Psychology*, *64*, 37-45. doi:10.1111/j.1742-9536.2011.00042.x

Lewandowsky, S., Geiger, S. M., & Oberauer, K. (2008). Interference-based forgetting in verbal short-term memory. *Journal of Memory and Language*, *59*, 200-222.

Mensink, G.-J., Raaijmakers, J. G. W. (1988). A model for interference and forgetting. *Psychological Review*, *95*, 434-455. doi:10.1037/0033-295X.95.4.434

Mercer, T. (2014). Wakeful rest alleviates interference-based forgetting. *Memory*. doi:10.1080/09658211.2013.872279

Morin, C., Brown, G. D. A., & Lewandowsky, S. (2010). Temporal isolation effects in recognition and serial recall. *Memory & Cognition*, *38*, 849-859. doi:10.3758/MC.38.7.849

Oberauer, K. (2009). Design for a working memory. In B. H. Ross (Ed.), *The Psychology of Learning and Motivation*, *51* (pp. 45-100). San Diego: Academic Press.

Oberauer, K., & Kliegl, R. (2006). A formal model of capacity limits in working memory. *Journal of Memory and Language, 55*, 601-626. doi:10.1016/j.jml.2006.08.009

Oudiette, D., & Paller, K. A. (2013). Upgrading the sleeping brain with targeted memory reactivation. *Trends in Cognitive Sciences*, *17*, 142-149. doi:10.1016/j.tics.2013.01.006

Rönnberg, J. (1980). Predictability as a task demand in single-trial free recall. *Scandinavian Journal of Psychology*, *21*, 83-95. doi:10.1111/j.1467-9450.1980.tb00345.x

Souza, A. S., & Oberauer, K. (2014). Time-based forgetting in visual working memory reflects temporal distinctiveness, not decay. *Psychonomic Bulletin & Review.* doi:10.3758/s13423-014-0652-z

Underwood, B. J. (1957). Interference and forgetting. *Psychological Review, 64*, 49-60. doi:10.1037/h0044616

Wang, S.-H., Morris, R. G. M. (2010). Hippocampal-neocortical interactions in memory formation, consolidation, and reconsolidation. *Annual Review of Psychology, 61*, 49-79. doi:10.1146/annurev.psych.093008.100523

Wixted, J. T. (2004). The psychology and neuroscience of forgetting. *Annual Review of Psychology*, *55*, 235-269. doi:10.1146/annurev.psych.55.090902.141555

Yonelinas, A. P. (2002). The nature of recollection and familiarity: A review of 30 years of research. *Journal of Memory and Language, 46*, 441-517. doi:10.1006/jmla.2002.2864

Figure Captions

Figure 1. Trial sequence across all four conditions in Experiment s 1 and 2. Conditions are defined by the duration of pre-study and post-study rest intervals: SS = short/short; SL = short/long; LS = long/short; LL = long/long. Numbers 1, 2, and 3 indicate study lists 1 (pre-study distractor list, in gray), 2 (target list, in black), and 3 (post-study distractor list, in gray). Pre-study and post-study rest periods were filled with an easy tone-detection task (TD). T2 and T1/3 indicate the memory tests (free recall of target list 2, in black, and free recall of either distractor list 1 or 3, in gray). Shaded areas indicate buffer intervals.

Figure 2. Recall performance across conditions in Experiment 1. Conditions are defined by the duration of pre-study and post-study rest intervals. Error bars indicate within-subjects standard error of the mean.

Figure 3. Intrusion-corrected recall performance across conditions in Experiment 1. Conditions are defined by the duration of pre-study and post-study rest intervals. Please note that intrusion-corrected recall scores can become negative and zero is thus not an absolute boundary of performance. Error bars indicate within-subjects standard error of the mean.

Figure 4. Recall performance across conditions in Experiment 2. Conditions are defined by the duration of pre-study and post-study rest intervals. Error bars indicate within-subjects standard error of the mean.

Figure 5. Intrusion-corrected recall performance across conditions in Experiment 2. Conditions are defined by the duration of pre-study and post-study rest intervals. Please note that intrusion-corrected recall scores can become negative and zero is thus not an absolute boundary of performance. Error bars indicate within-subjects standard error of the mean.

Figure 1.

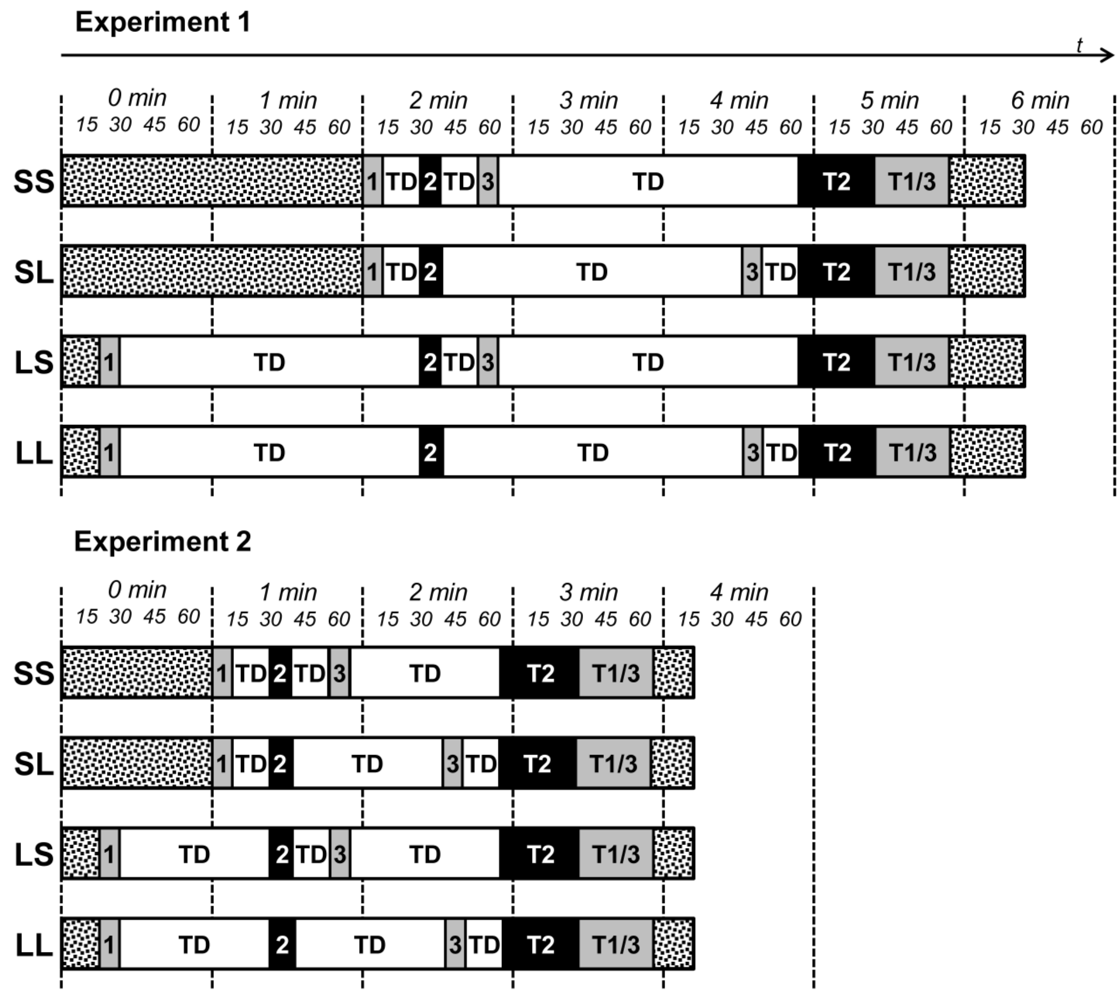

Experiment 1
t
0 min
1 min
2 min
3 min
4 min
5 min
6 min
15 30 45 60
SS
1 TD 2 TD 3 TD T2 T1/3
SL
1 TD 2 TD 3 TD T2 T1/3
LS
1 TD 2 TD 3 TD T2 T1/3
LL
1 TD 2 TD 3 TD T2 T1/3
Experiment 2
0 min
1 min
2 min
3 min
4 min
15 30 45 60
SS
1 TD 2 TD 3 TD T2 T1/3
SL
1 TD 2 TD 3 TD T2 T1/3
LS
1 TD 2 TD 3 TD T2 T1/3
LL
1 TD 2 TD 3 TD T2 T1/3

Figure 2.

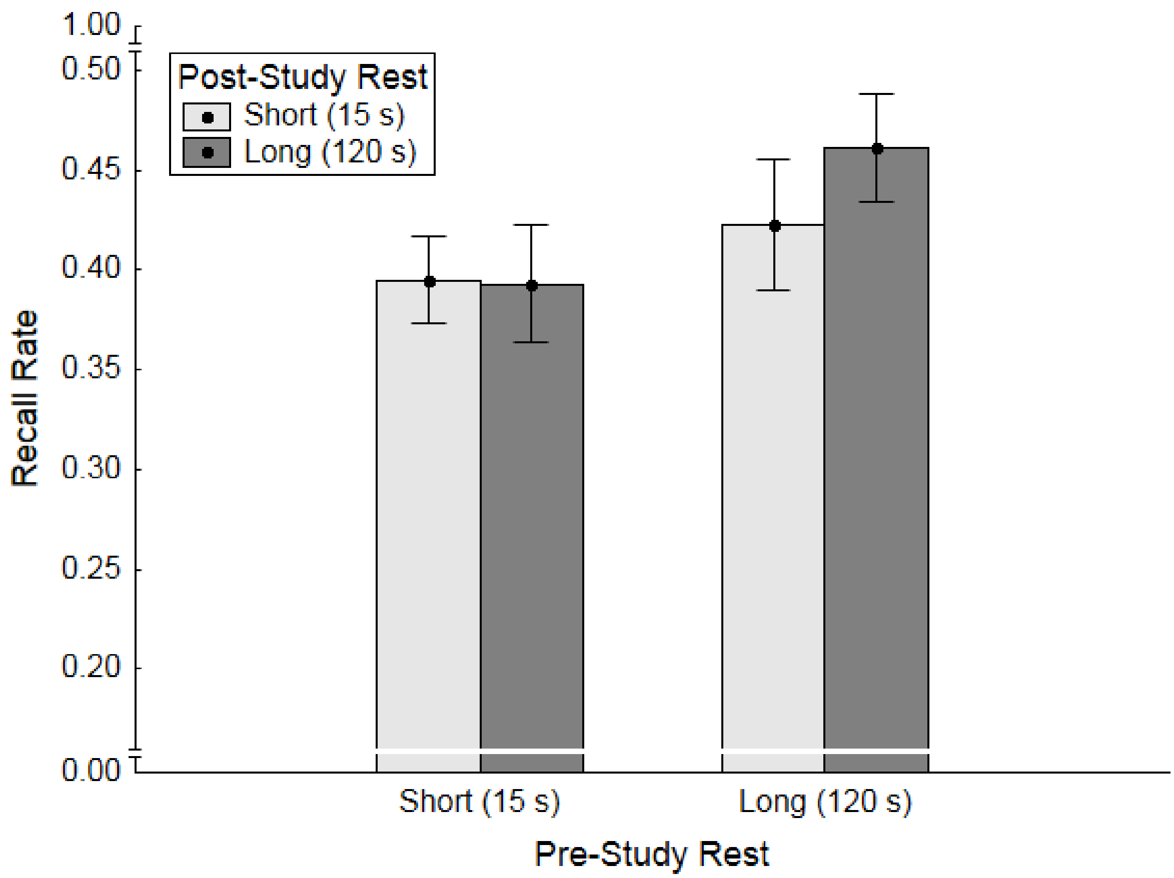

Post-Study Rest
Short (15 s)
Long (120 s)
Recall Rate
1.00
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.00
Short (15 s)
Long (120 s)
Pre-Study Rest

Figure 3.

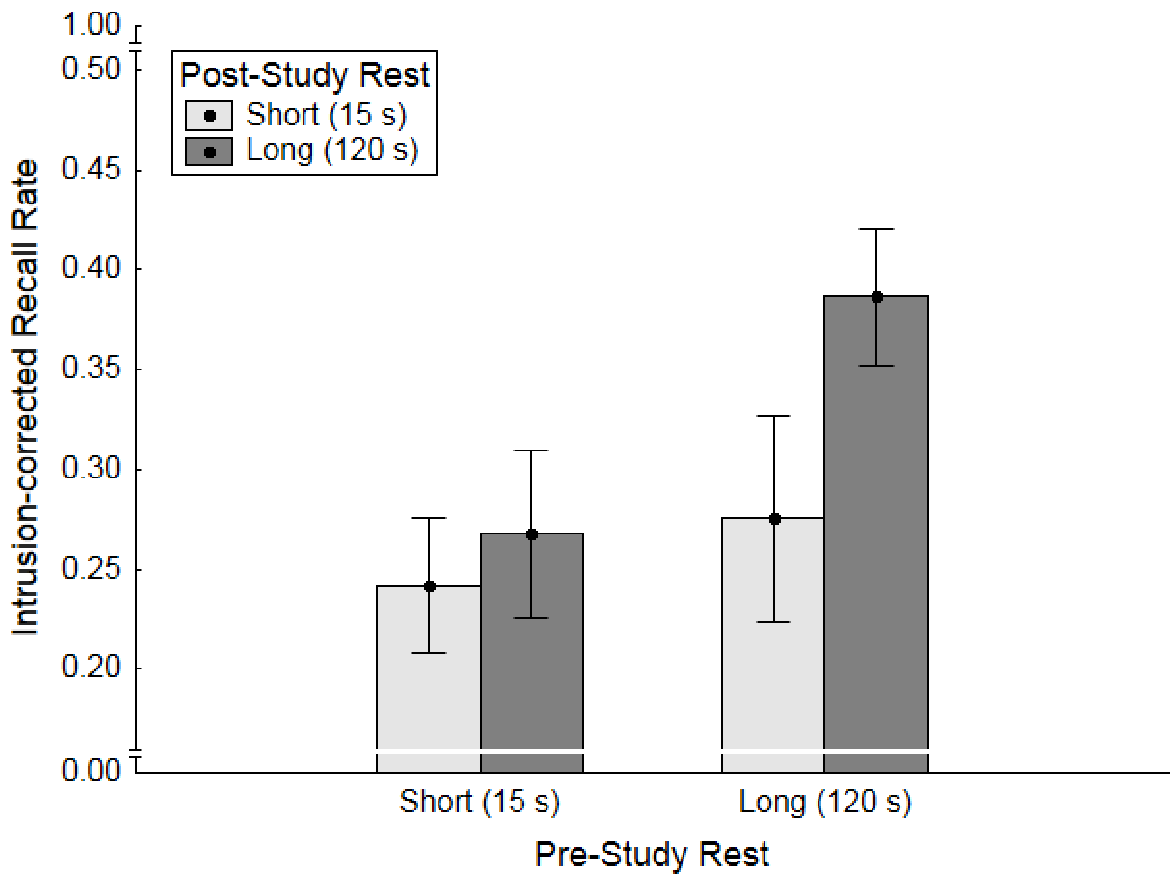

Post-Study Rest
Short (15 s)
Long (120 s)
Intrusion-corrected Recall Rate
1.00
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.00
Short (15 s)
Long (120 s)
Pre-Study Rest

Figure 4.

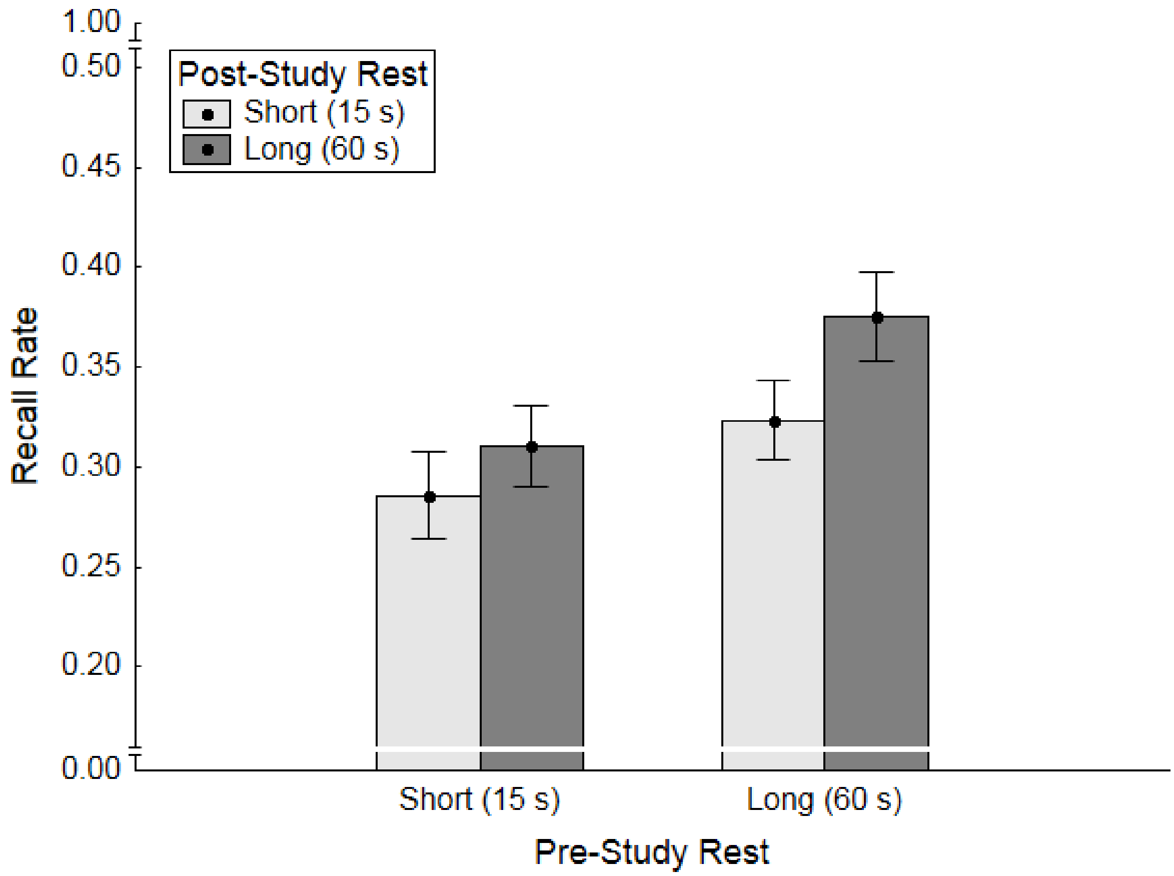
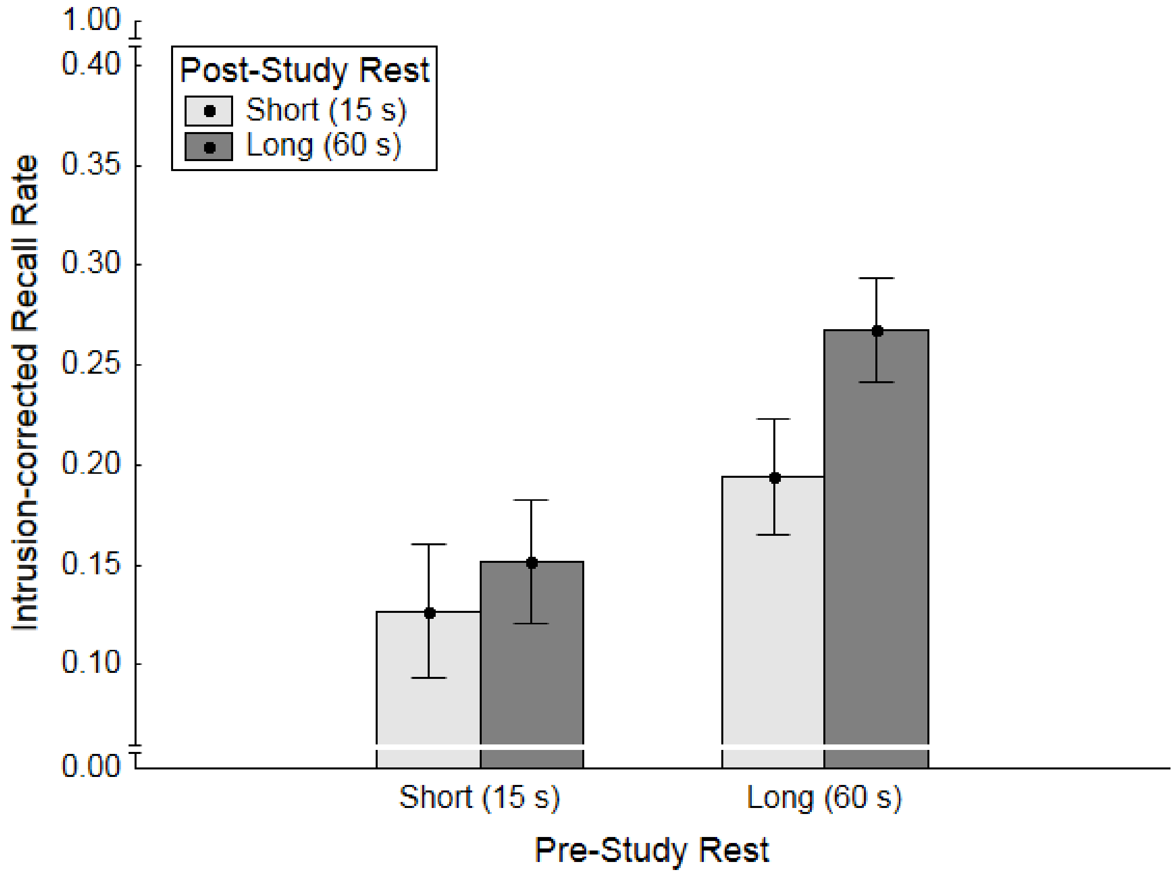

Post-Study Rest
Short (15 s)
Long (60 s)
Recall Rate
1.00
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.00
Short (15 s)
Long (60 s)
Pre-Study Rest

Figure 5.



Post-Study Rest
Short (15 s)
Long (60 s)
Intrusion-corrected Recall Rate
1.00
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.00
Short (15 s)
Long (60 s)
Pre-Study Rest