Can Sleep Enhance both Implicit and Explicit Processes?

Andrea C. Smyth (andrea.smyth@gmail.com)
University of Winnipeg, 515 Portage Avenue
Winnipeg, MB R3B 2E9 Canada

Shuichiro Taya (s.taya@qmul.ac.uk)
Experimental Biology and Psychology Centre, Queen Mary University London
London, E14NS, UK

Chris Hope (c.hope@surrey.ac.uk)
Dept of Psychology, University of Surrey,
Guildford, GU2 7XH, UK

Magda Osman (m.osman@qmul.ac.uk)
Experimental Biology and Psychology Centre, Queen Mary University London
London, E14NS, UK

Abstract

This experiment examined the effects of sleep on learning, while employing an experimental design that minimizes time of day and fatigue effects. Using a modified two-phase contextual cuing task, we show that sleep benefits consolidation and offline learning minimally, and hindered subsequent conscious awareness on an explicit memory test. These differential effects of sleep on implicit learning and explicit memory can be taken as evidence that these types of information are processed differently and based on entirely distinct memory stores.

Keywords: Contextual cuing; offline learning; sleep

Introduction

Although there is a lack of consensus concerning the exact function of sleep, recent empirical evidence substantiates claims that a good night's sleep is more than just a biological necessity. Playing an important role in homeostatic restoration, thermoregulation, tissue repair, immune control, and memory processing (Walker, 2008), sleep may just be Mother Nature's version of a miracle drug.

A key issue of interest is whether sleep can also lead to offline learning – that is, when sleep enhances learning such that performance following a nights sleep is comparably better than without a period of preceding sleep. Studies using associative learning tasks have demonstrated that indeed, sleep after learning shows offline consolidation of knowledge acquired during training (Walker & Stickgold, 2004). Furthermore, it is speculated that consolidation benefits are mediated by overnight neural reorganization of memory resulting in more efficient storage of information, affording improved next-day recall (Gais, Molle, Helms, & Born, 2002). Sleep before learning also appears to be critical for brain functioning. Specifically, one night of sleep deprivation markedly impairs hippocampal function, imposing a deficit in the ability to commit new experiences to memory.

Despite the apparent benefits of sleep on both implicit and explicit memory, recent evidence has suggested that many of the demonstrations of offline learning in the above studies are an artifact of the type of averaging methods used to reveal sleep effects, or biased by time-of-day testing (Keisler Ashe, & Willingham, 2007), and can often be artificially enhanced as a result of the gradual build up of amassed fatigue effects through repeated or concentrated training periods (Rickard, Cai, Rieth, Jones, & Ard, 2008). Rickard et al's (2008) demonstration of these factors involved training participants using a typical motor task in which people typed out a sequence of 5 button presses (with a reliably repeating sequence) across 12 training blocks and 2 test blocks. This research has serious implications, particularly because the criticisms apply to techniques commonly employed by many sleep studies (e.g., Gais et al, 2002; Robertson, Pasual-Leone, & Press, 2004; Wagner et al, 2004; Walker & Stickgold, 2004).

One concern with Rickard et al's (2008) study is that their criticisms are based on evidence from a motor learning task, in which fatigue effects are more likely to be generated, and so may not generalize to visual search tasks, or tasks involving explicit memory. Therefore the current study is concerned with examining the issues raised by Richard et al (2008), but using a task designed to examine both implicit and explicit processing in learning: the spatial contextual cueing paradigm (Chun & Jiang, 1998). Contextual cuing refers to improved visual search performance with repeated exposure to a configuration of stimuli. Participants are shown displays containing a set of 12 letter stimuli and are required to detect a target stimulus (a letter T) within the subset of distracter stimuli (11 letter L's). Crucially, the location of the target in half of the displays appears repeatedly with the same arrangement of the distracters surrounding it. This learning is expressed through the gradual development of search efficiency for these repeated displays, indicating that repetitive exposure to these distracter configurations results in the acquisition of a mental representation that becomes relied upon to guide search.

The benefits of employing the contextual cuing paradigm in the study are that massed practice involves visual search instead of motor processing and employs within-subjects comparisons between learned and random trials, and so the generalization of fatigue effects as claimed by Rickard et al. (2008) to other non-motor tasks can be examined. Moreover, contextual cuing has not previously been used as a task paradigm to examine offline learning in this manner (but see, Mednick, Makovski, Cai, & Jiang, 2009), but evokes the same insight into processes (implicit and explicit memory, visual perceptual learning) that are common to many tasks that have been used to study offline learning effects (e.g. sequence learning tasks, Fisher et al., 2002; word-pair memory tasks, Gais & Born, 2004; insight problem solving task, Wagner et al., 2004).

Many researchers claim that contextual cuing relies exclusively on implicit processing; therefore, participants showing more efficient visual search during the detection task should not show subsequent conscious access to this information in a test of awareness (Chun & Jiang, 1998; 1999; 2003; Chun & Phelps, 1999; Manns & Squire, 2001; Nabeta, Ono, & Kawahara, 2003; Pollman & Manginelli, 2009; Schankin & Schubo, 2009). However, this notion of a distinct presence of awareness is consistent with our own earlier findings (Smyth & Shanks, 2008), and other studies have also provided evidence of awareness occurring in contextual cuing (Brockmole & Henderson, 2006; Endo & Takeda, 2005; Olson & Jiang, 2004; Olson, Jiang, & Moore, 2005; Ono, Jiang, & Kawahara, 2005; Preston & Gabrieli, 2008; Vaidya, Huger, Howard, & Howard, 2007). Greene, Gross, Elsinger, and Rao (2007) confirmed that the hippocampus was involved with contextual cuing, even when recognition did not exceed chance (but see Preston & Gabrieli, 2008). Greene et al. (2007) argued that activation of the hippocampus during performance signals that the processing involved with encoding the complex associative relationships entailed in contextual cuing can only proceed intentionally. Such a result also implies that a behavioral dissociation between learning and awareness for a given piece of information may not necessarily reflect its possession of a unique implicit property, but instead may indicate that this information is represented at a lower level of quality or strength which makes it unable to support performance on an explicit test (Shanks, 2005).

In this study contextual cuing will be assessed using the original version of the detection task during a training phase, then the magnitude of the learning effect will be compared to contextual cuing ability 12 or 24 hours later. A modified titrated version of the detection task will locate the point at which participants are demonstrating learning at test by tailoring the length of the detection task during the testing phase for each participant according to the point at which he exhibited the same level of contextual cuing as occurred at the end of the training phase. After expressing significant learning, participants progress onto the explicit generation test. If unconsciously acquired contextual cuing knowledge is exclusive to a distinct implicit memory store, as proposed by the dual-systems theory, then we would expect the onset of a learning effect in the testing phase not to be accompanied by the ability to support conscious retrieval as revealed in a generation task.

Method

Participants

Forty participants (22 women) were recruited from the University of Surrey and University College London to take part in the experiment. All participants were between the ages of 19 and 34 years old (*M* = 23.97, *SD* = 4.16), and naïve to the purpose of the experiment. All participants received a baseline fee of £20 for attending both experiment sessions, and an additional 10 pence for each correct response during the generation task.

Participants were randomly assigned to one of four experimental groups: a 10 AM training session followed by a 10 PM testing session, 12 Hour No Sleep (*n* = 11); a 10 PM training session and a 10 AM testing session 12 hours later, 12 Hour Sleep (*n* = 10); a 10 AM training session and a10 AM testing session 24 hours later, 24 Hour AM (*n* = 10); or a 10 PM training session and a 10 PM testing session 24 hours later, 24 Hour PM (*n* = 9).

Design

The **training session** included a detection task which was a 2 x 2 x 30 (Time of Day x Repetition x Block) mixed factorial design. Time of Day (Morning or Evening) was manipulated between-subjects, and Repetition (Repeated and Non-Repeated) and Block (1-30) were manipulated within-subjects.

The **testing session** included a titrated-version of the detection task and an explicit generation test. The number of trials a participant received in the detection task was tailored individually according to the onset of contextual cuing, but all participants' data included at least 1 block of detection trials, and 30 blocks was the maximum they could complete. Therefore, the titrated detection task was a 2 x 2 x 2 x variable (Time of Day x Time Since Training x Repetition x Block) mixed factorial design, with Time of Day (Morning or Evening) and Time Since Training (12 hours or 24 hours) manipulated between-subjects, and Repetition (Repeated and Non-Repeated) and Block (varying from 1-29) manipulated within-subjects. The generation test was a 2 x 2 x 2 x 4 (Time of Day x Time Since Training x Repetition x Block) mixed factorial design.

Materials and Apparatus

The detection and generation tasks were modified versions of the contextual cuing task described in Smyth and Shanks (2008), and were conducted using Visual Basic software to generate all stimuli and measure participant responses. On each trial, the participant viewed a configuration of white 11 letter-L distracters and 1 rotated letter-T target against a grey background, and was asked to identify the orientation of the target letter (either left or right) in the display as quickly as possible. A set of 12 Repeated configurations of letters was presented in each block, while the remaining 12 trials in the block contained new configurations that were shown only once during the experiment (Non-Repeated configurations). A unique set of 12 Repeated and 720 Non-Repeated configurations was generated for each participant, and the order of presentation of Repeated and Non-Repeated configurations was randomized in each block.

All letter stimuli appeared in 30 pt. Arial font at a visual angle of 0.76° at a viewing distance of approximately 60 cm. The 21cm x 21cm screen was divided into an 8 x 8 grid of possible locations, and subdivided into an invisible 4 quadrant matrix. The spatial locations of the target letter Ts were evenly distributed across the four quadrants of the screen within each block and configuration condition to control for location probability effects. The locations of the target letter T in the Non-Repeated configurations shown in each block were always chosen from the same set of 12 counterbalanced spatial locations generated at the beginning of the task. Each T was rotated 90° to the right or left, and each L was shown at 0°, 90°, 180°, or 270°. The location of all letters in each Repeated configuration were kept constant with each presentation, with the exception of the varying and unpredictable orientation of the letter T: the location, but not the orientation, of the T was predictable from the distracter configuration on Repeated trials.

The generation task was made up of 4 blocks of 24 trials each. The format of a single block was identical to a block in the detection task: 12 Repeated configurations and 12 Non-Repeated configurations shown in a random sequence in each block. The Repeated configurations were carried over from the detection task, while a new set of 48 Non-Repeated configurations was created specifically for the generation task. However, all of the configurations shown in the generation task differed from the detection task stimuli in that all T's in the detection configurations were replaced with L's.

Procedure

The experiment began with instructions to participants about the detection task. The instructions provided onscreen examples of configuration stimuli and the 2 possible orientations of the T, and asked participants to locate the letter T within the configuration of Ls then respond by indicating the direction it is pointing using the left and right arrows on the keyboard. Participants were advised to respond quickly and accurately, but they were not informed that they should pay attention to any of the configurations for patterns or repetitions. The main experiment began after six practice trials to establish task familiarity. The presentation of each configuration was preceded by an orienting white dot (1 cm x 1 cm) for 1 sec in the centre of the screen. Each configuration was displayed until a response was made, then auditory feedback was provided to the participant according to the accuracy of the response. A high-pitched tone signified a correct answer, and a longer, low-pitched tone signified an incorrect answer. Each individual trial was separated by a further 700 ms inter-trial-interval. The blocks of detection trials were separated by a break of at least 10 sec., after which participants could either continue resting if necessary, or press the space bar to progress to the next block. After the detection task, the training session concluded and participants were asked to return for a training session either 12 or 24 hours later.

The testing session included a detection task similar to that used during training, except that the duration task was contingent upon the participant's performance. After each block of trials, an independent samples t-test was used to compare the difference (i.e., contextual cuing) between the RTs of Repeated and Non-Repeated configurations at the end of each block of trials to the difference between the RTs of Repeated and Non-Repeated configurations in the last of block of the detection task during the training session. If the amount of contextual cuing during testing was statistically larger than the amount of contextual cuing that occurred during training this detection task ended, otherwise the participant received another block of detection trials. When participant showed little (< 5 msec) or no sign of contextual cuing at the end of the training phase, the program calibrated the length of the detection task using a paired-samples t-test to compare the RTs of Repeated and Non-Repeated configurations at the end of each block of trials. If a participant's detection performance in a given block was statistically faster ($p < .05$) for Repeated configurations than for Non-Repeated configurations, it was inferred that contextual cuing had occurred. All participants received at least 1 block, but no more than 29 blocks of detection trials. An accuracy criterion of 20/24 correct responses was imposed to ensure contextual cuing was not contaminated by inaccurate search performance. After expressing significant learning, the detection task ended, and participants answered questions designed to assess their awareness for the repeated configurations.

After completing the test detection task, participants received instructions for the generation task; however, the program terminated if a participant failed to show contextual cuing during the titrated detection task after 30 blocks of trials. The instructions informed participants that a repetition of certain configurations had occurred throughout the detection task, and that the generation task would gauge their knowledge of these repeated configurations. The task requirements were presented as a slight variation of the detection task, in that participants were told that they would see a set of configurations similar to those seen previously, but this time the T would be replaced with an L. The instructions for the generation task prompted participants to respond with the quadrant location of this substitute L using the numeric keypad on the keyboard. It was emphasized that responding as accurately as possible was a priority in this phase of the experiment, and that it was more important to concentrate on the correct answer, not the time taken to respond.

Results

General Performance during Training Session

Two participants from the 24 hour AM and the 24 hour PM conditions were excluded from all data analyses due to poor response accuracy in the detection task of the training session, i.e., their mean accuracy was more than 3 standard deviations below the overall group mean of 98%. There were no group differences in overall accuracy, F's < 2.14, p's > .11, or in detection accuracy between Repeated and Non-Repeated configuration responses in any group for the detection task in the training or testing sessions, all t's < 1.84, p's > .10.

The median RTs for correct responses for each set of Repeated and Non-Repeated configurations were calculated in each block of the detection task from the training session. A repeated-measures ANOVA was conducted to analyze whether a contextual cuing effect was present with Time of Day (Morning or Evening) as a between-subjects variable, and Repetition (Repeated versus Non-Repeated) and Block (1-30) as within-subjects variables. A significant main effect of Repetition, $F(1, 29) = 9.73$, $p < .004$, and a highly significant Repetition x Block interaction, $F(29, 1044) = 2.18$, $p < .001$, demonstrated that reliable contextual cuing was present, as characterized by faster detection of the target in Repeated compared to Non-Repeated displays. A main effect of Block also emerged from this analysis, $F(29, 1044) = 35.65$, $p < .001$, meaning that acclimation to the task led to faster responding. Overall, there was no effect of Time of Day, F's < 1.32, p's $> .11$, suggesting that whatever stage training took place had no bearing on performance. However, the contextual cuing effect (Non-Repeated RT – Repeated RT) in the last block of the detection task was numerically (though not statistically) larger in the Evening group ($M = 67$ ms, $SD = 119$) in relation to the Morning group ($M = 31$ ms, $SD = 104$), $t(36) = 1.00$, $p > .30$, which gives some indication that performance may have been confounded by time of day effects. Perhaps the design of this study was not powerful enough (0.25) to detect this difference in performance during the training phase ($d = .32$)

These results are an illustration of the inconsistency of the learning that takes place in a contextual cuing task (Smyth & Shanks, 2008), and cause us to conclude that some signs of contextual cuing, though neither substantial nor reliable, were present in both the Evening and Morning participant groups by the end of the training session.

General Performance during Testing Session

Given that the number of blocks differed between participants, but all participants performed at least 1 block of trials, we subject RTs from the last block of detection trials in the testing session to a mixed-measures ANOVA with Repetition a within-subjects variable, and Condition (12 Hour No Sleep, 12 Hour Sleep, 24 Hour AM, or 24 Hour PM) as a between-subjects variable. There was a main effect of Repetition, $F(1, 34) = 94.55$, $p < .001$, confirming faster target detection for Repeated configurations by the final block of testing. More importantly, this analysis also suggests that in general the amount of contextual cuing that occurred during the testing phase was high, since there was neither a main effect of Condition, $F < 1$, nor Repetition x Condition interaction, $F < 2.05$, $p > .12$.

Further planned comparisons of the amount of contextual cuing (Non-Repeated –Repeated) in the last block of the testing session by Time of Day, Sleep and Time Since Training were also performed. If contextual cuing is susceptible to time of day confounds, as implied by the difference in detection performance of the Morning and Evening groups in the last block of the training phase, then we would expect this to carry over to the testing phase. However, there was no indication that when people were tested (the 24 Hour PM or 12 Hour No Sleep groups) affected performance, $t(36) = 0.16$, $p > .8$, and the time that elapsed between training and test sessions also didn't affect performance, $t(36) = 1.20$, $p > .2$. However, participants who did not sleep between training and testing sessions (12 Hour No Sleep participants) on average showed much less contextual cuing during the testing session ($M = 115$ ms, $SD = 78$ vs. $M = 181$ ms, $SD = 116$), but this effect was only marginally significant, $t(36) = 1.67$, $p = .10$.

In summary, contextual cuing knowledge did persist across training and testing sessions. While the length of time interval between these sessions and the time of day of test did not seem to affect later performance, there was some evidence to suggest that sleeping between training and test benefited overall performance during the testing session.

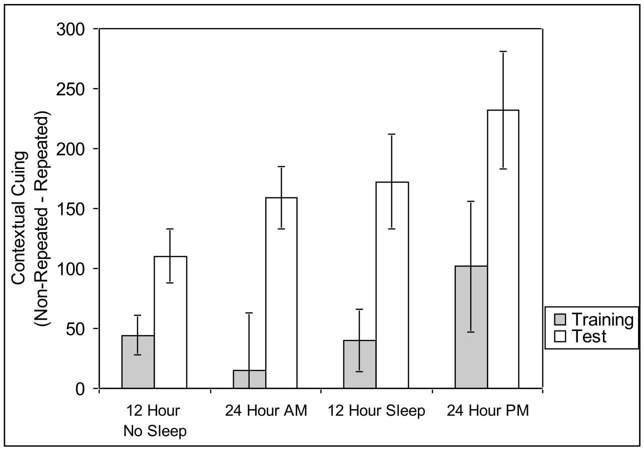

Figure 1: Mean contextual cuing scores (ms) in the final block of the training and testing sessions.

Effects of Sleep (offline) on Implicit Learning

Offline learning was quantified by taking the difference between participants' contextual cuing scores (Figure 1) in the last block of trials between the training and the testing sessions. If offline learning transpired, we would expect this difference to be positive. Pairwise comparisons of contextual cuing during training and testing sessions confirmed that offline learning took place in all four conditions, t's > 2.28, p's < .05. There appeared to be a difference in the amount of offline learning shown, with the most offline learning occurring in the 24 Hour AM condition ($M = 144$ ms, SE = 57); the least in the 12 Hour No Sleep condition ($M = 66$ ms, SE = 29); and a moderate amount of improvement in the 24 Hour PM ($M = 130$ ms, SE = 56) and 12 Hour Sleep conditions ($M = 132$ ms, SE = 50). However, there was no main effect of Condition in a one-way ANOVA of these offline learning scores, $F < 1$, and planned comparisons of offline learning by Time of Day, Sleep and Time since Training also showed no sign of learning differences, t's < 1.26, p's $> .20$.

Recall that the number of blocks in the detection task of the testing session depended on how long it took participants to meet their customized learning criterion. The number of blocks participants received on average seemed to vary between groups by the time that had elapsed between the training and testing sessions with shorter time intervals leading to faster recovery of contextual cuing, (12 Hour, *M* = 5.70 blocks, *SD* = 8.34; 24 Hour, *M* = 9.72 blocks, *SD* = 11.37), but this difference was not reliable, *t*(36) = 1.25, *p* > .20. There was no effect of Time of Day on the length of the detection task in the testing session (Morning, *M* = 8.65, *SD* = 10.30; Evening, *M* = 6.44, *SD* = 9.78), *t*(36) = 0.68. *p* > .50. However, it took longer on average for the Sleep group to show contextual cuing (*M* = 8.9 blocks, *SD* = 10.7) in relation to the No Sleep group average (*M* = 3.9 blocks, *SD* = 7.1), though, this difference was not statistically significant, *t*(36) = 1.36, *p* > .17.

Effects of Sleep on Explicit learning

Results from the generation test were analyzed using a repeated-measures ANOVA with Repetition and Block (1-4) as within-subjects variables and Condition as a between-subjects variable. The main effect of Block and the Block x Condition interaction were not significant, *F*'s < 1.23, *p* > .29, meaning that generation accuracy did not differ in any single block. Despite a null main effect of Repetition and Repetition x Block interaction, *F*'s < 2.13, *p*'s > .15, the Repetition x Block x Condition interaction, *F*(9, 102) = 2.75, *p* < .006; and the Repetition x Condition interaction was marginally significant, *F*(3, 34) = 2.33, *p* = .09. This result suggests that generation accuracy was different across blocks by participant group.

Pairwise comparisons of performance overall and block-by-block for Repeated and Non-Repeated displays were performed by Condition to determine the source of the aforementioned statistical interactions. Although overall generation accuracy across the entire task was only marginally better for Repeated vs. Non-Repeated displays in the 12 Hour No Sleep condition, *t*(10) = 2.02, *p* = .07; it bears mentioning that significant generation ability was also present in this condition in both Blocks 2 and 3 of the task, t's > 2.78, p's < .02, all other t's < 1. The 24 Hour AM group also showed marginal evidence of higher generation accuracy for Repeated configurations overall in the task, *t*(8) = 2.06, *p* = .07, and in Block 1 individually, *t*(8) = 3.04, *p* < .02. However, higher accuracy for Repeated displays overall or block-by-block did not result in the 24 Hour PM and 12 Hour Sleep groups, t's < 1.53, p's > .17, and so we can assume participants in the 24 Hour PM and 12 Hour Sleep groups did not possess explicit awareness of their contextual cuing knowledge.

An additional ANOVA of generation task data with Sleep as a between-subject's variable was used to examine whether group differences in generation performance can be accounted for by the presence or absence of sleep before the testing session. This suspicion was confirmed by a significant three-way Repetition x Block x Sleep interaction, F(3, 108) = 7.79, p < .001; all other F's < 2.57, p's > .11. Pairwise comparisons within each block showed that response accuracy for Repeated trials only exceeded that of Non-Repeated trials in Block 1 of the generation task in the Sleep group, t(27) = 2.29, p < .03; all other t's < 1.17, p > .25, while the same analyses in the No Sleep group showed that significantly higher generation for Repeated displays occurred in Blocks 2 and 3, t's > 2.88, p's < .02. Separate individual ANOVAs were used to look at the effects of Time of Day and Time Since Training as between-subjects variables, but the main effects of Repetition and Block and all interactions with Time of Day and Time Since Training were unreliable, F's < 2.67, p's > .11.

Table 1: Mean Generation Performance across Sleep and Non-Sleep Conditions.

	Repeated Generation Accuracy	Non-Repeated Generation Accuracy
12 Hour No Sleep	***M* = 28.60%** *SD* =8.89%	***M* = 23.67%** *SD* =7.35%
12 Hour Sleep	***M* = 20.00%** *SD* = 10.81	***M* = 24.38%** *SD* = 10.58
24 Hour Sleep AM	***M* = 19.21%** *SD* = 12.45%	***M* = 15.05%** *SD* = 9.25%
24 Hour Sleep PM	***M* = 18.75%** *SD* = 17.00%	***M* = 14.84%** *SD* = 14.37%

A reasonable conclusion to draw from these analyses is that the No Sleep group showed the most evidence of explicit awareness of contextual cuing knowledge, while this same conscious ability was not present to the same degree (or at all) in the other participants.

Discussion

In sum, sleep does promote offline learning of contextual cuing knowledge, despite the initial effects of time of day on knowledge acquisition. However, the consolidation benefits of sleep on offline learning in contextual cuing were at best only marginally better than that which occurred after a sleepless interval between training and testing sessions.

Explicit generation knowledge failed to show the benefits afforded by the offline processing during sleep, and was highly susceptible to temporal degradation intrinsic to this two phase contextual cuing experiment. Given that it has been established previously that a contextual cuing effect is accompanied by an awareness effect when the design of the generation task possesses adequate power and reliability and immediately follows the detection task (Smyth & Shanks, 2008), we can assume that the smaller magnitude of the awareness effect in the generation test shown in participants in the Sleep condition was an indication that sleep does not prevent degradation of the informational trace that supports performance during the generation test.

The results of this experiment indicate that there may be a point at which knowledge may be accessible only via unconscious facilitation mechanisms after sleep, and therefore not immediately available to conscious processing. The different contributing influences on contextual cuing and generation obtained also lend some credence to the popular argument proposed by dual-systems perspective of memory. However, it is still possible that when learning and awareness are measured simultaneously, these abilities can coincide (unconscious acquisition and conscious retrieval) within the same task. Given the general problems with measures of unconscious memories in the contextual cueing paradigm (Smyth & Shanks, 2008), further experimentation with more participants and greater control over variables pertaining to sleep is needed to cement claims that offline learning differentially affects implicit and explicit memory and learning processes.

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