The Long Range Effect of Sleep On Episodic Memory

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In past studies on the relationship between sleep and episodic memory, enhanced recall performance has usually been observed with short retention intervals of eight hours of sleep or waking. Experiments addressing the question as to whether this effect is also detectable for longer retention intervals of 16 hours up to six days have been scarce and particularly inconclusive. The present study therefore examined free and cued recall of a categorized word list in a 2 _ 2 design, completely between subjects, with a period of either sleep or wakefulness following initial learning and the recall test administered either seven or 72 hours later. Results indicated superior memory performance after the long, but not after the short retention interval. **(Sleep and Hypnosis 2007;9(1):24-29)**

Key words: sleep, episodic memory, retention interval, long-term effect

INTRODUCTION

Today's ongoing debate about a potential involvement of sleep in enhancing memory performance (1,2) was originally inspired by early investigations reporting superior episodic recall after interpolated periods of two to eight hours of sleep as opposed to waking (3,4). Subsequent investigations partially confirmed these results for retention intervals of similar length (5-9) although other factors such as circadian phase (10,11), different sleep stages (12,13), and sleep cycle integrity (14) soon turned out to play a critical role as well. Due to their limited duration the retention intervals that were used in these studies were either filled with pure sleep or pure waking.

From any presumption of a functional involvement of sleep in memory processing it follows that at least part of the direct sleep memory effect should remain stable over intermediate time periods. However, empirical evidence becomes scarce and less consistent when we turn to the impact that sleep has on episodic memory in the long run. Table 1 summarizes the results of six studies which systematically tested prolonged retention intervals of up to six days following eight hours of post-learning sleep or waking. As may be observed, the overall picture is rather confusing even though nonsense syllables served as learning material in all of the studies but one (6) which used paired associate lists instead.

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Table 1. Results of studies comparing recall as a function of post learning sleep or waking after different retention intervals

	Retention interval [h]					
Study	16	24	48	72	96	144
Benson and Feinberg (5)		ø				
Benson and Feinberg (6)	ø	+				
Gibb (17)		ø	+	ø	ø	
Graves (15)		ø	ø	+	+	+
Idzikowski (8)	+	+				
Richardson and Gough (16)		ø	ø			+

+: superior recall after sleep, ø: no difference between recall after sleep and waking.

Results for time periods of more than 48 hours are particularly rare as they come from only three studies, two of which allow for only limited conclusions. Graves (15) found a sleep benefit effect for intervals of 72 to 144 hours, but these data have to be viewed with caution since the investigation was designed as a single case study with the experimenter acting as her own subject. Following the report of Richardson and Gough (16), Gibb (17) failed to replicate Graves' results in performing a repeated measures experiment with six subjects. However, not much can be said about the methodological adequacy of his study since the original manuscript has never been published. Almost three decades later in a methodologically sound approach Graves' finding was replicated for the 144 hour interval (16).

Despite such an intricate state of affairs, to our knowledge no other attempt has been made to assess the long term effect of sleep on retention ever since. The present study was therefore designed to compare verbal recall after either post-learning sleep or wakefulness in the short range of 7 h, which served as a control condition, and in the long range of 72 h. For both time intervals we predicted superior retention when acquisition was followed by sleep.

METHOD

Subjects

Sixty university students (46 female, 14 male) with a mean age of 23.3±4.7 years participated in the experiment in exchange for financial compensation. All subjects were healthy nonsmokers with a regular sleep schedule. They were obliged to refrain from alcoholic beverages, caffeine, and daytime napping beginning 12 hours before and continuing throughout the entire experiment. All participants gave written consent to take part in the study after the experimental protocol had been fully explained.

Memory testing

The learning material consisted of a list of 56 nouns with four words each belonging to one of 14 categories. All items were taken from the category norms provided by Battig and Montague (18) and were translated into German. To prevent ceiling (guessing) and floor effects during later category-cued recall, only words with category-association ranks between 4-10 were selected for creating the lists.

During learning, the 56 words were presented individually on a computer screen with a rate of one word per 1500 ms and a delay of one second between each word. The complete list was presented twice in succession, with different fixed random orders of words for both sequences. Words were not blocked according to category, nor were the category names presented. The subjects were instructed to pay attention to the presented words and to repeat each word overtly or silently. To prevent subsequent active rehearsal, the learning session was immediately followed by a brief cover task. Subjects had to rate 16 non-aversive pictures taken from the International Affective Picture System (19) on their perceived level of pleasantness and arousal. Together, the learning and the dummy session took about 10 min.

Delayed memory performance at the end of the different retention intervals was assessed by two separate software-driven recall sessions. During the first test, subjects were given 10 minutes to freely recall as many of the previously presented words as possible. They were instructed to enter the remembered words into an empty text field providing unlimited line space. The second test was a 10 min cued recall test. Fourteen text fields with the category labels serving as cues were presented simultaneously on the screen. Subjects were instructed to assign each remembered word to the correct category. Each text field was limited to four lines and no white space character was accepted as input, so that a maximum of four words could be entered. This way, subjects were not able to produce hits by simply listing all members of a given category that came to their mind.

Design and procedure

The study followed a 2 _ 2 factorial design. The first factor was defined by either night sleep or daytime wakefulness subsequent to the initial learning session. The second factor was the overall retention interval of either 7 h or 72 h. Both factors were varied between subjects. We decided to apply a daytime instead of a nighttime interval for the two waking conditions to prevent effects of sleep deprivation and hence severe fatigue on recall in the 7 h wake condition as well as to ensure comparability with studies of previous authors (cp. Table 1) all using the same design of comparing night time sleep with daytime wakefulness.

Subjects in the sleep conditions reported to the laboratory at 23.30 h to prepare for retiring. Thereafter, they underwent the learning session and were put to bed with lights turned off immediately. After seven hours, they were awakened by the experimenter. Subjects with a 7 h retention interval performed the recall session immediately thereafter. Those with a 72 h retention interval were dismissed from the laboratory and returned for recall three days later at 23.30 h, i.e. 72 h after initial learning. Subjective sleep quality was assessed by a nine-item scale of a standardized self-questionnaire (20). In both wake conditions, subjects had their original learning at 08.30 h and were subsequently dismissed from the laboratory to follow their usual daytime activities. They returned for recall the same day at 15.45 h (7 h condition) or three days later at 08.30 h (72 h condition).

RESULTS

Self-reported sleep quality (mean± standard deviation) was 3.82±0.67 in the sleep / 7 h condition and 3.68±0.56 in the sleep / 72 h condition. These values are only slightly below the reported norm values (20) of healthy subjects (3.97±0.82) and therefore indicate adequate subjective sleep quality.

By visual inspection, subjects in both sleep conditions reproduced more words on the free recall task (Figure 1A) as well as on the categorized recall task (Figure 1B) than their wake counterparts. The average (mean±

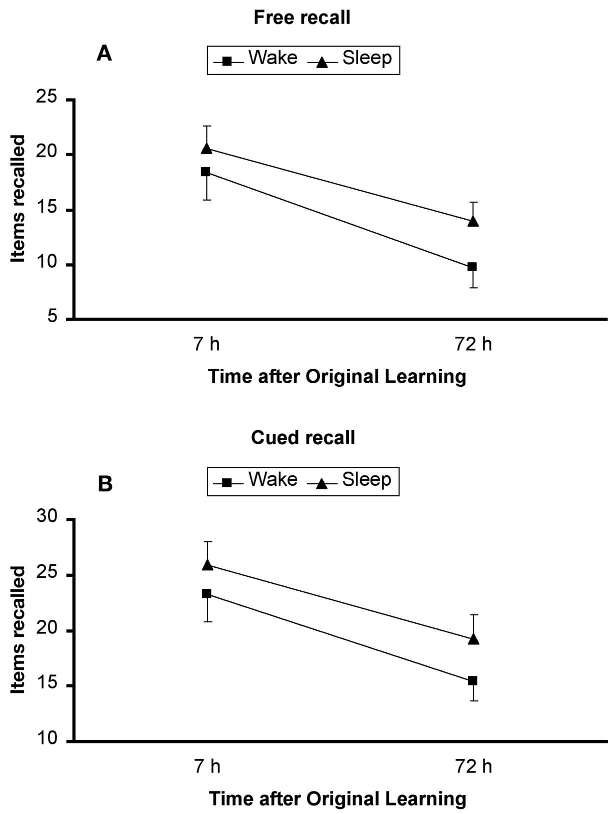

Figure 1. Number of words (M ± SEM) retained after retention intervals of 7 h and 72 h when original learning was followed by either sleep or wakefulness. A. Free recall. B Cued recall.

standard error of mean) free recall rate after seven hours was 20.53±2.46 in the sleep condition and 18.33±2.04 in the wake condition. As expected, retention declined markedly over time, yielding free recall rates of 13.93±1.78 and 9.67±1.74 in the 72 h sleep and wake condition respectively. Cueing by category labels improved recall in all groups to an extent of 5.10 items on average. Cued recall was 25.86±2.94 and 23.27±2.11 after seven hours of sleep and waking and 19.20±1.93 and 15.40±2.18 for the respective 72 h retention conditions.

The product-moment correlation between free recall and cued recall was r= 0.95, so that both scores virtually measured the same property. We therefore restricted the inferential statistics to a univariate analysis of the free recall measure. Pairwise planned comparisons (sleep vs. wake after 7h, sleep vs. wake after 72 h) using one-tailed t tests and the pooled mean error variance (MSE= 61.52) revealed an insignificant effect of sleep for the 7 h retention interval [t(56)= 0.77; P= .223] as well as for the 72 h retention interval [t(56)= 1.49; P= .071]. Note, that the latter comparison reaches statistical significance when the overall error variance is replaced by the individual error variances of the two involved groups (sleep / 72 h: s2= 47.75; wake / 72h: s2= 45.56) in the calculation of the t statistic [t(28)= 1.71; P= .049].

DISCUSSION

With the present study we aimed to clarify whether the beneficial effect of sleep on retention is stable over a prolonged time period of 72 hours. The seven hour retention interval was included as a control condition, but contrary to predictions, no short term sleep advantage could be demonstrated. Regarding memory performance after 72 hours, the statistical inference is not definite, but does suggest a beneficial effect from sleep over a longer time frame. This pattern of results - sleep becoming effective only after a certain time span has elapsed - is similar to the findings obtained by Graves (15) and Richardson and Gough (16), but stands in contrast to the outcome of Gibb's (17) experiment. From a methodological viewpoint it should however be noted that recall in the sleep / 7 h condition might have been higher with a longer interval between awaking and testing. Although other studies with a comparable test schedule (13,21) did find significant effects in favor of sleep, the possibility that recall after 7 h sleep was hampered by effects of sleep inertia cannot entirely be ruled out.

Turning back to Table 1, the situation somewhat resembles the state of affairs concerning rapid eye movement (REM) sleep windows. These are supposed to represent critical episodes of increased REM sleep following exposure to learning demands which, when disrupted, impair memory consolidation of the learned task. While the basic idea is straightforward, the moving character of REM windows - their reported time of occurrence ranging between one and 56 hours after learning (22) - is an issue of major concern (23).

Although from a theoretical viewpoint the assumed time dependency of the sleep-related memory facilitation is difficult to explain, consolidation theory might offer a preliminary account. Consolidation theory proposes the gradual shift of newly acquired memories from an initially volatile state to a stabilized memory trace which is less fragile and less sensitive to disruption. Since the precise time course of the underlying process appears to be a free parameter of the theory (24), it may be speculated that post-learning sleep offers optimal initial conditions for triggering consolidation but that the entire process in fact continues far beyond that period. Thus, the effectiveness of the initial sleep period would not become obvious until complete termination of the process. Of course, this approach remains somewhat fuzzy as long as the precise duration of the presumed sequence of events is not specified.

As was outlined in the introduction, sleep has been shown many times to enhance episodic recall in a short time frame. However, the relationship between sleep and episodic memory seems to be neither simple nor robust (25,26). Other factors appear to contribute equally or even more in determining what is retained and what is not, and altering one of them is likely to change the overall picture. Accordingly, several investigators found no effect of sleep on episodic memory when they systematically varied factors such as circadian phase (10,11), amount of rapid eye movement sleep (27), emotional salience (28), significance of the learning material (29), and level of cerebral acetylcholine (30). The time span between acquisition and retrieval might be yet another factor contributing to the complicated relationships.

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