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An ultra short episode of sleep is sufficient to promote declarative memory performance

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SUMMARY Various studies have demonstrated that a night of sleep has a beneficial effect on the retention of previously acquired declarative material. In two experiments, we addressed the question of whether this effect extends to daytime naps. In the first experiment we assessed free recall of a list of 30 words after a 60 min retention interval that was either filled with daytime napping or waking activity. Memory performance was significantly enhanced after napping as opposed to waking but was not correlated with time spent in slow wave sleep or total sleep time within the napping condition. The second experiment was designed to clarify the role of total sleep time and therefore included an additional third group, which was allowed to nap for no longer than 6 min on average. In comparing word recall after conditions of no napping (waking), short napping, and long napping, we found superior recall for both nap conditions in contrast to waking as well as for long naps in contrast to short naps. These results demonstrate that even an ultra short period of sleep is sufficient to enhance memory processing. We suggest that the mere onset of sleep may initiate active processes of consolidation which – once triggered – remain effective even if sleep is terminated shortly thereafter.

KEYWORDS declarative memory, napping, recall, retention, sleep

INTRODUCTION

As research on the effect of sleep on memory rapidly proceeds, an increasing number of studies ultimately suggest a functional significance of the sleeping brain for the processing of newly acquired information (Stickgold and Walker, 2005). Whereas, early studies typically focused on declarative memory tasks like nonsense syllables, word lists, and paired associate lists (Benson and Feinberg, 1975, 1977; Ekstrand, 1967; Hockey *et al*., 1972; Idzikowski, 1984; Jenkins and Dallenbach, 1924; Lovatt and Warr, 1968; Nesca and Koulack, 1994), more recent research also established a sleep-related memory facilitation for a variety of perceptual (Fenn *et al*., 2003; Stickgold *et al*., 2000) and motor skills (Fischer *et al*., 2002; Walker *et al*., 2002), and even for complex cognitive tasks such as gaining insight into hidden rules or schemas (Wagner *et al*., 2004).

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While many of the above-mentioned investigations demonstrated a sleep memory effect by comparing a full night of sleep with an equivalent period of waking, bi- and polyphasic sleep patterns are abundantly encountered in mammalian and non-mammalian species (Tobler, 1989). Even within the individual human lifespan, the monophasic night sleep placement that many adults are accustomed to seems to be limited to a period where the sociocultural demands oblige a synchronization of educational and productive duties. However, polyphasic sleep patterns are ubiquitous in early infancy and are resumed in the elderly when more permissive schedules allow for daytime napping (Webb, 1989).

Given the relative robustness of the night sleep effect on declarative memory on the one hand and the widespread presence of polyphasic sleep cycles on the other, it might be speculated that a sleep-related memory enhancement also applies to short episodes of napping which usually consist mainly of stage 1 (S1) and 2 (S2) sleep, but of only little or no slow wave sleep (SWS) and rapid eye movement (REM) sleep as compared with a regular night sleep period.

In this respect, three studies with similar designs and nearly identical tasks but contradicting results have been published recently. Tucker *et al.* (2006) as well as Backhaus and Junghanns (2006) investigated the effectiveness of a 1-h daytime nap in promoting the acquisition of a list of 40 word pairs in comparison with a wake control group. While the first study did find a significant sleep memory effect, no reliable difference between sleeping and waking was found in the second. One reason for this discrepancy might have been the different amounts of SWS, subjects obtained during napping. Although total sleep time (TST) was nearly identical in both studies (47.0 and 45.5 min), subjects in the Backhaus and Junghanns experiment obtained only 8.7 min of SWS while those of Tucker *et al.* had as much as 22.4 min of SWS.

Schabus *et al.* (2005) also used a 1-h sleep interval and a paired associate word list to assess the effect of napping. However, because of the lack of a waking control group, their study is limited to correlational interpretations. Nevertheless, when subjects were split into two groups, one of which had obtained SWS during the napping episode and one of which had not, a significant over-nap improvement was only found for subjects with SWS. Similarly, Backhaus and Junghanns demonstrated for their data that recall improvement was significantly higher for SWS nappers than for non-SWS nappers. Tucker *et al.* (2006) on the other hand reported an insignificant correlation between individual time spent in SWS and performance improvement over the napping episode. Discrepant results between different studies also occurred with regard to TST, for a significant positive correlation with recall improvement was found by Schabus *et al.*, but not by Tucker *et al.* (Backhaus and Junghanns (2006) did not report this statistical value).

To summarize, findings concerning a 'nap memory effect' for declarative tasks are found to be scarce and contradictory in at least three respects: (i) Is there a beneficial effect of daytime naps on declarative memory at all (one study says yes, one says no)? (ii) If so, is this effect mediated by SWS (two studies say yes, one says no) or by (iii) TST (one study says yes, one says no)? To help clarify the issue, the present paper reports two experiments on the effect of daytime napping on declarative memory. In the first experiment, we assessed explicit word list recall after a 1-h retention interval which was filled with either daytime napping or waking activity. In the second experiment, we added a third group which was allowed to sleep for no longer than 6 min on average within the 1-h retention interval. This was performed to obtain direct (causal) instead of correlational evidence concerning the role of TST.

EXPERIMENT I

Method

Participants

A sample of 26 university students (19 female, seven male) aged between 20 and 29 years (mean = 24.8) participated in the experiment in exchange of financial compensation. All subjects were healthy non-smokers reporting a regular night sleep schedule and the absence of sleep-related problems or psychoactive medication. All participants gave written consent to take part in the study after the experimental protocol had been fully explained. One subject was excluded from data analysis because she had been unable to sleep in the napping condition.

Memory task

Two parallel lists of 30 adjectives equated for concreteness, imagery, meaningfulness, evaluation, potency, activity, word length, and frequency of use were created with the software program provided by Lahl and Pietrowsky (2006a) and printed on separate paper sheets. During the learning sessions, subjects received one of the lists and were informed that they had 2 min time to carefully read all the words to memorize as many of them as possible for later testing. They were also told that the order of words was irrelevant for scoring. At the end of the 1-h retention interval, subjects were orally tested for free recall of the list, which was tape-recorded. Subjects had an unlimited amount of time for report.

Design and procedure

Each subject underwent both the nap and the wake condition on two different occasions with a washout period of one week between sessions to prevent carry-over effects. The order of conditions and list presentations was completely counter-balanced across subjects who were not informed as to their individual order. The retention interval was always scheduled from 13.30 to 14.30 h. Assuming that the constraints of the counterbalanced repeated measures design we adopted were adequate to equalize the level of initial learning across conditions, this level was not directly tested by means of immediate recall to prevent possible ceiling effects caused by overlearning. For the study days, subjects were obliged to rise not later than 08.00 h and to refrain from alcoholic beverages, caffeine, and napping 12 h before embarking on the experimental sessions.

In the sleep condition, subjects reported to the sleep laboratory at 13.00 h. Application of electrodes for standard polysomnography always took about 25 min. When subjects had finished the learning session, they were put to bed in a sound attenuated sleep chamber to enable napping. Sleep was monitored according to standard criteria (Rechtschaffen and Kales, 1968) throughout the retention interval. After 50 min subjects were awakened by calling their name over the intercom. Ten minutes later, when electrodes had been removed and subjects were fully awake, they were tested for recall. In the wake condition, participants spent the period between learning and testing in playing simple computer games. To prevent direct effects of retrograde interference, the selection of available games was restrained to games of a strictly non-verbal nature (picture card games, games requiring visuomotoric skills or mathematical strategy).

Data analysis

Sleep recordings were analyzed off-line according to standard criteria (Rechtschaffen and Kales, 1968). Relevant sleep parameters were S1 sleep onset latency (SOL), TST, and amounts of sleep stages 1, 2, and SWS. Recall scores after waking and napping were tested for a significant effect of conditions by a paired *t*-test and partial Eta-squared (η_p^2) was calculated as index of effect size. The supposed recall gain because of napping was operationally defined as the difference between words recalled after sleep and words recalled after waking. Pearson product–moment correlations were calculated between sleep parameters and recall gain and were subjected to *t*-tests for correlation coefficients.

RESULTS

Table 1 summarizes the sleep parameters in the napping condition. As can be seen, on average subjects needed about 10 min to fall asleep and slept for half of the 50 min napping period. Sleep was clearly dominated by the occurrence of S1 and S2. Ten subjects also entered SWS yielding an overall average amount of about 4 min of SWS. None of the subjects showed signs of REM sleep.

The mean number of words subjects gave at the end of the retention intervals is presented in Fig. 1. Daytime napping led to better recall (M = 8.08; SD = 2.58) than waking (M = 6.48; SD = 2.93) and this performance benefit was highly significant (t_{24} = 2.57; P = 0.008; η_p^2 = 0.22). This effect was still clearly demonstrable when the first and the last five items of both word lists were treated as primacy and recency buffers, i.e. when these items were omitted in scoring to eliminate possible serial position effects of primacy and recency (waking: M = 3.72; SD = 2.41; napping: M = 5.24; SD = 1.99; t_{24} = 2.73; P = 0.006; η_p^2 = 0.24). To decide whether the effect was mediated by certain sleep parameters, these parameters were correlated with the sleep-related performance gain between napping and waking (Table 2). As may be observed, all of these correlations were far from reaching significance. In particular, performance gain was not associated with SOL, TST, or with time spent in SWS, regardless of whether the analysis involved the entire sample or only the subsample of subjects, which had actually entered SWS during the napping episode.

Table 1 Sleep parameters in Experiment I

Sleep parameter (min)	*Mean*	*SD*
TST	25.5	10.5
S1-SOL	10.9	6.3
S1	11.0	4.7
S2	10.2	6.5
SWS	4.3	6.9

TST, total sleep time; S1-SOL, stage 1 sleep onset latency; S1, stage 1; S2, stage 2; SWS, slow wave sleep.

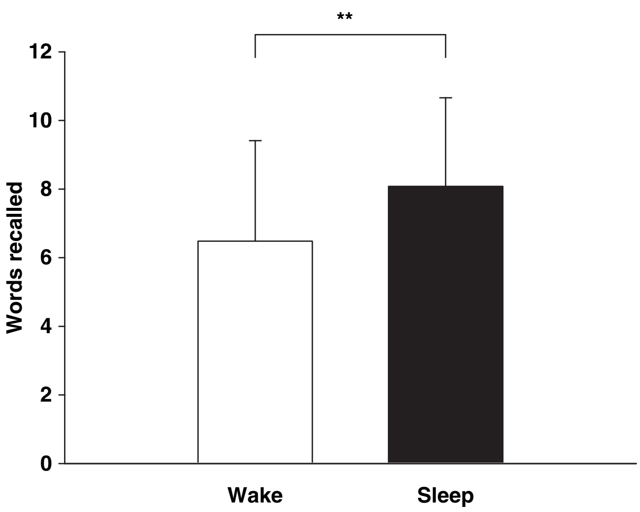

Figure 1. Number of words recalled (M ± SD) in Experiment I after 60 min retention intervals filled with napping or waking. **P < 0.01.

Table 2 Values and test statistics for the correlations between sleep parameters and sleep-related recall gain* in Experiment I

Sleep parameter	*r*	t_{23}
TST	−0.05	−0.23
S1-SOL	−0.01	−0.05
S1	0.02	0.10
S2	−0.07	−0.35
SWS	−0.02	−0.08
SWS > 0†	−0.17	−0.48

TST, total sleep time; S1-SOL, stage 1 sleep onset latency, S1, stage 1; S2, stage 2; SWS, slow wave sleep.
*Defined as the difference between words recalled after sleep and words recalled after waking.
†These values refer to the subsample of n = 10 subjects who had entered SWS during the napping period.

DISCUSSION

The first experiment revealed a clear memory benefit in favor of the napping condition, hence the supposed 'nap memory effect' in addition to the well-known night-sleep memory effect. The magnitude of this effect – 22% of the variance within subjects is explained by sleep – is even more remarkable in light of the relatively short time period of 25 min subjects actually spent sleeping.

It might be suspected that subjects in the napping condition enhanced their memory performance by utilizing maintenance or elaborative rehearsal strategies (Benjamin and Bjork, 2000) during the average 10 min period between lights off and sleep onset. In that case, however, the observed memory effect (i) mainly should have been dependent on the first and last list items which usually form the main target of rehearsal strategies and (ii) should have been correlated with the amount of time that was actually available for adopting these strategies, i.e. with SOL. In contrast to these predictions, further analyses revealed that the memory advantage was (i) just as well detectable with trimmed word lists and (ii) was uncorrelated with SOL. The assumption that a strategy of maintenance or elaborative rehearsal, which could have been adopted by subjects independently of the instructions given by researchers, would have been a confounding variable cannot be completely ruled out. However, this notion appears fairly weakened by the findings of the two supplementary analyses, which went against the most plausible expectations, namely, that maintenance rehearsal should have enhanced retention of the first and last items of the list, while elaborative rehearsal should have been more successful over long intervals.

Most remarkably, there were no signs of a relation between memory performance and TST, an outcome, which closely parallels the result obtained by Tucker *et al.* (2006) but was nevertheless unexpected. The apparently missing association between sleep duration and memory performance inspired us to add a third condition to the original design. Subjects under this condition were permitted to sleep for an ultra short period of 6 min. We hypothesized that if sleep duration was not essential for the sleep memory effect, this treatment would also lead to a considerable recall advantage in contrast to waking.

EXPERIMENT II

Method

Participants

A sample of 18 paid university students (10 female, eight male) aged between 21 and 29 years (mean = 23.7) participated in the second experiment. None of them had taken part in Experiment I but all fulfilled the same inclusion criteria and gave written consent to participate after the experimental protocol had been fully explained. Of this sample, four subjects had to be excluded from data analysis, three of them because they had not fallen asleep in the long nap condition, one other because it had not fallen asleep in the short nap condition.

Memory task

The same software application as in Experiment I was used to create a set of three parallel lists, each containing 30 adjectives equated for concreteness, imagery, meaningfulness, evaluation, potency, activity, word length, and frequency of use. The procedures for learning and recall were the same as in the first experiment.

Design and procedure

The experiment followed a complete repeated measures design with each subject undergoing all three conditions on three different occasions. There was a washout period of 1 week between sessions. The order of sleep/wake conditions was completely counterbalanced across subjects. The order of lists was incompletely counterbalanced according to a Latin square design across the six possible orders of condition. Subjects were informed that on each session they might have to remain awake or might be allowed to take a short or a long nap but no information about frequency or order of conditions was given. For the same reasons as in Experiment I, no level of initial learning had to be assessed.

For all study days, subjects were obliged to rise not later than 07.00 h and to refrain from alcoholic beverages, caffeine, and napping 12 h before embarking on the experimental sessions. All retention intervals began at 13.00 h and were of 60 min duration. The procedures for the two nap conditions and the wake condition were the same as in Experiment I, except that in the short nap condition, subjects were awakened when approximately 5 min of uninterrupted sleep had been scored in the online polygram. From then on, they followed the same activities as in the waking condition, i.e. playing non-verbal games until the end of the retention interval.

Data analysis

The analysis of sleep parameters was the same as in the first experiment. To assess the effect of napping condition on memory, recall scores after short napping, long napping, and waking were subjected to an overall analysis of variance (ANOVA) for repeated measures with subsequent specific contrasts protected by Fisher's least significant difference (LSD). These contrasts also included a trend analysis with the average TST under the three conditions as the independent variable (waking = 0 min). The orthogonal polynomial coefficients for the unequal intervals of sleep duration were computed according to the procedure described by Kirk (1995). As in Experiment I, the partial Eta-squared (η_p^2) index was calculated to assess the magnitude of effect. Following the definition in Experiment I, sleep-related recall advantage was defined as the difference between recall scores after short napping and waking and after long napping and waking, respectively. Correlations of both measures with sleep parameters were analyzed the same way as in Experiment I.

RESULTS

Table 3 illustrates the successful realization of short and long napping. TST was about six times longer in the long nap than in the short nap condition. SOL was nearly identical for the long nap conditions of Experiment I and Experiment II, but was about 6 min longer under the short nap treatment. Also, subjects under the long nap condition of Experiment II slept about 10 min longer than in the corresponding condition of

Table 3 Sleep parameters in Experiment II (Mean ± SD)

Sleep parameter (min)	*Short nap*	*Long nap*
TST	6.3 ± 1.7	35.8 ± 8.9
S1-SOL	16.9 ± 10.3	11.0 ± 6.3
S1	4.3 ± 1.3	11.9 ± 5.4
S2	2.0 ± 1.8	13.9 ± 5.6
SWS	0.0 ± 0.0	10.0 ± 9.0

TST, total sleep time; S1-SOL, stage 1 sleep onset latency, S1, stage 1; S2, stage 2; SWS, slow wave sleep.

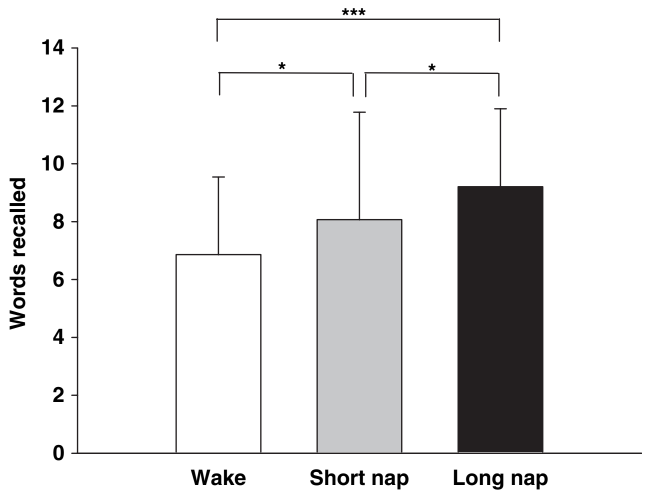

Figure 2. Number of words recalled ($M \pm$ SD) in Experiment II after 60 min retention intervals filled with short napping, long napping, or waking. *$P < 0.05$; ***$P < 0.001$.

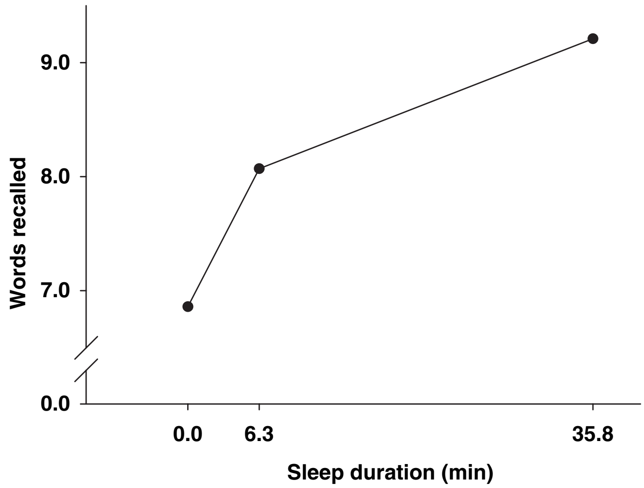

Figure 3. Mean number of words recalled in Experiment II as a function of sleep duration.

Experiment I and hence spent more time in S2 and SWS. Only two subjects did not enter SWS in the course of the long nap. As in the first experiment, no signs of REM sleep were encountered.

The average number of words given ($M \pm$ SD) was 6.86 ± 2.68 after waking, 8.07 ± 3.71 after short napping, and 9.21 ± 2.69 after long napping (Fig. 2). The ANOVA indicated a highly significant inequality of means ($F_{2;26} = 7.54$; $P = 0.003$; $\eta_p^2 = 0.37$). As in Experiment I, this effect was robust against treating the first and last five list items as rehearsal buffers and accordingly trimming the lists of scored items (waking: 3.79 ± 1.72; short napping: 5.14 ± 3.04; long napping: 5.71 ± 2.23; $F_{2;26} = 5.16$; $P = 0.013$; $\eta_p^2 = 0.28$). All subsequent results refer to the complete word lists.

On the basis of the significant overall effect, we calculated various *post hoc* contrasts, which are given in Table 4. As can be seen, both napping conditions led to significant better recall when compared with waking. Also, recall after long napping was superior to recall after short napping. The trend analysis with the average TST as the independent variable (waking: 0 min; short napping: 6.3 min; long napping: 35.8 min) revealed a highly significant linear trend component. Although suggested by the change in slope, the parabolic component was not significant. The apparent rank order of conditions waking < short napping < long napping as a function of sleep duration is illustrated in Fig. 3.

Table 4 Test statistics of contrasts calculated from the recall data of Experiment II

Contrast	*Coefficients**	t_{26}	*P-value*	η_p^2
Wake < short nap	−1; 1; 0	2.00	0.028	0.13
Wake < long nap	−1; 0; 1	3.88	< 0.001	0.37
Wake < sleep	−2; 1; 1	3.40	0.001	0.31
Short nap < long nap	0; −1; 1	1.88	0.036	0.12
Linear trend†	−14.1; −7.7; 21.8‡	3.62	0.001	0.34
Quadratic trend†	90.8; −110.5; 19.7‡	1.42	0.169	0.07

*Contrast coefficients for conditions wake; short nap; long nap.
†With TST as the independent variable.
‡Orthogonal contrast coefficients for unequal intervals of TST.

Table 5 Values and test statistics for the correlations between sleep parameters and sleep-related recall gain* in Experiment II

	Short nap		*Long nap*	
Sleep parameter	*r*	t_{12}	*r*	t_{12}
TST	0.29	1.05	0.15	0.51
S1-SOL	−0.53	−2.19†	−0.47	−1.83
S1	0.29	1.05	−0.13	−0.44
S2	0.01	0.04	0.19	0.67
SWS	–	–	0.11	0.39

TST, total sleep time; S1-SOL, stage 1 sleep onset latency; S1, stage 1; S2, stage 2; SWS, slow wave sleep.
*Defined as the difference between words recalled after sleep and words recalled after waking.
†Two-tailed $P < 0.05$.

Correlations between sleep-related recall gain and relevant sleep parameters are given in Table 5. With the exception of SOL none of these sleep parameters yielded correlations beyond chance level. However, SOL in the short nap condition was inversely correlated with recall gain to a significant degree.

DISCUSSION

Experiment II provided a clear-cut replication of the nap-related memory enhancement we had found in Experiment I. With a ratio of 37% of inner-subject variance explained by sleep this effect was even more pronounced than in the first experiment. Moreover, in view of the near-zero correlations of the first experiment between recall advantage and sleep parameters we had speculated that the mere induction of the sleeping state might suffice to promote memory performance. This prediction was strikingly confirmed by the finding that a sleep episode as short as 6 min was enough to significantly boost memory performance. Still, extension of the sleep episode to 35 min duration further improved memory output to a significant degree.

Despite the clear increasing relationship of sleep duration and recall *between* conditions, just as in Experiment I no such association was found *within* conditions, i.e. TST and recall were not correlated within the two nap conditions. This pattern of results suggests a progression in discrete quanta rather than a continuous relationship between sleep duration and memory benefit but the current data basis is not yet sufficient for a proper test of this hypothesis.

The duration of specific sleep stages also appeared to be uncorrelated with recall performance, a finding which is in good agreement with the data of the first experiment as well. There were, however, considerable *negative* correlations between SOL and recall advantage under both napping treatments (although insignificant in the long nap condition), meaning that subjects' memory profited the more from short sleep the sooner they fell asleep. Two conclusions can be tentatively drawn from this fact. First, rapid sleep onset might be a critical factor in the effectiveness of very brief sleep episodes in promoting memory. Second, active rehearsal is unlikely to have mediated the observed effect since in that case, a *positive* correlation between SOL and recall benefit would have been expected. As in Experiment I, the assumption of rehearsal strategies as a confounding variable is further discouraged by the finding that the effect is not limited to primary and recency items of the lists.

GENERAL DISCUSSION

The main findings of the two studies reported here may be summarized as follows: (i) a period of about 30 min of daytime napping significantly enhances declarative memory performance. This effect was demonstrated in Experiment I and could be replicated seamlessly in Experiment II. (ii) The nap memory effect – as we may call it – seems not to be mediated by a specific non-REM (NREM) sleep stage. (iii) An ultra short period of only 6 min of napping is already sufficient to significantly boost declarative memory performance beyond waking control levels. Evidence concerning the precise role of TST in this respect is conceived to be preliminary on the current data basis, but we suggest that memory performance progresses in discrete quanta as sleep duration increases.

The finding that the sleep memory effect extends to brief napping episodes may be viewed as a relevant progress in its own right, but it also bears important methodological implications regarding suitable research paradigms in the field of sleep and memory. Because of their inherently brief retention intervals, daytime napping protocols provide a simple method to avoid typical stress-related confounds of classical night sleep deprivation routines (Horne, 2000; Vertes, 2004) or circadian confounds associated with day-/night-time comparisons (Frank and Benington, 2006; Lahl and Pietrowsky, 2006b).

The lack of correlations we found between recall and any of the NREM sleep parameters are in line with the results of Tucker *et al.* (2006), but not with those of Schabus *et al.* (2005) and Backhaus and Junghanns (2006). It might be that other sleep parameters like spindle activity or spectral power density in the delta and sigma frequency bands provide a deeper insight into the precise *electrophysiological* mechanisms of sleep and learning, but these were not a primary target of the present study with its main focus on the *behavioral* level of the problem. Currently, the question of 'what in sleep is for memory' (Ficca and Salzarulo, 2004) is debated by at least three different opponents: (i) interference theory (Coenen and Van Luijtelaar, 1997; Jenkins and Dallenbach, 1924) proposing the effectiveness of sleep *per se*, (ii) dual process theory (Plihal and Born, 1997, 1999) suggesting a critical role of SWS for declarative memory and of REM sleep for procedural memory, and (iii) sequential theory (Ambrosini and Giuditta, 2001), which holds that the integrity of the naturally occurring NREM-REM sleep sequence is of critical importance for an effective memory enhancement. With the data of the second experiment, we may contribute yet a fourth proposal asserting that the mere onset of sleep already provides a significant facilitation of retention.

To our knowledge, Experiment II demonstrated for the first time that an ultra brief sleep episode provides an effective memory enhancement. Whereas further replication is definitely required, we may nevertheless begin to ask for a theoretical explanation of this intriguing outcome. The best *ad hoc* account we can think of would suggest a neurobiological (most likely hippocampus-related) process, which is triggered during sleep onset but which quickly after initialization becomes largely independent of any further maintenance of the sleeping state. Sleep prolongation potentially provides optimal conditions for the presumed process but is apparently not a requirement to push recall levels well above those of waking controls. This suggestion is of course an extreme form of what is commonly known as the consolidation account of the sleep memory effect (Cipolli, 1995; Ekstrand *et al.*, 1977), the essential difference being the emphasis on the briefness of the minimal sleep period that is required to activate the consolidation process (where consolidation is defined as the 'postacquisition stabilization of long-term memory', Dudai, 2004). However, continuation of the sleep period did lead to a further significant improvement of memory performance and currently there seems to be no evidence for a prolongation of sleep-specific neurophysiological processes *beyond* the sleeping state. So currently the attempt of a comprehensive explanation is complicated by a discrepancy in the results, suggesting respectively that sleep duration is crucial for consolidation (36 min of sleep superior to 6 min of sleep) or is not (6 min of sleep superior to waking). Further research will hopefully clarify the precise nature of what happens during sleep onset and in the course of sleep continuation.

In view of the growing body of results demonstrating sleep-related memory improvements, today probably only few researchers would still claim that there is absolutely no relationship between sleep and memory and the study of daytime naps provides yet another facet within this converging line of evidence. What is much less clear is the question of whether this relationship is of any significance regarding the *function(s)* of sleep, i.e. whether the role of sleep in memory consolidation is a passive or a functionally active one (Ellenbogen *et al.*, 2006). Interference theory is the main theoretical framework for a passive role of sleep holding that sleep simply shelters memories from retrograde interference. For the interference account, it is hard to explain why a very brief sleep episode should provide a significant effect on memory since the only critical factor is the length of the sleep period during which the brain is protected from new information input. Consolidation theory on the other hand proposes an active or functional role of sleep in memory consolidation by triggering active processes of encoding during sleep (onset). If it was possible to confirm the effect of strengthening memories during sleep initialization in future research this would provide a strong argument for the consolidation account and therefore for the idea that memory consolidation is actually a functional target of sleep.

Although we feel that the results of the present study are promising, there are some methodological limitations to bear in mind that should be addressed in future research. Subjects' potential use of elaborative rehearsal strategies during the period between lights off and sleep onset is a critical issue in sleep/wake designs as the experimenter usually cannot control the time point subjects fall asleep. As outlined in Experiment I and Experiment II, the zero or negative correlations between recall and SOL as well as the observed effects with respect to serial position weaken the possibility of rehearsal as a confounding variable in the present study. Nevertheless, this issue should be taken into account in the design of further research, e.g. by the implementation of explicit anti-rehearsal activities following initial learning.

Another constraint refers to the type of memory task. The evidence provided here is based on only one type of declarative material, but obviously, a concept as broad as that of declarative memory covers a wide range of different tasks each of which focuses on specific aspects of the concept. It should also be noted that lists of single words may also activate non-declarative domains of memory depending on semantic familiarity and that semantically unrelated word pairs may provide a more pure type of declarative memory here because of the arbitrary coupling of otherwise unrelated words. As such, the present study may be viewed as one of the first steps. Further research using a variety of declarative tasks like paired associate lists, sentences, prose passages, and spatial tasks is required to confirm and extend our knowledge about napping and declarative memory. This applies all the more as the idea of task-specific effects of sleep is currently one of the actively discussed topics in sleep research (Rauchs *et al.*, 2005; Walker and Stickgold, 2004).

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