REM Sleep and Visuo-Motor Skill Learning: A Correlational Study

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A considerable amount of studies have shown that sleep facilitates memory consolidation. For procedural memory, some findings support the association with REM sleep but other studies linked motor learning with stage 2 sleep. The present study investigated the relationship between sleep physiology and a procedural task (mirror tracing) involving visual and motor learning. The results indicate that overnight improvement is related to the amount of REM sleep but not to any other sleep stage and thus complement the findings obtained by a REM deprivation study and an early/late night deprivation study. Future research should aim at identifying the underlying mechanisms and the brain areas which are involved in different procedural memory tasks such as perceptual learning, motor learning, visuo-motor learning and complex motor learning (e.g., piano playing, trampolining). **(Sleep and Hypnosis 2007;9(2):52-59)**

Key words: Procedural memory, REM sleep, dream content

INTRODUCTION

Since the paper published by Jenkins and Dallenbach in 1924 (1), a considerable number of studies have shown that sleep facilitates memory consolidation (reviews: [2-7]). Different paradigms have been applied to investigate the relationship between sleep and memory. First, the performances after equal periods of sleep versus wakefulness between acquisition and retrieval have been compared. The critical points are possible confounding effects of circadian rhythms and of sleep deprivation (comparing a normal night with a night awake), although some researchers used as additional groups persons who slept during the day (8-10) or delayed retesting after at least one recovery night to check on fatigue effects (11). Since the discovery of REM sleep (12), this paradigm has been developed by depriving sleep in the first part of the night and the second part of the night (13,14). Early sleep is dominated by slow wave sleep whereas late sleep by REM sleep, so differential effects of different sleep stages could be measured (15). Non-sleep related factors, low cortisol levels (16) and low acetylcholine levels (17) in the first part of the night have been shown to be important in early sleep-dependent declarative memory; demonstrating the importance of considering circadian effects.

Another paradigm for studying the effects

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Accepted July 20, 2007

of different sleep stages is selective sleep deprivation, e.g., REM sleep deprivation, by forced awakenings. The major disadvantages of this approach are the substantial fragmentation of sleep architecture and the emotional and attentive disturbances in the morning which might affect retest performance (18). More naturalistic paradigms are to correlate sleep parameters with the performance gain from an evening training session with those of a morning retest session (19,20) or measuring the effect of learning on subsequent sleep (21). Each of the paradigms yields some specific information about the relationship between memory and sleep and - as shown below for perceptual learning - contributes to a comprehensive theory.

A large variety of tasks has been studied and they can be divided into two groups: declarative tasks (e.g., word pair association learning) and procedural tasks (e.g., motor learning). Although, some evidence supports the idea that declarative memory is more closely associated with slow wave sleep and procedural memory with REM sleep (15), several researchers (4,22-24) proposed a two-step model emphasizing the importance of NREM sleep and REM sleep for memory consolidation.

This paper will focus on procedural memory, especially on perceptual and motor learning. For example, spatial learning - a paradigm often applied in animal research (25) - showed a sleep-dependent memory consolidation in humans (26). For perceptual learning, Karni et al. (27) have shown that REM sleep deprivation interfered with the performance of a visual discrimination task trained the day before. Slow wave sleep deprivation had no negative effect. But subsequent studies found a positive effect of early sleep (predominantly slow wave sleep) but no effect of late sleep (28) and a high correlation for slow wave sleep and REM sleep with overnight improvement (23). In this case, it was important to complement the deprivation paradigm with the early/late sleep deprivation and the correlational approach. Finger tapping, a motor learning task, showing a strong sleep-dependent consolidation effect (8,9) was associated with the amount of stage 2 sleep in a correlation study (9) and spindle activity in the post-learning night (29). Another motor learning task (pursuit rotor) was associated with stage 2 sleep (30). This data implies that even within the procedural memory domain differential effects of sleep stages on memory consolidation might be possible, i.e., the plasticity of different brain areas, e.g., motor cortex involved in motor learning (31,32) and visual cortex involved in perceptual learning (33), depend on mechanisms associated with different sleep stages.

For a visuo-motor skill learning task (mirror tracing), Plihal and Born (15) have demonstrated a clear effect of late night sleep (including high amounts of REM sleep) but no effect of early night sleep (including slow wave sleep). A REM deprivation study (34) and a study showing an enhancement of REM density but not percentage of REM sleep after learning (35) provides further evidence that this combination of complex visual and motor learning depends on REM sleep parameters. The present study applying the same task was designed to study, in more naturalistic way, the correlation between sleep physiology and the over-night skill improvement. It was predicted that REM sleep is the major factor for increased speed in this visuo-motor task.

MATERIALS AND METHODS

Participants

Overall, twenty healthy individuals (10 women, 10 men) participated in the study. Their mean age was 24.7±3.6 years, their ages ranging from 20 to 32 years. A brief sleep history was taken to ensure that the participants had neither current sleep complaints nor an organic sleep disorder in the past. The volunteers had given written informed consent and were paid for their participation.

Design

All participants spent two consecutive nights in the sleep laboratory. Night 1 served as an adaptation night and was also used to rule out sleep apnea or periodic leg movements by measuring nasal and oral airflow, chest and abdomen movements, blood oxygen saturation and anterior tibialis electromyogram in both legs. In the evening prior to the second night (9 p.m. to 10 p.m), participants were trained in the mirror tracing task and the California Verbal Learning Test (CVLT). In the morning, the retest of the mirror tracing task and the long-delay recall section of the CVLT took place.

Sleep

Sleep was recorded between 11 p. m. and 7.00 a. m. by means of the following standard procedures: EEG (C3-A2, C4-A1), electrooculogram (EOG), submental electromyogram (EMG) and electrocardiogram (ECG). Sleep records were scored under blind conditions by applying the commonly used criteria of Rechtschaffen and Kales (36).

The following sleep parameters were computed:

Sleep continuity: Measures were taken of sleep period time (SPT; time between sleep onset and final morning awakening), sleep efficiency (ratio of time in bed minus time awake to time in bed) and sleep latency (time span from „lights off" to occurrence of first stage 2 or REM).

Sleep architecture: The following sleep stages were measured: wake, 1, 2, slow-wave sleep (stage 3 and 4) and REM (expressed in percent of SPT).

REM sleep: REM latency is the time period between sleep onset and the first REM period. REM density is the ratio of 3-second mini-epochs with rapid eye movements to all 3-second epochs of REM sleep.

Mirror tracing task

The figures of the Plihal and Born (15) were used in this study and kindly provided by the authors. Participants were asked to trace the black lines of the figures with an electronic light sensor (attached to a computer) while viewing their dominant hand and the figure only through the mirror in front of them. Direct view was prevented. The total time completing a figure and the time off the black line expressed in percentage of the total time were included in the analysis. The evening session began with practicing five times with a simple figure (five-pointed star) in order to acquire a basic level of the mirror tracing skill. Thereafter, seven more complex test figures (schematic outlines of human figures) were presented twice consecutively. At the end of the evening training session, the star was to be traced again. In the morning, the retest began with tracing the star two times in order to accustom the participants again. Then, the seven figures of the evening session were presented once, followed by seven quite similar human figures with smoothed edges. At the end of the session, the star was presented again. For testing the hypothesis, mean total times of all human figures in the evening and in the morning session were computed as well as the means for the percentage of error time.

California Verbal Learning Test (CVLT)

For assessing declarative memory, a German version of the California Verbal Learning Test (37) was applied. A "shopping list" (list A) containing 16 items (4 items of each category: clothing, fish, kitchen tools, vegetables) was presented five times (with eliciting the amount of recalled items after each trial). Then, a second "shopping list" (list B) was presented once, again with immediate reproduction of the recalled items. The evening session ended with the free recall of list A (short-delay free recall) and the cued recall of list A by prompting the participant with the categories (short-delay cued recall). In the morning, the free recall and cued recall procedure was repeated (long-delay free and cued recall). Finally, a list of 45 items including the items of list A and list B was presented and the participants were asked what items had been on list A (long-delay recognition). The raw values were transformed into a T score (mean: 50, SD: 10) for the recall performance of list A and z scores (mean: 0, SD: 1) for all the other measures.

Statistical analysis

In order to test the relationship between sleep parameters and memory, the morning performance scores were correlated with one of the sleep parameters while partialling out the between-subject variance of the evening performance, i.e., partial correlation coefficients were computed. This is similar to the approach of correlating difference score in evening and morning performance but avoids the problem of increased measurement error variance of the difference scores. Since for REM sleep the direction of the effect was predicted, one-tailed tests were applied. All other sleep parameters were tested two-tailed. Statistical analyses were carried out with the SAS for Windows software package (Version 9.1). The level of significance was p= .05.

RESULTS

In Table 1, the means and standard deviations of the sleep variables of the two sleep laboratory nights are depicted. The typical first night effect with reduced sleep efficiency and percentage of REM sleep and prolonged sleep latency and REM latency was present in the data. The sleep parameters of the second night are in a normal range.

The progress in the mirror tracing task could be seen in Table 2. The total time for completing the star was considerably reduced at the end of the evening session.

Table 1. Sleep parameters (Means ± SD)

TVariable	Adaptation Night	Learning Night
Sleep period time (min.)	441.8±26.1	454.6±15.4
Sleep efficiency (%)	81.7±9.0	86.1±6.5
Sleep latency (min.)	28.6±19.4	17.7±8.6
Time awake (% SPT)	12.2±7.3	9.5±6.8
Stage NREM 1 (% SPT)	11.2±4.5	10.2±3.9
Stage NREM 2 (% SPT)	52.3±7.0	51.8±6.7
Slow-wave sleep (% SPT)	14.3±6.9	16.3±7.8
REM sleep (% SPT)	9.8±2.9	12.0±3.6
REM latency (min.)	138.0±73.6	97.0±40.7
REM density (%)	16.6±7.7	19.1±6.3

SPT= Sleep Period Time

Table 2. Mirror tracing (Means ± SD)

Variable	Time (1/10 sec.)	Error Percent
Star (first five trials)	497.4±334.9	28.2±12.3
Star (last figure of evening)	197.5±71.8	15.3±10.9
Star (first figure in the morning)	245.3±87.0	12.4±9.6
Star (second figure in the morning)	228.6±81.4	12.7±10.8
Star (last figure in the morning)	196.4±91.7	9.2±9.0
Human figures (mean of 14 figures; evening)	512.0±178.6	14.1±8.0
Human figures (mean of 14 figures, morning)	416.6±172.0	7.5±5.4

Table 3. California Verbal Learning Test (Means ± SD)

Variable	Time (sec.)	Statistical test (reference group)	
Evening session			
List A (five trials; T score)	55.3±9.1	2.6	.0178
List B (z score)	-0.2±1.2	-0.8	.4469
Short-delay free recall (z score)	-0.1±1.3	-0.4	.7250
Short-delay cued recall (z score)	-0.5±1.2	-1.9	.0761
Morning session			
Long-delay free recall (z score)	-0.3±1.3	-1.1	.3006
Long-delay cued recall (recall; z score)	-0.6±1.3	-2.1	.0486
Recognition hits (z score)	-0.5±0.7	-3.3	.0042

While speed didn't further increase in this simple task, the error percentages still improved. For the human figures, the speed and accuracy improved from the evening to the morning session. The performance of the sample regarding the learning of list A was slightly above the norm values. Long-delay cued recall and long-delay recognition were below the normal values which reflect that the retest interval of this study (about 10 hrs.) was much longer than the retest interval (about 20 minutes) normally used.

As predicted, the percentage of REM sleep correlated significantly with the mirror tracing speed performance of the morning session ($r= -.435$, $p < .05$; partial correlation with evening speed performance partialled out) but not with other sleep variables (total sleep time: $r= -.079$, n.s., percentage of slow wave sleep: $r= -.016$, n.s., percentage of stage 2 sleep: $r= -.024$, n.s., REM density: $r= .130$, n.s.). The improvement of the error percentage in the mirror tracing task was not related to REM sleep percent ($r= .123$, n.s., partial correlation with evening error percentages partialled out). Long-delay free recall and long-delay cued recall was not significantly correlated with any of the sleep variables (total sleep time, slow wave sleep percentage, REM sleep percentage, stage 2 sleep percentage or REM density).

DISCUSSION

The results of the present study were in line with the preliminary analysis of the data ($r= .430$, $N= 12$; [38]) and confirmed the hypothesis that improvement in a visuo-motor task like mirror tracing is linked to REM sleep (cf. [15, 33]). Although the correlation coefficient is smaller than the coefficient ($r= .74$, REM% and improvement in the visual discrimination task) reported by Stickgold et al. (23) for perceptual learning, REM sleep seems to be important for both kinds of procedural memory. Also, Nissen et al. (39) reported an association between overnight improvement in the mirror tracing task and REM density in a small sample. However, a significant effect of slow wave sleep as it had been demonstrated for perceptual learning ($r= .46$; [23]) or of stage 2 sleep found in motor learning tasks ($r= .66$; [9]) have not been present in this study.

Smith et al. (4) listed three factors which might explain the differing results regarding the influence of stage 2 sleep and REM sleep on procedural memory consolidation: (1) level of complexity, (2) different memory systems and (3) novelty. First, Aubrey et al. [34] reported that REM sleep deprivation affected the mirror tracing task but not the simple tracing task. This task was affected by stage 2 sleep interruptions. In favor of the second point, Smith et al. (4) cited studies revealing that, patients with Huntington's Disease, for example, have problems with motor tasks like pursuit rotor but not with mirror tracing. The imaging studies clearly show that specific tasks alter the brain plasticity in different brain areas, e.g., perceptual learning in the visual cortex (33) and motor learning in the motor cortex (31,40). So it might easily be conceivable that a visuo-motor task, combining visual and motor learning, yields to changes in other brain areas and, therefore, other sleep-dependent mechanism might be at work. Lastly, Smith et al. (4) pointed out that well-learned motor coordination routines (e.g., pursuit rotor, simple tracing task) might be based on stage 2 sleep whereas the development of new motor programs (e.g., mirror tracing) rely on REM sleep.

From a methodological point of view, the findings of the present study using a correlational approach have to be complemented with experimental studies (sleep deprivation, selective sleep deprivation, and investigation of post-training sleep) because the relationship between REM sleep and improvement in the mirror task might not be causal but explained by other variables. Hornung et al.

(41), for example, reported that phasic REM sleep augmentation with donepezil was beneficial for the morning performance in the mirror tracing task but not phasic REM sleep augmentation achieved by preceding REM sleep deprivation (REM rebound effect); a finding which implies that cholinergic mechanisms are of importance. Similarly, Schredl et al. (19) found a significant relationship between the percentage of REM sleep and the improvement in a word list relearning task for donepezil nights but not for baseline nights and, thus, also imply that the beneficial effect is at least partially explained by cholinergic mechanisms independent of REM sleep physiology.

Since tasks which include some kind of visual learning (perceptual learning; (27); mirror tracing, present study) are associated with REM sleep, the question arises whether dreaming as subjective experience present during sleep (most intense and visual in REM sleep; cf. [42]) is involved in memory consolidation. This would fit in the framework of the continuity hypothesis of dreaming which states that waking-life experiences are incorporated into dreams (43). Smith and Hanke (44), for example, reported that dreams from a night after training in a mirror tracing task more often included driving topics such as "trying to stay on the road" which somewhat resemble the mirror tracing. Although there have been studies linking declarative memory and dream content (45-47), only one study (48) found a significant correlation (r= .71) between the performance of a reading task wearing goggles inverting the visual field (with training during the previous day) - a task which could be classified as procedural - and the incorporation of task-related elements into the dreams.

To summarize, the present study support the idea that different consolidation mechanisms for different kinds of procedural memory may exist. Future imaging studies, especially those carried out during sleep (49), will shed more light on the different brain areas which are involved in procedural memory consolidation. As these brain areas are differentially active in different sleep stages (50,51), the association between sleep stages and memory consolidation will become clearer. It also will be promising to study even more complex procedural tasks like piano playing (52) or sports like trampolining (53) in order to understand the underlying brain mechanisms.

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