Is sleep-dependent memory consolidation of a visuo-motor task related to dream content?

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Summary. A considerable number of studies have shown that sleep facilitates memory consolidation. For procedural memory, some findings support the association with REM sleep but the relationship between memory consolidation and dreaming has been scarcely studied. The present study did not find an effect of direct incorporations of the mirror tracing task into the dream on over-night improvement. On the other hand, bizarre, long, and intense dreams were associated with poorer performance regarding speed but also with decreased amount of errors. Whether this can be explained by altered sleep physiology or negative effects of dreams on mood and performance can not yet been answered. Future research should study more complex and demanding procedural memory tasks and the relationship between dreaming and sleep-dependent consolidation of emotional memories.

Keywords: Dream content, REM sleep, sleep-dependent memory consolidation, procedural memory, declarative memory, cortisol

1. Introduction

A large variety of studies have shown that sleep facilitates memory consolidation (reviews: (Diekelmann, Wilhelm, & Born, 2009; Stickgold & Walker, 2007; Walker, 2005). Declarative memory consolidation has been associated with slow wave sleep and some of its characteristics like low cortisol and acetylcholine levels (Born & Wagner, 2004; Gais & Born, 2004; Plihal & Born, 1999), whereas motor learning has been associated most often with REM sleep (Laureys, Peigneux, Perrin, & Maquet, 2002; Walker, 2005) – although NREM stage 2 sleep and sleep spindles might also be of importance in consolidating procedural memory (Fogel & Smith, 2006; Smith, Aubrey, & Peters, 2004).

Intense dreaming is an integral part of REM sleep (Nielsen, 2000), so the question arises whether memory consolidation processes that take place during REM sleep are accompanied by corresponding dreams. The continuity hypothesis of dreaming (Schredl, 2003) stating that waking life is reflected in dreams is in favor of this idea. Schredl and Hofmann (2003), for example, reported that the amount of time spent driving a car during the day was positively correlated with the number of car dreams. Sport activities were more prominent in sport students compared to psychology students (Erlacher & Schredl, 2004; Schredl & Erlacher, 2008). I.e., activities that can be classified as procedural are reflected in dreams. Systematic research into whether dream content is associated with the over-night improvement in procedural task performance is almost completely lacking. Only one study (De Koninck, Prevost, & Lortie-Lussier, 1996) has addressed this question. The participants (N = 8) were asked to wear goggles with prism that change the angle of vision during the day. Because this needs major adaptation the participants were escorted and supervised at all times. The first two nights were uninterrupted showing an increased amount of REM sleep compared to control nights after wearing plain goggles and, thus, reflecting the adaptation processes. In the third and the forth night, REM awakenings were carried out. Fifty percent of the participants had at least one dream related to the altered vision experienced during the day and the number of incorporations were correlated positively with the reading test the participants performed during the study period to document the adaptation. The participant who experienced four dreams with incorporations of the altered visual perception outperformed the other participants in almost every test. De Konink's study concluded that dreams can reflect the process of reorganization of perceptual structures in the brain.

The present study was designed to investigate whether dream characteristics are related to the over-night improvement of a visuo-motor task (mirror tracing). Mirror tracing was chosen because several studies have shown that for this task consolidation is related to REM sleep (Hornung, Regen, Danker-Hopfe, Schredl, & Heuser, 2007; Plihal & Born, 1997; Schredl & Erlacher, 2007; Smith, Nixon, & Nader, 2004).

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2. Materials and methods

2.1. Participants

Overall, twenty healthy individuals (15 women, 5 men) participated in the study. Their mean age was 22.7 ± 2.4 years, their ages ranging from 19 to 29 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.

2.2. 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 (1968).

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 (defined as time span from „lights off“ to occurrence of first stage 2 or stage 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 onset of 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.

2.3. Mirror tracing task

The figures of Plihal and Born (1997) 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 to complete a figure and the time off the black line expressed as 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 time with errors in relation to the total time.

2.4. California Verbal Learning Test (CVLT)

For assessing declarative memory, the German version of the California Verbal Learning Test (Bachetzky & Jahn, 2005) 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 the immediate free reproduction of the recalled items after the presentation. The evening session ended – after presentation and free recall of List B – with an additional 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 (M = 50, SD = 10) for the recall performance of List A and z scores (M = 0, SD = 1) for all the other measures.

2.5. Cortisol

Saliva cortisol was analyzed using radioimmunoassay in the laboratory of Professor Clemens Kirschbaum, Department of Biopsychology, Technical University Dresden, Germany (intra- and interassay coefficient of variation < 8%). The reported saliva cortisol levels are presented as mean values of all samples taken at night. In order to take into account the increase of cortisol during the second part of the night and the variance of sample times, the cortisol levels were standardized using the time interval from midnight to the time the sample were taking, (this controlled for a linear increase in cortisol). Because the awakenings started with the second REM period, the earliest sample for all participants was taken 106 minutes after midnight.

2.6. Dream content analysis

The dream content analytic scales used in this study were adopted from Schredl, Sahin and Schäfer (1998): realism/bizarreness (1 = realistic to 4 = two or more bizarre elements within the dream), positive and negative emotions (two four-point scales: 0 = none, 1 = mild, 2 = moderate, 3 = strong). For the emotional tone of the dream, the difference between positive and negative emotions was computed. The sum of positive and negative dream emotion scales was used as indicator of overall emotional intensity of the dream. The occurrences of laboratory references, participating in an experiment, and specific references to the mirror tracing task were coded binary (1 = present or 0 = not present).

The interrater reliability of these scales are satisfactory (Schredl, Burchert, & Grabatin, 2004): r = .765 (realism/bizarreness), r = .642 (positive emotions), and r = .825 (negative emotions). The exact agreement figures of binary coded items were all above 90% (Schredl, et al., 2004).

2.7. 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 (9:00 pm to 10:00 pm), participants were trained in the mirror tracing task and the California Verbal Learning Test (CVLT). In the morning (7:30 am. to 8:00 am), the retest of the mirror tracing task and the long-delay recall section of the CVLT took place. REM awakenings were carried out in the second night, starting with the second REM period. Five minutes after the beginning of the second REM period, the participant was awakened via intercom by calling his/her name and was asked to report any content that was on her/his mind before she/he was awakened. Exactly 5 minutes after awakening, the participants were asked to sample saliva by using small cotton rolls (Salivette, Sarstedt, Nümbrecht, Germany). Therefore, the minimal time awake was 5 minutes – even if no dream was recalled and reported. After reporting the dream, the participants were asked to estimate the intensity of positive and negative emotions on two four-point scales: 0 = none, 1 = mild, 2 = moderate, 3 = strong. Emotional tone was derived as difference between positive and negative emotions ranging from +3 to -3. Summing up positive and negative emotions yielded the intensity score. Every subsequent REM period, the procedure was repeated, except the time interval increased to 10 minutes from the third REM period to the awakening and to 15 minutes from the start of the forth and all following REM periods to the awakening. This protocol was chosen to minimize possible effects of REM deprivation by not allowing sufficient REM sleep during the night.

The dream reports were transcribed and everything not reflecting the dreamer's experience was deleted (Schredl, 1999). Then the dream reports were permutated randomly and were rated along the scales described in the dream content analysis section by a "blind" judge. The dream scores were averaged according the measurement levels of the scale, e.g., mean for word count and median for dream bizarreness, over the night to obtain total scores for each participant.

2.8. 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 scores in evening and morning performance but avoids the problem of increased measurement error variance of the difference scores. Non-parametric coefficients (Spearman rank correlations) were computed. One-tailed tests were carried out for the correlations between mirror tracing parameters and REM sleep parameters. Statistical analyses were carried out with the SAS for Windows software package (Version 9.2).

3. Results

In Table 1, the means and standard deviations of the sleep variables of the two sleep laboratory nights are depicted.

Table 2: Mirror tracing (Means ± SD)

Variable	Time (Seconds)	Error Percent
Star (first five trials)	669.8 ± 371.7	30.7 ± 14.4
Star (last figure of evening)	263.9 ± 128.8	16.7 ± 14.0
Star (first figure in the morning)	319.8 ± 200.1	12.4 ± 12.8
Star (second figure in the morning)	278.4 ± 156.8	12.0 ± 10.0
Star (last figure in the morning)	239.3 ± 135.2	11.0 ± 10.8
Human figures (mean of 14 figures; evening)	635.4 ± 315.3	16.5 ± 9.9
Human figures (mean of 14 figures, morning)	465.2 ± 239.1	9.9 ± 8.2

Since there is no point in comparing the first night in the sleep laboratory with the second night interrupted by several awakenings statistically, the following comparison remains on a purely descriptive level. Sleep efficiency and the time awake were of course increased due to REM awakenings. The amounts of slow wave sleep and REM sleep were slightly reduced whereas REM density was increased. Other sleep parameters like sleep period time, sleep latency, NREM 1 sleep, NREM 2 sleep, and REM latency were comparable between the first and second laboratory night.

The progress in the mirror tracing task can be seen in Table 2. The total time for completing the star was considerably reduced at the end of the evening session. While speed didn't further increase in this simple task carried out at the beginning of the morning session, the error percentages still improved. For the human figures, the speed and accuracy improved significantly from the evening to the morning ses-

Table 1: Sleep parameters (Means ± SD)

Variable	Adaptation Night	Learning Night
Sleep period time (min.)	422.4 ± 65.7	429.9 ± 32.1
Sleep efficiency (%)	86.9 ± 8.6	80.2 ± 4.4
Sleep latency (min.)	29.7 ± 29.4	28.5 ± 17.5
Time awake (% SPT)	6.4 ± 7.7	13.6 ± 5.2
Stage NREM 1 (% SPT)	5.4 ± 2.4	5.9 ± 2.1
Stage NREM 2 (% SPT)	52.8 ± 6.2	50.1 ± 8.4
Slow-wave sleep (% SPT)	18.8 ± 8.5	16.9 ± 9.3
REM sleep (% SPT)	16.2 ± 5.4	13.2 ± 3.2
REM latency (min.)	97.2 ± 40.7	99.1 ± 52.3
REM density (%)	14.5 ± 7.0	17.2 ± 6.9

SPT = Sleep Period Time

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

Variable	Standardized Values
Evening session	
List A (five trials; T score)	54.5 ± 12.5
List B (z score)	0.2 ± 0.8
Short-delay free recall (z score)	0.0 ± 1.2
Short-delay cued recall (z score)	-0.6 ± 1.2
Morning session	
Long-delay free recall (z score)	-0.5 ± 1.1
Long-delay cued recall (recall; z score)	-1.0 ± 1.3
Recognition hits (z score)	-0.7 ± 1.0

Table 4: Dream parameters (Means ± SD, Percentages)

Variable	All dreams (N = 71)	Averages per night (N = 20)
Emotional tone (self-rating)	0.00 ± 1.51	0.10 ± 0.85
Emotional intensity (self-rating)	1.83 ± 1.21	1.60 ± 1.07
Word count	100.5 ± 96.9	92.1 ± 59.4
Bizarreness	1.77 ± 0.83	1.65 ± 0.65
Emotional tone	-0.45 ± 0.95	-0.33 ± 0.49
Emotional intensity	0.65 ± 0.90	0.38 ± 0.51
References to experiments	8.5 %	20.0 %
Laboratory references	7.0 %	15.0 %
References to motor task	1.4 %	5.0 %

sion (speed: t = 6.1, p <.0001; error percentage: t = 7.8, p < .0001). The correlation between speed and error percentage for the human figures in the morning session was high (r = -.696, p = .0006). The performance of the sample regarding the learning of List A was slightly above the norm values (Mean = 50) where as List B performance and short-delay recall was comparable with the norms (see Table 3). 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.

Overall, 74 awakenings were carried out (mean: 3.7 per participant; range: 2 to 6). 71 dreams were reported, the recall rate was 95.9 %. Each participant reported at least on dream (average: 3.6 dreams; range: 1 to 5). The dream parameters are depicted in Table 4. Only one subject dreamed directly about the mirror tracing task.

The percentage of REM sleep correlated significantly with the improvement of mirror tracing error percentage in the morning session (r = -.515, p < .02; partial correlation with evening error percentage partialled out) but not with the improvement in speed (see Table 5). REM density, on the other hand, was related to the improvement in speed but not in error percentage. The number of REM awakenings carried out in the night did not affect the mirror tracing performance in the morning. For sleep efficiency, the correlation coefficients showed the same pattern as REM sleep percentage but were smaller.

In view of the number of statistical tests computed, the findings regarding the effect of dream variables on the morning performance should be regarded as preliminary. The pattern that stands out is that having long, bizarre, and negatively toned dreams are related to a slower performance but also with a lower percentage of errors. The incorporation of the mirror tracing task (N = 1) or the incorporation of other aspects related to the experiment were not associated with the morning performance.

Cortisol levels did not affect the mirror tracing performance in the morning but higher cortisol levels were associated with a poorer performance in the declarative task (see Table 5). The CVLT performance did not correlate with any of the sleep parameters significantly, even though the correlation coefficient between percentage of slow wave sleep and morning performance was positive (r = .228).

4. Discussion

Overall, the findings of the present study suggest that dreaming might be associated with the memory consolidation processes during REM sleep; however the effect was not specific, that is, related to the incorporation of the procedural task but to general dream characteristics like bizarreness and emotional intensity. The performance in the declarative memory task which was solely included as a control task showed a small and expected correlation with slow wave sleep.

Performance in the mirror tracing task was related to REM sleep parameters but in a different way to that found for an uninterrupted night (Schredl & Erlacher, 2007). In the previous study, REM percentage was related to performance speed whereas the present study found a positive relationship only for the improvement of accuracy. REM density was related to an increase in performance speed which was also reported by Hornung et al. (2007) correlating the percentage of phasic REM sleep in relation to the mirror tracing performance. One might speculate that interrupting REM sleep by forced awakenings might affect the consolidation process (even though general performance was not affected by the number of REM awakenings) and that consolidation depends on different aspects of REM sleep. The reduction of REM sleep (compared to the first night) might be partly compensated by an increase in REM density. Overall, REM sleep parameters seem to be related to the over-night improvement in this procedural task.

The incorporation rate of the task was very low – much lower than the figures reported by De Koninck et al. (1996). Their procedure was much more invasive and demanding for the participants compared to one hour of mirror tracing. For testing the hypothesis whether direct incorporations are related to memory consolidation other tasks have to be selected, maybe sport skills like trampolining (Buchegger, Fritsch, Meier-Koll, & Riehle, 1991) or martial arts (Schredl & Erlacher, 2008) because they have strong effects on REM sleep and/or dreaming. Also, training sessions with a downhill skiing simulator (Alpine Racer II) had a strong effect on sleep-onset dreams (Stickgold, 2003) and, thus, simulators involving multi-sensory experiences seems to be apt for testing dream-related memory consolidation. Another paradigm to test the effect of dreams on subsequent performance is lucid dreaming. Erlacher and Schredl (2010) were able to demonstrate that training of a coin tossing task within a lucid dream improved performance in the retest the next morning. I.e., the lack of a relationship between incorporation and performance in the present study might be explained by the small effect of the task on dream content.

The main effect of dreams on performance was that participants with bizarre, long, intense and negatively toned dreams tended to produce less errors but took longer to complete the mirror tracing task. This parallels the finding that nightmares have a negative effect on daytime mood and performance (Köthe & Pietrowsky, 2001). Interestingly, Stickgold, Malia, Maguire, Roddenberry, and O'Connor (2000) reported that poor initial performance on a computer game (Tetris) was related to higher amount of sleep-onset dreams including Tetris pictures, suggesting that stress and the negative experience of not performing well increased the probability of incorporation. To control for these aspects, it would be valuable to include some measure of state anxi-

Table 5: Spearman Rank correlations with evening performance and gender partialled out

Variable	Mirror tracing (time) r = (p =)	Mirror tracing (error %) r = (p =)	CVLT (long-delay free recall) r = (p =)
Sleep efficiency (%)	.369 (.1314)	-.340 (.1670)	.067 (.7926)
Slow-wave sleep (% SPT)	.055 (.8295)	.245 (.3270)	.228 (.3627)
REM sleep (% SPT)	.322 (.9043) [1]	-.515 (.0145) [1]	-.175 (.4871)
REM density (%)	-.383 (.0584) [1]	.236 (.8267) [1]	-.388 (.1121)
Number of awakenings	.104 (.6798)	-.146 (.5641)	-.072 (.7760)
Emotional tone of the dream (self-rating)	-.064 (.8019)	-.024 (.9238)	.023 (.9286)
Emotional intensity of the dream (self-rating)	.542 (.0202)	-.472 (.0479)	.403 (.0971)
Word count	.400 (.1005)	-.041 (.8702)	.161 (.5246)
Dream content analysis:			
Bizarreness	.709 (.0010)	-.591 (.0098)	.110 (.6643)
Emotional tone	-.416 (.0863)	.371 (.1294)	-.183 (.4667)
Emotional intensity	.449 (.0618)	-.332 (.1789)	-.019 (.9389)
References to experiments	.120 (.6361)	-.150 (.5541)	.128 (.6114)
Laboratory references	.143 (.5709)	-.196 (.4350)	.093 (.7130)
References to motor task	.123 (.6266)	.061 (.8086)	-.448 (.0619)
Saliva cortisol (standardized)	.028 (.9157)	.195 (.4525)	-.412 (.0834)

SPT = Sleep Period Time, [1] one-tailed

ety during the learning and retest period. In the present study, the intense dreaming did not affect the performance of the declarative memory task in the morning but it would be desirable to include a second motor task which has not been trained in the evening to ensure that intense dreaming does not affect motor skills in general. Since the present findings are based on a between-subject design, one might speculate that trait aspects might be of importance. Nightmare sufferers might have altered sleep physiology (Germain & Nielsen, 2003) and, therefore, memory consolidation is impaired. Insomnia patients whose sleep physiology is characterized by low sleep efficiency and high number of awakenings showed a smaller over-night improvement in the mirror tracing task than healthy controls (Nissen, et al., 2006). Thus, it would be very interesting to study idiopathic nightmare sufferers and persons suffering from posttraumatic nightmares regarding their sleep-dependent memory consolidation.

Cortisol levels were not related to the morning performance of the procedural task. One has to keep in mind that cortisol samples were taken at different times (to account for this, the standardization using the time interval from midnight to sampling was applied) and, thus, did not allow to map the nocturnal cortisol profile of the participants. In the present study, the samples were taken as a measure for the physiological stress that might have been caused by the negatively toned dreams. Since the analysis of this data is very complex, e.g. modeling the diurnal profile of cortisol secretion, and requiring larger sample sizes, it has not yet been done and cannot be presented within the context of this paper. On the other hand, higher cortisol levels in the second part of the night were associated with poorer performance in the declarative task. This is in line with previous research (Born & Wagner, 2004), one might speculate that high cortisol levels in the second part of the night correspond with higher levels also in the first part of the night which seems to be crucial for consolidation of declarative memory tasks (Plihal & Born, 1997).

To summarize, the general effects of dreaming on memory consolidation found in the present study have to be followed up by including measures to rule out confounders like the effect of negative dreams on mood and performance. A wonderful tool which might be available in the future is the fMRI technique applied during REM sleep in order to ‘read’ the dream without disturbing the sleeper (Dresler, et al., 2008). Simple actions like hand clenching can be detected in the EEG (Erlacher, Schredl, & LaBerge, 2003) or the fMRI scans (Dresler, et al., 2008) of the sleeping person while performing the movements within a lucid dream. Another area that should be pursued in the future is the relationship between REM sleep associated consolidation of emotional memories (Wagner, Gais, & Born, 2001) and dreaming because during REM sleep the amygdala has been found to be very active (Maquet, et al., 1996). If dreaming is related to memory consolidation, lucid dreaming will offer an opportunity, for example for athletes, to improve their performance during sleep (see anecdotal evidence in (Erlacher, 2005))

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