LEARNING DURING SLEEP: AN INDIRECT TEST OF THE ERASURE-THEORY OF DREAMING

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Summary.—In this study the hypothesis, put forward elsewhere, that dreams are functional through the erasure of 'incidental' and weakly represented information was indirectly explored. 12 subjects were presented paired-associate word lists during each Stage-2 period of their sleep. According to the erasure-hypothesis these associations are destroyed during the subsequent dream if their representation is weak. Two effects might be expected. Firstly, associations which are formed during the last Stage-2 period (which is not followed by a dream-stage) will not be destroyed. Secondly, a stimulus frequency threshold-effect could be expected. Associations which are repeatedly presented (more often than a certain critical number) might become strong enough to withstand the 'erasure.' In the present study no indication was found for the latter expectation but a significant effect was found for those associations presented during the last Stage-2 period. Furthermore, there was suggestive evidence that sleep-rehearsal (of previously learned associations) yielded long-term effects.

During the last decades a number of studies on sleep-learning have been done (Simon & Emmons, 1956; Bruce, Evans, Fenwick, & Spencer, 1970; Cooper & Hoskovec, 1972; Levy, Coolidge, & Staab, 1972). In most of these studies simple learning tasks like paired-associate list learning were used. The material was presented through a tape-recorder during, in some studies, specific stages of sleep. On the subsequent day subjects were then tested for retention of this material. Over-all, the results of these studies are rather inconclusive. Positive results can be 'explained away' in most cases on the basis of lack of adequate control for the subject being awake, e.g., through EEG-recording. On the other hand, negative results could reflect inadequate stimulation, whereby the signal never gets processed centrally.

An interesting alternative explanation for the negative results can be derived from the work of Crick and Mitchison (1983). In a theory about the functionality of REM-sleep they proposed that certain 'irrelevant' associa-tional links in memory are being destroyed through the dream. This would help to reduce memory 'overload/ Of course, the weak point in their formulation is the label 'irrelevant.' How is it decided what links are 'irrelevant'? Therefore, de Jong (1984) reformulated the hypothesis by stating that the mechanism consists of a global weakening of all synaptic connections. As a consequence those connections that are already weak are destroyed whereas the strong connections are only weakened. Regarding the strong connections as the 'signal' and the weak ones as 'noise,' such a mechanism would result in an improvement of the signal/noise ratio. It should be pointed out that Crick and Mitchison in their original paper state that . . . *it is not clear how to test the theory* . . .; however, if the mechanism of erasure of weakly represented material is responsible for the negative findings in sleep-learning studies, then we might have a paradigm to test this theory, be it indirectly.

So, an experiment was set up in which the following expectations that were derived from the acceptance of the erasure model were explored. These were: (a) Word-pairs presented during the last Stage-2 period (which is not followed by a dream Stage) will be better retained than material presented during the previous Stage-2 periods, (b) Word-pairs that are presented a number of times during each Stage-2 period (interREM) will only be retained if the number of presentations within this period exceeds a critical threshold (resulting in synaptic connections which can withstand the erasure mechanism), (c) The retention of word-pairs learned the previous night will benefit from rehearsal during the Stage-2 (interREM) periods.

The last expectation is not directly related to the erasure theory but its confirmation would strengthen the idea that neural connections can at least be influenced by stimulation during the Stage-2 period. One could argue that negative findings in sleep-learning can be explained by the assumption that the signal does not have a lasting effect on the neural connections whatsoever. If there is nothing to erase, we do not need the erase-hypothesis to account for these negative findings!

METHOD

Subjects

Twelve subjects, 4 men and 8 women, volunteered two nights, one adaptive and one experimental. The average age was 23 yr. (SD = 7) whereas the median was at 20 yr. They were checked for sleep and/or hearing problems.

Material

The material to be learned were pairs of words in the native language of the subjects and were matched for number of syllables (two syllables in the adaptive night and one in the experimental night). Further, for each pair whether subjects associated them on a free association test was checked. If this was the case, the pair was rejected and a new pair was randomly chosen. From the total of 40 word pairs so selected, six lists were prepared.

Four lists of four word pairs were used for presentation during the sleep-only: 'Sleep-only List A' was presented two times during each Stage-2, 'Sleep-only List B' was presented four times during each Stage-2, and 'Sleep-only List C' was presented six times during each Stage-2. The fourth list, ‘Last Stage2-only list’, was presented only during the last Stage-2 of the sleep. If subjects did not wake up after this last stage but showed signs of going into an REM-stage, they were awakened by the experimenter. This last list then was never followed by a dream-stage.

Two lists of 12 words were prepared to explore the effect of sleep rehearsal. Both lists were learned on the evening preceding the experiment. One list was 'rehearsed' during each Stage-2 period; the other one was used as control with which the retention of the former list could be compared to evaluate the extra effect of the 'rehearsal' during the sleep.

Experimental Set-up

The experimental set-up was a standard EEG sleep recording according to the 10-20 system where the EEG was obtained from the C3-A2 and C4-Al derivations. EOG and chin-EMG were recorded too. A Nihon Kohden EEG-5210 polygraph was used as registration device. The stimuli were presented through a speaker at 1 meter from the subject's head with an intensity measured at the subject's head position which varied between 35 and 45 dB. The ideal level was determined for each subject separately during the adaptive night as the level that resulted in central processing but not in awakening.

Procedure

During each Stage-2 period the three sleep-only lists and the sleep-rehearsal list were presented. Pairs were separated by 15 sec. of silence. The intensity level was continuously adjusted by the experimenter according to the following rules: if the stimulus does not provoke a K-complex response in the EEG, increase the intensity level. And, if there are signs in the EEG of awakening, decrease the intensity level (or stop the presentation).

Retention tests were taken the following morning about 30 min. after wakening and about four weeks later in the same room.

Dependent Measures

There were three dependent retention measures, free recall, stimulated recall, and multiple choice. During the free recall test, the subject had to mention word pairs that spontaneously came to mind. During the stimulated recall test the experimenter presented one word of the pair and the subject had to respond with the other. In the multiple choice test, the subject was given one word and was requested to select one out of four possible alternatives as the second.

For the rehearsed material the free recall measure was used since the multiple choice retention score for this material was unsuitable due to a ceiling effect (scores near 100%). For the new material only the multiple choice scores were used since they were assumed to be the most sensitive.

RESULTS

New Material

Irrespective of the number of presentationss, the retention scores for the sleep-only lists were completely at chance (mean chance expectation = 25%), so there was no indication of learning for new material presented during in-terREM periods (Table 1). The expected presentation threshold for sleep-learning could not be confirmed.

TABLE 1

RETENTION SCORES IN MULTIPLE-CHOICE TEST FOR NEW MATERIAL

List	Retention-score (%)			
	The next Day		After 1 month	
	M	SD	M	SD
Sleep-only List A (2* Repetition)	29	21	21	14
Sleep-only List B (4* Repetition)	29	23	31	24
Sleep-only List C (6* Repetition)	21	26	25	26
Last Stage-2 List	35*	17	40**	24

*p<.02. **p<.05.

In contrast with the material presented during interREM periods that could have been erased by the subsequent dream stage, the material presented during the last Stage-2 shows evidence of learning; comparing 10 subjects' retention scores on the next day with chance scoring t=1.81, (df = 9; p<.07 one-tailed). For the retention scores after one month t=1.96 (df= 9; p<.05). Two subjects awoke by themselves during the last Stage-2 and were omitted from the analysis.

TABLE 2

RETENTION SCORES IN FREE-RECALL TEST FOR SLEEP-REHEARSAL EFFECT

GROUP	Retention Scores					
	The Next Day				After 1 Month	
	Total		First Half		Total	
	M	SD	M		M	SD
Rehearsed	34	18	21	12	7	10
Control	32	14	14	7	3	4

Note.—*The retention score is the number of correct instances of free recall divided by the list length in %.*

Sleep-rehearsal

Table 2 summarizes the results for material learned the previous evening to 100% correct. Although the retention score for the material rehearsed during the night is higher, it is by no means significantly better than the score on the unrehearsed control list. However, it appeared *posthoc* that often the recalls mentioned first by the subject were correct. Therefore the responses of the subjects were split into two parts. Indeed, the first half of the responses contains more than half of the correct free recalls but also there appears to be a rehearsal effect for these data (2-sample t-test between control and rehearsal list for 12 subjects = 1.91, $p<.05$ one-tailed). Although there is still a difference after one month, it is not significant any more, given the large intersubject variance; see the discussion below.

DISCUSSION

The results of the present experiment are by no means conclusive. The approach is nevertheless presented because sleep-learning research in this form appears to be a potentially relevant technique, not only to test hypotheses from theories of learning but also from theories about the functionality of sleeping and dreaming, like the one of Crick and Mitchison (1983). The strongest effect found in this experiment and the one that is most relevant for the theory of Crick and Mitchison (1983) is the apparent learning during the last Stage-2. However, a word of caution is needed here since this last Stage-2 is the most prone to awakening. Although presentation was stopped immediately when there were EEG signs (most notable alpha activity) indicating awakening, it could not be avoided that a few times the last word of a pair was presented while there was alpha activity. A *post hoc* worst-case analysis performed by two independent researchers, in which all 14 pairs were omitted from the data, reduced the learning effect during the last Stage-2 from 40 to a nonsignificant 35%. According to generally accepted sleep criteria (Lasaga & Lasaga, 1973), this analysis is very conservative since at least the first word was presented when there were no signs of alpha activity.

The statistical significance of the results was generally reduced because intersubject variability was high. For example, one subject (by far the oldest) consistently produced null data while one month after the experiment another subject could freely recall 33% of the sleep-rehearsal list (against 7% average for all subjects). Clearly, in designing studies more consideration should be given to the problem of subjects' variability.

In conclusion it should be noted that the phenomenon of sleep is poorly understood and that its study produces surprising results. For instance, most subjects maintained muscle tonus during sleep until after presentation of the first stimuli of that night. This suggests that, even while asleep, they had been waiting for them!

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