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Acquisition and Processing of Information During States of REM Sleep and Slow-Wave Sleep

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14. ABSTRACT *(Maximum 200 words)*:
Review, analysis and summary of experimental literature on "Sleep Learning." Findings:

a. Serious methodological flaws found in all reported positive results. No evidence that semantic learning occurs when verbal material is presented to sleeping subjects.
b. A critical, but open-minded test of sleep learning has not been done. Recommendations made for an appropriate experiment.
c. If novel material is presented to the sleeping subject, there is danger that it may interfere with normal night-time processing of earlier, day-time experiences.
d. It is possible that external stimuli could be used to prompt and direct information processing during sleep to favor one set of material in preference to others. This could apply to skill learning as well as declarative memory with considerable potential relevance to soldier training.

15. SUBJECT TERMS

Sleep learning   Night-time processing   Information processing   Soldier training   REM

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ACQUISITION AND PROCESSING OF INFORMATION DURING STATES OF REM SLEEP AND SLOW-WAVE SLEEP

CONTENTS

Summary

(i) The evidence for sleep learning is critically reviewed. Serious methodological flaws are found in all studies that report positive results. It is concluded that there is no evidence that semantic learning can occur when verbal material is presented to a sleeping subject.

(ii) Nevertheless, it is also the case that a critical but sympathetic test of sleep learning has never been performed. Proposals are made for such an experiment, which would include: pre-sleep suggestion; procedures designed to engage the attention of the sleeping subject; a control group that received all the same treatments as the experimental group except for the form of the material presented during sleep; and EEG monitoring of the stage of sleep in which material was presented.

(iii) Theories of information processing during sleep are reviewed. If novel material is presented to the sleeping subject, there is the danger that it may interfere with the normal night-time processing of earlier, day-time experiences.

(iv) However, it is possible that external stimuli could be used to prompt and direct the information processing that occurs during sleep, causing the sleeper to process one set of material in preference to other material that is socially or personally more salient for him. The importance of this possibility is that it would apply to skill learning as well as to declarative memory and thus might be especially relevant to the training of soldiers.

1. Introduction.

When the concept of sleep learning was introduced, there was an implicit or explicit assumption that one third of our lives was wasted in sleep. It therefore seemed advantageous to occupy these wasted hours with useful instruction. In the last two decades there has been a growing suspicion that important cognitive processing occurs nightly during our normal sleep. These new ideas (see § 3) have two implications for the concept of sleep learning:

(a) Even if sleep learning is demonstrated under particular conditions, the experimenter must check that the gain is not at the expense of some different mental function that would otherwise be performed during sleep (Mollon, 1967).

(b) There is the interesting possibility that external stimuli, presented during sleep, might serve not to yield new learning but to prompt and direct the processing that does normally occur during sleep.

Therefore, as a preliminary to assessing studies of sleep learning, the nature of sleep is reviewed and recent ideas about cognitive function in sleep are discussed.

2. The inhomogeneous nature of sleep.

There are two major forms of sleep. The two forms differ in the electrophysiological state of the cerebral cortex and it is a priori unlikely that sleep learning, if it occurred, would occur with equal readiness in the two states.

2.1 In 'slow-wave' or 'orthodox' sleep the electroencephalogram (EEG) is characterised by large-amplitude waves of low frequency. Several levels of slow-wave sleep are usually distinguished, according to the frequency of the waves and the presence of 'sleep spindles', bursts of activity at 13-15 cps.

Thresholds for awakening the subject vary with the level of slow-wave sleep, but are never as high as in the second form of sleep, REM sleep (Jouvet, 1975). This might be taken to suggest that the subject is more likely to assimilate external information during slow-wave sleep. However, the presence of large-amplitude slow waves in the EGG suggests that little information processing is occurring in the cortex during this form of sleep. For a large-amplitude wave in the gross scalp potential is not an indicator that a large amount of information is being transmitted by the cortex. On the contrary, the large-amplitude slow waves can arise only if the responses of thousands of neurons are synchronised. And if neural activity is thus correlated, then the signals of individual units are redundant (in the informational sense) and it is unlikely that differentiated processing is taking place.

2.2 In 'Rapid Eye Movement' (REM) or 'Paradoxical' sleep the electroencephalogram is desynchronised and resembles that of the waking state. Short periods of REM sleep occur at intervals of about 90 minutes during the night. If a subject is woken from REM sleep, there is a 80% probability that he will report that he was dreaming. REM sleep is 'paradoxical' in that the desynchronised EEG, otherwise characteristic of an alert and awake subject, is accompanied by very high thresholds for awakening and by a profound inhibition of muscle tone (Jouvet, 1975). So the characteristics of REM sleep speak for and against the possibility that new material can be assimilated in this state: the desynchronised EEG suggests that information processing is occurring in the cortex and that there might therefore be the potential for the sleep learning, whereas the high threshold prima facie suggests that this is not the time for the experimenter to be presenting material to be learnt.

3. Theories of cognitive function during sleep.

With regard to the possibility that daytime experiences are processed during sleep, we can distinguish four related hypotheses in the recent literature:

(a) Classification. It may not be advantageous for an organism to store a large number of specific memories, specific records of the many experiences of each day of its lifetime. Instead, the successful organism is likely to be one that draws generalisations, and recognises analogies between partially dissimilar experiences. The sorting and classification of experiences may be very time-consuming, owing to the size of the data bases that are to be searched; and so these operations may well occur during sleep. The idea can be traced back to the neurologist Hughlings Jackson. It is noteworthy that dreams are often subjectively characterised by the drawing of analogies.

(b) The computer analogy of Newman & Evans. Any large computer installation must be taken off line at regular intervals in order for housekeeping to be carried out and Newman and Evans (1965) have suggested that something similar is true of brains. In a computer installation, back-up copies of files need to be deleted; discs need to be 'squeezed', that is, files need to be rearranged to remove wasteful small gaps; files may need to be rearranged on disc or tape in a different sequence in order to reduce access times and search times; operating systems need to be updated to take account of changing demands on the system. The human brain is unlikely to resemble a digital computer in detail - its operations appear to be analogue and parallel in nature - but it is plausible that operations of the above type need to be carried out in any information-processing system.

One form of hypothesis (b) would correspond to a computer analogue of hypothesis (a). During the waking day, information may be stored in real time in a sequential representation, as on a serial computer tape. Access to this "episodic" memory would be by serial order, by time-of-occurrence, and by cues that were coincidentally present during the learning process. During the night, data would be transferred to a random-access memory, analogous to a hard disc. In the latter memory, events and observations would be sorted by category; and material would be stored with earlier material to which it was related. By this account, then, the sleeping brain is seen as a machine for converting episodic memories to semantic memories.

An early metaphor rather like the above proposal was that of Gaader (1966), who likened the specific experiences of the day to 'data' and accumulated wisdom - character - to 'programs': during sleep, data are cleared from the limited store available, but programs are modified in the light of each day's experience.

(c) Unlearning in an associative net. This hypothesis, advanced by Crick and Mitchison (1983, 1986), places the emphasis on selective loss of associations during sleep. The brain is taken to be an associative net. New associations, acquired in the waking state, are stored by the formation of new, excitatory, connections within the net. Any given synapse may be involved in the representation of more than one memory. As more and more excitatory connections are formed in the net, the net will become increasingly vulnerable to 'parasitic modes': that is to say, inputs to the system may generate unwanted and unintended resonances. Crick and Mitchison demonstrate this by computer simulation and they propose that a special mechanism operates during sleep to remove the unwanted parasitic modes. During REM sleep, they suggest, the system is isolated from external input, and random inputs are provided to the net from an internal source. The excitatory responses that then result are weakened by a special process of unlearning that occurs only during sleep. Crick and Mitchison tentatively identify the random inputs with the PGO (ponto-geniculo-occipital) waves that are known to be characteristic of REM sleep.

(d) Jouvet's hypothesis. In cats, bilateral destruction of the caudal part of the locus coeruleus appears to remove the motor inhibition that is normally present during paradoxical sleep (Jouvet, 1975, 1978): the sleeping animals then exhibit dramatic stereotyped behaviours, such as leaping, stalking, toying with prey. Their behaviour is normal when they are awake or are in slow-wave sleep. Jouvet supposes that the period of paradoxical sleep is used to develop, and maintain, the organization of complicated sequences of motor behaviour: efferent patterns are generated, and are monitored by re-afference, but they do not normally issue in overt behaviour, owing the inhibition of muscle tone that is characteristic of paradoxical sleep. Jouvet's hypothesis is of especial interest in the present context, since it supposes that it is skills, rather than semantic memories, that are rehearsed during mammalian sleep (see § 6, below).

All these hypotheses are speculative, and they are not exclusive, but they reflect a growing suspicion that some form of information processing is a primary function of sleep. Evidence in favour of the idea includes the following observations: (i) The duration of REM sleep is increased if the subject is engaged in intellectual or social activity during the previous day (Hennevin & Leconte, 1971; Smith, 1985); (ii) deprivation of REM sleep may impair memory for material presented previously (Tilley & Empson, 1978); and (iii) The duration of REM sleep is highest in the neonate (Roffwarg et al, 1966) and declines throughout life [although it should be said that the electrophysiological definition of paradoxical sleep is difficult in the neonate, and the tonic inhibition of muscle tone is less marked (Hennevin & Leconte, 1971)].

All four of the hypotheses (a - d above) suppose that dreams are a subjective counterpart of the information-processing that is occurring during sleep. The hypotheses differ with regard to the question (it is one of the classical questions of psychology) of whether dreams represent the discarded debris of the day or whether they represent the information that is most salient for the organism. But very suggestive for our general argument is the process that Freud called "condensation": the objects, persons, and events that arise in dreams are often mixtures of experiences that occurred at different times but which nevertheless share some feature in common. We might expect dreams to exhibit this property either if paradoxical sleep subserves the drawing of analogies between old and new experiences (see (a) above) or if (Crick and Michison, 1986) it serves to separate memories that have overlapping representations.

In sum, the possibility of sleep learning cannot today be considered without reference to current ideas on the information processing that occurs during sleep.

4. The evidence for sleep learning.

4.1 Verbal learning during sleep.

The number of satisfactory experiments on sleep learning is remarkably limited.

Simon and Emmons (1955) reviewed ten studies that they were able to trace in the existing literature, the first of which was an (unpublished) military study of Morse code learning, carried out by Thurstone in 1916. Simons and Emmons found all ten of these early studies to be inadequate. In some cases there was no control group; in others, the subjects were used as their own controls but the conditions were not counterbalanced, so that practice effects ("learning to learn") could affect the results. In other cases, where positive results had been reported (e.g. Fox and Robbins, 1952), there was no electroencephalographic monitoring of sleep, to ensure that subjects were always asleep when the material was presented (and to check that they were not awakened by it).

Emmons and Simons (1956) themselves reported a study in which the EEG was monitored throughout, and material was presented only when alpha wave activity (8-13 Hz) had been absent from the trace for at least 30 seconds (they selected nine subjects who showed a clear alpha rhythm in the relaxed waking state). The stimuli were lists of ten one-syllable nouns, which were played repeatedly during sleep. Before they went to sleep, the subjects were told explicitly that a list of words would be played to them and that they should learn it. On wakening, they were asked to select the target words for a set of fifty words. They did not perform better than control subjects in selecting the target words. Nor did they choose the training words more frequently than they chose an equivalent group of control words.

In a separate study, using twenty-one experimental subjects, Simon and Emmons (1956) gave single presentations of questions and answers during a range of states ranging from wakefulness to deep sleep. Subjects attended for only one night. They were asked to indicate if they heard any given item. On wakening next morning, they were given recall and recognition (multiple-choice) tests of the material. Evidence of learning was found only for items presented in wakefulness or drowsiness. Experimental subjects achieved a performance no better than controls for those items presented when no alpha activity was present in the EEG [Note: the work of Simon and Emmons was carried out before the existence of paradoxical sleep was widely recognized.]

Particular weight can be placed on a careful study by Bruce et al (1970). In this experiment, novel verbal material was presented to sleeping subjects. The EEG was monitored throughout. Twenty-one subjects were divided into three groups ('facilitation', 'interference' and 'control') which were matched for their learning ability in a preliminary test. The first group received, during slow-wave sleep, repeated presentations of a set of fifteen pairs of low-association nonsense syllables. The second group received the same material, but with the pairings scrambled. The control group was presented with computer-generated musical noise for the same amount of time. Subjects in all groups were woken a few minutes after the end of presentation and, as soon as they were alert, were required to learn the list presented in sleep to the first group. There was no difference between groups in the number of trials required to learn the list of associates; in other words, no sleep learning could be demonstrated even though testing was by the "savings method", which is commonly held to be a very sensitive indicator of learning and which does not require the subject to be aware of having learnt.

In a summary review of his own work, a veteran soviet authority on sleep learning (Svyadoshch, 1962) supported the view of Simons and Emmons, that there is no significant acquisition of material that is merely presented to sleeping subjects. A short story was read twice to 100 sleeping subjects (of different ages and sexes), with instructions to remember what they heard. Those who were not wakened by the presentation "remembered nothing of what had happened". In another experiment, only 1 of 20 subjects was reported to show any savings in the daytime learning of a poem that had been presented twenty times in sleep. Svyadoshch, however, claimed that the faculty of sleep learning could be developed, by suggestion during a previous hypnotic trance or by suggestion during the waking state. Success was most readily obtained in the case of suggestible subjects, and especially those who possessed the ability to wake up at will at a given time or in response to a strictly defined stimulus. Kulikov (1964, 1965) agreed that nothing was learnt if the material was presented without prior suggestion but he claimed that it was sufficient to give the suggestion to the sleeping subject at the beginning of the hypnopaedic session ("...listen to this and remember what is said, try and memorize it as much as possible, you will remember this all your life, and whenever wanted you will be able to relate it. Listen and memorize..."). The material presented by Kulikov was coherent text rather than arbitrary associations and some of his subjects apparently gained a spectacularly good grasp of conceptually difficult material (e.g. on perceptual constancy). But one's confidence in Kulikov is reduced by his credulous and confused account of western studies, by the absence of electrophysiological monitoring of sleep state in his own research, and by his failure to introduce an appropriate control group.

The study by Levy, Coolidge and Staab (1972) did use pre-hypnopedic suggestion, but has a fatal methodological weakness. Lists of pairs of equivalent Russian and English words were presented during sleep to 10 male high-school students. A 15-minute suggestion tape (not unlike Kulikov's) was played as the subjects fell asleep; and further suggestion was given during the night, before the presentation of the memoranda. The subjects slept in the laboratory for two initial nights, which served to habituate them to the unfamiliar conditions. Five training nights followed. The memoranda were divided into 4 sets of 12 associates, the same list being presented to a given subject on the first two nights and then a fresh list on each subsequent night. For half the subjects, the presentation was during paradoxical sleep on the first two nights; and for the other half it was in Stage 4 sleep; and on subsequent nights, the sleep state was alternated for given subjects. Free-recall tests on waking showed no evidence of learning, but Levy et al claim a small but significant effect in a multiple-choice recognition test. However, average scores on the latter test were 9.8, 17.2, 8.5, 32.6 and 21.6 (mean: 17.94) and it is not clear that they differ significantly from the chance level of 16.67. What the authors did was (illegitimately) take the "chance" level as effectively zero, because a group of naive subjects, tested separately, were misled into choosing pseudo-cognates (e.g. "Ko-vyor" - "caviar"), one of which was included in each set of six. But the experimental subjects were (a) tested repeatedly and (b) offered a prize of 100 dollars for best performance: they may well have been less ready to choose the pseudo-cognate distractors.

During the 1960's, positive results were reported from a number of Russian and Czechoslovakian studies in which hypnopedia was combined with daytime teaching, sometimes conducted by radio broadcasts (see Hermann, 1966, Hoskovec, 1966, Bliznitchenko, 1968). The daytime teaching was often quite extensive: Bliznitchenko (1968) describes one language-teaching "experiment" that consisted of a course of thirty-six waking lessons, each lasting 40 minutes and being given at 7.25 a.m. The material was actively rehearsed by the student in a pre-sleep session (10.45 - 11.00 p.m) and was then re-presented early in the night and once more before wakening. Similarly, in a well-publicized Czech experiment, five hours of normal teaching were given on ten consecutive Saturday afternoons; after each of these sessions the students received one hour of instruction while half asleep; the lesson was then repeated for five hours over a loudspeaker while the students slept; and there was homework to be done, and records listened to, during the week (Hermann, 1966). Studies such as these are of little scientific value, owing to the absence of placebo control groups (see below), or even control groups of any kind, against which to assess the performance of the hypnopedic students. Nevertheless, we shall return to these studies in § 6.

The British study by Tilley (1979) resembled the Russian work in so far as a pre-sleep presentation was reinforced by repetition during sleep. Thirty subjects were run in pairs for two consecutive nights, the first night being for familiarization. Prior to sleep on the second night, the subjects were presented with 20 pictures of single items; and during the night a word series, corresponding to a subset of 10 of the pictures, was presented. Half the subjects received the names of the even-numbered pictures, and half the names of the odd-numbered pictures. The material was presented at a moment during the night when one of the yoked subjects was in paradoxical sleep and the other in Stage 2 slow-wave sleep. On waking, subjects were given recall and recognition tests for the pictures. It was found that repeated items were recalled significantly better than non-repeated items, provided that the repetition occurred during Stage 2 sleep. There was no advantage to repeated items presented during paradoxical sleep. This study is discussed further below (§6).

4.2 Classical and instrumental conditioning during sleep.

Although there is little evidence for the acquisition of new semantic information during sleep, we might well expect to find that simpler forms of learning can occur: it is an everyday observation that sleepers habituate to noises that regularly occur during the night and that sleepers seldom fall out of beds and bunks. There are, in fact, experimental reports that both pavlovian and instrumental conditioning can be achieved during sleep.

Beh and Barratt (1965) paired a 300-Hz tone with a shock of an intensity that did not wake the subjects but did produce "K complexes" (large amplitude slow waves) in the EEG. 500-Hz tones were also presented but were not paired with shock. A control group received both 300-Hz and 500-Hz tones, but neither were paired with shock. The experimental group showed differential conditioning of K-complexes to the 300-Hz tone; and in the subsequent waking state the same tone produced blocking of alpha activity. The subjects in this experiment were 20 young women and they were given chloral hydrate to induce sleep.

Operant learning during sleep was reported from the Walter Reed Institute in 1961 by Granda and Hammack. The subjects were deprived of sleep for 36-40 hours before the study and the EEG was monitored. During presentation periods, a shock was given to the leg if 3 sec elapsed without a button press by the left hand. In addition the sleeper could secure time-out periods by responding with the right hand on a fixed-ratio schedule. Subjects learnt both the responses without returning to the waking state.

5. Comments on the empirical evidence for semantic learning during sleep.

5.1 The absence of incidental learning in the awake subject.

Edridge-Green (1891) demonstrated our remarkably poor recollection for material that is repeatedly presented to us in the daytime but to which we do not attend. Although people might look at the same watch several times a day for a number of years, very few could reproduce accurately the configuration of the face; in particular, subjects would reproduce the figure four as IV unless they were aware of the horological peculiarity that the Roman four is given as IIII on timepieces. Similarly, Edridge-Green's medical students could not recognize as familiar the leaf of the plane tree, one of the commonest trees in London. A modern demonstration of the lack of incidental learning is given by Morton (1967) who invited his subjects to reproduce the arrangement of digits and letters on the telephone dial then current in England: although the sample of 200 subjects included all members of the MRC Applied Psychology Unit as well as a number of individuals who had worked as switchboard operators, not one could correctly pair digits and letters.

If sheer repetition of exposure produces no learning in the awake subject (and if moreover perceptual thresholds are raised during some stages of sleep), then we should be little surprised that no learning has been demonstrated in those hypnopedic studies in which the material was merely presented to the sleeping subject, with no attempt to "make contact with" him or her (as the Eastern European literature would express it.) Although the studies in socialist countries may have been flawed, this is no reason to reject the idea that tests of sleep learning should be preceded by suggestion in the waking state and by attempts to gain the subject's attention during sleep.

It is curious that none of the reported studies use presentation of the sleeping subject's own name to gain his or her attention. In a celebrated experiment, Oswald, Taylor and Treisman (1960) found that the EEG's of sleeping subjects exhibited more "K-complexes" (large amplitude slow waves) to their own names than to the names of other subjects or to their own name played backwards. It does seem that the use of personal names, at the onset of hypnopedic sessions, might assist in penetrating the screen that protects the sleeping brain from external stimuli.

5.2 The problem of state-dependent learning.

A number of recent experiments have demonstrated that memory is often specific to the context of learning, that is to say, recall is better if the environmental cues at the time of recall, or the internal state of the organism, correspond to those that obtained at the time of learning. Thus, in a now classic study, Godden and Baddeley (1975) presented to divers 40 unrelated words, either on the beach or under 10 feet of water. The divers were then tested in the original environment or in the alternative one. Significantly more words were recalled when testing was in original environment rather than a novel one. Similarly, internal state has been manipulated by drugs or by procedures that change an animal's hormonal levels; and recall has been found to be better when testing takes place in the same state. The usual theoretical account of these results is that the internal state provides important retrieval cues. Since the state of the organism in sleep is so profoundly different from the waking state, there are reasons to suppose that little transfer of learning will occur. It is conceivable that there are special military conditions under which it is desirable to learn a response to be made only during sleep.

The work of F. J. Evans and his collaborators might be seen as evidence of memory that was specific to the sleeping state. Their several reports (Evans et al, 1966, 1970; Evans, 1972) appear to describe the same study, in which verbal suggestions were given to subjects in light (but electroencephalographically confirmed) sleep, and cue words were given later the same night and on a subsequent night. The subjects were young male student nurses. The reponses required were overt bodily movements, which were directly recorded by the experimenter who gave the cue. About 20% of the cue words attracted a correct response when presented during light sleep on the same or on the following night; and a subset of subjects gave correct responses during a sleep test 5 months later; but there was very little evidence of memory for cue words when tests were administered to the waking subjects the morning after the suggestions had been given. This might be taken to show memories that could be retrieved only in the sleeping state in which they were acquired. But the study remarkably lacked an obvious control. Consider the nature of the suggestions given. They were all of the type: "Whenever I say the word 'leg' your left leg will feel extremely cramped and uncomfortable until you move it." (The other three other frequent suggestions referred similarly to 'itch', 'blanket' and 'pillow'.) Since in each case there was a natural semantic link between the cue word and the action required, an essential control would be to present the same cue words to sleeping subjects who had not previously received the corresponding suggestion and whose responses were scored by an experimenter who was unaware of which cue word had been presented. Despite the sleeper's raised thresholds for external stimuli, we do know that some processing of verbal stimuli occurs during sleep (see preceding section and Arkin and Antrobus, 1978) and external stimuli may be incorporated into dreams. So it is plausible that some percentage of cues such as 'pillow' or 'leg' would, without prior suggestion, yield responses that the informed experimenter would consider correct. Our suspicion can only be reinforced by the reportedly long latency - sometimes exceeding 50 sec - of the 'correct responses'.

5.3 Hawthorne effects.

It is well recognized in psychology that industrial or educational innovations are difficult to assess: the workers or students in the experimental group may do better only because they receive attention or because they (or their supervisors and teachers) believe that the innovation will improve performance. Such effects are sometimes called Hawthorne effects, although the nature of the original Hawthorne effect has been questioned (Parsons, 1974). It is often peculiarly difficult for the experimenter to design a satisfactory 'placebo' control: what is needed is a bogus innovation that is yet plausible enough to convince the control group (and their teachers, where appropriate) that they are taking part in an experimental condition that will improve their performance.

In some of the studies on sleep learning, the problem of the Hawthorne effect has been simply ignored. The NRC's Committee on Enhancing Human Performance is reported (Science, 11 December 1987, p 1501) as believing that "one of the most compelling studies was conducted in 1916 by L. L. Thurstone, who reportedly shortened Morse Code training of sailors by 3 weeks by giving additional training during sleep"; and the Committee's editors, Druckman and Swets (1988 p 40), suggest that Thurstone's experiment was flawed only by the absence of EEG recording. But the real difficulty with Thurstone's study (and one that should eliminate it completely from further discussion) is the absence of a placebo control. The subjects and instructors definitely knew whether they were in an experimental or control group; and the situation was a competitive one. For Thurstone, in his personal communication to Simon and Evans (1955), reported that his second study (the one with a control group) was discontinued "when it was discovered that ambitious Navy instructors of the control group had been giving extra daytime instruction in order not to be out-taught." Similarly, the absence of a placebo control clearly invalidates the experiments of Blitznitchenko (1968).

One solution to the problem of Hawthorne effects is to mislead the subjects as to the purpose of the experiment, i.e. to conceal entirely the fact that it is an experiment on sleep learning; but this manoeuvre may in itself prevent a positive result, for the reasons considered in § 5.1 (above): we may need to prime the subject, if we are to ensure that the sleeping brain is ready to admit, and attend to, external inputs. A better design is to lead all the subjects to expect to learn, but to give some of them facilitatory and some of them interfering material during sleep.

If the design includes the presentation of pre-sleep material to the waking subject, then the experimenter may be tempted (as in the study of Tilley, 1979) to use a within-subjects design and to divide the material into two arbitrary subsets, only one of which receives repetition during sleep. The drawback of this design will be discussed in § 6 (below).

6. Is it possible to direct the information processing that occurs during sleep?

The empirical evidence for semantic learning during sleep is very weak. There are theoretical reasons why it may be difficult to achieve (see §§ 2 and 3); and, even where it occurs, it is necessary to check that the learning is not at the expense of some normal processing that occurs during sleep.

However, the idea of sleep learning should not be set aside completely. If we suppose that some form of information processing is occurring during normal sleep (§ 3), we may ask what it is that determines the material chosen for processing. From all that is known about the content of dreams, we might guess that it is events of emotional significance that particularly engage the nocturnal processor. Now, this may often be useful for us, and it is biologically appropriate that the mammalian brain should rehearse in sleep the daytime events that rather directly increase or decrease the probability of survival of its owner's genes. But there may be occasions where we should like to direct our processor (or someone else's) towards some non-emotional material in order to enhance our waking grasp of it or to assist in problem solving. The sleeping soldier, left to himself, may wish to rehearse the circumstances and behaviors that led to his enjoying sexual success, or sexual failure, in the hours before sleep; but his instructors might rather that he rehearsed the misfire procedures on an M72A2 light antitank weapon. Is it possible that by presenting suitable stimuli at a suitable stage of sleep we could deflect our sleep processing in a particular direction?. As we have seen, in many of the (flawed) Russian studies that reported positive results, and in the study of Tilley (1979), the presentation of material during sleep followed the presentation of the same, or related, material during waking. There is the interesting possibility that the presentation of material during sleep - while not leading to true learning - prompted or directed the processing of material that had been presented during waking. Although the nature of the cognitive activity during sleep remains uncertain, we can nevertheless ask whether we could prompt it in a particular direction by external cues. It is already known that the content of dreams can be influenced by stimuli presented to the sleeper (Arkin and Antrobus, 1978).

If it is possible to influence the direction of cognition during sleep and if this is why positive results were obtained in the Russian studies, then the material actually presented in sleep need not be identical with the formal material of waking lessons. On the contrary, the stimuli need only be associates of the learned material. Thus to soldiers receiving formal tuition in Russian as one of several daytime activities, we might need only to play Russian folk music or a tape of a young woman speaking fluently and seductively in Russian; and to soldiers instructed in the loading of a rifle, we might play the characteristic sound of the magazine being inserted.

We can now see the limitation of the design of Tilley (1979). He compared performance on training items that were named during the night with those that were not named. But the named pictures, revived during sleep, would be strong associates of the unnamed pictures. So the nocturnal cues would be likely to prompt processing of those pictures that were not named during sleep. If Tilley had made the comparison between two very distinct daytime tasks, learnt at different times and in different contexts, then he might have secured a much stronger effect of nocturnal cuing, and might have secured a positive effect in paradoxical sleep.

In recent research on human memory, a clear distinction has emerged between "procedural" and "declarative" memory: the former comprises what would traditionally be called skills, and the latter comprises all the semantic and episodic information that the subject can explicitly report. The dissociation of the two memories is well seen in the Korsakoff syndrome or in post-encephalitic amnesia, where the patient may acquire motor skills (or other skills, such as mirror-reading) as rapidly as control patients in the same hospital, but will make no verbal acknowledgement that he or she has met the task before (Cohen & Squire, 1980). Now, what the Army wishes to teach to its trainees is largely procedural: the material included in "Soldier's manual of common tasks" (STP 21-1-SMCT) is mostly of this character. Although verbal instruction may be used in the teaching of loading and unloading weapons, or the donning and removing of protective clothing, the Army wishes the trainee to progress to a stage where these operations become automatized skills. Such procedural knowledge can hardly be gained from hypnopedia as it has historically been understood, since the instructor is limited to the presentation of auditory verbal material during sleep. But if it is the case that nocturnal stimuli may prompt and direct the information processing that occurs during sleep, then merely the presentation of associates of the skill (such as the sound of loading a magazine) may cause the soldier to work on this skill during sleep rather than on other skills less relevant to his success on the battlefield.

In this context, we may refer back to the work of Jouvet (1975), who proposed that it is skills (he assumed innate skills in the case of his cats) that are rehearsed during paradoxical sleep (see §3).
And we may also note here that motor skills have recently been said to gain from 'mental training' (see Druckman and Swets, 1988, ch 5) and that older authors held that the phenomenon of 'reminiscence' - improvement during intervals between training - is particularly pronounced in motor learning (Woodworth & Schlosberg, 1954, ch 25). There is thus the interesting possibility that night-time processing would be found to enhance procedural learning more than other forms of learning.

7. Conclusions.

(a) There is no evidence that semantic learning can occur when novel verbal material is presented to a sleeping subject.

(b) It is the case, however, that a satisfactory experiment has never been performed. Such an experiment would include: pre-sleep suggestion; procedures designed to engage the attention of the sleeping subject; a control group that received all the same treatments as the experimental group except for the form of the material presented during sleep; and EEG monitoring of the stage of sleep in which material was presented.

(c) During sleep, and particularly during paradoxical sleep, there is evidence for information processing of daytime inputs. The nature of this processing is not understood, but it is thought to be crucial to the daytime cognition of higher mammals.

(d) It is possible that external stimuli could prompt and direct the information processing that occurs during sleep, causing the sleeper to rehearse one set of material in preference to other material that might be socially or personally more salient for him. The importance of this possibility is that it would apply to procedural memory as well as declarative memory, and thus is more relevant to the training of soldiers than is classical hypnopedia. Research on this possibility is strongly recommended.

8. Appendix: Proposals for research

8.1 Sleep learning.

Twenty young male subjects take part in the experiment and each attends the sleep laboratory for four consecutive nights. Depending on the capacity of the laboratory, two or four subjects are run in parallel. Half of each of these subsets of subjects are to be controls, but the subjects are assigned to condition only by the laboratory computer during the experimental procedure.

The first and second nights serve to accustom the subject to sleeping in the laboratory and to the presence of recording electrodes. On the third night, after the subject has retired and recording electrodes have been attached, a standardized recording is played by pillow speakers to each subject, suggesting that the subject will attend to, and successfully learn, material presented during sleep. The subjects' EEG's are continously monitored by computer and are subject to an on-line Fourier analysis to identify stage of sleep. For half of all subjects, experimental presentations are given in REM sleep on the third night and in slow-wave sleep on the fourth night; for the other half of the subjects, these arrangements are reversed.

For all subjects, each experimental presentation during sleep is preceded by presentation of the subject's own first name, and by a brief request to remember the material that follows. During this period, the computer adjusts the stimulus volume to a level that does not produce evidence of arousal in the EEG.

The stimuli are drawn by the computer from a pool of low-frequency nouns. The computer stores the EEG trace following any given word and identifies words that attract an explicit arousal response in the EEG. Each word is presented several times. On the following day all subjects are asked to learn to criterion a list of words drawn from the pool. For the 'experimental' subjects, these are words presented during the night; for the 'control' subjects they are other words from the same pool. The list of words is played to the subject over headphones and he is then asked to type as many as he can recall into the computer. Presentation and response are continued until the list is typed perfectly. Evidence for sleep learning would be shown by savings in the number of repetitions required for learning by the experimental group. The stage of sleep in which presentation occurred is an independent factor in the analysis.

8.2 Prompted processing during sleep.

20 young male subjects are taught, during the daytime, two very different tasks. One is to learn a set of Russian words and their English equivalents. The other is to learn, to a given criterion, a tracking skill, which is presented in the form of a computer war game and which provides the experimenter with a continuous measure of time-on-target [This game could be made to resemble a specific military tracking task]; at certain points in the game (e.g. when the fire button is pressed, when a strike occurs), the computer emits characteristic noises - as is the case in commercial games of this type.

During the following night, half the subjects, chosen randomly, are presented with 'reminders' of the language task: these would not be the actual words learnt during the previous day but would be other Russian words delivered in a strong Russian accent, perhaps interspersed with Russian music. The other half of the subjects receive 'reminders' of the tracking game - the characteristic noises of firing, striking etc. The EEG is monitored, stimuli are presented only during sleep, and the acoustic level is adjusted if signs of arousal occur.

Next day both sets of subjects are re-tested on both tasks. The performance of the two groups is compared for each task. It is predicted that superior performance on a given task will be shown by those subjects who received the reminders corresponding to that task.

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