Discrimination and Conditioning during Sleep as Indicated by the Electroencephalogram

Abstract. *Changes in electroencephalograms indicate that subjects respond more frequently to significant or meaningful stimuli during sleep than to nonsignificant stimuli, and that conditioned reactions may be induced in sleeping subjects.*

Studies of humans alerted during sleep (*1, 2*) have suggested that certain "critical" stimuli have the power of evoking an alerting response as indicated by the electroencephalogram (EEG), whereas "neutral" stimuli do not. The results of our investigations confirm earlier findings that the critical stimuli are those which possess some personal significance for the organism, and we have shown that this stimulus significance may be experimentally "built-in" by conditioning. Our results also extend earlier findings by indicating that the organism, even during low levels of vigilance such as sleep, is capable of responding to changes in stimulus significance brought about by conditioning.

The experimental situation allowed for continuous recording of the EEG so that we could observe the records obtained before, during, and after sleep, from 20 female subjects (10 experimental and 10 control subjects). Each subject attended one session late at night during which she took part in three experiments.

The criterion of response for the records obtained during wakefulness was taken as desynchronization or "blocking" of the alpha rhythm of the EEG, while the response criterion during sleep was taken as the K-complex, a phenomenon characteristic of stage C of sleep (*3*).

In the first experiment we attempted to "build-in" stimulus significance during wakefulness by means of conditioning, and to test for discrimination of the conditioned stimulus during sleep. Two tonal stimuli (500-cy/sec and 300-cy/sec sine wave), produced by an oscillator, were employed as the stimuli which required differential response. To ensure that both tones were neutral prior to conditioning, random presentations of each were given until habituation had taken place and there was no evidence of desynchronization of the alpha rhythm contingent upon presentations of the stimuli.

After habituation, the experimental subjects received presentations of the 500-cy/sec tone paired with pulsed shock (six pulses per second) to the right forefinger at a level "painful" to the subject. The tone was presented 15 times for 2 seconds each time, and was followed immediately by 2 seconds of shock. These presentations were interpersed with ten presentations of both the 500-cy/sec tone and the 300-cy/sec tone alone. Intervals between stimulus presentations varied from 20 to 90 seconds. The control subjects underwent the same procedure except that neither of the tones was ever paired with the shock.

Student's t-tests, applied to the data obtained during the pre-sleep conditioning session, revealed that the experimental subjects responded at a significantly higher level to the 500-cy/sec tone than to the 300-cy/sec tone ($p < .001$), whereas the control subjects did not ($p > .7$). A test between the two groups revealed that the experimental subjects responded at a significantly higher level to the 500-cy/sec tone than the control subjects ($p < .001$); hence, it was reasonable to conclude that conditioning of the alpha rhythm had occurred in the experimental group and that the 500-cy/sec tone had acquired significance for this group.

Subjects were then tested for discrimination between the two tonal stimuli during stage C of sleep. Percentage response and trials to extinction were calculated for each of the two stimuli for each subject. Analyses of variance revealed a significant interaction for stimuli versus the two groups of subjects, both for the percentage-response data ($F = 55.07$; $p < .001$) and the data for trials to extinction ($F = 5.72$; $p < .05$). Table 1 shows that the significance of this interaction is accounted for by the relatively high frequency of response of the experimental subjects to the 500-cy/sec tone. From these results it is clear that discrimination of the significant stimulus (500-cy/sec tone for the experimental subjects) had occurred.

The second experiment was the major concern of our study since genuine learning during sleep, if demonstrated, has far-reaching practical and theoretical consequences. Here we set out to build-in stimulus significance during sleep of medium depth, and to test for discrimination of the conditioned stimulus both during and after sleep. Chloral hydrate (0.6 g) was administered to help induce sleep and, in all but two subjects (rejected from the study), the onset of sleep was rapid and sleep lasted for about 3 hours. Training and test trials were carried out in stage C of sleep only.

Table 1. Mean response of subjects to stimuli presented during sleep.

Measure	Subjects*	Tone 500 cy/sec	 300 cy/sec
	Experiment 1		
Percentage response	E	51.7	21.1
	C	32.9	29.8
Trials to extinction	E	22.9	13.4
	C	14.5	14.2
	Experiment 2		
Percentage response	E	14.7	48.5
	C	20.6	14.8
Trials to extinction	E	7.1	15.6
	C	8.8	7.3

* E, experimental; C, control.

Although it is not difficult to condition arousal reactions of the EEG during wakefulness (*4*), evidence of such conditioning during continuous sleep is lacking, perhaps for want of a suitable unconditioned stimulus. We found that pulsed shock (six pulses per second) from an electrostimulator produced clear K-complexes when "turned up" to a critical level, without waking the subject. This stimulus-response unit was therefore selected as an indication of Pavlovian conditioning.

The other stimuli used in this experiment were again the 500-cy/sec tone and the 300-cy/sec tone, both of moderate to low amplitude, responses to which had already been extinguished or habituated in the first experiment. In the second experiment the 300-cy/sec tone was selected as the stimulus to be paired with the shock for conditioning, while the 500-cy/sec tone was never paired with an alerting stimulus. The same conditioning schedule as for the first experiment was used. Hence, the experimental subjects received the 300-cy/sec tone paired with shock and single presentations of the 500-cy/sec tone, while the control subjects received single presentations of all stimuli. At the conclusion of the conditioning trials, the subjects received random presentations of both tones until there was no response to either. One crucial feature of our study must be emphasized. During all the experimental maneuvers there was no evidence (electrical or behavioral) of a shift, in any subject, from stage C to a lighter stage of sleep or to the waking state. We contend that sleep was continuous and unbroken.

Percentage responses and trials to extinction were calculated from the EEG records. Analysis of variance revealed a significant interaction for the stimuli versus the groups of subjects, for both the percentage-response data ($F = 68.4$; $p < .001$) and trials to extinction ($F = 9.56$; $p < .05$). Table 1 shows that the significance of this interaction is accounted for by the relatively high frequency of response of the experimental subjects to the 300-cy/sec tone. Thus, during sleep the subjects had been conditioned to respond with K-complexes to a stimulus which previously held little significance for them.

In a session conducted after sleep following the third experiment, subjects were tested for blocking of the alpha rhythm by responses to the 300-cy/sec and 500-cy/sec tones. Percentage responses were calculated and t-tests applied to the data. The tests revealed that in the experimental subjects, spontaneous recovery occurred with the conditioned 300-cy/sec stimulus ($p < .02$), and that no significant response was made to the 500-cy/sec tone.

We regard the results of this experiment to be of both theoretical and practical importance in relation to the control of human behavior. We cannot yet predict what results would be obtained if the stimuli were complex "psychological" ones such as verbal instructions. Nevertheless, within the narrow limits of our experimental arrangement, we have established and extinguished conditioned cortical responses during uninterrupted stage C of sleep, and have demonstrated spontaneous recovery immediately after waking. To our knowledge there is no other clear evidence of learning during continuous sleep. It does not appear to be necessary for subjects to shift to a lighter stage or to awaken after the presentation of the unconditioned stimulus for conditioning to occur. This is one essential difference between our study and studies of Williams *et al.* (*5*) in which an overt motor response (presumably requiring awakening) was used in conjunction with reinforcing stimuli which these workers described as resulting "in severe consequences: a high-intensity fire alarm, a flashing light, and electrical shocks to the foreleg."

Table 2. Mean percentage response for each stimulus presented during sleep.

Measure	Subjects*	Stimuli		
		Tone	Number	Name
Percentage response	E	42.5	17.0	60.5
	C	31.5	19.0	15.0

* E, experimental; C, control.

In the third experiment we played a tape-recording to the sleeping subjects, after the manner of Oswald *et al.* (*2*). The recording consisted of 20 presentations each of a 600-cy/sec tone, numbers, and a name. For experimental subjects the name on the tape was the subject's own name, while control subjects were given presentations of one of the experimental subjects' names. The other stimuli remained the same for both groups. Percentage response was calculated for each stimulus for each subject. The results are presented in Table 2.

Student's t-tests, applied to the data obtained from the experimental subjects, revealed a significant difference in response between "own name" and the 600-cy/sec tone ($p < .01$); between the 600-cy/sec tone and numbers ($p < .001$); and between "own name" and numbers ($p < .001$). For the control group, t-tests revealed a significant difference in response between the 600-cy/sec tone and "other name" ($p < .01$) and between response to the 600-cy/sec tone and numbers ($p < .01$). Between the groups of subjects the only significant difference was that between name stimuli ($p < .001$). Thus, although number stimuli and "other name" stimuli failed to produce a significant level of response in sleeping subjects, "own name" stimuli produced the most discriminations, followed by a supposedly "neutral" tone which did not show significant variation between subject groups. This last finding might be accounted for by the significance attached to the tone by virtue of its novelty, since discriminations were fewer toward the end of the experiment, indicating that habituation was taking place.

Our findings indicate that it is not only possible for the human organism to discriminate between stimuli during sleep on the basis of their significance, but that stimulus significance "built-in" during sleep appears to carry over to the waking state. Thus, it would seem that, even during lowered levels of vigilance, some sort of scanning mechanism operates, sifting important from unimportant information as it impinges on the organism. Deutsch and Deutsch (*6*) have proposed a model which illustrates just how such a scanning mechanism would operate to select stimuli according to their importance for the organism at a particular time. Our present findings and earlier work (*7*) appear to support the model proposed by Deutsch and Deutsch.

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