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Operant Behavior during Sleep: a Measure of Depth of Sleep

Most animals spend approximately 30 percent of their lives asleep, yet remarkably few experimental investigations of sleep have been conducted, possibly because of the difficulty of measuring sleep. Processes that are difficult to measure may be studied in behavioral as well as in physical sciences by analyzing the frequency, duration, and degree of their interference with a more easily measured process (*1*, *2*). In this report I present a method for measuring the duration and depth of sleep by recording how much it suppresses the rate of a reinforced operant response and compare the results with those obtained by measurement of body movements (*3*).

A sleep-deprived subject wearing an aviator's helmet was placed in a comfortable bed; the helmet contained an earphone through which a pure tone of 2000 cy/sec was delivered to the subject's ear. Each response (subject's thumb closing a microswitch taped into his preferred hand) was recorded on a counter and a Harvard cumulative recorder. A rate analyzer (*4*) controlled a potentiometer which reduced the intensity of the tone after each response. Rapid operation of the switch reduced the tone to zero intensity, and the subject could avoid the tone by continued responding. Slow operation of the switch kept the tone at a moderate intensity. If the switch was not operated, the tone rose to and was maintained at its full intensity (30 db). Thus the subject's rate of response controlled the intensity of the tone.

To record body movements, the base of a brass rod (9 in. long and 1/4 in. in diameter) was suspended through the center of a brass washer (5/8 in. inside diameter) by a light spring from the center of the bed spring. A body movement was recorded when slight movements of the subject made the rod contact the washer.

Sleep records were taken under conditions of (i) 15 hours' sleep deprivation; (ii) 15 hours' deprivation plus 1½ grains of seconal ingested 5 minutes before retiring; (iii) 38 hours' deprivation; and (iv) 15 hours' deprivation without the tone. Since the latter condition was presented last, it provided a control for conditioned responding effects. Prior to the control session, the subjects were instructed to respond whenever they were awake at the rate they had on previous nights. Thus, behavior maintained by escaping the aversive tone could be compared with behavior maintained by recalled verbal instructions and previous conditioning. Two adult males, aged 20 and 34, served as subjects.

Figure 1 contains sample cumulative response records (selected as representative of 40 similar records) for one subject during eight continuous hours in bed on each of six different nights. Records for the first 4 hours (Fig. 1, top) show operant behavior during the deep initial sleep, and records for the last 4 hours (Fig. 1, bottom) show the subsequent light waking state characterized by bursts of responding. Records of short daytime naps contain response bursts very similar to those of the light waking state. The major effects of sleep deprivation and sedation on operant responding during sleep occur during the first 4 hours of sleep.

The two records for 15 hours' deprivation show the pattern of normal sleep. The subject spent 24 minutes in bed before the response rate dropped (sleep latency), and an additional 16 minutes passed before the rate dropped to zero (sleep onset). The period of deep sleep (from the time responses dropped to zero rate until 100 responses were emitted and during which the tone sounded at its full intensity) was 2 hours. Notable is the fact that approximately the same amount of responding occurred over the whole night on both 15-hour deprivation records, despite the separation of the two curves by 400 responses after 4 hours of sleep. The same effect appeared for the condition of 15 hours' deprivation plus seconal.

The addition of seconal to 15 hours' deprivation produced deep sleep sooner (sleep latency, 13 minutes) and more abruptly (sleep onset, 3 minutes) than did 15 hours' deprivation alone. Also, seconal doubled the deep sleep period (4 hours) and produced deeper sleep since fewer response bursts were emitted.

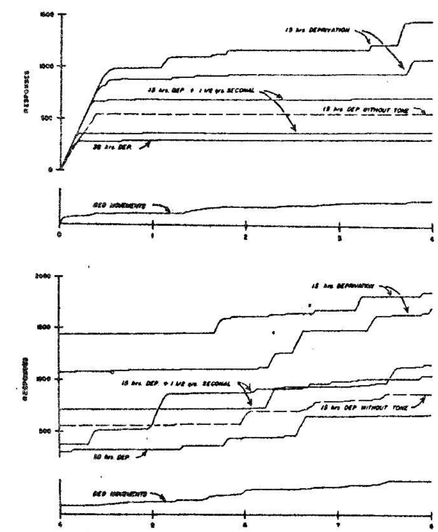

Fig. 1. Cumulative responses reinforced by a reduction in tone intensity are plotted against time in bed. (Top) First 4 hours in bed; (bottom) second 4 hours in bed. The lower the slope of the curves, the more intense was the tone and the deeper was the sleep. A cumulative record of body movements is presented at the bottom of each part.

The 38-hour deprivation record was similar to the seconal record, with a short sleep latency (7 minutes) and an abrupt sleep onset (5 minutes). The deep sleep period (5½ hours) was longer and was characterized by fewer response bursts than it was for both normal and drugged sleep conditions.

The control record showed a 23-minute sleep latency (similar to unconditioned responding) but an immediate sleep onset (0 minutes). Thus, conditioned responding did not show the gradual sleep onset characteristic of unconditioned responding. Note also that the initial conditioned response rate during the latency period (base line) was lower than the unconditioned rate, showing inaccurate recall. The deep sleep period was longer (5¾ hours), and the rate of response during deep sleep was lower for conditioned responding than for unconditioned responding.

The records of body movements did not show the sleep-latency or sleep-onset differences for the conditions of deprivation and sedation that were shown by operant responding. Fewer movements were made during deep sleep than during the later waking state for all conditions, however, and therefore the method could show that deprivation and drugs increase the duration of deep sleep. This effect has been reported previously (*5*).

The subjects' reports of the number of times they recalled awakening were not related to the number of response bursts in the sleep records. Neither subject reported ill effects of the experiment, and both felt rested after the sessions.

These observations show that unconditioned operant responding to turn off an aversive stimulus during sleep is more sensitive to intermediate sleep levels and to deprivation and drug effects than is responding supported by verbal instructions with previous conditioning or the recording of body movements. This sensitive and widely applicable method should enable scientists to study sleep behavior more effectively. It can be used to investigate the effects of drugs, neurosurgery, deprivation, and awakening stimuli on the sleep of lower animals as well as on that of human beings. Records of operant responding during sleep and hypnosis should be compared with electroencephalographic records in normal and abnormal subjects.

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References and Notes

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3. This investigation was supported by a research grant (M-977) from the National Institute of Mental Health, National Institutes of Health, U.S. Public Health Service. The assistance of Douglas Bowden is gratefully acknowledged.
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