Sleep and Paradoxical Sleep in Ruminants.* (30850)

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Previous investigators have contended that ruminants, unlike other animals, do not sleep. Although cows, sheep, and goats lie down frequently, most of this time is spent in ruminating. It has been suggested that inasmuch as the eyes seldom close, ruminants rest but do not sleep as other animals(1). Other workers failed to demonstrate signs of sleep in adult cattle, sheep, or goats(2,3). Only transient drowsiness with the eyes open was observed.

One explanation offered is that rumen function precludes typical sleep. It certainly requires a sternal recumbent position. Other evidence put forth is that young ruminants which have not developed rumination functions sleep quite often(4).

The study reported here was undertaken by employing electroencephalography to clarify the question of whether ruminants have the physiologic capacity for sleep. Moreover, the study was designed to test the hypothesis on the sleep-inhibiting influence of rumen contraction.

The results revealed that adult goats do exhibit a sleep which is transient and polyphasic. Moreover, rumen contraction does not prevent sleep, but continues at normal rates during these periods.

Materials and methods. Seven goats were studied, of which 5 were adult females. The 2 young goats were twins (1 male, 1 female) which ruminated, although they were only 43-57 days old during testing.

Because of electrostatic shielding and instrumentation requirements, all goats were continuously confined, beginning 3 days prior to testing. The pens measured 2 × 3.5 feet, and were designed to permit feeding, watering, and automatic collection of urine and feces. The goats adjusted quickly to this environment and ate, ruminated, and rested.

The studies were conducted during daylight hours. Inasmuch as goats are less active at night(5), studies during the day represented the most unlikely time for sleep to occur. A standard feeding routine was established 3 days prior to testing in which 0.25 lb of oats was fed *ad libitum* from 7:30-8:00 A.M. and alfalfa hay was fed *ad libitum* from 8-9 A.M. Then all food was removed, and testing began. A similar feeding schedule was established in the evening to assure an adequate diet. Water was available at all times.

Each goat was studied continuously throughout the day for at least 5 days. Various physiological functions were monitored during all stages of behavior. Physiological functions were monitored by recording the electroencephalogram (EEG), the electromyogram (EMG), eye movement potentials, the electrocardiogram, rumen contractile activity, and respiration movements. These potentials were recorded with a six-channel electronic recorder and associated pre-amplifiers.†

The influence of rumen activity on behavior was tested to learn whether it regulates the states of consciousness or whether these states regulate rumen activity. Rumen stasis was induced in each adult with atropine (0.2 mg/kg, subcutaneously) and the various behavior states subsequently monitored. On a separate day tranquil behavior in adults was induced with chlorpromazine (1-2 mg/kg, intramuscularly) and subsequent rumen activity monitored.

The EEG was recorded monopolarly from the frontal and occipital skull regions, with the area over the nasal bones as a reference. Electrodes were stainless steel and subcutaneously implanted. Implantation in bone was considered but abandoned because this method still did not prevent chewing artifacts in the experiments reported by Bell(3).

The EMG was obtained from subcutaneously implanted stainless steel electrodes

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† Physiograph, E & M Instrument Co., Houston, Texas.

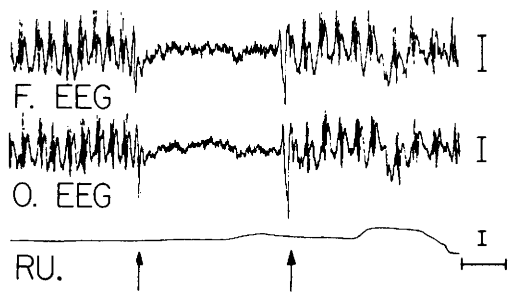

FIG. 1. Records illustrating presence of alert EEG patterns when goats are lying quiet and ruminating. The alert EEG patterns which are obscured by chewing artifacts become quite distinct during a lapse in rumination. Arrow at left indicates swallowing of bolus; arrow on right indicates regurgitation. F. EEG = frontal electroencephalogram; O. EEG = occipital electroencephalogram; RU = impedance changes of rumen contractions. Calibrations: horizontal line, 2 sec; vertical lines 100 μv (EEG) and 5 ohms (impedance of rumen).

placed on each side of the neck. The electrodes for monitoring eye movements were placed subcutaneously, 1 cm posterior to the lateral canthus of the eye. Electrocardiograms were obtained from subcutaneous electrodes placed at the locus of the heart on each side of the chest.

The rumen contractions were monitored by placing stainless steel electrodes (for impedance measurement) 15 cm apart in the dorsal sac of the rumen. These electrodes did not penetrate into the rumen. The plastic-insulated lead wires were anchored with sutures to the rumen wall, the flank muscles, and the skin. Surgery was performed under local anesthesia (lidocaine), with general sedation produced by chlorpromazine injection (1-2 mg/kg, intravenously). Penicillin and dihydrostreptomycin (in oil) were injected intramuscularly daily for 3 days as prophylaxis against infection.

Respiration was monitored by increasing the amplification in the impedance channel. All lead wires were anchored to the skin with dermal sutures and were united at the top of the scapula and soldered to a multicontact, miniature connector, which was also anchored with sutures. Post-surgically, the wires and the sutures did not cause any undue discomfort to the goats.

Generally, statistical analysis of data was by paired analysis for each goat. Data are expressed as the mean difference and standard error. The many observations of each animal for each behavior state were averaged before analysis and this value used in computing mean differences.

Results. The goats' behavior was most conveniently characterized by one of the following classifications: "Standing, Standing-Ruminating, Lying, Lying-Ruminating, Sleeping, and Paradoxical Sleeping."

When the goats were awake, either standing or lying, the EEG was usually of the aroused type, with low voltage and fast activity. During rumination, chewing artifacts obscured the EEG, but fast activity was clearly evident during the interval after swallowing and before regurgitation (Fig. 1).

True sleep was observed in all 7 goats, and 29 episodes were studied in detail. Goats slept in sternal recumbency, sometimes resting their heads on the cage or on their flanks. The average duration was 5.1 $\pm$ 0.6 minutes. The criteria for determining the presence of sleep included dorsal recumbent position, drooping of head and ears, closing of eyes, cessation of eye movements (Fig. 2), relative unresponsiveness, relaxed muscles (Fig. 2), slower heart rate (Table I), slower respiration rate (Table I), and slower EEG frequencies (Fig. 2). The frequency of sleep was quite variable. On some days a goat would not sleep at all, whereas on other days

TABLE I. Physiological Changes with Behavior in Adult Goats.

	Heart rate	Respiratory rate	Rumen rate
Standing	93	24	1.1
Standing, ruminating	-4 ± 5	0	$+1.0 \pm .4$ (5%)
Lying	-3 ± 7	$+2 \pm 2$	$-.1 \pm .2$
Lying, ruminating	-2 ± 6	$+1 \pm 6$	$+.7 \pm .2$ (2%)
Sleeping	-17 ± 6 (5%)	-10 ± 4 (5%)	$-.2 \pm .2$
Sleeping, paradoxical	-10 ± 5	-6 ± 1 (2%)	$-.2 \pm .2$

Numbers in parentheses indicate level of significant difference.

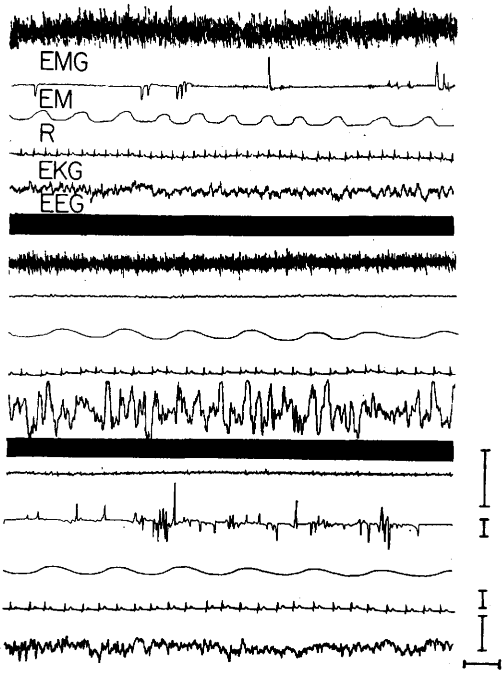

FIG. 2. Records illustrating physiological changes in goats during different behavioral states. ABOVE: goat standing, not ruminating; MIDDLE: goat exhibiting typical sleep; BELOW: goat exhibiting paradoxical sleep. EMG = electromyogram; EM = eye movement potentials; R = respiration; EKG = electrocardiogram; EEG = frontal electroencephalogram. Calibrations: horizontal line, 2 seconds; vertical lines, 100 μv, except 1 mv for EKG.

as many as 6 sleep episodes would occur.

Paradoxical sleep (PS)(6) was also observed in every goat. Forty-six episodes were studied in detail. A given PS episode always followed a period of typical sleep. PS was usually terminated by sudden awakening. The average duration of PS was similar to that for typical sleep, 5.5 $\pm$ 0.4 minutes. Every episode which was considered as PS met all the criteria which are known to be indicative of this stage of sleep(6): onset after typical sleep; superficial similarity to typical sleep; rapid eye movements (Fig. 2); phasic twitching of ears, limbs, and facial muscles; disappearance of nuchal muscle tone (Fig. 2); and arousal EEG with low voltage, fast activity (Fig. 2). The heart and respiratory rates were slower than during wakefulness, but not as slow as during typical sleep (Table I).

As expected, the goats (including the young twins) ruminated frequently during the day. Rumen contraction rates were always higher during rumination (Table I). Contraction rates of the young goats were similar to those of the adults (young goats had faster heart and respiratory rates). Rumination was never observed during either typical sleep or PS. The rumen contraction rates during sleep and PS were similar to those during wakefulness.

When rumen contraction rate was brought to zero by atropine, all states of behavior were observed, including 4 episodes of typical sleep and 3 episodes of PS in 3 goats. All were of typically short duration. Chlorpromazine enhanced the onset and duration of sleep, yet did not change rumen contraction rates; no PS was observed.

Discussion. Bell(3) had speculated that ruminants compensate for lack of sleep by resting during rumination. This research, however, shows that brain activity indicates alertness during rumination and that true sleep occurs during absence of rumination.

The clear demonstration of both true sleep and PS conflicts with previous reports. In addition, sternal recumbency does not prevent sleep, as Balch theorized(2). The low frequency and brevity of sleep and PS episodes, as well as the controlled laboratory conditions of this study, may explain why these phenomena have not been clearly demonstrated before.

The discovery of PS in ruminants adds impact to the speculation that this phenomenon, known as dreaming in man, is widespread among higher animals. Species in which PS have been heretofore observed include man, chimpanzees, cats, rabbits, and birds(6).

Rumen function apparently has little causal relation to sleep. Although rumination never occurred during sleep or PS, rumen contraction rates were the same during nonruminating wakefulness and during sleep. Rumen activity does not enhance sleep because the highest observed rates were during wakefulness. Clearly, rumen contractions do not prevent sleep. Nor does absence of contraction enhance the onset or duration of sleep or PS, as indicated by the atropine studies. Tranquilization does enhance sleep, yet does not change rumen activity.

If rumen activity does not regulate behavior, it then is either independent of behavior or, more likely, a consequence of it. First, autonomic control which is exerted over the rumen is known to be affected by the state of alertness. Rumen contraction rates are suppressed in excited animals(3), due no doubt to sympathetic activation. During rumination, the rates are accelerated, probably caused by parasympathetic activation.

Not explained by the data is why sleep and PS periods are so brief, especially when compared with other species. It is possible that these episodes are longer and more frequent at night.

Summary. This study proved that ruminants have the physiologic capacity for sleep and paradoxical sleep. Daytime ruminant sleep in goats was transient and polyphasic, averaging 5.1 $\pm$ 0.6 minutes per episode. The frequency was variable, ranging from 0 to 6 episodes during daytime. In addition, the goats exhibited paradoxical sleep, known as dreaming in man, with average durations of 5.5 $\pm$ 0.4 minutes. Rumen contraction rates apparently had no causal relation to behavioral states, but rather were a consequence of the animals' state of alertness.

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Serum Antibody Response in Sarcoidosis.* (30851)

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Although the cutaneous anergy associated with sarcoidosis has been well documented (1-3), a defect in the production of circulating antibody has not been demonstrated. Whereas decreased circulating antibody production has been reported following immunization with tetanus toxoid(4), normal levels have been observed in patients immunized with pertussis and typhoid vaccine(5), and increased titers of isoagglutinins have been noted following transfusion of mismatched blood(6).

The studies referred to have dealt with the total antibody concentration, and did not distinguish between the IgG and IgM varieties of antibody which might be present. The initial serum response to a large number of antigens has been shown to be an IgM (19S) immunoglobulin, while the predominant antibody response to secondary stimulation has been an IgG (7S) type of antibody(7-9). In the present investigation, the production of 19S and 7S antibodies by patients with sarcoidosis has been studied following primary and secondary immunization with typhoid antigens.

Methods. Five adult patients with active sarcoidosis were studied. All had biopsy evidence of non-caseating granulomas from one or more sites, and all were found to be anergic at the beginning of the study when injected intracutaneously with the following

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