

Discussion. The results show that the electrolytic lesion of the placenta on the 14th day of pregnancy in the rat induces poor fetal growth, whose effects influence body weight and brain electrical organization in post-natal life.

These data can easily be related to the well known time concordance between the development of VER in the rat and the periods of greater protein and DNA synthesis in the 1st month of life of this animal^{12,14}. One can then speculate that the decrease in the supply of energy which follows placental insufficiency interferes with protein synthesis and leads to a delay of myelination as indicated by greater latencies of the low frequency evoked responses (transient VER). The differences between treated and control rats disappear in the 4th week of life. That is they do not exceed the time in which myelination of the optic pathways occurs in the rat.

In this sense the observed changes should be considered as reversible alterations in the maturation and development of the visual system. One should remember that alterations in the development of VERs have also been observed in undernutrition and other restricted conditions^{2,4,5}.

The 2nd, and perhaps the most interesting, part of our present experiment is that dealing with the investigation of the development of evoked responses in the range of the rhythmic after discharge (RAD) described by Anderson¹⁵ in animals, that is about 8 Hz. The amplitude of the evoked response in this range of frequency is evaluated by power spectra after frequency analysis of EEG traces during stimulation. This range of frequency was selected as it showed a good display of power spectra and a regular development in amplitude during the 1st month of life. Moreover this kind of evoked response (steady-state VER) is possibly related to the onset of synapses in the visual cortex¹⁶ and the organization which has been called by Regan⁷ a frequency region addressed to the elaboration of luminance changes. On the basis of these last data one

could conclude that poor fetal growth due to placental lesion not only results in a delay of myelination but also to a transitory alteration in the onset of some aspects of functional organization in the visual cortex.

The data presented are to be confirmed by parallel investigations in histology and biochemistry which are at present in progress.

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Hibernation at moderate temperatures: a continuation of slow wave sleep¹

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Summary. Golden-mantled ground squirrels (*Citellus lateralis*) displayed virtually continuous electrophysiological states of sleep when hibernating at moderate ambient temperatures (22 °C). Rapid-eye-movement sleep progressively diminished with the fall in body temperature so that at a body temperature of 23 °C it was completely absent. At this temperature hibernation was characterized by slow wave sleep isomorphic with slow wave sleep episodes at non-hibernating (euthermic) body temperatures.

Recently, the adaptive value of sleep has been considered from an ecological perspective. Thus, sleep has been viewed as a process that reduces the energy requirements of endotherms^{2,3} while also affording seclusion from predators^{4,5}. Decreases in body temperature (T_b) and metabolism that accompany sleep are independent of, but normally superimposed upon the normal circadian variation of T_b ⁶. Therefore, such declines in T_b are specific to sleep itself. Qualitatively similar, but much greater, declines in T_b occur during the entrance into hibernation⁷. We have proposed homology between sleep and hibernation based on electrophysiological and thermoregulatory continuities between these 2 processes^{7,8}. Marmots and ground squirrels in a cold environment enter hibernation through sleep, but, as T_b decreases, the amplitude of electroencephalographic (EEG)

activity progressively declines, becoming almost isoelectric at about 5 °C^{9,10}. This EEG attenuation makes the records increasingly difficult to score for states of sleep and wakefulness at T_b s below approximately 25 °C^{9,10}. Therefore, we studied complete bouts of hibernation in ground squirrels subjected to a moderate ambient temperature (T_a) of 22 °C, which prevented T_b from falling to low levels. Under these conditions, the hibernating ground squirrel showed electrophysiological patterns of sleep isomorphic with those occurring during sleep at non-hibernating (euthermic) T_b s.

8 adult golden-mantled ground squirrels (*Citellus lateralis*) were implanted under sodium pentobarbital anesthesia with chronic cortical and hippocampal EEG, electrooculogram (EOG), and electromyogram (EMG) electrodes. The EMG electrodes were implanted in the dorsal neck muscles

and heart rate (EKG) could be recorded from them during periods of reduced muscle activity. Brain temperature (T_{br}) was measured by inserting a 36-gauge copper-constantin thermocouple in a small stainless steel reentry tube (0.6 mm outside diameter) implanted into the cortex with its tip at least 3 mm below the dura. Electrode leads were soldered to Amphenol terminal connectors anchored to the skull with acrylic dental cement. The recording cable terminated in a concentric mercury slip-ring assembly which allowed the animals freedom of movement.

Following surgery animals were housed individually in a $26 \times 25 \times 48$ cm wire cage containing a wooden box with cotton nesting material. They were maintained in the animal colony at a T_a of 22°C on a 12L:12D photoperiod (light on at 08.00 h) with food and water available ad libitum. Between November and March each animal and nest box was placed in a similar cage within a recording incubator, which in turn was inside a 45-dB sound-attenuating, electrically shielded chamber. Photoperiod, T_a , and food availability in the recording chamber were the same as in the animal colony. Electrophysiological and T_{br} measurements were recorded continuously over periods of 15–30 days from each animal.

4 animals entered hibernation under these conditions and

14 complete bouts of hibernation were recorded (at least 2 bouts from each animal). Entrance into hibernation (defined as the point at which T_{br} progressively decreased below 34°C) usually occurred in the late afternoon or evening but also occurred at other times of day (table 1). Bouts of hibernation lasted from 9 to 61 h ($\bar{X}=24$ h), beginning with the initial decline in T_{br} and ending with the return to euthermia. The minimum T_{br} for each hibernation bout ranged from 23 to 29°C and was inversely related to the length of the bout. Average bout length was 46 h at a T_{br} of 23°C , but only 11 h at a T_{br} of 29°C . This relationship held across the 4 animals (table 1) and within 1 animal which displayed 6 separate bouts of hibernation. This finding is consistent with that of Twente and Twente¹¹ where the length of dormancy in ground squirrels (regardless of whether it was euthermic sleep, shallow or deep hibernation) was inversely proportional to the T_b of the animal.

EEG and EMG amplitude and heart rate decreased in parallel with T_{br} during entrance into hibernation. Nevertheless, electrophysiological states of wakefulness, slow wave sleep (SWS), and rapid-eye-movement (REM) sleep could be identified according to conventional criteria throughout entire bouts of hibernation (fig. 1)¹⁰.

Table 1. Number, mean length and times of onset of bouts of hibernation and mean brain temperature minima during hibernation for 4 golden-mantled ground squirrels maintained at a T_a of 22°C

Animal No.	No. of hibernation bouts	Duration* (h)	Time of entrances (h)	Lowest T_{br} ($^\circ\text{C}$)
7601	4	11.3	20:00, 11:30, 22:01, 20:44	27.5
7603	2	30.1	00:14, 17:40	24.6
7607	2	22.2	21:10, 01:31	26.9
7608	6	32.3	20:07, 21:30, 01:21, 17:25, 03:14, 08:30	24.0

* From initial decline in brain temperature to return to euthermia.

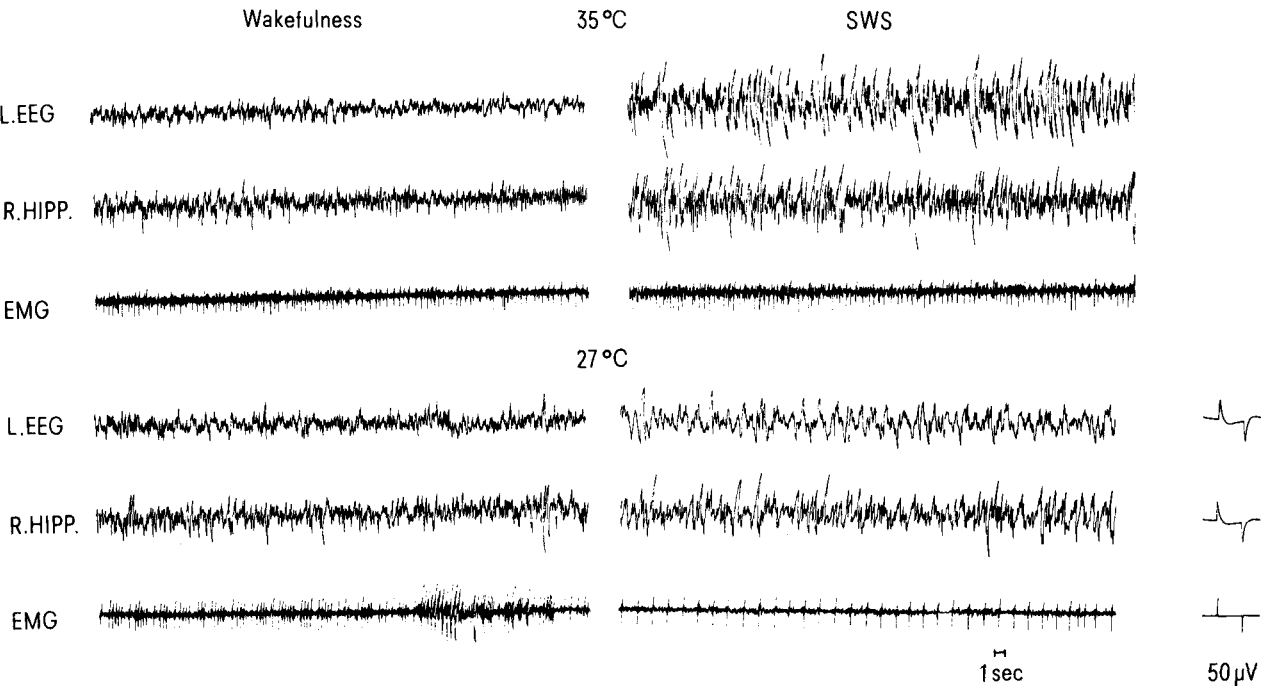


Fig. 1. Examples of wakefulness and slow wave sleep (SWS) in the golden-mantled ground squirrel when non-hibernating (euthermic, $T_{br}=35^\circ\text{C}$) and during hibernation ($T_{br}=27^\circ\text{C}$).

Table 2. Parameters of REM sleep, slow wave sleep (SWS) and wakefulness (W) for 2 golden-mantled ground squirrels during a 24-h period of non-hibernation and a comparable period of hibernation where brain temperature stabilized at 23°C

	Non-hibernation (Euthermia)									Hibernation								
	Percent recording time			Percent sleep time			Mean duration (min)			Percent recording time			Percent sleep time			Mean duration (min)		
	W	SWS	REM	SWS	REM	W	SWS	REM		W	SWS	REM	SWS	REM		W	SWS	REM
20.00–08.00 h	14.4	67.5	18.1	78.9	21.1	2.6	8.4	5.2		10.1	89.9	0.0	100.0	0.0		1.9	16.0	0.0
08.00–20.00 h	44.9	46.9	8.2	85.1	14.9	3.1	3.0	3.3		12.9	87.1	0.0	100.0	0.0		2.4	16.3	0.0
Total	29.6	57.2	13.2	82.0	18.0	3.0	4.6	4.4		11.5	88.5	0.0	100.0	0.0		2.2	16.1	0.0

T_{br} declines signalling the onsets of hibernation always began during periods of SWS. Subsequent episodes of wakefulness were usually brief and associated with a leveling off or retardation of the T_{br} decline. However, there were 2 instances when T_{br} continued to fall by as much as 2°C during periods of wakefulness.

As animals entered hibernation sleep patterns were predominant in the records and were essentially the same regardless of the point within the circadian cycle that hibernation occurred. The proportion of time asleep for all 4 animals averaged 90% during hibernation but only 70% during equivalent sidereal time periods when the animals were euthermic. REM sleep constituted 18.5% of total sleep time during euthermia, but decreased as T_{br} fell, becoming absent at T_{br} s below 24°C. There were several 4-h periods during which T_{br} stabilized at different levels during hibernation in 2 animals. Analysis of these revealed a high positive and linear correlation ($r=0.95$, $P<0.001$) between percent REM sleep and T_{br} (fig. 2). The decrease in REM sleep reflected a lower REM frequency, since the mean duration of REM episodes did not change as T_{br} decreased. Unambiguous wakefulness and SWS continued to be evident in 2 animals in which T_{br} fell as low as 23°C. At this T_{br} wakefulness was characterized by brief episodes (mean=2.2 min) of increased tonic and phasic EMG activity, associated with a desynchronized mixed frequency EEG (6–12 cps, 50 μ V; fig. 1). Wakefulness comprised only 11.5% of a 24-h hibernation period (table 2). SWS was characterized by a moderate amplitude EEG (0–2 cps, 75–125 μ V; fig. 1) with occasional spindles (3–6 cps, 50–100 μ V). Episodes of SWS had a mean length of 16.1 min and constituted 88.5% of hibernation. During hibernation total sleep time was the same in the light as in the dark phase of the 24-h period, slightly exceeding that of nocturnal euthermia (table 2).

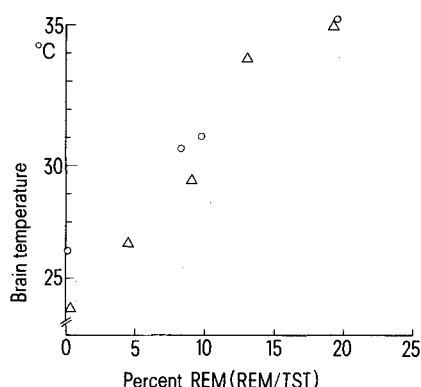


Fig. 2. Percent total sleep time spent in REM sleep at different brain temperatures (T_{br}) for 2 golden-mantled ground squirrels (O and Δ) during hibernation. Percent REM sleep was calculated only for periods where T_{br} remained stable for at least 4 h. Note the decrease in REM sleep with decrease in T_{br} .

Spontaneous returns to euthermia from hibernation generally took 2–3 h. Although increased wakefulness (34%) was evident in the records, they continued to be dominated by SWS; REM sleep was absent. Returns to euthermia deliberately induced by strong sensory stimulation were characterized by sustained wakefulness with increased EMG activity and a more rapid rise in T_{br} .

Our results now demonstrate the physiological similarities between estivation (daily shallow torpor) and hibernation. Electrophysiological characteristics of sleep and sleep stage distribution during hibernation in this alpine species of ground squirrel were identical to those observed at similar T_{br} s during estivation (shallow torpor) in desert ground squirrels¹². Moreover, pocket mice¹³ and doves¹⁴ deprived of food exhibit similar patterns of virtually continuous sleep during estivation or shallow torpor.

Hypothalamic thermosensitivity thresholds and T_b both fall during SWS in the same regulated manner as during entrance into hibernation, but to a lesser degree⁷. Since the entrances into hibernation or estivation are initiated during SWS, and are electrophysiologically isomorphic, it is likely that thermoregulatory adjustments during entrances into hibernation and estivation are an extension of those associated with the onset of SWS. Estivation and hibernation are physiological adaptations that conserve energy through their substantial decrement in metabolism. During the course of evolution sleep, with its reduced metabolism of lesser degree, might have represented a similar adaptation; but under ecological conditions in which energy constraints were less severe than those typically prevailing for estivators and hibernators.

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