mary endings is linear in our experiment only for displacement amplitudes of 50 to 100 μ, in the range of frequencies used, the motoneuron output (electromyogram) is still linear for stretches of up to about 2 mm. This averaged output from the motoneuron population is sinusoidal for input amplitudes greatly exceeding those at which linear behavior ceases for primary endings and single motoneurons (Fig. 3). Although the contribution by individual motoneurons to this linearization process is still to be assessed, there can be no doubt that the distribution of activity in parallel output channels is the factor mainly responsible for extension of the linear range of the overall reflex; the distribution of thresholds in the participating motoneuron population could largely account for this result. However, the effects of nonmonosynaptic excitatory actions upon α-motoneurons, which may depend on either primary-spindle ending or other receptors, cannot be excluded. We have excluded only the possibility that the presence of inhibitory actions from antagonistic muscles may favor linearization. In a series of experiments in which the innervation of muscle antagonistic to the triceps surae was initially intact, the stimulus being applied to the foot so that the activities of flexor and extensor muscles were interacting normally, removal of the influence from antagonistic muscles caused no apparently significant difference; the gain was reduced by only 5 to 10 percent, the suggestion being that inhibition from antagonistic flexor muscles has no great effect on the output of extensor motoneurons under the stated conditions.

Preliminary data indicate that Renshaw negative feedback may have a measurable effect on higher input frequencies than those encompassed here (above 8 hz), at which the feedback seems to synchronize the activity of motoneurons. This synchronization provides the possibility of increase in peak tension after recruitment of motoneurons ceases to contribute. However, there is no indication of a detectable contribution by Renshaw inhibition to extension of the linearity.

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Paradoxical Sleep: Effect of Low Partial Pressures of Atmospheric Oxygen

Abstract. *When cats are subjected to an atmosphere of 100 percent oxygen at a sufficiently low pressure, their sleeping patterns are changed: paradoxical sleep disappears and drowsiness increases. This change appears when the pressure decreases to a level close to that at which the hemoglobin begins to dissociate. Return of a cat to a normal atmosphere produces a rebound: the cat spends more time in paradoxical sleep than it did during the base-line period. This finding suggests that a mechanism, closely related to the metabolism of oxygen in the brain, must play an important role in the production of paradoxical sleep. Yet the increase in paradoxical sleep after decompression indicates that still other mechanisms must merge to produce paradoxical sleep.*

While seeking the effects of different tensions of atmospheric oxygen on the spinal reflexes of monkeys and cats, we noticed alterations in sleep patterns in the experimental animals (*1*). The most striking change was disappearance of the paradoxical phase of sleep when atmospheric pO_2 reached a certain low. Recent studies of animals indicate correlation between changes in behavior, metabolism, and circulation and the onset of paradoxical or REM (rapid eye movement) sleep (*2*). These studies suggest directly or indirectly changes in the metabolic patterns of neurons, which seem to reach a particular state of increased metabolic activity during REM sleep (*3*), but the mechanism by which REM is released or provoked remains unknown. Most reported measurements are concerned with changes in a physiological process: for example, change in brain-tissue impedence indirectly implies changes in activity within the brain (*4*). The electroencephalogram (EEG) changes (*5*), temperature changes (*6*), and alterations in cerebral blood flow (*7*) imply the same. One result suggests that the changes in temperature are achieved by peripheral diversion of blood rather than by brain metabolism (*8*); other reports are of concomitant changes in hormonal levels in the blood and the urine during paradoxical sleep (*9*); but none of these findings can be manipulated for induction or deprivation of paradoxical sleep in an animal. Some ingenious methods have been designed to prevent REM, but they are mainly concerned with waking or manipulating the animal as soon as it enters paradoxical sleep (*10*). Ability to deprive an animal of a phase of sleep, particularly paradoxical sleep, without having to wake it, offers a new approach toward understanding of the significance of as well as the mechanisms involved in sleep. Our experiments show how a low partial pressure of oxygen can deprive cats of paradoxical sleep.

We used five cats in which surgical stainless steel electrodes were implanted in the roof of each orbit to monitor ocular movements. Stainless steel screw electrodes were placed bilaterally on the occipital and frontal cranium to ob-

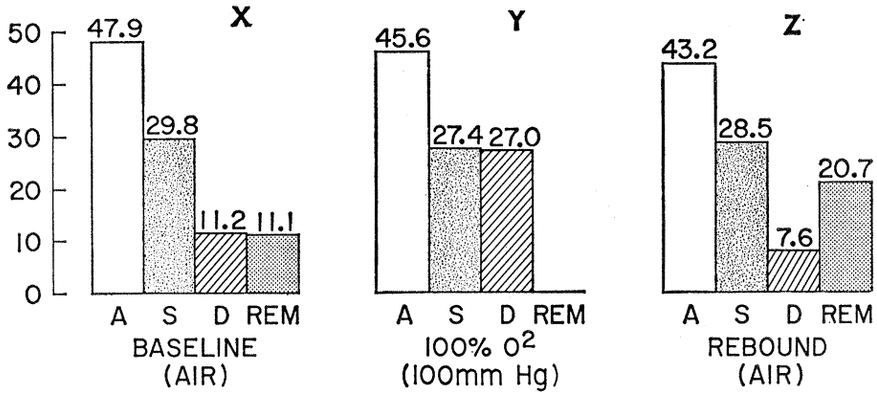

Fig. 1. The ordinates show the percentages during a 24-hour period. (X) The values obtained from four cats during the base-line period: *A*, awake; *S*, slow sleep; *D*, drowsy. (Y) The effect of 100 percent oxygen at 100 mm-Hg; note the increased drowsiness and the absence of REM. (Z) When the cats were returned to the air, drowsiness decreased even below the base-line value and REM sleep doubled the base-line value.

tain an EEG. For the neck myograms, stainless steel surgical-wire electrodes were placed in the splenius capitis. Each test animal was placed in a hermetically sealed 0.42-m^3 chamber. Pure oxygen, humidified by bubbling through distilled water, was delivered to the chamber at 12 liter/min. The temperature within the chamber was kept at 24°C. Analysis of the atmosphere showed these percentages: hydrogen, 0.2; water vapor, 2.6; nitrogen, 2.8; oxygen, 93.5; and carbon dioxide, 0.9 (argon, a trace). Several random samplings during each experiment showed that the compositions were constant.

Each cat was isolated in the chamber for at least 2 weeks before the manipulation of the environment, in order to acquaint it with the new ambient; it was observed through windows throughout the experiment. During the experiment the data were collected continuously on magnetic tape for computer analysis and by an ink-writing oscillograph for visual inspection. With the available pO_2 meters one could not record with a calibrated and implanted device beyond the 1st day, so we shall give no values of brain or blood pO_2.

The cat was considered adapted to its new milieu and ready for changes in its environment when its sleeping habits became stereotyped and the restlessness that characterized its early days in the chamber ceased. Base-line data were taken for 2 weeks after adaptation. The differentiation of the phases of sleep that we used is that described by Jouvet (*2*).

The waking, drowsy, sleeping, and paradoxical-sleep phases varied greatly in time, ratio, and order from cat to cat, so the total time spent in each state within 24 hours was summed and expressed as a percentage. Once the proportions of different stages were determined for all cats, the variable, 100 percent oxygen at reduced pressure, was introduced. For 24 hours immediately after decompression the cat was kept under 100 percent O_2 at 250 mm-Hg; earlier reports (*11*) are that such an atmosphere at this pressure does not affect the EEG for as long as 70 days. After this 24-hour confirmation of the base-line steady state, but in the new atmosphere, the pressure was further reduced in steps during 2 to 3 days until changes in sleeping patterns appeared. In these experiments we did not effect anoxia of the central nervous system by decreasing the partial pressure in an atmosphere of 100 percent oxygen to a level at which organic damage is apparent. The partial pressure was manipulated to a degree at which the sleep pattern was definitely altered, and from which the cat recovered completely after decompression; we never reduced the pressure below 98 mm-Hg. Histological studies of one cat exposed to this minimum pressure showed no organic damage.

Figure 1 shows the averaged results from four cats. Figure 1X shows the relative distribution of the four arbitrary stages of consciousness for a pO_2 of 150 mm-Hg in air. At a pO_2 of 100 mm-Hg, drowsiness increased and paradoxical sleep disappeared. When the animals were returned to air at 150 mm-Hg, paradoxical sleep increased (rebound); at the same time, drowsiness decreased below any previously recorded value.

All five animals followed the same pattern: paradoxical sleep disappeared at pO_2 100 mm-Hg. This situation remained unchanged until decompression increased the pO_2 (for 24 hours), after complete decompression and return to air. A rebound phenomenon was consistent (Fig. 1). Although the data for one cat were qualitatively the same as those described, they are omitted because of instrumentation problems.

Consumption of oxygen by the brain is greater during paradoxical sleep than during other stages of consciousness (*12*). Consequently one expects that, when the partial pressures of oxygen approach the levels at which hemoglobin begins to dissociate, the sleep pattern that requires the most oxygen will be affected. This may be the mechanism that causes disappearance of paradoxical sleep during low pressures of oxygen. However, when the atmosphere is returned to the normal sea-level environment having the same amount of oxygen as prevailed before the experiment, a marked rebound causes paradoxical sleep to exceed in duration the amount observed during the base-line conditions; slow sleep is apparently unaltered. Our data indicate that factors other than oxygen availability are concerned with the sleeping function, particularly the paradoxical-sleep function. The finding that paradoxical sleep can be manipulated and temporarily suspended may prove useful in this line of research.

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