FUNCTION OF SLEEP

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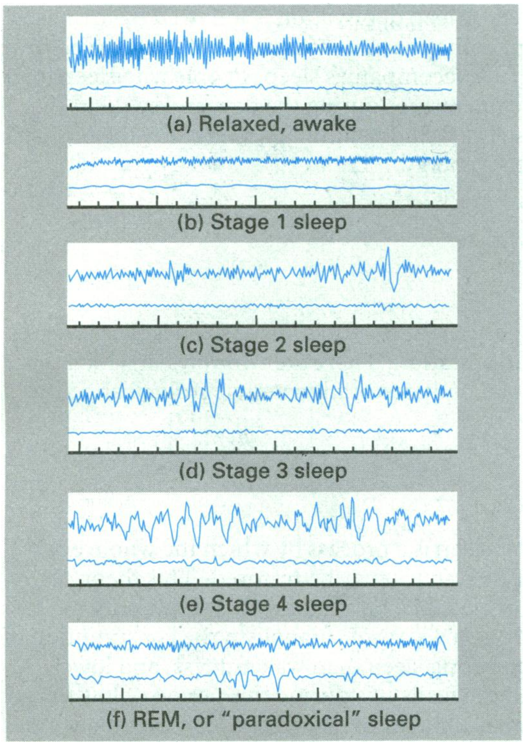
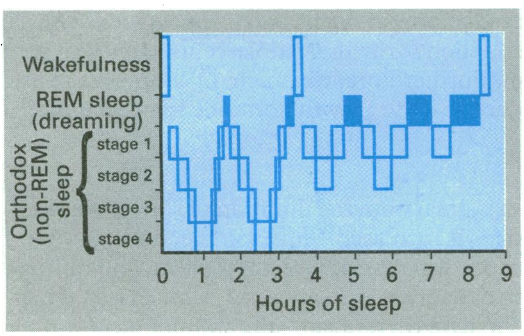


Electroencephalographs of a college student. The horizontal axis of each tracing is divided into units of one second. The top tracing is from one electrode on the scalp and the lower tracing indicates eye movements. Note the presence of slow waves in stages 2, 3, and 4.



Cycles of REM and non-REM sleep. Each cycle lasts roughly 90 minutes; slow wave sleep predominates during the first third of the night and REM sleep during the last third.

Sleep comprises two distinct physiological states, as different from each other as each one is from wakefulness; they are known as rapid eye movement (REM) sleep and non-REM sleep.

Non-REM sleep is made up of four stages: stage 1 is a light, drowsy phase—the transition from wakefulness to sleep; stage 2 is the first real stage of sleep, with the appearance of sleep "spindles" and "K complexes" on the electroencephalogram; and stages 3 and 4 are known collectively as "slow wave sleep," or deep sleep, because of the emergence of low frequency, synchronised waves.

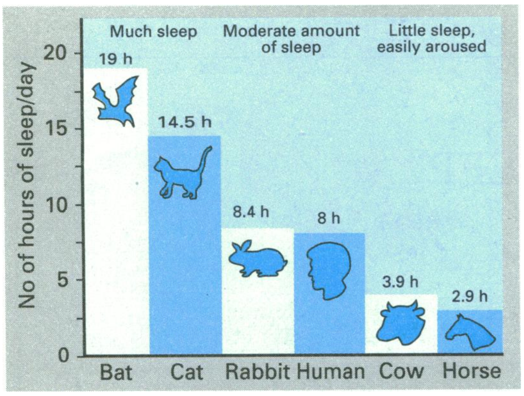
REM sleep is the stage during which most dreaming occurs. As people fall asleep they progress through the non-REM stages and then about 90 minutes later they have the first episode of REM sleep. There is a cycle of non-REM and REM sleep throughout the night, and as the night progresses the episodes of non-REM sleep become shorter, and those of REM sleep longer. Most slow wave sleep occurs during the first third of the night, and most REM sleep during the last third.

Only during the past few decades has sleep been described in electrophysiological terms. As a result there has been a vast increase in the number of techniques that clinicians and research workers use to record and analyse the electrophysiological measurements of sleep. As knowledge about the physiology of sleep has increased, doctors have become aware of the variety of problems and abnormalities associated with sleep that are common among the general population, and so the discipline of sleep disorders has developed. Despite the wealth of information that is accumulating about the biochemistry and physiology of sleep, its precise nature and function are not known. A number of theories have been proposed, which include the hypotheses that sleep is needed: for consolidation of memory, for binocular vision, or as part of thermoregulatory evolution. In this introduction we will deal with two of the more accepted theories, and this explanation will provide both a synthesis of relevant research, and background to subsequent articles that deal with details of the pathology of sleep.

Conservation of energy

> The metabolic rate is reduced at night, and particularly during sleep, by 5% to 25%

Most people's general activities increase during the day compared with the night. The concept of homoeostasis may be extended to explain that energy that is expended during the day must be balanced by a recuperative period. This forms the foundation of one of the theories of the function of sleep—that of conservation of energy. Expenditure of energy is measured mainly by the metabolic rate, which is raised during the day and reduced during the night (particularly during sleep) by between 5% and 25%.



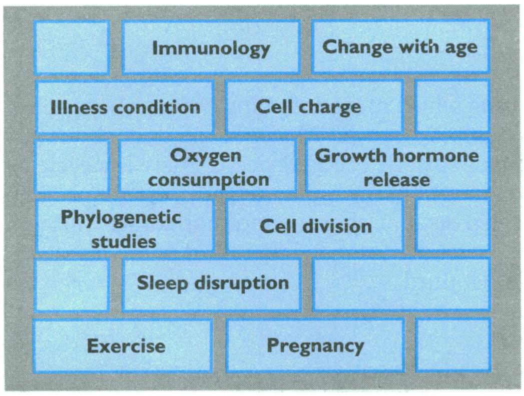
Number of hours of sleep/24 hours required by various animal species. Animals that are seldom attacked sleep a great deal; those in constant danger of attack sleep little.

Oxygen consumption, heart rate, and body temperature decline during the first few hours of sleep—the time particularly associated with slow wave sleep—and it is postulated that slow wave sleep is strongly associated with conservation of energy. There is a relationship across species between metabolic rate and sleep pattern, and there is evidence that people whose metabolic rates are high during the day have more slow wave sleep and sleep longer than people whose metabolic rates are lower.

Infants have the most slow wave sleep, and the amount declines with age (particularly stage 4 sleep). It has been suggested that this parallels the decline in cerebral and body metabolism that accompanies old age. High expenditure of energy during the day—for example, after sustained exercise in a fit person—is associated with both increased duration of sleep and increased slow wave sleep. Sleep deprivation is followed by increased amounts of slow wave sleep, perhaps as a consequence of the delayed drop in metabolic rate that normally accompanies sleep. People who sleep for a long time have high body temperatures during the day, and so their metabolic rates may be raised as well. In summary, therefore, the primary function of sleep is to preserve energy.

Theories of restoration

The most widely held theory about the function of sleep is that it serves as a period of recuperation or restoration. There are two ways in which this hypothesis is interpreted: total body restoration and neurological restoration.

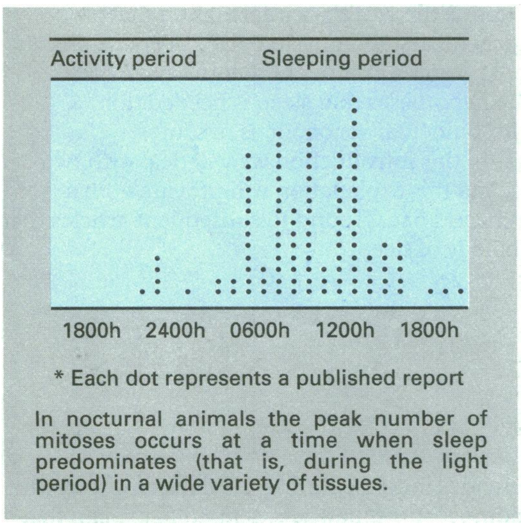


Types of research the results of which have built a "wall of evidence" to support the restorative theory of sleep.

Total body restoration

The first hypothesis is that sleep is a process by which the whole body (including the central nervous system) may be restored. This theory is based on an accumulation of evidence rather than on a single critical observation. When the body is in a state of catabolism the consumption of oxygen increases. It is lower during sleep than wakefulness, and lowest during slow wave sleep. Paradoxically it is during this period of low oxygen consumption that anabolism is thought to take place. Low metabolic rates during sleep allow the net concentration of protein to increase as a result of both an increase in synthesis and a reduction in degradation. Though the processes of catabolism and anabolism are continuous, the relative rates vary according to whether the subject is awake or asleep, and it has been shown that the rate of anabolism is at its peak during sleep.

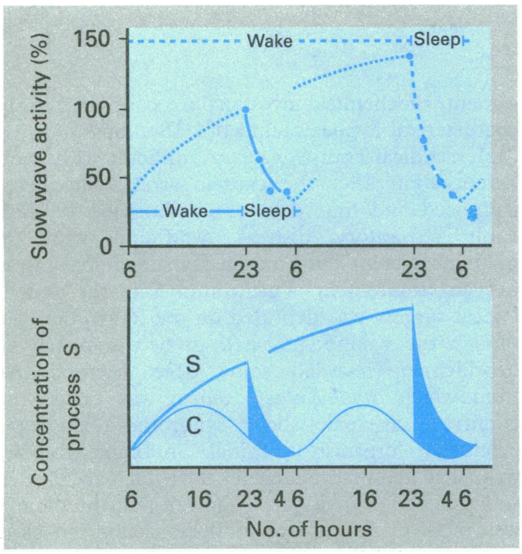
Growth hormone is released mainly at night, also in association with slow wave sleep. Direct measures of bone growth in adolescents show that sleep is associated with anabolism. Furthermore, treatment of short stature by growth hormone is more effective if the growth hormone is given at night rather than during the day.



Cell mitoses during sleep and wakefulness.

When the need for growth is great both the duration of slow wave sleep and the overall amount of sleep is increased—for example, during pregnancy, after exercise or loss of sleep, in hyperthyroidism, and during adolescence or the refeeding of patients with anorexia. Conversely, when less energy is expended—as in hypothyroidism—the amount of slow wave sleep is reduced. During periods of protein degradation ATP from cells is consumed. If protein synthesis predominates over protein degradation during sleep ATP concentrations should increase, and this is indeed the case. These observations are supported by the finding across species that cell mitosis is at a peak during sleep.

There are several variations on the theme of total body restoration. It has been postulated that slow wave and REM sleep have different restorative functions, slow wave sleep being important for macromolecular synthesis and REM sleep for removing the synthetic products of slow wave sleep to maintain synaptic connections. It has also been suggested that during REM sleep neuronal connections in the catecholamine system are formed and that this activity is necessary to maintain cognitive function.



Time course of sleep processes after regular and extended periods of waking. Above: exponential decline in slow wave activity during four consecutive sleep cycles (value of first cycle 100%) for a baseline night (continuous line) and after sleep deprivation (dashed line). The exponential increase in propensity for slow wave sleep during time awake is indicated by the dotted line. Below: time course of process S and the negative function of process C.

Neurological restoration

Some research workers have postulated that it is the brain not the body that recuperates during sleep, and that sleep counteracts the effects of the metabolism of the brain during the day. They argue that the changes in physiological function that seem to accompany sleep may be interlinked, but are not exclusively interdependent; during sleep the overall protein content of the body is less than the amount of protein that is broken down, and opposing arguments may have been misinterpreted and are therefore misleading. These scientists also claim that the exercise induced increase in slow wave sleep can be explained by an increase in brain temperature and metabolism, and after sleep deprivation it is psychological rather than physiological deficits that are most apparent. This emphasises that the restorative function is central rather than general.

One hypothesis is that there is a substance—"process S"—that accumulates in the brain during the day and declines exponentially with sleep. If, for example, after strenuous exercise (or under any condition during which the metabolic rate is raised) the concentration of process "S" is raised, then its decline from an initially higher level during sleep could account for the subsequent increase in the amount of slow wave sleep. Superimposed on this is a circadian influence called "process C," which is thought to play a part in the regulation of circadian body temperature and the length of sleep. Another theory is that the cycling of non-REM and REM sleep is fundamental to the restoration accomplished during sleep. Each sleep cycle results in partial restoration, and after a number of cycles recuperation is complete, which reduces the need for further slow wave sleep. This theory partly explains why the duration of periods of slow wave sleep reduces over the course of a night's sleep.

Brain restoration and conservation of energy

One group of workers has put forward the idea that there are two systems of sleep that are initiated simultaneously and which together fulfil the requirements of both brain restoration and conservation of energy. The first system is known as "core sleep" and is thought specifically to restore the brain. During this type of sleep, slow wave sleep (particularly stage 4) and REM sleep repair and restore the effects of daytime cerebral "wear and tear." As the night progresses this core sleep declines, but the second system—"optional sleep"—continues. This promotes conservation of energy and is governed by the circadian and behavioural drive to sleep. This concept can be seen to be related to the theory of "process S" and "process C."

Conclusion

In summary there are two main theories about the function of sleep—conservation of energy and restoration of energy—based on the drop in metabolic rate that occurs during sleep. There are several variations and subdivisions within the energy conservation theory; no one hypothesis completely explains the complexities and vagaries of sleep, but taken together they may form the foundation of the explanation for the indisputable need for sleep.

If sleep has a restorative function it is understandable why patients who do not sleep normally—for example, those with insomnia, medical disorders that disrupt sleep, or those who take drugs to alter their sleep pattern—may be more likely to develop psychiatric illnesses; why patients with hypersomnia have shorter life spans; and why patients with medical conditions that disrupt sleep complain that the effects of their condition are more profound and their quality of life is worse than those whose sleep is not disturbed.

Useful address:

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The sources of the data presented are: Kalat JW, *Biological psychology*. 3rd ed. Wadsworth Publishing Company, 1988, for the electroencephalograms of the male student and the hours of sleep required by various animal species; Adam K, *et al, Clin Sci* 1983;**65**:561-7 for cell mitoses; and Borbely AA, in Kupfer DJ, *et al*, eds. *Biological rhythms and mental disorders*. New York: Guildford Press, 1988.

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