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To what extent can sleep be influenced by diurnal activity?

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There are various pieces of evidence suggesting that daytime activity has an influence on the subsequent period(s) of sleep: first, there is everyday experience which has shown that some kinds of activity favor sleep, while others are detrimental to it. In every language, there is a score of books dealing with «What to do to enjoy a good-or-better-sleep». Second, we have data, more or less documented, obtained in laboratories by means of physiological and psycho-physiological studies. Almost all of these studies have been carried out in order to prove an hypothesis concerning the roles of sleep, sleep's internal architecture or of REM-sleep.
One can classify the data in the following groups:

1. The SWS-exercise hypothesis

Because there is no doubt that during sleep the body is recompensated for the physical exertion during the day, it has been hypothesized that sleep is associated with a process of restoration and even that 'sleep is for restoration'[2]. In addition, energy conservation resulting from the lack of movement during sleep has been widely documented and has led to the hypothesis that one role of sleep would be to allow (or force) that immobility. To date this approach has been documented by many phylogenetic and ontogenetic studies (e.g. Horne[19]). But it must be kept in mind that bedrest without sleep can by no means replace sleep[23]. Of course, these conclusions refer to average results which required that animals or humans were placed over a long period in stable, standard situations. Thus, if the conditions of diurnal life are, at least for a short period, abruptly modified relative to the lifespan of the animal (for instance by means of setting an activity rate above the usual, regular level), modifications of sleep can be expected.

2. Phylogenetic data

The phylogenesis of internal sleep architecture has shown that some sleep characteristics are linked to the metabolic rate of the species[17,37]. The average sleep duration seems to be positively correlated with the metabolic rate; the duration of REM-sleep is negatively correlated. Therefore, the assertion that sleep is a function of metabolism, that is, of total energy consumption, leads to the conclusion that an abrupt modification of the diurnal environment must change energy demand and thus finally alter sleep patterns.

3. The chronobiological approach

This has, to date, abundantly documented the temporal interdependency of most of the physiological variables. In this respect, a 'map' of mutual phase relationships among the acrophases (i.e. estimated peaks) of secretion of a variety of neuroendocrine variables can be designed. Under normal circumstances their time courses appear to be more or less tightly correlated to schedules and characteristics of sleep.
At the present time, very little is known about the functional significance of those temporal relationships. In particular, it is generally impossible to obtain evidence of causality of such relationships. However, if the diurnal time course of some endocrine variables is artificially modified, for instance by means of an intense physical demand or forced abnormal times of feeding, other variables are likely to be modified (e.g. HGH)[5,26] which in turn would alter sleep characteristics.
At any rate, in order to study how the environment influences sleep, it is first necessary to define 'normal diurnal activity'. Taking into account the practical impossibility of coming up with such a description, it would seem somewhat paradoxical to publish a quantitative description of 'normal' human sleep[36]. In contrast, studies carried out in animals such as the Papio showed that important ecological modifications resulted in significant and lasting changes in sleep patterns within the same species[8,9,28].
For the human species every attempt to describe a standard environment seems to be futile. Within a single industrial society for instance, there are huge differences in the daily energy expenditure, and therefore in the nu-

tritional demand between white and blue collar workers. The environment in a big modern city and that existing in the Sahara with regard to temperature, noise, air pollution and stress of all kinds can hardly be compared. Despite the lack of data in this field, we can easily imagine significant differences in the quality of the sleep experienced by people living in these two environments.

Sleep and physical exercise

A great number of studies have been devoted to the influence of physical exercise on subsequent sleep. This is probably because their design is relatively simple and surely because of the strength of hypothesis No. 1 (sleep is a time of energy restoration). In the wake of the pioneer study by Baekeland and Lasky[6] further results[11,29-31,39,40] have concluded that an intense physical activity results in increasing the duration of both total sleep and SWS. For instance, in Shapiro et al.[30], the exercise consisted of a run of 92 km; in that case it took a subject 4 nights to regain a sleep having a duration and structure equivalent to that of a reference night. In contrast, a somewhat greater number of other studies led to the opposite conclusion: sleep following notable physical exertion is not significantly modified[3,13,18,20,21,25,34,35].

The first study[6] demonstrated that there is a problem of how to choose the subjects for an experiment. While the aim of these studies was to show a differential effect of physical exercise, it was essential to define the reference level of the selected subjects with respect to physical characteristics such as VO_2 max., basic metabolism, maximal capacity, and so on. The differences can be enormous between a highly trained athlete and an individual accustomed to a sedentary life style.

It is not perfectly clear to what extent the differences obtained by the various studies previously mentioned are due to the samples which were utilized as subjects. The general conclusion that can cautiously be drawn is that an intense diurnal exercise does not result in a significant alteration of the subsequent sleep. In contrast, highly trained subjects (such as the athletes utilized in many studies) showed several sleep characteristics which were consistently different from those of non-trained subjects.

The differences essentially had to do with total sleep duration (TST) and SWS amount. Both proved to be higher in trained individuals[16,25,34]. These results are in good agreement with Dunleavy et al.[14] who concluded that abrupt changes in EEG are not to be expected after heavy daytime exercise because metabolic changes are extremely slow in producing modification of sleep EEG. To sum up, hypothesis No. 1 (sleep is for restoration) has been verified only concerning long range effects: total sleep duration and SWS amounts are increased above the average by a regular heavy physical exercise and the adaptation of the organism to this regimen (fitness).

The studies mentioned above led to some other interesting concusions:

– The amount (absolute and relative) of REM-sleep was found to be remarkably independent of both experimental conditions and degree of fitness. However Trinder et al.[33] demonstrated a negative correlation between the periodicity of REM-sleep and the habituation to physical exercise: the better the fitness of the individual, the shorter his average REM-sleep cycle length. This result is in good agreement with data obtained by Adam[1] in obese subjects whose overweight rate was negatively correlated with REM-sleep period. Therefore the 90–100-min rhythm which has proved to be so stable in the human species in spite of all the experimental manipulations undertaken thus far, might reflect slow oscillations in the process of synthesizing some proteins.

– As could be expected from the chronobiological approach No. 3, sleep's 'responses' to an intense physical exercise are affected by the time of day when it is performed. Horne and Porter[20,21] showed that a physical activity carried out in the morning did not alter the sleep of the subsequent night. In contrast, an afternoon exercise resulted in a disorganization at the onset of sleep. Particularly during the first REM-cycle SWS amount was above its average value. This increase might be accounted for less by a recovery process in the strict sense of the word than by a transient perturbation of the biological rhythm as a whole.

However, as Torsvall and Akerstedt[32] aptly pointed out, the hypothesis of a fault of the conventional scoring of sleep cannot be discarded. That is to say a stability of SWS and REM-sleep amounts could mask some changes occurring in the electrical patterns of stage 2 and may be of SWS.

An attempt to synthesize the studies concerning the effects of non-physical tasks on sleep is more complicated. 'Non-physical' stands for any activity that does not require a physical expenditure above the reference level corresponding to normal sedentary life. For facility of expression, we shall call them 'mental' tasks but without excluding the possibility that 1. they might imply a sensory load (especially in the case of a visual task); 2. they might be, from a psychological standpoint, extremely different, according to their cognitive or perceptual nature; 3. they have to some extent an affective, motivating or stressing character.

They way in which the sleep-mental activity relationship has been approached is essentially different from that concerning sleep-physical activity. As a matter of fact, the studies in this field have been aimed at demonstrating the validity of the hypothesis relative to the role of REM-sleep in 'processing' the information gathered during waking time. In particular, it has been hypothesized that during REM-sleep the process of memory consolidation is likely to take place. That is why a number of experiments (human and animal) have been designed in order to study the relationship between REM-sleep and learning[10,15,24]. The experimental protocols have been extremely varied but all of them were based on the hypothesis that REM-sleep is a time of cerebral activation necessary for information processing.

Surprisingly enough, there are practically no studies dealing with the relationship between sleep and an intense intellectual activity not intended to result in any learning or memorization, but as it occurs in the daily experience of many jobs.

Several studies, though, have been devoted to the effects on sleep of events with an affective load (for instance the 'mood-disturbing events' of Cartwright[12]. Even though they are hardly comparable because of different starting points and methodologies, some studies[7,38] have reached the conclusion that stressing or affectively charged situations tend to modify REM-sleep characteristics.

For instance, several research laboratories have studied in humans the possible relationship between sleep and abnormalities of the visual input when it has been artificially distorted. In one case, the subjects of Allen et al.[4] had to wear prismatic goggles that inverted the visual field. Results, on a whole, have been rather contradictory: REM-sleep mechanisms were affected in some studies and not affected in others by the heavy learning required by the novelty of the situation. Of course one has to take into consideration the strong stress induced by this situation: the lack of effect found in a study might be acccounted for the contradictory effects of stress and learning.

Horne and Walmsley[22] tried to delineate the respective effects on sleep of daytime 'visual load' and of the stress induced by a possible overload due to the experimental protocol. For this purpose they designed a situation where the visual stimuli were abundant (high load) and another one where they were scarce (low load). Surprisingly enough, REM-sleep was equivalent in both situations but SWS was significantly higher in the high load conditions.

None of the reviewed studies proved to be crucial to the hypothesis wherein sleep is regarded as a time for synthesis of cerebral proteins in relation to memory processes. The impossibility of finding clear cut results from EEG patterns might be explained by the fact that the supplementary amount of proteins to be synthetized is very small compared to the amount of those regularly required for the replacement of cellular components.

In the same way as the effects of physical activity, some results suggest that there can also be a 'time-of-day effect' of mental activity on ensuing sleep. One study in good agreement with common experience, shows that an intense mental activity performed at the end of the day or at the habitual bedtime (The case in point dealt with journalists of a press agency working until midnight) resulted in a lengthened sleep latency and thus postponed bedtime.

Biological processes which could account for such a result still remain unclear. It has often been reported that a high level of motivation or interest in a task can be sufficient to compensate for the effects of time of day and allow individuals to perform at their best at the most unfavorable times of the nycthemer. But so far, one has not been able to explain to what extent and by which mechanisms performances which are out of phase relative to the biological rhythms can in turn alter these rhythms as a whole and, more particularly, after the time when sleep occurs.

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Ambient temperature and human sleep

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Ambient temperature is a common factor of the environment, but some of its effects on human biology are still unknown. In laboratory situation, ambient temperature levels are often mentionned but rarely controlled. Moreover accurate variations within a narrow range are difficult to obtain and specially to maintain. Mostly, if mentionned, environmental condition is defined by the air temperature inside the experimental room. However, all the thermal characteristics of the environment should be taken into account and importance of wall temperatures, air humidity and air velocity on a defined climate should also be emphasized.

The effects of ambient temperature on human sleep have been increasingly studied in the last decade, the main reason being that in animals thermoregulatory processes have been found present in SWS and absent in REM sleep[9,35].

In laboratory situations, the general interest was first focused on low and mainly high ambient temperatures[14,18,39] and very little attention has been paid to the influence of ambient temperatures fluctuating around thermoneutrality. It appears, however, that even slight changes of the ambient temperature within the thermoneutrality zone can induce modifications of sleep structure.

Apart from studies performed under laboratory conditions, real life studies in extreme ambient conditions have also been carried out[2,23]. They have revealed the important adaptative ability of man to live in harsh environments where tough ambient temperature is only one aspect of these difficult living conditions.

Effect of the ambient temperature on the EEG stages of sleep

Most sleep laboratory studies on the effect of temperature on sleep have included all-night electroencephalogram monitoring which provides objective and traditional measures of sleep quality.

Within a certain range of ambient temperature that should be referred to as 'thermal comfort zone', the quantitative measures of sleep such as sleep stage latencies, time spent in each sleep stage, number and duration of nocturnal awakenings, and occurrence of phasic events such as activation phases, are only slightly modified[8,29]. Affecting this thermal comfort zone are clothing and bed covering of the sleeping subjects. In a study where clothing and covering consisted of pyjamas, two cotton sheets and one wool blanket, Candas et al.[5] found that the microclimate temperature established inside the bed varied from 28.6°C to 30.9°C, while the ambient temperature (air and wall temperatures being equal) varied from 16°C to 25°C. In this experiment the microclimate temperature measured inside the bed was found to be constant at 29.6°C for both ambient temperatures of 19°C and 22°C. These results suggest that thermoneutrality inside the bed lies around 30°C, a value in agreement with results of McPherson[27]. The preferred room temperature during sleep was found to be around 19°C and subjects' reports showed that subjective discomfort increased as room temperature deviated from this condition[5].

As ambient temperature increases or decreases from the above mentioned thermoneutral range, the structure of sleep is modified. At both high and low temperatures there is a marked increase in the number and duration of the periods of wakefulness[17,18,29]. Kendel et al.[18] pointed out that unclothed and uncovered subjects awoke from cold at 26°C and below. This ambient temperature is very close to the value found in another study where 26.1°C recorded inside the bed corresponded to an ambient temperature of 13°C and where an increase in nocturnal awakenings was clearly observed[29].

Fever has also been found to be associated with a greater number of awakenings, increased total waking time, and reduced amounts of REM sleep and slow wave sleep[15]. The elevated ambient temperature induces very similar effects on the structure of these two stages of sleep[16,34] while stage 2 was found to be remarkably constant[18]. Haskell et al.[11] noted that although REM sleep latency was increased at high and low temperature, REM sleep was depressed to a greater extent by lower than by higher temperatures whereas the reverse was observed for SWS. The duration of the REM phases is shortened in artificially-induced fever[15] as well as at high ambient temperature[41].