cours du sommeil. Rapport CEB-CNRS No. 76-22 pour le Ministère de l'Environnement, Strasbourg 1980.
40 Ohrstrom, E., and Rylander, R., Sleep disturbance effects of traffic noise. A laboratory study after effects. J. Sound Vibration *84* (1982) 87–104.
41 Ohrstrom, E., and Bjorkman, M., Sleep disturbance before and after traffic noise attenuation in an apartment building. J. acoust. Soc. Am. *73* (1983) 877–879.
42 Organisation mondiale de la santé, Environmental Health Criteria 12; Noise. WHO, Geneva 1980.
43 Oswald, I., Taylor, A.M., and Treisman, M., Discriminative responses to stimulation during human sleep. Brain *83* (1960) 440–453.
44 Rechtschaffen, A., Hauri, P., and Zeitlin, M., Auditory awakening thresholds in REM and NREM sleep stages. Percept. Motor Skills *22* (1966) 927–942.
45 Relster, J., Effects of traffic noise on psychical health, 1981. National Danish Road Laboratory, personal communication.
46 Rice, C., Sonic boom exposure effects: sleep effects. J. Sound Vibration *22* (1972) 511–517.
47 Robinson, L., and Dawson, S., EEG and REM sleep studies in deaf people. Am. Annls Deaf *120* (1975) 387–390.
48 Rylander, R., Sorensen, S., and Berglund, K., Sonic boom effects on sleep, a field experiment on military and civilian population. J. Sound Vibration *24* (1972) 41–50.
49 Thiessen, G.J., Disturbance of sleep by noise. J. acoust. Soc. Am. *64* (1978) 216–222.
50 Thiessen, G., Habituation of behavioral awakening and EEG measures of response to noise, Congr. on Noise as a Public Health Problem, Freiburg 1978. Proceedings American Speech-language Hearing Association, report No. 10, pp. 397–400. Eds J. Tobias, G. Jansen and W. Ward. Rockville 1980.
51 Townsend, R.E., Johnson, L.C., and Muzet, A., Effects of long term exposure to tone pulse noise on human sleep. Psychophysiology *10* (1973) 369–376.
52 Vallet, M., Blanchet, V., Bruyere, J.C., and Thalabard, G.C., La perturbation du sommeil par le bruit de circulation routière, étude in situ. Rech. Envir. vol. 3, pp. 183–212. La documentation française, Paris 1977.
53 Vallet, M., Gagneux, J.M., and Simonnet, F., Effects of aircraft noise on sleep; an in situ experience. Congr. on Noise as a Public Health Problem. Proceedings of American Speech-language Hearing Association, report No. 10, pp. 391–396. Eds J. Tobias, G. Jansen and W. Ward. Rockville 1980.
54 Vallet, M., and François, J., Evaluation physiologique et psychosociologique de l'effet du bruit d'avion sur le sommeil. Trav. hum. *45* (1982) 155–168.
55 Vallet, M., Gagneux, J.M., Blanchet, V., Favre, B., and Labiale, G., Long term sleep disturbance due to traffic noise. J. Sound Vibration *90* (1983) 173–191.
56 Vernet, M., Effects of train noise on sleep for people living in houses bordering the railway line. J. Sound Vibration *3* (1979) 66–74.
57 Webb, W.B., Sleep as a biorhythm, in: Biological Rhythms and Human Performance, pp. 149–177. Ed. W.P. Colquhoun. Academic Press, London 1971.
58 Webb, W.B., and Agnew, H.W. Jr, Sleep stage characteristics of long and short sleepers. Science *168* (1970) 146–148.
59 Wehrli, B., and Wanner, H.U., Auswirkungen des Strassenverkehrslärms in der Nacht. Kampf dem Lärm *25* (1978) 138–149.
60 Wilkinson, R.T., and Campbell, K., Traffic noise at night: effects upon physiology of sleep, subjective report, and performance the next day. J. acoust. Soc. Am. 1984, in press.
61 Williams, H., Effects of noise on sleep: a review, Dubrovnik 1973. Proceeding of the Int. Congr. on Noise as a Public Health Problem, pp. 501–511. Ed. W. Ward. Environmental Protection Agency 550.9.73008, Washington D.C. 1973.

0014-4754/84/050429-09$1.50 + 0.20/0

Homeostatic and adaptive roles of human sleep

by O. Benoit

Laboratoire de Physiologie, U_3 INSERM, 91, Boulevard de l'Hôpital, F-75634 Paris Cedex 13 (France)

In order to respond to the demands of life and reproduction, a living organism must develop multiple functions. The more these functions are integrated by and into higher levels of the central nervous system, the more complex they become. This is the case for sleep function since sleep has biological as well as psychological aspects, and interacts with two environments:
1. *internal,* characteristic of an individual with regard to similar functions both of lower level of integration and/or a more general type such as the circadian function, and
2. *external,* corresponding to the physiological and psychological environment.

Recent advances in the knowledge of the biological aspects of sleep have stimulated the development of studies concerning the interrelationship between its biological function (mainly related to the internal environment) and its psychological function (more related to the external environment). Where the latter is concerned the individual must integrate himself in the psychosocial world with the pressures, demands and needs it exerts upon him.

Phylogenetic studies of sleep in mammals have shown that during the nycthemeron the total duration of sleep, the number of its episodes as well as their composition vary from one species to another[4,40]. In farm animals[34] and in monkeys[6] sleep varies with the environment. Similarly, human sleep behavior depends upon at least 2 categories of factors, internal and external. The internal factors modulate the innate rhythmic alternation of waking and sleeping while the external ones may change from time to time during a lifespan. The precise degree of contribution of either factor to actual sleep behavior is not yet known. However it would seem that sleep depends mainly on the 'internal state'.

Before describing these factors in greater detail, it is interesting to recall a few descriptive principles of the general living systems theory as reviewed by Miller[25]. Such a theory has allowed a new approach to the complex biological systems which have multiple levels of integration. This theory describes 2 different types of systems, closed and open. The closed systems are governed solely by the cybernetic rules of homeostasis and by feed back controls. The open systems are ruled in a similar manner but in permanent interaction with a complex enviroment in which relationships are generated for a specific, evolutive, adaptative organization in the framework of reciprocal, flexible and integrative processes. As for the relationship between sleep and biological functions, it appears to be more of a mixed but stabilized system called 'steady state'. This can be studied either from the point of view of homeostatic steadiness or from its complex adaptative aspect, e.g., psychosocial. There is a permanent complex interaction between these aspects which requires different methodological approaches in order for them to be differentiated.

The 'internal' state

The internal state to which sleep primarly responds can be considered the result of many influences (genetic factors, maturation, age and the psychophysiological status) which are functions of the conditions of life.
Few data about genetic influence upon human sleep are currently available. However the possibility that genetic factors could play a role in some sleep disorders has been raised in connection with sleepwalking, night terrors, childhood insomnia and narcolepsy (see reviews of Abe[1]; Karacan and Moore[23] and Kales et al.[22]). Sleep organization has been studied in monozygotic (MZ) and dizygotic (DZ) twins[42]. These authors found a high concordance in MZ twins as regards REM parameters and number of shifts in sleep stages while a discordance was observed in DZ twins for the same parameters. Chouvet (personal communication) noted that rapid eye movement (REM) patterns and sleep parameters differ less between one twin and the other of the MZ pair than among different individuals of same age. Other genetic studies have shown that eye movement density during REM sleep in Malaysian pygmies[31] and in a primitive African tribe, the Bassari[21], is less than the eye movement density in Western Caucasian people. The recent study of Partinen et al.[30] indicates that sleep length is also partly (one third of the variance) due to genetic influence and that MZ twins are more similar than DZ in this respect. These results give clear evidence that sleep behavior is influenced by genetic factors but the extent of such influence remains to be defined.
In addition to genetic factors, the internal state is related to the waking activity. Its level can be estimated by fatigue and sleepiness either subjectively assessed or objectively measured. The endogenous wake-sleep rhythm represents a major source of variation. But we know that there are large interindividual variations in habitual sleep duration, preferential sleep schedules, ability to adjust to unusual sleep schedules, sleep structure and its restorative value (subjectively assessed). The different degrees to which genetic factors, lifestyle and ontogenetic development contribute to such variations are difficult to determine.

'Internal' – 'external' interactions

In adult humans, there is one long sleep episode per 24 h. It is not known when this monophasic pattern developped in the course of human evolution. However the industrial revolution certainly has contributed to the development of this habit. The afternoon nap which is still common to many countries having a hot climate was also possibly used in many other rural civilizations, especially from spring to fall. It could have been a way to cope not only with the climate but also with the requirements of agricultural work (early rising at dawn) without reducing in any considerable way the total sleep duration. And even in modern times, Soldatos et al.[35] noted that 42.2% of the urban Greek population take a nap at least three times a week without a nocturnal sleep deficit. Moreover, in most adults there is a clear sleep tendency in the early afternoon which has been demonstrated by multiple sleep latency tests[33]. It appears that the modern urban way of life has forced a tendency toward biphasic rhythm to give way to a monophasic pattern. In the phase of early human evolution, the sleep-wake behavior would have been more strongly related to seasons, cultures (characterized by hunting-gathering, nomadic life, rural economy and so on) and to the safety of the nocturnal environment than it is now. The relative flexibiliy of the sleep-wake rhythm in relation to external factors such as light-dark cycle or internal need (fatigue, drowsiness, length of prior wakefulness) is probably a major factor in the ability of humans to cope with so many various ways of life – life once influenced by prehistoric conditions and now by modern space flights.
The sleep amount per 24 h is also dependant on environmental commitments. A gradual restriction[20] as well as an imposed limitation of sleep without[11] or with sleep displacement[37] have shown that vigilance and subjective functionning are strongly impaired when the sleep quota is equal to or less than 5.5 h per day. When sleep is displaced in relation to the circadian rhythm of temperature, the minimal sleep lengths are obtained near the temperature minimum[14,41]. In shiftworkers[3,15,24] as well as in normal subjects[5] day sleep amounts to an average of 4–5 h. Since a restriction of sleep to under 6 h appears to be detrimental to waking quality, this length of time can represent the obligatory part of sleep as proposed by Horne[19]. The difference between the habitual and the minimal sleep amounts would represent a facultative part which can be influenced by environmental factors: sleep is extended when the external pressures are reduced. In contrast, in all situations such as stress, danger, or high levels of motivation or occupations, sleep can be restricted for days and weeks, with a postponement of the recovery. The relative extent of obligatory and facultative parts of sleep may vary among individuals as would indicate the results of Carskadon and Dement[12]: only half of their subjects became pathologically sleepy during the day when submitted to a 5-h sleep regime. The facultative sleep is probably composed of 2 parts, one of which is necessary but flexible and can be displaced or omitted for a while but has to be recovered after deprivation; its amount may vary according to internal and external factors. The other part, or 'extrasleep', occurs either when an individual seeks to occupy unproductive hours or to feel the best subjectively during waking. No recovery need would follow the extra-sleep deprivation. This extra-sleep could be measured by the length obtained during vacations, which for most people would far exceed their weekly average (daily and week end).
The role of an individual's sleep history in his sleep behavior can be suggested by indirect evidence. Most of us experience sleep onset and sleep maintenance difficulties when in a totally new environment. The degree of the disturbance and the time necessary to adapt to

the new conditions greatly vary among individuals. This fact strongly suggests the role of conditioning influences upon sleep and also reveals the persistance in modern humans of the waking response, a valuable means for survival in former times. Parmeggiani[29] noted that in mammals 'the behavioral repertory of the onset of sleep consists of the search for a safe ecological niche and the preparation of the body for the natural sleep posture'. We may suppose the same holds true for humans. The feeeling of security, the confidence in one's ability to sleep well and the preparation of the body in order to fall asleep could all have partly been conditioned by the actual experience as concerning sleep and the environment in which it has occurred since early infancy. Sleep ceremonials are well known in children; adults also conform to a given behavioral sequence before sleep with some or most parts being acted on in a rather automatic way. Occasional modifications of the pre sleep sequence may entrain sleep disturbances. On the other hand, Hauri[17] has stressed the possible role of a negative conditioning in some insomniacs. Therefore it can be assumed there is a facilitating or permissive role of this internal conditioning upon subsequent sleep onset. As important or perhaps even more so than the psychophysiological conditioning is the influence, of a regular schedule in the adjustment of the sleep 'clock' to a good 24-h synchronization. This influence has been demonstrated by means of chronotherapy applied to delayed sleep phase insomnia in order to reset the circadian clocks[13].

The sleep-wake rhythm has been proposed by Borbély et al.[9] as a 2-component system: a homeostatic process 'which is reflected by the constant average level of sleep and by its compensatory increase following sleep loss; and a circadian rest-activity rhythm controlled by a highly stable circadian oscillator' (p. 240). Usually sleep coincides largely with the trough of the circadian rhythm, but it can be displaced to the activity phase (after sleep deprivation or night work for example). The possible dissociation between the temperature rhythm and the sleep-wake rhythm indicates that they are relevant parts of separate mechanisms. Sleep can be considered as an adjustment process helping the organism to maintain the internal state within certain limits; this process may vary relative to the internal and external environment. Miller[25] defined ajustment processes as follows: 'they change the rates or other aspects of the system variables in such a way that the matter-energy or information processing of the system or significant part of it, is adjusted to the changed conditions within the system or in its environment' (p. 105). Whatever the sleep functions may be (restorative, conserving energy, body or brain restitution processes, information processing)[2,18,28], the every-day need for sleep suggests that sleep plays a role in maintaining some steady state relative to an internal reference level which varies during the waking part of the cycle. Sleep is a self regulated process 'represented by a regulatory variable whose level increases as a function of waking time and decreases as a function of sleep time[8]. The level of this variable also depends on the conditions and activities of the preceeding waking period. One can suppose that the range of its variation is limited during everyday life with the consequence that there is a relative stability of sleep (with regard to length and composition) for a given individual. Occasional changes in life style, work load, or physical or mental conditions may entrain the level of the regulatory variable outside of the habitual range and consequently be followed by a corrective response of sleep.

'External' factors

The external environmental factors, such as thermal ambiance, climatic factors, clock time and so on may influence sleep in 2 ways: first, they may induce modifications in the level of the internal regulatory variables, and secondly they also may act on the sleep adjustment process itself. The obligations of our modern way of life impose very rapid changes on individuals in clock time or in climatic or altitude conditions. Some people have to face situations of physiological stress, such as space flights[36], hyperbaric cabin[38], high altitude[26,27,32], or polar conditions[7,10,27] which are far from normal conditions and possibly out of the range of the sleep process's ability to adjust.

Sleep has a homeostatic function, but it is also a state when the individual is more vulnerable. For one, the occurrence of sleep itself may be dangerous in unsafe environments where a vigilant behavior is required for survival. One knows that sensory perception thresholds are increased during sleep when compared to wakefulness. In our modern environmental conditions for sleep, the beneficial aspect of sleep largely outweights its negative aspect. Of course, this was not always true at the beginning of human history and it may still be the case in some hostile environments. From an ethological point of view, the insomnia or the light sleep of some individuals could have been valuable for the survival of the group in prehistoric time. Secondly, during sleep, the level of most physiological regulations changes in relation to NREM and REM sleep. NREM sleep is accompanied by closed-loop operations maintaining homeostasis. During REM sleep the level of regulation (at least for thermoregulation, respiratory and cardiovascular controls) is less precise and controlled at lower levels of the central nervous system (rhomben-cephalic and spinal) or by peripheral reflexes[29]. Therefore, REM sleep represents a special time of risk, particularly if external conditions are far from normal (very cold or hot environments[16], hypoxic conditions... etc.). The arousal response caused by the external and internal stimuli appears to be the safety mechanism which during sleep is able to promptly reestablish homeostasis by bringing the most effective control mechanisms into play. As can be observed in many studies, this arousal response disturbs sleep in a rather nonspecific way.

Therefore, sleep can be viewed as a homeostatic response to the waking activity within the framework of an environment which is not too far from the possibilities of human survival. In this case internal and external factors may both play a role towards in establishing a better adaptative response of sleep[39]. In a very abnormal environment, where the survival is most precarious, the internal need for sleep and the external factors may be contradictory producing both stress and strain. The survival priority because of the external or internal conditions does not permit a normal occurrence or maintenance of the sleep actually needed. It should be pointed out that internal conditions are mostly pathological cases such as respiratory or cardiac diseases. Nevertheless if the need is too high (extreme fatigue, long sleep deprivation...) an inappropriate sleep with regards to these conditions may occur. In these extreme cases, the detrimental effects of sleep can overwhelm its beneficial value.

1 Abe, K., Psychopharmacogenetics-physiological genetics and sleep behavior, in: Human Behavior Genetics, pp. 347–363. Ed. A.R. Kaplan. Ch. Thomas, Springfield, Ill., 1976.
2 Adam, K., Sleep as a restorative process: and a theory to explain why, in: Progr. Brain Res. *53* (1980) 289–305.
3 Akerstedt, T., and Gillberg, M., Sleep disturbances and shift work, in: Night and shiftwork biological and social aspects. Advances in the biosciences, pp. 127–131. Pergamon Press, Oxford 1981.
4 Allison, T., and Cicchetti, D.V., Sleep in Mammals: Ecological and constitutional correlates. Science *194* (1976) 732–734.
5 Benoit, O., Foret, J., Bouard, G., Merle, B., Landau, J., and Marc, M-E., Habitual sleep length and patterns of recovery sleep after 24 hour and 36 hour sleep deprivation. Electroenceph. clin. Neurophysiol. *50* (1980) 477–485.
6 Bert, J., Balzamo, E., Chase, M., and Pegram, V., The sleep of the Baboon, Papio-Papio, under natural conditions and in the laboratory. Electroenceph. clin. Neurophysiol. *39* (1975) 657–662.
7 Bogoslovsit, M.M., Polar insomnia on the antartic continent. Lancet *1* (1974) 503–504.
8 Borbély, A.A., A two-process Model of Sleep Regulation. Hum. Neurobiol. *1* (1982) 195–204.
9 Borbély, A.A., Tobler, I., and Groos, G., Sleep homeostasis and the circadian sleep-wake rhythm, in: Sleep disorders: Basic and Clinical Research, pp. 227–243. Eds M.H. Chase and E.D. Weitzman. MTP Press Limited, Spectrum Publications, New York 1983.
10 Buguet, A.G.C., Livingstone, S.D., Reed, L.D., and Limmer, R.E., EEG patterns and body temperatures in Man during sleep in Arctic winter nights. Int. J. Biometeor. *20* (1976) 61–69.
11 Carskadon, M.A., and Dement, W.C., Cumulative effects of sleep restriction on day time sleepiness. Psychophysiology *18* (1981) 107–113.
12 Carskadon, M.A., and Dement, W.C., Nocturnal determinants of daytime sleepiness. Sleep *5* (1982) S 573-S 581.
13 Czeisler, L.A., Richardson, G.S., Coleman, R.C., Zimmerman, J.C., Moore-Ede, M.C., Dement, W.C., and Weitzman, E.D., Chronotherapy: resetting the circadian clocks of patients with delayed sleep phase insomnia. Sleep *4* (1981) 1–21.
14 Czeisler, C.A., Weitzman, E.D., Moore-Ede, M.C., Zimmerman, J.C., and Knauer, R.S., Human Sleep: its duration and organization depend on its circadian phase. Science *210* (1980) 1264–1267.
15 Foret, J., and Benoit, O., Structure du sommeil chez des travailleurs à horaires alternants. Electroenceph. clin. Neurophysiol. *37* (1974) 337–344.
16 Haskell, E.H., Palca, J.W., Walker, J.M., Berger, R.J., and Heller, H.C., The effects of high and low ambiant temperatures on human sleep stages. Electroenceph. clin. Neurophysiol. *51* (1981) 494–501.
17 Hauri, P., Sleep disorders, in: Basic Psychiatry for the Primary care Physician, pp. 137–158. Ed. H.S. Abram. Little, Brown and Co, Boston 1976.
18 Horne, J.A., Restitution and human sleep: a critical review. Physiol. Psychol. *7* (1979) 115–125.
19 Horne, J.A., Interacting Functions of Mammalian Sleep, in: Sleep, 1982, Proc. Eur. Congress Sleep Res., pp. 130–134. Ed. W.P. Koella. Karger, Basel 1983.
20 Johnson, L.C., and Mac Leod, W.L., Sleep and awake behavior during gradual sleep reduction. Percept. Motor Skills *36* (1973) 87–97.
21 Jouvet, M., Sastre, J.P., and Sakai, K., Toward on etho-ethnology of dreaming, in: Psychophysiological Aspects of Sleep, pp. 204–214. Ed. I. Karacan. Noyes Med. Publ., Parkridge, USA, 1981.
22 Kales, A., Soldatos, C.R., Bixler, E.O., Ladda, R.L., Charney, D.S., Weber R.G., and Schweitzer, P.K., Hereditary factors in sleep walking and night terrors. Br. J. Psychiat. *137* (1980) 111–118.
23 Karacan, I., and Moore, C.A., Genetics and Human Sleep. Psychiat. Annls *9* (1979) 11–23.
24 Knauth, P., and Rutenfranz, J., Duration of sleep related to the type of shift work, in: Night and shiftwork biological and social aspects. Advances in the biosciences, pp. 161–168. Pergamon Press, Oxford 1981.
25 Miller, J.G., General living systems theory, in: Comprehensive Textbook of Psychiatry, pp. 98–115. Eds H.I. Kaplan, A.M. Freedman and B.J. Sadock. Williams and Wilkins, Baltimore 1977.
26 Miller, J.C., and Horvath, S.M., Sleep at altitude. Aviat. Space envir. Med. *48* (1977) 615–620.
27 Natani, K., Shurley, J.T., Pierce, C.M., and Brooks, R.E., Long term changes, in: Sleep patterns in Men on the South Polar plateau. Archs intern. Med. *125* (1970) 655–659.
28 Oswald, I., Sleep as restorative Process: Human clues, in: Progr. Brain Res. *53* (1980) 279–288.
29 Parmeggiani, P.L., Regulation of physiological function during sleep in mammals. Experientia *38* (1982) 1405–1408.
30 Partinen, M., Putkonen, P.T.S., Kaprio, J., and Koskenvuo, M., Hereditary and environmental determination of human sleep length, in: Sleep 1982, Proc. Eur. Congress Sleep Res., pp. 206–208. Ed. W.P. Koella. Karger, Basel 1983.
31 Petre-Quadrens, O., Hussain, H., and Balaratnam, C., Paradoxical sleep characteristics and culture environment: Preliminary results. Acta neurol. belg. *75* (1975) 85–92.
32 Reite, M., Jackson, D., Cahoon, R.L., and Weil, J.V., Sleep physiology at high altitude. Electroenceph. clin. Neurophysiol. *38* (1975) 463–471.
33 Richardson, G., Carskadon, M., Flagg, W., Van den Hoed, J., Dement, W.C., and Mitler, M., Excessive day-time sleepiness in man: multiple sleep latency measurement in narcoleptic and control subjects. Electroenceph. clin. Neurophysiol. *45* (1978) 621–627.
34 Ruckebusch, Y., The hypnogram as an index of adaptation of farm animals to changes in their environment. Appl. Animal Ethol. *2* (1975) 3–18.
35 Soldatos, C.R., Madianos, M.G., and Vlachonikolis, E., Early afternoon napping, a fading greek habit, in: Sleep, 1982, Proc. Eur. Congress Sleep Res., pp. 202–205. Ed. W.P. Koella. Karger, Basel 1983.
36 Strughold, H., and Hale, H.B., Biological and physiological rhythms, in: Ecological and Physiological Bases of Space Biology and Medicine, pp. 535–548. Eds M. Cakvin and O.G. Gazenko. Foundations of space administration, Washington D.C., 1975.
37 Taub, J.M., and Berger, R.J., The effects of changing the phase and duration of sleep. Human perception and performance. J. exp. Psychol. *2* (1976) 30–41.
38 Townsend, R.E., and Hall, D.A., Sleep, mood and fatigue during a 14 day He-O_2 open sea saturation dive to 850 fsw with excursions to 950 fsw. Undersea biomed. Res. *5* (1978) 109–117.
39 Webb, W.B., Sleep as an adaptative response. Percept. Motor Skills *38* (1974) 1023–1027.
40 Zepelin, H., and Rechtschaffen, A., Mammalian sleep, longevity and energy metabolism. Brain Behav. Evol. *10* (1974) 425–470.
41 Zulley, J., Distribution of REM sleep in entrained 24 hour and free running sleep wake cycles. Sleep *2* (1980) 377–389.
42 Zung, W.W.K., and Wilson, W.P., Sleep and dream patterns in twins, in: Recent Advances in Biological Psychiatry, IX, pp. 119–130. Ed. J. Wortis. Plenum Press, New York 1967.

0014-4754/84/050437-04$1.50 + 0.20/0