BRAIN FUNCTION AND CULTURE.

Olga Quadens, Belgium.

Introduction.

When one reflects upon the very great increase of research into brain function and into sleep in particular, during the past 30 years, one has to recognize that the early investigators felt sure that studies on the brain would answer questions on the mind. This was even more obvious when Nathanael Kleitman and his fellow investigators discovered in 1953 that there was a stage of sleep in which eye-movements appeared and that it was associated with dreaming. What remained true after more than three decades was that sleep research has offered a most useful technique indeed for looking at the human brain.

Studies on REM sleep have evidenced the open nature of the brain. They have shown how, in spite of the genetic character of the Rem patterns, the environment has an organizing function in their activity. On its turn, the brain plays an organisational role on other systems.

The signs of Sleep and Dreaming.

In the alternation of sleep and wakefulness, sleep has long been considered as an interruption not only of our daily activity but of our consciousness as well. We know now that, during sleep,

there is a consciousness which is different from wakefulness but intimately connected with it.

As from the beginning of this century, the studies of Piéron have called attention on the vital importance of the alternation of sleep and wakefulness : he suspected that it was an essential part of brain physiology (1).

Twenty years later, Pietrusky recognized the claim of Pieron but he was convinced that sleep is a uniform state and he wanted to describe it completely by observing only one physiological variabl at a given time during the night (2). In 1922, he published a "definitive" study of the eye position during sleep : he observed 300 sleeping subjects and he concluded that the position of their eyes was divergent, in contrast with waking during which their position is convergent. The thruth is that the position of the eyes is far from being stable during sleep, and Pietrusky could have arrived at the same conclusion by observing the eyes of one sleeper at 300 different times during one single night. Thirty years later, Aserinsky and Kleitman identified the REM (rapid eye movement) stage of sleep and identified it with the state in which dreaming occurs (3).

On the physiological level, the structure of REM sleep is variable. It is correlated with the cycles of the hormones and also with the level of attention during the day, with mental activity and with mood disturbance (4).

After Claude Bernard and Cannon had proclaimed the dogma of homeostasis, saying that the physiological functions and, among

others, the levels of the hormones were stable, Pincus in 1943, casted some doubt on that concept. He evidenced that the concentration of hormones differed at different times of the day, the levels of the steroïds, f.i. being higher in the morning than at night (5). The concept of homeostasis then changed and the concepts of open and closed systems were introduced into medicine. These concepts became essential in order to understand the function of sleep and dreaming.

From a physiological standpoint, dreaming is made of signs showing a particular pattern, mainly the eye movements. While the duration of the dream cycle - which is the lenght of time after which a new REM epoch appears - is of approximately one hour, that of the oculomotor signal is of 1 second. The eye movements appear either in bursts or isolated. They apparently represent some time code, a language of the brain. When they appear during sleep, there is a simultaneous increase in temperature and in oxygen consumption, an irregularity of the heart and respiratory rhythms and an activation of the eletroencephalogram (EEG), calling for a protection of the organism. The latter developed with the evolution of the species and ended up with the inhibition of the peripheral motor neurones and the interruption of the sensory input. In other word, during REM sleep, we are unable to move.

There was however one disturbing evidence in the area of sleep research, namely the great variability of the REM architecture in humans. Therefore it was necessary to establish the time-dependency of the eye-movements of sleep (or REM's).

The eye movements of sleep (REM's) and brain information.

Since the discovery of the existence of the corneo-retinal potential, described by Dubois-Reymond in 1845, it has been known that the eye is a polarized system, the retinal part being charged negatively with relation to the cornea; the difference in potental is 5 to 6 μV and is independent of illumination (6). Electro-oculographic recordings are based upon the existence of this potential. Electrodes placed at the periphery of the eye enable eye-movements to be recorded since the displacement of the corneo-retinal dipole changes the electric field between the electrodes. The direction of the electro-oculographic reading indicates the direction of the eye-movement. Therefore, the electrodes are placed at the centre of the superior superciliary arches and at the external angle of each eye. The first two are recording the vertical ocular movements and the other two the horizontal ones. Preliminary data show that, in the horizontal plane alone, the direction of the eye-movements towards the left or the right, is as important during sleep as it is during wakefulness in function of selective learning. They are determined by the left or right hemispheric dominance which regulates the information processing in the brain during sleep as it does during wakefulness.

For more than 30 years, the relation between sleep and waking has been a challenge to physiologists. Already in 1954, Teitelbaum hypothesised that the eye movements of sleep and those

of wakefulness have a common physiological basis (7). A diurnal phenomenon with REM characteristics was therefore to be found and attention was a suitable candidate for it: eye-movements are typical for attention (8). When one talks to us, we turn our head and eyes towards the source of the stimulation. If we are looking at a picture, a cat can cross our visual field without our seeing it. Furthermore, every neurologist knows the activiation of the electroencephalogram which is as typical for attention as for REM sleep. Just as REM sleep and quiet sleep alternate during the night, periods of attention and of relaxation are alternating during the day. The fundamental ultradian rhythm of rest and activity is most obvious in the young child, the kitten or he puppy. With development, attention eventually supersedes the neuromotor activity during the day.

Edmond Dewan claims that attention is a logical system with multiple entries, which selects, according to pre-established rules, i.e. a "progamme", among the number of random information, those which respond to the needs of the organism (9).

Analysis of REM sleep by way of the time dependency of the eye movements, evidenced constant features in clinically distant fields. It led to the idea that the eye-movements of sleep correspond to the programme, hypothezised by Dewan, i.e. the functional neuronal structure, which allows storage of the information needed for attention, motor adaptation and memory (4,11).

The significance of the oculo-motor signals is not related to visual function as could be expected. It is determined by the

patterns of the eye-movements which, on their turn, are determined by the redundancy of the brain structures which are responsible for them. This redundancy is essential for the information processing in the brain. In other words, the occurrence of the eye-movements during dreaming is intermittent in nature.

Only the eye movements (Rem) signals the frequency of which is higher than 1 Hz., are linked with learning. Studies of our laboratory have shown that, in children and adults, the REM frequencies higher than 1 per sec. are positively and significantly correlated with the I.Q.($p < .001$) indeed (4,12).

Within the bursts of eye movements, the time interval between a given signal and the next one is more likely equal than higher or lower than the previous one. The internal structure of each of the signals in one burst defines its position in time and space. At this point, it was tempting for the physiologist to limit his observations and to consider the concepts of time and space as the ultimate concepts, life itself expressing but different time and space relationships. Logic however drives the investigator to find mathematical formula allowing him to express all of the relations which define the oculo-motor signals in function of the previous and of the following ones (11). The structure of occurrence of REM's has been recently quantified by transition probability matrixes. The latter have confirmed our first observation by proving that the REM's correspond to a two-state first-order semi-Markov process (13,8). This structure remains unchanged from one REM period to the next one.

It has also been shown that the ratio between the REM frequencies over 1 per sec. and those lower than 1 per 2 sec., remains relatively stable in adults over periods of several years (11). From the relation between the higher REM frequencies with the function of learning, we are entitled to consider the REM frequency ratio as a ratio between 'order' and 'noise'. Their relative independency of REM period rank confirms the existence of a dual mechanism for the REM generation, which we suggested already in 1969 (4,10).

Our studies on the rapid eye movements during REM sleep have evidenced intimate connections between their patterns of occurrence and the general psycho-physiological state of the human organism. According to Holden, a strictly periodical patterned activity in the nervous system would be incapable of adapting to a fluctuating irregular environment. Such an activity is seen in epilepsy and the ensuing amnesia confirms his claims. The variability in neural activity is necessary for adapting behaviour (14). On the other hand, an information has to be repeated in the central nervous system in order to be learned. For the cognitive function of the brain, the redundancy which manifests itself in the eye movement patterns and in the EEG sleep-spindles is an essential feature (the spindles waves are bursts of waves appearing during sleep; they bear a relationship with learning similar but not identical to the bursts of REM's). This redundancy must however be limited in time for the repetition of the signal must be discontinued for information to occur.

As I have shown, in the mentally retardates, the higher eye-movement frequencies are decreased whereas little changes appear in the lower frequencies. The redundancy of the signals - their 'order' - is selectively altered, the 'noise' remains. In fact, the relation between the degree of organisation of the REM signals and the intellectual coëfficient is direct, significant and is to be found in all of the varieties of mental retardation, independent of their origin.

Autocorrelation studies of the REM's suggest that their organisation is determined. Would it mean that mental function results from a given balance between determined and randomly organised events in the brain ?

A study of the Rem patterns of dreaming was performed with one of the astronauts during the Spacelab 1 mission in 1983. It showed that there was a tenfold increase in the total number of eye-movements during the first sleep epoch in space. However, the 'order to noise' ratio in the Rem signals remained within the earth based limits. This should be correlated with the outstanding performance of the astronauts during their mission. The same was true after landing in the Mojave desert inspite of a dramatic decrease of the total number of eye-movements. Would the stability in the ratio between the higher and the lower eye-movement frequencies of dreaming indicate that the brain is a dissipative structure ?

The data from the Spacelab 1 experiment have clearly shown that the higher eye movement frequencies are related to the

integration of sensori-motor information whereas the lower frequencies behave as random noise. They confirm the synergetic function of the brain (15). This function remains unchanged whatever variations occur in the total number of eye movements. In other words, the order/noise ratio varies within limits which are determined by the nature of the individual.

The Nature - Culture Controversy.

Another way to meet the challenge of the nature/nurture controversy, was to compare the physiology of sleep, on one hand in closed societies which seem to remain unchanged because of their build-in repetitive dynamics, and in rapidly changing, open societies on the other hand. We spent thus some time in Malaysia, first with a peaceful tribe living in the north of the peninsula, called the Temiar, then with the Iban of Borneo. The Temiar live by hunting, fishing and gathering. Sleep recordings were made in subjects aged between 20 and 25 years that is to say those who, during the night, go fishing or stand watch over the fire. The nocturnal watch is designed to keep tigers from the village.

Two questions were raised. One was to test the hypothesis that the break-up of sleep might prevent the phases of dreaming from developng to their full intensity. In other words, the question was wether cultural factors would determine the REM process. Even if this were the case during nights 'on duty', the interruption of sleep would however be a matter of necessity due to

the need for food and security. Observation has shown that, spontaneously, Temiars sleep uninterrupted for approximately 6 hours, which is relatively little. Yet the very notion of insomnia is unknown to them. The reason is very likely the exclusive attention to dreams during which the 'spirit' manifest themselves. Thus the shaman of the tribe is also a proven dreamer.

Is the insomnia so widespread in our Western world then not perhaps an indication of a deficiency in the state of vigilance, of a state of depression, where the oblivion of sleep is preferred to the wealth of dream fantasy ?

The second question referred obviously to the order/noise ratio. The data on Rem sleep indicated that during dreaming, the density of eye movement frequencies over 1 Hz. did not differ significantly from those found in the recording of my students at the University of Antwerp. They are similar to those found in young normal adults of the same age in Western civilizations. The order/ noise ration in the REM's is an innate characteristic. The higher frequencies belong to a temporal code - perhaps genetic - which is specific to our species. It is remarkable indeed that, during dreaming, the ocular frequencies which carry the information necessary to the functioning of vigilant behaviours, linked to learning, are universal. They are to be found in all human beings irrespective of the socio-cultural conditions under which they live.

The data with the Temiar were confirmed by new experiments which were done a year later with the Iban of Borneo. The sleep

data, collected in the jungle, were similar to the results obtained with the Temiar. With the Iban, we carried the experiment somewhat further by flying the subjects over to Kuala Lumpur where they were housed in the laboratory. The purpose of this setup was to explore the effects of a drastic change in the environment on sleep physiology. After their transfer, mainly the higher, and, to some extent, the lower REM frequencies were decreased in the sleep of our Iban subjects. Therefore, the ratio between those frequencies was decreased, but not significantly. After a few days of acclimatizing to their new environment, the REM's of the Iban recovered their original values, the 'order' was restored in their brains.

In the West, changes in the environment are more likely associated with changes in working situation than with geographical moves. One of these changes occurs inevitably at the time one retires from the job. Studies have shown that, after retiring, there is a selective increase in the lower REM frequencies, an increase in 'noise' (16), which means, here too, a decrease in the ratio between 'order' and 'noise', but the mechanism is different from what is seen when mental function is impaired. With the Iban in the city and with the retired subjects in the West, the decrease in the 'order' to 'noise' ratio in the REM signals is linked with mood disturbance and depression. We must add that the increase in 'noise' did not appear in retired people who remained active.

Last but not least, one of my students, J.Meirsman, has recen-

tly investigated the REM patterns in subjects practicing T.M. (Transcendental Meditation Techniques). The T.M. was first introduced in the public in 1958 by an indian philosopher and physicist, Maharishi Mahesh Yogi. The technique goes back to the Shankaracharyan tradition which started about 2.500 years ago and which is said to represent closely the ancient Vedic culture.

Meirsman showed that subjects who are well trained in the T.M. techniques tend to score higher in the REM frequency ratio than non T.M. practitioners. Their REM signals are more organized, the factor 'order' scores higher in their brain. The results tend to objectivate their subjective feeling of well being. As scientists, we would see the T.M. technique merely as a successful relaxation technique. However it is of interest that this technique originated in the Orient and created subjective experiences which are expressed in several religious traditions.

Time-associated biological activities are codified in our genetic system. The temporal characteristics of sleep, like those of other biological events are the expression of an hereditary memory which has developed during the evolution of our species. The problem for the scientist is wether he can modify this temporal memory. Research here is only just beginning. Eastern tradition tought us for more than 2.500 years that, by improving our relation with the environment, we improve our mental health. 20th century science discovered only the mechanism underlying it. In other words, science has offered the techniques which have allowed to understand a well established, empirical fact.

When did the understanding begin ? During the Sancharakaryan tradition, 2.500 years ago ? Or very recently, in 1979, when the synergetic function of dreaming was statistically established and expressed in mathematical forms ?

Summary.

Our research aimed at first to describe a limited phenomenon, the physiology of dreaming. The method of the eye-movement analysis allowed us to uncover its nature, its architecture and origin. The eye-movement (Rem) signals during sleep have proven to be a reliable index of the function of the brain. They are governed by physical laws and the spontaneous appearance of the coherent structures of eye-movements is accounted for by the non-linear characteristics of the interneuronal links responsible for them. The Rem process is the result of a complex dynamical system which can be evaluated with the techniques of non linear dynamics.

The study of dreaming led us from the laboratory to the jungle of the so-called primitive tribes, from earth to space. The impact of the environment on this particular index of brain activity has been evidenced by field studies in South-East Asia and in the West as a function of retirement as well. Research which was performed by J.Meirsman on the REM organisation in subjects practising the TM - (Transcendental Meditation) and the TM-Sidhi techniques, showed that the ratio between the higher and

the lower eye-movement frequencies (the 'order to 'noise' ratio) is increased in the experimental group as compared to non TM practitioners. Let us remind that the two types of REM's were found to be statistically independant of each other indeed: the higher REM frequencies (over 1 per second) are associated with the I.Q. (Intelligence Coefficient) whereas the lower REM frequencies (lower than 1 per 2 seconds) correspond to random noise.

It has been impossible to describe the phenomenon of dreaming without looking deeper into other aspects of men. We first established the relation between dream architecture and intelligence. With the study of dreaming, we penetrated into the center of human existence, of the structure of reality and of time. The intermittency of the dream signals reminds us of the intermittent character of the events of nature. By speeding up the initial time-space relations, the brain accelerated its corollary, namely intelligence. So, after billions of years, intelligence became what we know now.

Dreaming is not the privilege of men only. We all have seen a cat or a dog dreaming. Who could say that our animals are devoid of understanding ? Intelligence is not limited to men nor to the rationality of western culture. The natural intelligence, of the earth, of the flowers and of the animals is closer to the true human intelligence which stems from dreaming than the uninhibited rationality of some fellow men.

The poet Calderon de la Barca was probably right when he named one of his works : "la vida es un suegno", life is a dream.

Bibliography.

1. Piéron H. -Le problème physiologique du sommeil. Edit. Masson, Paris, pp.520, 1913.
2. Pietrusky F. - Das Verhalten der Augen im Schlafe. Klin Augenheilk 68, 355-360, 1922.
3. Aserinsky E. and Kleitman N. - Regularly occurring Periods of Eye Motility and concomitant Phenomena during Sleep. Science, 118, 273-274, 1953.
4. Petre-Quadens O. - Contribution à l'étude de la phase dite paradoxale du sommeil. Acta Neurol Belg, 69, 769-898, 1969.
5. Pincus G. - A diurnal Rhythm in Excretion of Urinary Ketosteroids by young Men. J Clin Endocrinol, 3, 195-199, 1943.
6. Dubois-Reymond E. - Untersuchungen über 'Tierische Electricität', G. Reisner (ed.), Berlin, 1948.
7. Teitelbaum H.A. - Spontaneous rhythmic Ocular Movements: their possible Relationship to Mental Activity. Neurology, 4, 350-354, 1954.
8. Petre-Quadens O. - The Eye-movements of REM sleep: the developmental Approach. In: Neurobiology of Sleep-Wakefulness Cycle. T. Oniani (ed.), "Metsniereba", Tbilisi, USSR, 1988.
9. Dewan E.M. - Cybernetics and Attention. In: Attention in Neurophysiology, C.R.Evans, T.B.Mulholland (eds.), Butterworth, London, 323-347, 1969.
10. Petre-Quadens O., De Lee C., - Eye Movement Frequencies and related Paradoxical Sleep Cycles: Developmental Changes. Chronobiologia, 1, 4, 385-395, 1974.

11. Petre-Quadens O., Hoffman G. - Maturation of the REM Sleep Patterns from Child-through Adulthood. In: Advances of Physiological Sciences: Brain and Behaviour. Adam G., Meszaros I., Banyai E.D. (eds.), Akademiai Kiado, Pergamon Press, Budapest, 17, 55-59, 1981.

12. Petre-Quadens O. - The Logic of Sleep and Brain-Dysfunction. Sleep, L.Popoviciu et al (eds.), S.S.Karger, Basel,126- 133, 1978.

13. Boukadoum A., Ktonas P.Y. - Non Random Patterns in the Occurrence of Rapid Eye Movements in Human REM Sleep. Proccedings of the 4th International Congress of Sleep Research, Bologna, Italy, 65, 1983.

14. Holden A.V., Muhamed M.A. - Chaotic Activity in Neural Systems. In: Cybernetics and Systems Research, 2, R. Trappl (ed.), Elsevier Publishers B.V. (North Holland), 245-250, 1984.

15. Quadens O., Dequae P.A., Green H.L., Stott S.F.D. - Eye Movements during Sleep and EEG in Zero-Gravity.IAF-84-192, pp.5, Proceedings of the 35th Congress of the International Astronautical Federation, 1984.

16. Petre-Quadens O. - Sleep Physiology and Environment. Totus Homo, XII, 10: 14-22, 1980.