Order and disorder in the brain function

Olga Quadens

Membre de l’IAA Académie Internationale d’Astronautique.
Member of the International Academy of Astronautics, IAA.

Correspondence to: Prof. Olga Quadens
Groeske 8, 5114 AE Castelré,
THE NETHERLANDS
TEL / FAX: +31 13 503 9707
EMAIL: quadens@freeler.nl

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Abstract

The interest in studying the brain electrical activity as a function of the development of intelligence has been spurred by the need to understand how the brain responds to environmental information. The description of sleep in mentally retarded children reveals deviant patterns of the EEG-spindles and of the eye movement activity (REM sleep) when compared to normal children. The patterns may be considered as a valuable index of mental function. According to experimental evidence, the distribution of the eye movements of sleep appears either as random or ordered. The latter are altered in the mentally handicapped in whom the appearance out of chaos, of the order which is needed for intelligence and memory to function, is altered.

The sleep signs are redundant as from birth. Their pattern is also related to the psychomotor development of the infant. If their distribution remains random, or appears in long uninterrupted sequences of waves as in epilepsy, intelligence does not develop. A similar strategy appears to function in the foetus when nature organizes the structures that will lead to the development of intelligence.

The eye movement patterns of sleep change in the pregnant women as a function of term and resemble those of premature babies of a similar gestational age. They also change as a function of the menstrual cycle and more generally as a function of age. The hypothesis that attention is the diurnal equivalent of REM sleep is discussed.

Attempts at modelling the eye movement patterns of REM sleep as a function of near zero gravity environments have been made.

1) By means of a Montecarlo simulation using the semi Markov model during the Spacelab 1 flight.

2) With the method of the single and multiple g-phase transition analysis of the strange attractor dimension ($d$) during parabolic flights. The implication of the latter for the neural processes involved in learning is that the central nervous system can preserve intact, from input to output, over a period of several days, all the information it receives.

3) The relation between spindles and eye movements has also been viewed by a quantum approach which is another medium between the information and the way of describing it.
Introduction

The human brain is one of the most complex systems encountered in nature. It is made of billions of cells endowed with individual electrical activity and interconnected in highly intricate networks. The average electrical activity of a portion of this network forms the electroencephalogram (EEG). It reflects the sum of elemental self-sustained neuronal activities over a relatively long period. Recordings from the human brain show that characteristic electrical wave form patterns correspond to various degrees of wakefulness or sleep.

The interest in studying the brain electrical activity as a function of the development of intelligence has been spurred by the need to understand how the brain responds to environmental information. Chaotic and other measures of the brain waves and the eye movements during sleep change their characteristics as a function of a host of relatively slow components, when compared with those in the EEG, such as the menstrual cycle, during gestation or in early human ontogeny.

In the brain, research in mentally retarded children started decades ago, as a natural history with the description of the different patterns of the EEG and the associated physiological endpoints, among which the activity of the eyes and of the muscles. Today, the early descriptions have been confirmed with more sophisticated means and we may consider the patterns of activity as a valuable index of mental function. It appeared that the capacity of learning is significantly related to the eye movement patterns during the so-called REM sleep episodes. The EEG spindles waves evidence a similar trend. They are related to the activity of the underlying neuronal mechanisms whose structural and functional redundancy may serve for adjustment to changes in the environment.

1. The eye movements of sleep and learning

The function of the brain was developed for the survival of the human species on this planet. We do not know how the brain has emerged nor how it functioned when it commanded the actions of our remote ancestors. We may at most guess a mutation that favored the emergence of men somewhere in the line of the great apes. With the last mutation, the probability of speech appeared but we do not know, more recently, when men created the first signs of what was to become language. Some authors, as Julian Jaynes [1] have speculated on the appearance of new connections between the left and the right brain, which correlated the appearance of a so-called discontinuity in writing, some 4000 years ago. Though this interpretation is not widely accepted, the species had to adapt, first to the changes of planet earth, then to the changes in the relations between the human groups. It had to learn.

In the brain, the states of consciousness are evidenced by the EEG and its associated physiological endpoints such as the eye movements and the activity of the muscles. The EEG may be considered as a reliable correlate of mental activity. It is generally assumed that a sensory stimulation induces slow oscillations in the activity of the subject’s brain. They are perceptible in the eye movements of REM sleep and in the EEG waves. They appear by means of neural operations of a different order, which are situated between the initial sensory process on one end and complex functions such as perception, memorisation and the execution of tasks associated with cognition at the other end. The traditional method of eyeballing the EEG does not allow detecting particular types of oscillations among the many wave forms but methods deriving from the analysis of chaotic systems allow to detect immediate changes in the EEG dynamics. The changes were evidenced by the analysis of the dimension of its strange attractors during parabolic flights [2]. We will discuss this point in a later part of this paper.

It has been repeatedly demonstrated that the learning capacity of a person is significantly correlated with the patterns of the eye movements during REM-sleep [3] (fig. 1). The two physiological endpoints, the waking EEG and the patterns of eye movements during sleep are reflecting some of the underlying neuronal mechanisms associated with learning. Sleep has fascinated the scientific community for several decennia. It was popularized by its pioneers, William Dement in the U.S.A. and by Michel Jouvet in France. As from 1962, a small European team studied the dynamics of the eye movements. In the sleeping adult, they appear either in bursts of 5 to 8 movements or they are isolated. Dreaming has been associated with the REM epochs but the mental images of dreaming are inaccessible to anyone but the dreamer himself. They are vanishing but nevertheless they rest on organic networks. Our purpose was the specification of the network, which relates the eye movements appearing during human sleep with intelligence. According to experimental evidence, the isolated eye movements appear as the random part of the rapid eye movement (REM) system whereas the bursts are the ordered and deterministic part of it. The bursts only are related to the intelligence level of the child and of the adult.

The number of eye movements appearing as isolated movements and those appearing in bursts are similar in the normal, healthy adult. Their proportions are

![Fig. 1. The higher eye movement frequencies (I-time intervals shorter than 1 sec.) as a function of the I.Q. (intelligence coefficient, Wechsler-Bellevue test) in 3 groups of children aged 6 to 8 years. Bottom line: number of the higher frequency eye movements in 40 sec. REM-sleep.](www.nel.edu)
changing when learning is impaired. In the mentally handicapped, the total number of eye movements is decreased during REM sleep and their distribution is mainly random [3].

Memory is an important parameter in the learning process and it appears that, in the mentally handicapped, the two kinds of memory, the long and the short term one, are altered. The networks responsible for memory are widely distributed in the brain with a greater number however in the thalamus [4]. The thalamic nuclei are more specifically involved in the production of the EEG spindle waves, which appear preferably before but sometimes after REM sleep, in what has been called stages 2 and 3 of sleep. As is the case with the eye movements, the spindles are a sign of the redundancy of the thalamic networks.

The organization of the spindle waves is as important as that of the eye movements in bursts with respect to learning. Their distribution is also altered in the mentally handicapped. The spindle-waves may be underlying the time correlation of the neuronal activities between the different parts of the brain system responsible for the data processing. They would be representing the link between different parallel operating systems. A number of links are virtual. They consist in the reserve of strategies, which the brain can use when needed by the circumstances. These links are actualized by acquiring new information that mobilize the strategies and change continuously the potential communication between the neuronal networks [5]. They indicate that the prefrontal cortex (which has feed-back loops with the intralaminar thalamic nuclei) contains cells that are active during the phase of retention in memory.

The two types of sleep signals, the eye movements and the EEG spindles, belong to similar logical functions, which support their redundancy. No wonder that they are both associated with intelligence in a different but complementary way. Learning results from a sequence of logical functions at different levels of activity. They are located in anatomical structures and in neuronal networks that are endowed with a great initial redundancy. By themselves, the signs are devoid of meaning. They perpetuate themselves in the brain, in an organized or random way. But their variety and their heterogeneity allow the anatomical structures that produce them to be capable of greater performances from the point of view of regulation and of autonomy from the random fluctuations of the environment.

The patterns of the brain signals are a code, a language of the brain. We can thus postulate the existence of a meaning in the complexity of the patterns of signals provided by the brain, of a reality, which goes beyond their purely pragmatic function of detecting abnormalities correlated with learning. This reality is ‘intelligence’, probably inborn but modulated by the specificity of learning.

The spindle waves and the eye movements represent an endogenous neuronal stimulation, which, thanks to the number of feedback loops, insures repetition. The loops function in parallel. Such a structure is characteristic of the thalamus. Information that has to be learned must be recurrent. An example is seen in the acoustic stimuli, which consist in the transmission of rhythmic movements to the inner ear. The vibration must last for several cycles in order to be perceived. But for memorization and learning to occur, the sequence has to stop. Hence the transitory character of the spindle waves and of the bursts of eye movements, which are interrupted after a few cycles. Thus, the memorization of the information is connected with the discontinuity in the repetition of the signal. An uninterrupted sequence of signals cannot be memorized. An example is seen in the uninterrupted sequences of eye movements during the sleep of the very young premature and of the epileptics.

In the thalamus, redundancy is linked with the parallel structure of its cell fibers and with the recruiting activity of some of its nuclei. This activity is shown by electrical signals that appear in bursts. Structurally, the components of the thalamic network are repeated a number of times. The same logical function will thus be performed not in one but in different places that are able to control each other. If the system is in good shape, it will to react to random effects of the environment by decreasing its redundancy but also its reliability. It will then, at least for some time, continue to function with a greater variety, which is a consequence of its decreased redundancy. The adaptation of the brain to its environment occurs in strategic terms, in a simple and rational way. It occurs with a continuous control of the in-going information and with adding the information that circulate in parallel loops of sensory fibers from the thalamus to the cortex. The information is modulated by interneurons which connect those parallel fiber systems. On their turn, they are connected by feed-back loops with the prefrontal oculomotor system [4].

The concept of consciousness has been extensively discussed for decades. Its alteration in the mentally handicapped is correlated with the changes occurring in the time structures of his brain waves. In these patients, the appearance, out of chaos, of the order that is needed for intelligence and memory to function, is altered. The time limits within which the brain activities have to function are narrow and precise. The dimension ‘time’ of the brain function may provide a partial answer to the problem of consciousness. Human time may be the infinitesimal increase of ‘order’ the brain is capable of. Conceivably, the limits of this increase are associated with that part of the human genome, which traces the physiological parameters of the intelligence of each individual.

2. Early human development

The redundancy that is observed, during sleep, in the spindle waves and in the bursts of eye movements, is present in the human baby as from birth [3] (fig.2). It is related to the psychomotor development of the infant and of the child and it remains a predictable measure of it. Changes in the redundancy of both endpoints as a function of age occurs stepwise. In the first year of
life, there are a number of those steps. After that age, they become more spaced. Some decades ago, David Hamburg [6] described similar steps in the behavioral evolution of the child and named them ‘critical periods’. During the first months of life, the sequence of electrophysiological and behavioral development appears to be determined by the chronological unfolding of an innate programme, probably genetic. They unfold stepwise, with periods of disorganization and reorganization. At times, during maturation, the brain activity appears to be disorganized, only to be reorganized some time later again. Discontinuities interrupt the previous time structures of the brain signals, the behavioral counterpart of it being periods of fussiness. At every step however in the normal baby’s development, order overcomes chaos and allows new milestones to be superimposed on the old ones.

This stepwise evolution, from a less organized to a more organized state, requires a considerable amount of structured information. Sometimes, there is a jump in the opposite direction, from a more structured to a less structured state. Given its complexity, the brain tolerates error. If, during the baby’s sleep, the distribution of the brain signals remains random, intelligence does not develop. The same is true when the signals appear in long uninterrupted sequences of waves as in epilepsy. In a preliminary study on the strange attractors in the EEG of epileptic patients, Babloyants evidenced a decrease of their dimension $d$, which indicates an increase in determinism in the brain function [7].

At the level of the brain activities as they are observed during spans covering several months or years, one can distinguish fairly long spans of stability before reaching a breakdown. Mathematicians have formalized this type of evolution by the theory of catastrophes. It means, etymologically, a discontinuity, the reaching of a threshold. As we have seen, this type of evolution corresponds to the transition periods between the stages of neurophysiological maturation, from infancy until senescence.

Learning starts during foetal life. In the mother’s uterus, the foetus explores the maternal internal environment, an early learning process that has remained unchanged as from time immemorial. In the neonatal period, the newborn has to integrate a great amount of information from its new environment to which it has to adapt. Hence, the increase in the redundancy of the eye movements of sleep.

We would suggest that a similar strategy is used by the brain when nature organizes in the foetus the structures that will lead to the development of intelligence. During pregnancy, the patterns of sleep are altered in the mother to be and they evidence similarities with the eye movement patterns in the premature baby of a similar gestational age, as if her brain was in resonance with the brain of her foetus. The changes observed in her sleep are among others, an increase in the number and in the amplitude in the EEG sleep spindles during the first months of pregnancy. During the last 3 months there is a significant increase in the number and bursts of the eye movements. As from the 7th month, the time structure of the eye movements of sleep are similar in the pregnant women and in the premature of a similar gestational age [8] (fig.3).

The nature of the information transmitted between the pregnant woman and her foetus is unknown. We believe that this information is genetic, that it is the memory of the species that passes from the mother to her foetus, in the way of a code. The pregnant woman is, in the early stages of foetal development, the temporary physiological support of its brain activity. One cannot rule out a link between the brain function of the pregnant woman and a cell memory of which the elements, like antigens, cross the placental barrier and cause cell links to become established in the foetus.
3. Altered states of consciousness

The infant’s environment becomes the cultural environment of the child and of the adult. In other words, the dynamics of the brain activities during sleep is a way of evaluating the integration of environmental data. The integration insures the survival of the species. When an illness strikes the pregnant woman, the genetic information of the foetus may be suspended or altered. The same is true with the intake of drugs that cross the placental barrier and alter the highly complex system, which is the foetal brain. It reorganizes itself but the result may be unpredictable and sometimes unpleasant. It has been hypothesized that particular sleep behaviors such as narcolepsy, catalepsy or catalepsy may result from such recombinations. The common characteristic to these disorders is a disorganization of the physiological parameters the synchronization of which defines the normal states of consciousness needed for normal social adaptation.

Already before birth, brain waves appear in the foetus. Their pattern will change with maturation and as a function of the states of wakefulness and sleep. We have no way to know the sensory content of the baby’s brain but it would be presumptuous to assume that there is none. By analogy with the physiological signs we can build scenarios and hypotheses about it. Sometimes, in adults, the physiological endpoints of sleep are dissociated and their recombinations resemble those found in newborns. These states are associated with vivid hallucinations. We have already mentioned narcolepsy and catalepsy. They look like intrusions into wakefulness of the states of sleep and dreaming. They resemble not only those found in ontogeny but also remind the association of the physiological variables of the states of rest and activity of fishes and reptiles in which Karmanova traced the stages as a function of phylogeny [9].

The question that arises here rests on assumptions and may appear highly unorthodox. Could there be a similarity between the sensory world of the baby and the hallucinations of subjects whose sleep parameters are dissociated? Are the hallucinations associated with narcolepsy and catalepsy a physiological memory, that of an epoch of one’s life where the perceptions of time and space are still absent, of a primary universe that will eventually lead to the intellectual and critical universe of the waking adult? One may wonder whether a brain function, still devoid of time structures can be associated with images, which are likewise devoid of time-references. It may lay the ground for human imagination, evolving into legends and thought.

We have retained the heuristic hypothesis that the human species with its 6 billion people and the brain with its 100 billion neurons have, in order to function properly, organization levels that are analog or parallel. Both are subjected indeed to the laws of chaos.

4. Attention

To be coherent, when establishing a relation between some sleep patterns and the learning capacities, one has to look into a periodic activity during wakefulness which may be equivalent to REM sleep. A candidate for this equivalence is attention. Body signs indicating the state of attention can be observed and measured. When the organism is solicited by stimulation, it turns itself towards the source of it. The orientation reaction is shown by movements of the eyes, the head and the neck. They are the observable signs of an extensive neuronal network. In the human, the evolution of the brain allowed the eye movements to be dissociated from the movements of the body. Therefore, the eyes alone move towards the source of the stimulation whereas, in the cat f.i. in which the brain structures (the frontal eye field) is still embedded in the mesial face of the frontal gyrus, the movements of the eyes, the head and the neck are not yet dissociated. In the ape the frontal eye field has already migrated towards the surface of the cortex. This migration may give more to the ape than just the capacity to move his eyes alone. His level of consciousness appears to be a correlate of his brain mechanisms of attention.

The physiological basis of attention is associated with a specific brain activity bound to wakefulness and occurring periodically during the day. The physiological endpoints of it – the desynchronisation of the EEG, the movements of the eyes and the inhibition of the muscular activity – remind those of REM sleep. This correspondence exists in the cat. When the attention of the cat is aroused by a bird or a mouse, it will remain motionless for some time before attacking his prey. In a laboratory situation, where the choices of the cat are limited, it will turn the head and the eyes towards the...
source of the stimulation. The EEG resembles that of attentive wakefulness.

The purpose of the behavior of attention can only be appreciated, with cats and with humans as well, in the context of the situation. Attention is to wakefulness what REM sleep is to sleep. During the night, quiet sleep alternates with REM sleep. During the day, periods of rest alternate with periods of attention. This alternation is part of the fundamental rest-activity cycle that belongs to life itself. In the cat, where the rest-activity cycle is ultradian (more than 1 cycle per 24 hours), selective and chronic deprivation of REM sleep entails hallucinations first, later the death of the cat [10]. Attempts at selective deprivation in human have induced states of confusion but the experiments have been withdrawn after a few days [11].

In this book, attention is linked with a genetic programme that drives him to chase birds and mice, in order to survive. In human, it is the drive to hominization that drives him to pay attention to others in order to explore his physical and cultural environment, then the whole of reality. This drive to explore and to create is the final purpose of attention. The cultural environment draws the lines and limits the objects of attention in the human in whom it meets periodically, during the day, the framework of the neuronal connections that it shares with REM sleep.

The alternation between attention and rest is obvious in the young child where attention becomes play. In the infant, attention and action coincide. His behavior is a psychomotor pattern the mental and motor components of which are not yet dissociated. With maturation, when developing the cortical inhibitory functions, a mental play will come to be substituted to motor play. According to Littré, “attention is a general capacity underlying the states of consciousness and which can be directed at any time towards any part of the sensory field. Its first operation is to create a perceptive or mental field”. This latter capacity, as I have made it clear earlier in this paper, happens by means of a number of neuronal operations between the initial sensory process and the resulting complex function of perception, memorization and action. The brain contains a number of generators of attention. Our experiences meet with our nervous structures either organically or in their relation with our memory. We have already seen that the intralaminar thalamic nuclei – by means of their feed-back loops with the prefrontal oculomotor area – are a privileged location for the elaboration of the survival strategies. Several options for motor responses coexist in the thalamus and it seems likely that the information soliciting strategic choices are processed already at the thalamic level that would be more than just a control center.

5. The aging of the brain

The ratio between the ordered and the disordered patterns of the eye movement activity during sleep increases in men and women alike, from birth until 50 years of age after which it is stabilized (fig. 4). It appears to be unrelated to menopause. As from puberty until menopause, step like discontinuities, from a less organized state to a more organized state are superimposed on the ascending curve of the brain function organisation. In women, periodic changes occur every two weeks, at the turning point of the hormonal cycles. The redundancy of the oculomotor signals during sleep, increases significantly during the second part of the menstrual cycle [12] when compared to the first part. The number of random signals is not altered. It has been demonstrated that the execution of manual tasks and of calculus operations are easier and faster during the second part of the menstrual cycle when compared to the first part. The number of random signals is not altered. It has been demonstrated that the execution of manual tasks and of calculus operations are easier and faster during the second part of the cycle. It appears from these data that attention is the counterpart of the eye movements of sleep. Towards the end of pregnancy and after delivery the changes in the organization of the signals are similar to those occurring in the postovulatory period. Symptoms of depression are not uncommon. There is an apparent correspondence between the appearance of the increased redundancy and depressive mood states. The milestones of psychomotor maturation in the baby, with the increase in fussiness, may be a similar phenomenon [13].

The relations between the endocrine system and the central nervous system are complex. Both sys-
tems undergo simultaneous periodical changes. Some neurones have receptors for hormones. According to De Lee, the increased redundancy is a non specific neuronal activity. It shows the activation of an endocrine-central nervous system feed back loop and appears as such during the second part of the ovulatory menstrual cycles and during pregnancy. Fluctuations of the mood states are associated with it.

In the course of the increasing brain order with age, there may be jumps in the opposite direction, from a more organized to a less organized state, suggesting an error in the information. Based on the above mentioned observation, we may assume that the counterpart of it varies from a lack of initiative to depression. However, insofar as the environment allows the brain to function according to its own programme, the psyche restores spontaneously its disturbed balance. The level of redundancy indicates the limits of the information capacity of the brain, a limit that is personal and probably genetic. The overshoot above this limit correlates with desinformation as shown with epilepsy.

After age 65, when people retire, the combination of the signals is different from that encountered until then. There is a decrease in the order to noise ratio of the eye movement patterns during sleep which is due to an increase in the random signals as if there was a lack of transformation of chaos into order. There might be a change into a suboptimal order. It was the surprising observation when investigating the brain activity during sleep in subjects aged 60 to 65 years, recorded before and after retirement [8].

Periods, in which the activity of the brain is temporarily disorganized only to be reorganized again, run through life. The rate of alternation is higher in the infant and becomes lower with age. They are determined by laws that we still ignore. One could imagine that epochs of reversed entropy of the brain functions are connected with what we call ‘time’.

The neurosciences evidence the incredible complexity of the brain with its genetic instructions and recombination capacities. They define the frame of intelligence and behavior. They allow the plasticity, which is evidenced by the brain. During development, it compensates for some deficit – either genetic or following an injury – by following alternative routes of maturation which end up at the same functional result. The alternative routes are uncommon indeed but they have the advantage of using intact nerve tissue. In the adult the problem becomes more complicated for he has already chosen his preferential modes of neuronal organization.

Some information is connected with the production of peptides [14]. It indicates that the information may precede the structure. The organic link between the signal and its substrate was suspected for a long time but in opposite direction, in the way of anatomical and/or biochemical determinism. One would expect a determinism at the level of the brain. But whatever the degree of it, the almost infinite complexity of the neuronal network has made of the brain an open, self-organized system which creates order out of noise. The brain system is at the same time free and deterministic, it is chaotic.

The central nervous system is a flexible structure with respect to any event. If its variability decreases, if it loses its chaotic character, the system may fail to function. This is probably what happens with diseases, which appear with old age. EEG studies show changes in the spindle activity. Let us remind that ancient studies have evidenced a slowing of the frequency and an increase in amplitude of the spindle waves in light handicapped children. This is consistent with the hypothesis that the threshold requirements for the brain waves to be redundant are met but not those for triggering the bursts of eye movements of sleep. When the learning capacities are weak, redundancy seems to be limited to the spindles only. Let us remind that in normal healthy subjects, the sequence ‘spindle waves – REM sleep’ is preferred above any other sequence of patterns.

6. The brain in different gravity environments.

The previous observations have led to a first attempt at modeling the eye movements’ patterns of REM sleep. They are merely viewed as a stochastic point process and the techniques used to quantify the statistical time dependency have been applied. Because of the existence of strong non-stationarities in the raw eye movement data, the usual techniques as correlation analysis and power spectrum analysis are of little use for they require large data sets. Homogeneous sets in the eye movements during sleep are time-consuming to obtain. The analysis of the time dependency of a stochastic point process requires the measurement of either the time between the events (the eye movements) or the number of events in an arbitrary time interval. Both are considered to be roughly equivalent. The variability in the distribution of their frequencies has been modelled in terms of Markov processes [15]. The Markov chains have the remarkable property that they can be described in terms of entropy and the entropy ratio could be used as an order parameter. The statistical order parameter D indicates an organizing influence on the environment. It is calculated by means of a Monte carlo simulation using the semi Markov Model. During sleep, the brain stores information for motor adaptation, for memory and for selective attention. This method was used to analyze the eye movement frequencies of an astronaut working and sleeping in space. This was the first experiment during which the eye movement patterns of sleep were recorded in space, namely during the Spacelab-1 flight which was conducted in 1983. To summarize, the number of high frequency eye movements (D) was higher during the first night in-flight and during the first night after landing. The numbers returned respectively to normal during the second night.

The higher values of D during the first night in-flight and the first night after landing indicate that the changes in gravity have a cumulative organizing
influence on the brain during the night. The very disclosure of a pattern in the eye movements of sleep, that clearly differ between the first and the second night, yet clearly evidence a similar pattern across the nights in-flight and post-flight is indeed challenging. It shows that gradients of gravity are a specific stressor of the brain as evidenced by D.

The lower order parameter that has been found with this method in mentally retarded children is consistent with the lack of integration of the environmental information. The present results also evidence that the eye movements of sleep cannot be regarded merely as an optical system but rather constitutes an important extension of the brain itself.

Since the neuronal organization is related with the emergence of intelligence, one would want to imagine a mathematical formula, which would express the whole of the neuronal relations that define at each moment the activity of the brain system in function of its aspect at the previous and the next moments. One has hoped to arrive at it by using matrices, in the mathematical sense, each one of them deriving from the previous one by a particular matrix operation. But the intelligence of the system, in which we have included the steps of foetal and neonatal development, leads to the assumption that there is a sequence of matrix solutions in which the human being is assisted as a whole by a memory in which the future and the past patterns are processed in the present configuration. This phenomenon which repeats itself all the time constitutes if not a programme, at least one of the invariants of our species. It is the source of indetermination.

The function of the brain, as we can see it today through its signals, develops in the uncertainty, in a chaotic way, with an apparent disorder within which order is hidden. The neuronal activity is capable to extract order or at least somevisibility, from apparently random events and vice versa. At each level of complexity, the brain is deterministic by its causes and is chaotic by its consequences. To complement these ideas, further experiments on the brain electrical activity in weightlessness, during repeated short periods of micro-gravity (up to 20 seconds) were performed on board research aircraft flying parabolic trajectories. The main goal of the proposed research was to confirm statistically that the increases in components of the power spectrum in some EEG frequency bands, measured in zero gravity, are bilateral in both hemispheres in subjects suffering from motion sickness and are asymmetrical (in one hemisphere) in subjects resistant to motion sickness. In the latter experiments, the method of the single and multiple g-phase (g = gravity) transition analysis allowed to show that d values (d = strange attractor dimension), although not subject to a simple one-to-one causal relationship, are certainly not random and differ from equiprobable distributions. This indicates that the strange attractor dimension d is not independent of previous values of d and of recent and more distant history, supporting the hypothesis of the effect of accumulated fatigue.

This makes one think of a cell whose output is never, or hardly ever, observed to be random, suggesting that a random series of events producing excitation of the cell does not result in a random discharge of the cell. There is a harnessing mechanism with certain combination of forbidden intervals between stimuli. The transmission of information when stimuli are delivered rapidly needs to be determined. We attribute this to the refractory period of the cell. Moreover the central nervous system is most potently organized for discrimination.

It was also seen that some types of variations (increase or decrease in d values) or combination of variations appeared in preference to others at certain g-phase transitions of interphases. Of particular interest was the possibility of inferring a certain level of predictability in the rate of change of d values, and an average parabola was deduced from the types of variations, which most often appeared, showing different signatures for flights in the morning and in the afternoon. They may be characteristic signatures of the individual’s brain [16].

Furthermore, there seemed to be a cyclic component in the attractor dimension d which resembles the alpha activation cycle documented by Mulholland [17] insofar as it reflects a system that oscillates relative to a threshold magnitude between upper and lower limits that are time varying. This system appeared to be modifiable by external feedback and appeared to recover to near its original state when disturbed by a transient stimulus or by a step change in stimulation. In response to redundant stimulation, this system seems to exhibit an adaptive change to an asymptotic state that is assumed to be an optimum value for the prevailing conditions. This system will shift to a new optimum when stimulation changes to a new stable level. However it also seems to exhibit a stochastic component in all of the variations taken into account. In short it behaves as a biological control system.

The implication for the neural processes involved in learning is that the normal, healthy central nervous system can preserve intact, from input to output, over a period of several days, all the information it receives. The shaping and maintenance of order working in conjunction with randomness has been accomplished in biological systems with much larger random variations and an even more unmistakable recourse to haphazard procedures than those found in physical machines, which can be made to work in both an orderly and indeterminate manner at the same time. The logical and realistic conclusion is that the fully developed nervous system follows the principle of disorder-to-order rather than that of order-to-order. The incompatably intricate organization of the central nervous system provides us not only with striking examples of co-ordination of time-determinate functions, which are always unmistakably present from the very start of an individual’s life, but also with no less remarkable instances of a gradual creation of order against a background of randomness. One could however wonder about the incredible waste of energy of a chaotic system. The corollary of this waste is the fragility of the system, the derivative of
which are failures such as we have seen are associated with mental retardation.

Though chaos has been recognized as an omnipresent phenomenon for the last three decades only, it has challenged a number of investigators during a whole century [18, 19]. It has long been mistaken for simple noise. Now, chaos has been documented in almost all disciplines, from astronomy to biology and medicine. Methods have been established for the study of such complex systems with multiple variables [20]. We have alluded to one of them that is specifically aimed at describing the time evolution of a great number of systems as a movement with respect to a strange attractor.

The relation between spindles and eye movements: A quantum approach

This chapter stems from a collaboration of several years between a mathematician, Willem Kuyk, and the author of this paper [21]. The quantum approach is a medium between the information and the way of describing it. It is usual at the atomic and subatomic level of matter, where space and time are a continuum in the context of relativity and where there is the wave-particleliness of the electromagnetic field of light. So is the ongoing activity inside the skull, namely of units of neuronal networks that are excited in a patterned way. At the level of the EEG, this theory can be applied only to the sleep spindles, which appear as cortical wave packets that spontaneously, without apparent cause, appear to stand out from chaos. We have seen already that they have a thalamic origin and that their function is the integration of the information.

The oscillation of the brain activity can give us but a vague idea of the underlying neuronal activity. The analogy with the quantum mechanics and the Heisenberg principle is striking indeed. This means that the position, the localization and the energy of an elemental particle can only be described in terms of probability. It may be that classical physics and mathematics are unable to describe the relation between mental or dream processes and the brain phenomena. One could borrow a descriptive model from quantum mechanics, which postulates the double nature of wave and particle of the brain waves. Quantum mechanics does not say that the waves and the particles are separate entities nor that they are identical. It admits the existence of a field, which includes the probability that particles can be observed. Similarly, there is no “particle” without the presence of a wave field. This would allow us to trace a continuity between neurophysiology and the mental counterpart.

The problem of the relations between the visible activity of the electrophysiological endpoints and behavior, including the hypothetical meaning of the dream images is yet unsolved. The relation might rest on a parallelism between the idea of “vacuum” in physics and the brain in quiet sleep.

One might compare a physical “vacuum”, in which no measurable particle is present, to a brain system in a state without functions other than the physiologically fundamental vital ones. In this state without particles, there are no physiologically perceptible activities such as a movement, a sensation or an image. The correspondence between a physical ‘vacuum’ and a brain in this state is to be found at the level of a quantum electrodynamic field that is always present in a vacuum and in which there is always the chance or “amplitude” that a particle appears now and then and disappears. There is also a neuronal field which is expressed in the EEG and underlies it. In the two fields the probability exists that a particle appears spontaneously. The quantum electrodynamic field which underlies the vacuum is a field of very active quantum fluctuations, filled with virtual particles, it is, with packets of probabilistic waves, which include the probability that a measurable particle leaves the field. This means that from time to time, there appears a burst of waves with an amplitude that is sufficient to interact with appropriate measuring instruments. When the life span of such a particle is precise, then the energy of the particle is imprecise and vice versa.

The electromagnetic quantum field of the brain is a field of quantum fluctuations the permanent activity of which is the psyche. It keeps its vital strategies during sleep, during anesthesia and even during coma. During slow wave sleep, there appear from time to time particles in the way of spindles, a recruiting activity of the brain waves with their first augmenting and then descending amplitudes. When a number of these waves, the duration of which is approximately one second, appear on the EEG, there appears at an unpredictable moment, a phase of REM sleep during which the bursts of particles (the eye movements) appear. The preferred sequence ‘spindle waves > REM sleep’ has been described as from 1967 [22]. The spindles waves of the EEG and the eye movements of REM sleep have a precise duration. But, the energy of the spindle waves has little precision whereas the energy born by the eye movements of sleep is high. The energy of a particle is measurable by means of its electrical amplitude. Each particle can be observed on the whole surface of the cortex, from whatever location it originates. The topography of the spindle waves does not evidence important differences in amplitude, which indicates that the energy of the spindle wave is uncertain and its location as well. For the eye movements, the situation is the opposite of that of the spindles : the topographical variations in amplitude are great which means that they are well localized and that their energy can be determined with precision. Thus, the analogy with the quantum electrodynamic field can be established.

As we have suggested in 1968 already, the sleep EEG spindles and the eye movements of sleep belong to a logical neuronal system, similar to the oneness of the waves and the particles of light. We have seen above that during eye movement sleep, information are integrated in the way of a code. The nature of the information is unknown. It may be a long term storage information. It may also be the overflow of information of the day which is eliminated.

From the ‘wave/particle’ standpoint, there is no main difference between a long term memory and its recall and the initialization of a sub-system of neurones which will allow the recall of future memories by means of this same sub-system. It is important to keep in mind that, in order to insure the conservation of a particle, one has first to increase its energy before being able to provide the synaptic changes which are needed for its coding. This may answer the question why the frequency and the duration of the spindle waves which we find in the human, are found only in organisms with a good capacity for memory.

The hypothesis of a memory carrying particles of spindle waves allows the eye movements of sleep to code more fundamental elements such as the insertion of more recent events at short term in a vast array of emotional strategies and of relation with the environment and with other people [23]. The hypothesis is coherent since it is admitted that we dream already during slow wave sleep when spindles appear in the EEG and that during REM sleep we have full blown dreams. If we strip the latter of fantasy and chance, either they confirm our strategies or inform us of an error somewhere.

With W. Kuyk [21] we may summarize the hypotheses as follows:

1. the spindles preceding REM sleep select the particles which are to be combined during the next eye movement episode. With this repetitive re-uptake their energy increases until they reach the point where they can be integrated during the next eye movement phase. The redundancy is part of the tools of complex organisms: it depends on the genome and maybe on the initial environment of the subject.

2. eye movement sleep is part of a natural instinct aimed at connecting past with future experiences, which means that new networks are established. We do not know which experiences will be selected. Hypothetically, in the line of the sequences of spindle sleep and of REM sleep, the whole of our experiences will be memorized. They are passing in disorder through the brain machine which will archive them.

An argument in favor of this hypothesis is found in babies and young infants where a lot of information has to be coded and a number of networks to be established. They have also long eye movement sleep epochs. In subjects with lethal neurological diseases, the bursts of eye movements tend to disappear. In other words, in youngsters the indeterminism in time is low whereas at the energetic level, the indeterminism is high.

In elderly people, the opposite is observed. The amount and the ‘quality’ of the spindles change correspondingly with the eye movements in sleep. The amount of spindles increase with age but their ‘quality’ decreases. The spindles are ‘breaking’ which implies that their precision in time decreases. This correlates an increase of their frequency with age, it is, with an increase in their energetic determinism.

One of the fascinating aspects of the recent development of the neurosciences is the constantly improving and increased precision of the instrumentation which allows new hypotheses on brain development to be tested and to cross the frontiers between the different disciplines of knowledge. However we must remind that the very existence of a quantum magnetic field at the level of the brain function limits his own measures.

REFERENCES