The Natural History of REM-Sleep and the Function of Dreams among Humans.

A reflection on Niels Engelsted's scenario for the evolution of REM-sleep, and the possible function of dreams in the evolution of the human mentality.

a. Introduction

In this article I will discuss the evolutionary origin of - and thus the function of - REM-sleep in mammals. A tentative scenario for the evolution of REM sleep in mammals, first developed by Niels Engelsted in 1977 (Engelsted 1977), will serve as a frame for the discussion. Major contemporary views on the function of REM-sleep and/or dreams will be assessed and related to this evolutionary scenario. Based on this discussion, I will suggest how REM-sleep and the mammalian "dreams" may have played an important role in the evolution of the specific human mentality – and consciousness.

b. General considerations concerning the evolution of REM sleep

The basic problem in sleep research concerns the function sleep serves for the organism. What feature of the organism needs sleep to function properly, or, to put it more specifically, what feature of the nervous system is supported or enhanced by our pattern of sleep? At present we do not have convincing answers to these basic questions. We can describe some of the possible functions served by sleep, but it is difficult on the basis of contemporary evidence from the various scientific traditions to explain precisely why it is a compelling necessity for us to sleep, and why we sleep in the way we do. And when it comes to the function of dreams, the answers become even more elusive.

From an evolutionary perspective, there is a problem in understanding the purpose of sleep in general. The sleep state must serve certain functions for the organism, offering distinct advantages to an animal in the struggle for survival. These advantages must outweigh the handicap of

remaining in a highly vulnerable condition for the greater part of the day. There may be various advantages for the animal in keeping quiet for long periods during the day. The most obvious advantage is that, by staying in one place, the animal can save energy and stay in hiding from predators. But the problem of assessing sleep from an evolutionary perspective is that sleep implies that the animal's perception of the environment is totally or almost totally blocked. How can the animal possibly benefit, in its struggle for survival, from having its contact with reality cut off? Why can't the animal simply lie quiet, with its senses alert, if the main point is just to save energy or to hide?

Secondly, but less significantly, the need for sleep dictates a pattern of activity and rest during the day that is independent of the actual need to save energy or to go into hiding – the two most obvious reasons for animals to stay quiet. Even if there is some degree of flexibility in maintaining this rhythm, animals still need to sleep a certain amount each day, irrespective of the actual circumstances of their lives. Despite the costs of maintaining this rhythm, however, the ability to sleep and to engage in different forms of sleep has developed among the most advanced animals, particularly among mammals.

There have been relatively few studies of sleep among animals other than mammals. Those studies that do exist suggest that, apart from mammals, only birds demonstrate the pattern of sleep that can be observed neurophysiologically as a rhythmic change between REM and SWS (cf. Tobler, 1984, p. 208ff, for a description and discussion of this). However, sleep behaviour, defined as bodily rests that occur systematically during the day, and which involve high perceptional thresholds and a need for compensation if the rest periods are disturbed, is also consistently observed among reptiles and among certain species of amphibians and fish. This might indicate that sleep, as a form of behaviour, is a general feature among vertebrates.

However, REM sleep and deep sleep (Slow Wave Sleep or SWS in this article) as defined by standardised neurophysiological measures, has consistently and reliably only been observed among mammals and birds.

When considering REM-sleep, there are two main types of evolutionary explanations suggested. One type of explanation takes as its point of departure the development of thermo-stability in mammals, i.e. the effort to stabilise the metabolism of the organism through control of its internal body temperature. The explanation for REM sleep, according to this view, lies in the fact that it plays a necessary role in the administration of drives in connection with the development of thermo-stability, or warm-bloodedness as it is sometimes known. From a biological point of view, the theoretical arguments put forward by the Danish psychologist Niels Engelsted, though tentative, seems to me the most interesting and profound example of this type of explanation (Engelsted, 1977). In what follows, I will briefly outline Engelsted's views on the evolution of REM sleep in natural history, which he formulates as a tentative scenario, and consider what this scenario implies about the biological function served by REM sleep. In the international literature a somewhat similar line of reasoning is formulated by Gerhard Vogel. Vogel's argument, however, is more clinical than biological, and his notion of the function of REM sleep is primarily linked to neurophysiology rather than to natural history (Vogel xxx).

The second main type of explanation for REM sleep links its development to a steadily more advanced nervous system. I call this kind of explanations "brain-oriented". The basic notion here is that REM sleep serves certain functions connected with the problems arising from the very complexity of the nervous system. In what follows, I will make an effort to inscribe the most convincing of the brain-oriented explanations into the basic scenario.

In both main types of reasoning, a possible explanation of dreams may be detected beneath the biological arguments. Sometimes this is explicitly formulated, while at other times it is merely implicit. In so far as the argument focuses on metabolism and the administration of drives, it is easy to see a direct link with Freud and psychoanalysis. Brain-oriented explanations, on the other hand, are linked to the general psychology of cognition and tend to assume that dreams are essentially meaningless.

If we now turn to what evolution can tell us about sleep and REM-sleep, the basic question becomes: at what point did the sleep function develop? When in the evolution of mammals did certain kinds of sleep arise? And in particular, when did mammals first start to exhibit sleep patterns akin to REM sleep or deep sleep in humans?

3

If it is possible to ascertain at what point in evolution a particular feature developed in a species, pinpointing *the* first species that exhibited that feature, one will have a basis on which to speculate about the possible functions this feature might serve. A general feature such as sleep is exhibited by many animals, but it is the existence of this feature among the evolutionary oldest species that is of special interest to us here. The feature must have had certain functions that helped the species to survive in the particular environment in which it developed, otherwise it would not have arisen. In order for us to be able to study it, the feature must still exist in present-day animals. This implies that it still serves a function in the animal's survival, otherwise it would not have been maintained, if there are costs in maintaining it, as is the case with sleep.

Thus, it is a reasonable first assumption that the feature in question serves the same function in present-day animals as it served when it originally developed. But this is not necessarily the case. Natural history presents numerous examples of features that have taken on functions quite different from those they originally had. Nature is a great opportunist in making use of concrete possibilities. Once a particular feature or capacity exists in a species, it can often be exploited for completely other purposes than those it was originally designed to serve. Besides, and even more significantly, it is often the case that characteristics that might serve an important function when fully developed are of no use at all – at least in regard to that purpose - when only semi-developed. However, since nature does not develop in leaps, and developments are not planned, there is in principle no such thing as a "semi-developed" feature. Any existing feature must serve, or must have served, some function in the evolution of the species. The semi-developed feature must originally therefore have had some raison d'être other than the function it now serves in its fully developed form. As we look at the evolution of different capacities in animals, we need to keep a look out for the steppingstones that can tell us how a given capacity or feature, which serves a specific function for the animal in one environment, might become relatively obsolete in a different environment. However, such an obsolete capacity may serve as the starting point for a modification that will allow it to serve a useful new function under the changed circumstances.

When we apply this type of reasoning to sleep in general and REM sleep in particular, we find some of the same questions arising. Sleep (including REM sleep) is a basic yet complex behavioural form common to many animals. There must have been good reasons for its development in the first instance, in order to outweigh the disadvantages of the animal's greatly increased vulnerability

while sleeping. Both sleep as such and REM sleep utilise neurologically very complicated processes, processes in which anatomy and neurochemistry subtly interact in ways that are still not completely understood. This very neurological complexity, and the subtle interplay between many different mechanisms, suggest that sleep has a long evolutionary history, and the different mechanisms involved may therefore have had different purposes at different points in time. There may originally have been one specific reason for sleep to arise. This in turn led to new forms of behaviour in animals that redefined the surrounding environmental conditions and thereby opened up new possibilities. Or it may have been the case that when a particular mode of sleep arose, it turned out to have consequences for other aspects of life that had nothing to do with the original reason for its evolution, but which were then utilised or exploited. Yet another possibility is that the sleep function gave rise to other difficulties for which a solution was then developed.

Evolutionary reasoning takes the form of a disciplined speculation. This discipline is based on a commitment to respect current, observation-based biology: a biology that draws not only on observations of animal behaviour, but on knowledge of the biomechanical structures and processes that are involved in the many different ways of maintaining such behaviour. Then there is a duty to respect what palaeontologists can tell us about prehistoric animals and their subsequent evolution. Last but not least the discipline is built on an adherence to neo-Darwinist principles regarding the way in which genetic material is transmitted from generation to generation through natural selection: principles that are essential in understanding how a given species, and its particular features, evolved.

c. Niels Engelsted's scenario

In his book on "Sleep, Dreams and Depression" from 1977 Niels Engelsted describes the development of REM sleep (which he calls paradoxical sleep) as one of the central functional elements in the evolution of mammals generally. Engelsted conceived of REM sleep as a universal and probably exclusive feature of the mammalian order, which was a reasonable assumption to make on the basis of the facts available in the middle 1970s.

In accordance with established biological thinking, Engelsted believed that there were two fundamental steps in the evolution of modern mammals. The first step was the development of

5

thermostability as the premise for the organism's metabolism. The second step was the evolution of live birth. His scenario ascribes a central role for REM-sleep in both these steps.

The first step towards thermostability occurred when some of the earliest reptiles, the therapsids, started to experiment with a more efficient way of absorbing nourishment, in the process developing a more stable and effective metabolism based on control of their internal body temperature. The first reptiles developed in the Permian Age (approximately 250 million years ago). They developed from the Coal Age amphibians as the climate of the earth became drier and colder, with more distinct changes between the seasons. This colder climate and greater seasonal variation were fundamental to the success of the therapsids and pre-mammals in the Permian Age. Their beginning control over their internal temperature meant that they were less influenced than other creatures by changes in the external temperature. But in the post-Permian ages the earth again became warmer, with less variation between the seasons. This meant that the therapsids lost some of the relative advantages they had gained through their internal temperature control. It was another line of reptiles, the thecodonts and their descendants, the dinosaurs, that came to dominate the environment for the next 150 million years, until their sudden disappearance around 65 million years ago.

Throughout this extraordinarily long period the descendants of the therapsids were able to survive thanks to the eco-niche they gained in the night-time, a period in which the (presumably, at least at the outset) cold blooded and sight-dependent dinosaurs were relatively passive. Night was the period in which the dinosaurs lost the advantage gained by their mobility and their visually-based hunting behaviour. Here the therapsids' descendants came into their own, remaining active during the night.

It was this night-time environment that set the evolutionary parameters for the second step in the evolution of mammals, their reproduction strategy. The relative cool of night provided the conditions for the development of a strategy of reproduction that culminated in live births, mammalian feeding and the extensive socialising of the young. The cool of the night was also prompting the descendants of the therapsids further to develop their senses of smell and hearing and to refine their internal control of temperature while hunting for insects and dinosaur eggs. . When conditions suddenly changed for the dinosaurs, leading to their extinction within a short time, the

scene was set for warm-blooded mammals to re-conquer the daytime and become the dominant species on earth in almost all environments.

The question that remains is why mammals (with their long experience of night-time living) developed the ability to sleep, both in REM and SWS modes - a feature that is almost exclusive to them. . It was during the long period from the beginning of the Triassic age to the extinction of the dinosaurs (from around 200 million to around 65 million years ago) that the central features of the mammalian order developed. During this time there was an evolutionary pressure towards activity during the night and passivity during the day.

I will briefly summarise the scenario Engelsted presents as to how REM sleep may be understood as a central element in these two steps in the evolution of mammals. Engelsted himself calls his scenario a simple working model, arguing that it can be used for "trying out our conceptions in order to discover the consequences of different points of view or different hypotheses as soon as possible in as many aspects as possible." (op.cit., p. 117). The main virtue of the scenario is that it makes an effort to knit different explanations into one coherent line of argument, creating a coherent evolutionary scenario for the development of REM sleep.

Engelsted's starting point is the reptile brain, in which behaviour is steered through a relatively mechanical accumulation of presumably neurochemical signals somewhere in the pons. These signals register the metabolism's need for nourishment. When the quantity of these neurochemical signals exceeds a certain point, i.e., when the drive reservoir is big enough, it allows the release of a neurological signal in the pons, which then mobilises the central nervous system for activity. Engelsted calls this neurological activating mechanism a "pontile go". The pontile go may be released by information from the sensory part of the nervous system, if the organism registers the presence of certain key stimuli. But if the drive reservoir is big enough, it can autonomously initiate a pontile go without the presence of a key stimulus.

A key element in the evolution of mammals, is the development of the limbic system as the central neurological steering system of behaviour. The limbic system steers the activity of the organism through its control of other systems, among them its control of the pontile go. The question then is how this control has developed, and how the limbic system executes this control. The evolution of

7

the limbic system starts when the line of reptiles that evolved into mammals, the therapsids, lost the advantage they had gained through their elementary control of their internal temperature due to changes in the surrounding climate. As we saw earlier, the climate during the Permian age had been cold, with great seasonal variations. During the Triassic Age it turned warmer, with fewer variations between the seasons. The therapsids were then forced out into the colder and darker environment of the night - the ecological niche in which their elementary control of their internal temperature still was an advantage. But as they were obliged to function mainly during the night, the evolutionary pressure on them also changed significantly. It forced an accelerated evolution of thermo-stability and a refinement of it in the form of a permanently high rate of metabolism (with a stable high temperature) and the development of fur. These constitute two of the central features of mammals. But life in this new eco-niche also meant that the sense of smell regained its dominance at the expense of sight. This in turn meant that the overall steering of the organism's activity was developed in mammals from a starting point in the oldest part of the brain - the olfactory brain - where chemo-perceptions had been processed since the beginning of time.

In the olfactory brain the activity of the organism was guided on the basis of what we might call an interpretation of the rather diffuse meaning of all the information gathered on the surrounding environment. This interpretation would prepare the animal for a non-specific type of activity, which would then be executed as a specific, goal-directed activity on the basis of its perception of specific circumstances. The mammals' limbic steering system was thus developed both to reflect general bodily alertness, and to reflect a specific perception of the environment in connection with the goal-directed activity of the organism. This contrasts with earlier guiding systems (e.g. among amphibians and reptiles) which were based on specific key stimuli that released a specific behavioural repertoire, and which functioned solely through the pontile go. Among the mammals it is the limbic system that decides when the pontile go will be released and to what extent, and this is achieved through an inhibition of the system that was based only on the key stimulus. This modification of the pontile go means that, when they are awake, mammals are able to administer the drive reservoir, and thereby also their activity, more flexibly. This flexible administration of drives is based on a coordinated and complex processing of sensory information that takes place in the pallium/cortex and in the limbic system, so that the pontile go is modulated into something specifically appropriate for the organism. Engelsted calls this steering system "a limbic go".

8

When a poikilothermic animal needs to sleep, its sense organs are disconnected, and with them the animal's perception of potential key stimuli which could release the drive reservoir. The animal is asleep. In the poikilothermic animal, this sleep can go on until the metabolism has built up a sufficiently large drive reservoir that the animal is driven to activity independently of the presence of a key stimulus. At the time when mammals were starting to evolve, i.e. around 200 million years ago, this meant that reptiles engaged in long periods of sleep during the night when their body temperature was low and their metabolism had therefore slowed down. It also meant shorter periods of sleep or almost no sleep during the day, when their rate of metabolism was high and visual key stimuli were present all around them. In Engelsted's scenario the development of warm-bloodedness, or thermo-stability, requires that the organism find a way to release the accumulated drives in the drive reservoir without behavioural consequences. Otherwise, the animal would be driven to activity around the clock, because thermo-stability means that the metabolic rate is independent of the temperature in the environment. Engelsted's idea is that this occurred through utilising a mechanism that blocks or disconnects the motor nervous tracts. This is a mechanism which was developed as a protective "go-dead response" among animal offspring when the mother left the nest, it is a mechanism also seen in birds. The development of the limbic system as the overall steering system means that the earlier pontile-based system can be disconnected during wake activity. Sleep shuts off sensory information and hence deprives the animal of the basis for the general arousal of the rudimentary limbic system. When the limbic system becomes passive in sleep as a result of the closing down of sensory information from the environment, the old system gains ascendancy and becomes functional once again. The drive reservoir is automatically filled and will be released when it reaches the critical limit even where there is no key stimulus. But it does not have behavioural consequences, because it has been connected to the "go-dead response". The result of this is REM sleep, where the drive reservoir is released in what can be called a neurological world analogue, and the muscles connected to the motor system are inhibited, and sleep is maintained.

Once this capacity for REM sleep was established, it provided the conditions for the development of the mammalian reproduction strategy. The ability to release the drive reservoir without behavioural consequences is essential in the later part of pregnancy to prevent the foetus from engaging in unprofitable activity throughout the day and night. The specific form of REM sleep among present-

day mammals may have developed precisely in order to serve these functions in the later part of pregnancy.

Engelsted's theory concerning the concrete neurological basis of depression is based on this global model of the way in which the drives are administered in mammals, and on the role that REM sleep serves in this administration. On this basis, Engelsted also made some specific suggestions concerning which nuclei and what kind of neurochemistry are involved in what he calls the depressive response. His suggestions concerning the precise neurological mechanisms of depression seem to accord well both with the empirical facts as we now know them now and with the models that neurophysiologists have developed on the basis of these.

Engelsted's scenario is not sufficiently precise and concrete to serve as a verifiable empirical model, although there did exist a reasonable empirical foundation for parts of the scenario even at the time it was formulated. This empirical foundation has been strongly reinforced over the last five to ten years. Some of the central assumptions that Engelsted made, which seemed dubious at the time and remained dubious over the next two decades, have turned out to be accurate. Most significantly, it has now been proven that REM sleep exists among the monotremes: the results from recent studies of the sleep pattern of platypuses turn out to fit very neatly into Engelsted's theories (cf. Siegel et al., 1997; Siegel, 1999). One of the major flaws in Engelsted's scenario when it was presented, was that the only monotreme whose sleep pattern had been studied was the Australian anteater. They do not have REM-sleep, wherefore most researchers assumed that REM-sleep evolved in connection with the evolution of live births. Siegel's discovery of the extensive REM-sleep in platypus changes this radically. As the platypus is probably the main evolutionary line, and the anteater an evolutionary dead end, see Siegel's discussion concerning this, a key element in Engelsted's scenario is confirmed by the observations of the platypus' sleep pattern. The other important confirmation of Engelsted's assumptions concerns the activation of the limbic system in REM sleep. It was impossible to detect this activation while EEGs were the only means of making online observations of brain activity. Most researchers therefore concluded, on the basis of the EEG data, that it was mainly the cortex that was activated during REM sleep. This notion, however, could not be maintained when the results of modern functional imaging of the brain during REM sleep became common knowledge. Observations both from positron emission tomography (PET) and functional magnetic resonance scanning (FMRI) show that the activation of

the limbic system is a central feature of the activity of the brain in REM sleep (cf. Hobson et al., 2000).

The ability to block all the muscles so that the drive reservoir can be released, and the brain mobilized to activity without this activity having any behavioural consequences is thus the necessary condition for the development of thermo-stability. From this perspective the central neurological mechanism in REM sleep developed as a mechanism of adjustment between the organism's metabolism/biochemistry and its behaviour. The part of the brain that administers the neurological drive reservoir – the reticular system in the brain stem - is mobilised without creating any behavioural consequences. What is mobilised, instead, is what might be termed a neurological analogue as an image of the environment, a neurological response that remains an analogue because the usual connection between the neurological system and the motor control, with its built-in feedbacks to the neurological system from the body, is disconnected.

It is plausible that the development of thermo-stability demands some sort of control over the organism's activities which allows these to be independent of its rate of metabolism. When the animals have been able to adapt to a nocturnal way of life, a central key in this adaptation is that thermo-stability, as we have seen, disconnects the very useful link between the rate of activity and the rate of metabolism that other reptiles have developed, and that determines their pattern of activity during the day and passivity at night. From a psychological perspective, however, the important part of Engelsted's account of the evolution of REM sleep is that those animals that were transformed into mammals as they developed thermo-stability also developed a capacity to execute self-generated neurological responses, responses that can be tentatively described as the creation of drive oriented world-analogues, in order to release a drive reservoir. The development of the capacity to create self-generated neurological responses was an evolutionary necessity, preventing animals from being driven to activity 24 hours a day by a constant rate of metabolism. But this capacity to activate the brain and thereby do a neurological "test run" of the surrounding world could also, once it arose, be used in other ways that might help the organism or the species to survive.

11

d. The brain as a biological computer: Evans & Newman's theory

The second distinct type of explanation for the biological function of REM sleep is based on an understanding of the brain as an information-processing organ. REM sleep may serve a purpose in dealing with the kinds of problems arising by the development of an increasingly complex central nervous system designed for processing information. Theories of this kind are today usually formulated in the language of computer terminology: the basic metaphor involves looking at the brain (and the nervous system) as an information processing system, as an advanced biological computer.

Evans and Newman introduced this perspective on the problem in a short note published in *Science* in 1964. In this note they drew attention to a specific feature of the most advanced computer-based information-processing systems that existed at the time, taking an insurance company's use of an electronic information processing system as their particular example. Such systems typically had a broad interface with the environment they operated in, with many different points of transaction between the system and the outside world. The system had to cope with a concrete, constantly changing world. Thus, its interface with the environment could never be exhaustively described in an algorithm. It was therefore necessary continually to develop small programmes to take care of all kinds of problems, both at specific transaction points and in the system as a whole. After a while, the number of such small programmes and their mutual interaction became a problem. The advantages gained by creating new programmes to cope with new situations were outweighed by the difficulty of defining what the new programmes would do in relation to all the other existing ones. In order to deal with this problem, the insurance company in Evans and Newman's example closed its operations for a weekend. The "on-line" system was put "off-line", so that all its connections with the environment were cut. Then the whole system, including each and every small programme within it, was put through a series of trial runs involving fictitious problems and tasks. The aim of these trial runs was to test whether the new programmes were actually necessary and, if they were, to modify and adjust their relationship to each other and to the basic programmes. In other words, the process involved a general tidying up and updating of the procedures developed since the system was last overhauled. Evans and Newman's idea, then, was that biological information-processing systems, just like their electronic counterparts, must periodically need to go "off-line" in order that new procedures and ad hoc programmes can be adjusted and modified. Advanced biological organisms learn all the time: in other words, new programmes are constantly

being developed in their information-processing systems in order to cope with new tasks. Unless these new programmes are properly adjusted to one another as a matter of course, they will soon start to interact in unproductive ways. Moreover, tidying up the system will save "computer" space. The idea that the brain, just like a computer, needs to tidy up its programmes could – so Evans and Newman suggested - provide the key to understanding the functions of REM sleep and perhaps dreams as such. Since it disconnects both sensory and motor contact with the environment and involves a high level of internally-generated activity in the brain, REM sleep displays precisely the kind of features one would expect to find in an updating procedure within a biological organism.

Various kinds of evidence support Evans and Newman's proposition. Some of the evidence relates to the general notion, shared by many contemporary researchers, that REM sleep serves some kind of maintenance function in the brain, where the brain is understood as an information-processing organ. Some of this evidence also supports Evans and Newman's specific version of this general idea. They suggest that the maintenance function is served by internally-generated "trial balloons". These "trial balloons" are what we experience as dreams, if we wake up while they are running. The content of these dreams must be relevant for testing new "programmes" adopted (i.e. the new forms of behaviour learned) or new experiences relating to existing programmes since the systems last went through a maintenance check.

In the 1960s experimental psychologists came up with evidence to suggest that REM sleep served a function in consolidating experiences in the long-time memory. Evans and Newman treat this evidence as an important supplementary argument in support of their theory. The contemporary evidence in this regard, however, is less clear-cut. There is some evidence, mostly from research in the eighties, that suggest that REM sleep serves a function in integrating existentially important experiences in a person's long-term memory. But most of the contemporary research, based on investigations in the nineties, suggests that it plays no functionally-significant role in memory consolidation as such. However, the issue is still open, both empirically and conceptually, and some of the most recent research seems to support the notion.

The fact that dreams are generally so difficult to remember also fits well with Evans and Newman's theory. Since the system has to go "off-line" in order to update experiences and adjust programmes, dreams must necessarily relate to *fictitious* problems and situations. They are "trial balloons" used

by the system in order to test and adjust new programmes and to find out which of the individual's new experiences and response patterns need to be integrated into the system as permanent adjustments. These mental "trial balloons" must contain fictitious analogues of the world and must relate to the existing notions of the world, in order to constitute a relevant test of programmes developed in relation to events in the real world. However, these mental trial balloons have no value for the organism beyond their function as testing devices, and their content can therefore be forgotten. One possible implication of this reasoning is that any new capacity - any new part of the behavioural repertoire or a more refined image of the world - will become a well-integrated part of the individual's basis for action in the long-time memory only *after* it has been processed in REM sleep: only, in other words, after the new information has been tested to discover what relevance it may have for the system as a whole and how it fits into that system. Considering the prominent role ascribed to it, the evidence for this function is hard to come by, as people may function very well without REM-sleep, e.g. in connection with regular use of certain kinds of drugs.

An attractive aspect of Evans and Newman's notion, nevertheless, is that it makes sense with regard to the phenomenological nature of dreams - both as we know them from our daily experience and in the context of therapy. The curious mixture of strangeness and familiarity that we find in dreams; the fact that they are *invented* pictorial narratives (not just reconstructed memories); their often striking personal significance, their egocentricity, even what Freud called the "residue of the day" that is exhibited in dreams - all these features become understandable if we assume that dreams function as personally relevant "trial balloons" created *each* night in order to adjust and update the neurological basis for the individual's image of himself and the world.

In the two decades that followed Evans and Newman's first airing of this notion, their account of the function served by REM sleep, and the computer metaphor they used to explain it, were treated as little more than an interesting curiosity, both by psychologists interested in dreams and by computer scientists. Over the past twenty years, however, this view has changed radically. The model of the brain as an information-processing organ in a biological organism - a kind of biological computer - has now become the dominant paradigm in modern cognitive psychology and understanding the function of REM sleep and dreams is high on the agenda. This shift is due mainly to a small article that appeared in *Science* in 1983, in which Francis Crick and Graeme Mitchison revived the computer metaphor as a way of looking at REM sleep and dreams. However, Crick and

Mitchison's theory ascribe a different function to dreams. For them dreams are "mental garbage", a residue after a cleaning operation in a brain organised as a PPD-system. One of their arguments for this, is their assertion that dreams mostly is existentially meaningless – and that is a notion that is difficult to maintain, considering the evidence to the contrary, both from therapy and from formalised research.

e. A tentative conclusion: Evolution of REM-sleep and its relevance for the evolution of human consciousness

The idea that through REM-sleep animals have evolved the capacity to produce self-generating analogues of the environment opens up the possibility that the realistic mental representation of the environment that animals create through their senses – their mental representation of what von Uexküll refers to as their "Umwelt" (*explanation of this concept earlier*!) - may also be internally generated. If this is the case, the drive release does not need to have behavioural consequences. Through its mental representations the animal satisfies its drives in its own neurological cyberspace. As Hobson would say, from the neurons' point of view the appetite is satisfied even if the animal doesn't do anything. The fact that Michel Jouvet's cats, whose motor inhibition mechanisms had been surgically removed, acted out their "dreams" during REM sleep, supports the view that animals can produce internally-generated world analogues which they would in principle act on if their motor nerves were not inhibited. Jouvet own theoretical answer - that the function of REM sleep is to stabilise the instinctual behavioural programmes – is seemingly a different explanation from Evans and Newman's. But it does not necessarily contradict Evans' view. Rather, what Jouvet assumes to be the main function of REM sleep can be seen as an example of the more general function that Evans posits: namely, the function of stabilising and adjusting behavioural programmes. Among mammals in general behavioural programs is inherited, they are basically instinctual, but that is not the case for humans. Our dreams might therefore concern our daily concerns in a cultured environment, not a genetically transmitted programs adjusted to an ecological niche.

If we take Engelsted's theory of the origin of REM sleep as our starting point and assume that the warm-blooded reptiles forced into the Triassic night were under massive pressure to develop their senses and behavioural repertoire in a way that would allow them to survive in this new habitat, then we may also assume that they would have needed enhanced information-processing capacities.

15

These animals already had other reasons to let their brains go "off-line" in order to lighten the pressure from their drives in their own biological cyberspace. It is tempting, therefore, to suppose that they would then "discover" that they could make "trial balloons" and thereby adjust and stabilise their world analogue, their mental representation of their "umwelt", and behavioural programmes within this cyberspace. This sets the stage for Evans' and Newman's idea. If we conceive of the brain as an information-processing system, a biological computer, then REM sleep may have taken on the essential function of cleaning, adjusting and updating the programmes associated with this complicated system. According to Evans and Newman, REM serves this function by testing existing images of the self and the world with the help of internally-generated "trial balloons". In other words, relevant fictitious situations are created and responses to these situations tested in a neurological cyberspace that was originally developed to ensure a behaviourally-independent administration of the drives. This function of cleaning and updating the programmes must have evolved *after* the ability to create internally-generated world analogues, since it was this ability that had to be utilised for this new purpose. In the platypus, REM sleep probably has no cognitive function, since the platypus' cortex is not very active in REM sleep. But among other mammals that have live births, the cortex is very active during this form of sleep.

In the sixties, Roffwarg's et al made the very significant observation that REM-sleep was a much more extensive part of sleep among neonates and infants than among adults – they have 50% and more of their sleep in REM. They also reported observation of extensive REM-sleep, up to 80%, in the foetus in late pregnancy. This observation I have not seen confirmed, but it is treated as a solid fact in the literature. The extensive REM-sleep among newly born has turned out to be a general feature of REM-sleep among mammals. These observations suggests an important role for REM-sleep among the new born, and Roffwarg et al's suggestion was that the heightened activity of the brain in REM sleep is a sort of training of the nervous system in its last development, helping the last growth of the nervous system and its myelinisation to take place quicker. This explanation does, however, not contradict Evans' and Jouvet's accounts of the functions of REM sleep but might be seen as a supplement to theirs. That REM sleep, as a device for testing instinctual programmes during the important process of completing the nervous system and establishing all its crucial functions, involves activity that stimulates the growth of the system, seems like a good idea. To have a mechanism that both controls the functioning of the software and simultaneously stimulates the growth of the hardware would appear to be very useful in a biological computer.

The next part of our scenario is connected to the evolution of the limbic system as the overriding control system governing the behaviour of mammals. The limbic system carries out this control through the affective arousal of the animal. Affective arousal modulates and overrides the inherited control of the behaviour through the key- stimuli's control of the animal's instinctual programs. Limbic control involves sorting out the sensory impressions that the organism receives in a new way, treating them as *information* rather than as signals. In order to function, limbic control requires an affect-laden neurological image of the world: a different kind of *umwelt* than that which is organised purely around key stimuli. The development of the limbic system thus meant that the animal had to be able to process sensory impressions in such a way as to extract their maximum value as sources of information – as contributions to their affect-laden *umwelt* - rather than merely react to them as signals. It also meant that the animal's inherited *umwelt* had to be adjusted to its individual history and experiences – which in turn presupposed the capacity for long-term memory. Long-term memory is a feature unique to mammals, which are the only animals to possess the specific neurons capable of maintaining long-term potential (LTP) (Eccles 1989). This capacity, at least in humans, is controlled by the limbic system, which determines which aspects of the information received by the senses should be transferred to the long-term memory. According to our scenario, the evolution of the limbic system, the affective control of behaviour, and the capacity for long-term memory, based on possessing neurons with LTP, all represent responses to the evolutionary pressure involved in the reproductive strategy of mammals. These neurological features and the cognitive capacities they made possible evolved in response to the mother's need to recognise her offspring - and the specific needs of her offspring – independent of key stimuli. This capacity must have played an essential role in the mother's ability to nurse and socialise her offspring – and this a central feature in the evolution of mammalian reproduction, as it is exhibited e.g. in the extensive socialisation of the platypus' offspring.

REM sleep may have gained an extra function in connection with the evolution of the specific neurons/neurochemistry that provide the material basis for the development of long-term memory. The mental activity that occurs during REM sleep as the brain processes the animal's *umwelt* may have served to accelerate the "fixing" of specific long-term memories. Indeed, the process may have occurred the other way around: perhaps the development of LTP - the particular neurochemistry that formed the foundation of long-term memory - was merely a fringe benefit of the development

17

of REM sleep, which stimulated the neurons for other reasons. Thus, the species/organism may have "discovered" the neurochemical potential inherent in LTP in connection with the evolution of REM sleep - "discovered", in other words, the potential for long-term memory. This is, however, speculation. The basic fact is that whatever the reason for its evolution, the evolutionary pay-off from long-term memory once it was established must have come pretty fast, and subsequently have led to the enlargement of the brain through the growth of the cortex.

The evolution of the cortex resulted from the establishment of a strong connection between the thalamus - the centre for the coordination of the external senses, especially vision - and the limbic system. The cortex evolved from the group of cells that transmit information from the thalamus to the limbic system. This connection between the thalamus and the limbic system is one of the factors that enabled the latter to gain overall control of the organism's behavioural responses. As Engelsted formulates it: "The function of the cortex is primarily to give the limbic system computer space in its control of the relationship between the organism and the environment." With the development of language, Engelsted argues, this limbic control of the behavioural system was at least partly renounced in favour of the cortex.

This - in some cases speculative - account of the way in which REM sleep evolved, and the various functions it may have assumed during the long evolution of the mammalian order, sets the terms for the discussion of the psychological functions of REM sleep and dreams. In the scenario I have outlined, REM sleep is seen as a biological capacity that may have served a number of different functions in the course of mammalian evolution. The key point in this scenario, however, is that brain activity in REM sleep creates an internally-generated analogue of the world without prompting any behavioural response. The activation of the brain in REM sleep creates a form of "neurological cyberspace". Mammals, or their close forerunners, developed this internally-generated analogue of the world in order to solve problems associated with the evolution of thermostability, but the capacity to form such analogues may also have served certain cognitive functions in connection with the evolution of the complex behavioural programmes that had to be developed as part of the reproductive strategy of mammals. In turn, this reproductive strategy constituted an evolutionary pressure, prompting the development of the limbic system as the overall neurological control system. I have also speculated that REM sleep may have had a role to play in

the "evolutionary discovery" of the possibilities inherent in LTP nerve cells: the neurochemical prerequisite for experience-based long-term memory.

By utilising this pre-existing neurological cyberspace to assess the emotional meaning of concrete experiences, REM sleep may have taken on additional cognitive functions, such as that of assessing and updating the animal's *umwelt*. Evans and Newman suggest that this assessment occurs through the launching of "trial balloons" – what we experience as dreams - to test the affective meaning of specific experiences in neurological cyberspace.

Last but not least, the capacity for REM sleep solves several problems associated with the evolution of live birth: in particular what Engelsted has dubbed "the synchronicity problem" between mother and foetus. REM mechanisms allow the foetus to receive internal biochemical stimulation from the mother without this resulting in any behavioural consequences. Equally important, however, is the stimulation of the nervous system as such that occurs during REM sleep. This stimulation would appear to play an essential role in completing the physical growth of the nervous system. The resulting acceleration of neurological growth may be essential in allowing foetuses with complex nervous systems to develop in the womb without stretching out the pregnancy too long.

Nevertheless, the key function remains the capacity to produce internally-generated world analogues that allow the organism to process a mental representation of needs without this entailing behavioural consequences. In this respect REM sleep must have been associated from the outset with dreaming – even though the nature and function of dreams has obviously changed in the course of the evolution of modern mammals, including ourselves, *homo sapiens sapiens*.

The scenario I have outlined concerning the role of REM sleep in natural history relates to this form of sleep as a general feature of mammals. Some of the functions attributed to it are psychological functions in the sense that they are concerned with the contribution of REM sleep to the animal's mentality and to its mental representation of the world. In evolutionary terms, these psychological functions – the animal's capacity to process information and its mental representation of the world - are seen as features of the species as such. But when it comes to human beings, this no longer applies. Although humans share some of their evolutionary history and genetic equipment with other mammals, our mentalities and our ability to process information and represent the world are to

a great extent the product of the particular cultures we grow up in and belong to. This sets us apart from all other species. Thus, it is important in understanding the evolution of humans as a species to determine when, and on what biological foundation, this capacity to produce culture evolved. Over the years, different branches of knowledge have come up with various answers, or partial answers, to these questions. The main contributions have come from palaeoanthropology on the one hand, and on the other from cognitive neuroscience – the fruitful alliance between information theory and neurophysiology. But philosophers, biologists and psychologists have also contributed theoretical interpretations of the empirical knowledge produced by these branches of science over the past few decades.

Despite numerous disagreements among these interpreters there is nevertheless a general consensus that the development of syntactic language marks *the* decisive fault line between natural and cultural history. Modern human beings - *homo sapiens sapiens* - are the only species to have developed this sophisticated form of language – a form that is universal among us: no tribe of human beings known to us does *not* have a syntactic language. The existence of language, and of cultural history as a product of language, has meant that genetic information no longer has to evolve in order for humans to develop new behaviour patterns, ways of life and mentalities. As far as we can judge from the evidence available, humans as a species have not changed in any important biological respect in the last 50,000 years. Indeed, this is probably an underestimate: most scientists believe that the human species has remained genetically unchanged since modern humans evolved between 100,000 and 200,000 years ago. 50,000 years is the smallest time span anyone - to my knowledge - has suggested for the existence of biologically modern humans (Jensen 1999). A summary of what we now know about human evolution is given in the appendix.

At the same time, our way of life as humans, our mentality, and our capacity for processing information, have changed radically since the first modern humans entered the scene. Contemporary humans exhibit enormous variation in all the features that a behavioural biologist would mention if he were describing another species. First and foremost, there are huge variations among different human societies. But there are also great differences, in terms of biologically significant aspects of behaviour, among individuals within the same society: for example, in the kinds of food they eat, the kinds of strategies they use to obtain it, their lifespans, the mating rituals they display and the way they care for their young. The very strangeness of using these terms from behavioural biology

to describe human behaviour indicates that the variations we find among humans are different in nature, and arise for different reasons, than the kinds of variation we find among other species. As the biologist Jesper Hoffmeyer puts it: "the difference between the speaking Homo sapiens and Homo erectus might not have been very much bigger than the difference between the older stone-age people and contemporary people" (Hoffmeyer 1993: 152).

From the point of view of psychology, the most significant function of REM sleep among mammals is the ability to generate internally a mental representation of the environment without this having any behavioural consequences. According to the evolutionary scenario we have outlined, this ability developed in order to solve a problem in the administration of drives that the forerunners of mammals were confronted with in their development of thermostability. According to our scenario, this ability to create an internal cyberspace later came to serve other functions, among which, as Evans have suggested, the psychologically most important was the to stabilise, clean and up-date neurological programmes relating to behavioural responses and images of the world. This presupposed the ability to generate fictitious scenarios of the world that were nevertheless relevant to the individual's real experience, and, with the help of these scenarios, to test and stabilise the pictures that the individual had developed of himself and the world. My assumption is that the need to stabilise, clean and update neurological programmes became of prime importance in connection with the transition from the simple control of drives by key stimuli to the organism's affect-based control of behaviour. In the evolution of mammals, this transition was connected with the development of the limbic system and the first step in the reproduction strategy of mammals, namely their protracted nurturing of their young. This process of stabilising and updating programmes may have acquired a stronger role in connection with the development of long-term memory, which allowed learned capacities and accumulated experiences, as opposed to inherited programmes, to play a greater part than hitherto in determining behaviour. Regulating the respective roles of learned and inherited capacities must have posed a constant challenge to the species from then on, a challenge the trial-balloons of REM-sleep have helped the animals in coping with. The important question from the point of view of human psychology is what happened to this ability to generate fictional mental representations of the world when, as happened with human beings, culture and language took the lead in allowing the species to develop new capacities and adjust to different external circumstances. Human languages and the culturally transmitted communities that humans have developed came at a certain point to play a substantial role in

creating and shaping human beings' mental representation of the *Umwelt* - a task carried out in other species through their inherited dispositions. The function that REM sleep served in automatically cleaning and updating the programmes used in interpreting the world might still prove useful in such a species. But this automatic updating process would have to become subordinate to the cultural shaping, and the individual's reflections on the meaning and relevance of events, that became possible through their ability linguistically to represent the world. Thus, the updating function of REM sleep must have been carried out under radically different conditions once this linguistic representation of the world became the supreme mechanism in controlling the individual's behaviour.

It appears that the updating function of REM-sleep has remained an essentially non-linguistic process: the fictitious scenarios that serve as "test balloons" are mainly expressed in images rather than sentences. As humans developed their ability to represent the world linguistically, and the consciousness that goes with this ability, REM may have taken on a more specialised role in modifying the way in which the affective schemes that represent responses to specific key stimuli were controlled. This control of affective schemes presupposes that syntactical language is responsible for forming the image of the world on which the individual's actions are based. The possibility for reflection and afterthought can adjust any spontaneous disposition to action.

But the development of a mentality based primarily on syntactical language may also have modified the function of REM sleep. The imaginary narratives that typify human dreams during REM sleep appear to thematise existentially meaningful relationships. The narrative aspect of these dreams also suggests that the language-oriented mentality of humans may have modified the way in which the updating function of REM sleep is carried out. Narrativity involves structuring the image of the environment, the "umwelt", in time, in the form of histories. The capacity to see the world in terms of meaningful histories is unique to human beings.

If we shift the focus a little and ask whether REM sleep, and the functions that REM sleep has assumed, may have played any role in the evolution of the key features of *Homo sapiens*, some tentative, affirmative answers might be formulated. The ability that distinguishes human beings above all from other animals is that of maintaining social, culture-producing communities through the use of syntactic language. Did the ability to create what we have called a neurological

cyberspace play a role in developing this capacity, along with the ability to represent the world in language? Syntactic language presupposes the ability to disconnect one's mental representation of the world from the immediate perception. It also opens up the possibility of freely reflecting on, fantasising about, and manipulating these new forms of mental representation before adopting them as the basis for action. The ability internally to generate a mental representation of the world was probably a necessary condition for this capacity to "disconnect" the mental representations from the immediate perception. Viewed in this light, syntactic language and human consciousness can be seen to have evolved from a very ancient feature of mammals. The evolutionary "trick" consisted in disconnecting the motor inhibition of REM-sleep from its ability create a neurological cyberspace, and then use the ability to create independent images of the world as a tool for sharing an *umwelt* within a social community. This sharing, as the Canadian psychologist Merlin Donald has suggested (Donald 1991), may in the first instance have occurred through a form of mimicry designed to heighten social coordination, or, as Harry Jerrison has suggested (Jerrison 1979), through the development of auditory/oral signals to identify certain features of a hunting territory to other members of the band among socially organised predators. According to both Donald and Jerrison, it is the ability to communicate to a social community - through standardised bodily or oral gestures - mental images relating, for example, to the concrete features of a landscape that constitutes the first decisive evolutionary step on the road to syntactic language. Donald and Jerrison contrast this form of language, aimed at coordinating activity within a social community, with the proto-languages found in apes and other social mammals, who use bodily or oral gestures to express an immediate mental attitude. Later on, as they evolved from mimicry to spoken, and subsequently written language, human forms of expression would gradually become more flexible and more useful. But from the point of view of cognitive psychology these developments were probably less decisive than the initial step of communicating, in a standardised way, one's own mental representation, and thereby sharing knowledge of a shared world within a social community.