

Sleep, rhythms, and school routines

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Executive summary

Our sleep rhythm is only one of the many rhythms our body and our brain have. It is called a circadian rhythm because it cycles every 24 hours for the whole of our lives. How does the brain achieve this? First of all, there are neuronal clocks in some brain regions, in charge of synchronizing the brain's activity with the light-dark cycle of nature. Secondly, the whole brain undergoes a daily transition from wakefulness to deep sleep, through various stages that include one particularly devoted to dreaming. Sleep is not only a way for our body and our brain to recover from daily activities, but also a period when some memories are selected to be forgotten, others to be stored. Sleep provides an opportunity to consolidate learning and should be taken into account when planning pupils' activities at home and at school.

Brain rhythms and body rhythms

There are things in life that we do religiously almost every day: eat, drink, go to the bathroom, sleep. For the first three, it is easy to find a biological reason. But for every night's sleep, what is the explanation? Why do we have to spend one third of each day (one third of our lives!) sleeping? If you think it is to provide rest from daily activities, you are only partially right: People do not sleep much more than they normally do when they are physically tired and, besides, they can rest without having to sleep. And people who are not tired sleep as much as those who are tired. So, again, what is the explanation? We will approach this issue mindful of its possible impact on education, inquiring how we can take advantage of sleep to improve learning.

Sleep is cyclic: It is one of the biological rhythms. That is, every 24 hours human beings sleep at least once. Not only does the act of sleeping repeat itself every day, there are daily cycles of motor activities and motor rest, sensory perception, secretion of some hormones, body temperature, and various other physiological and psychological phenomena. These rhythms that repeat every day are called circadian. But not all rhythms of life are circadian, some repeat with a longer cycle (e.g., once every month), and others have a shorter cycle (e.g., four times a day, or more). Examples of monthly rhythms are women's menstrual cycle and ovulation, and examples of short cycle rhythms include heart beats and respiratory movements. Even sleep itself has, within it, a number of cycles that repeat many times during one night (see Figure 1).

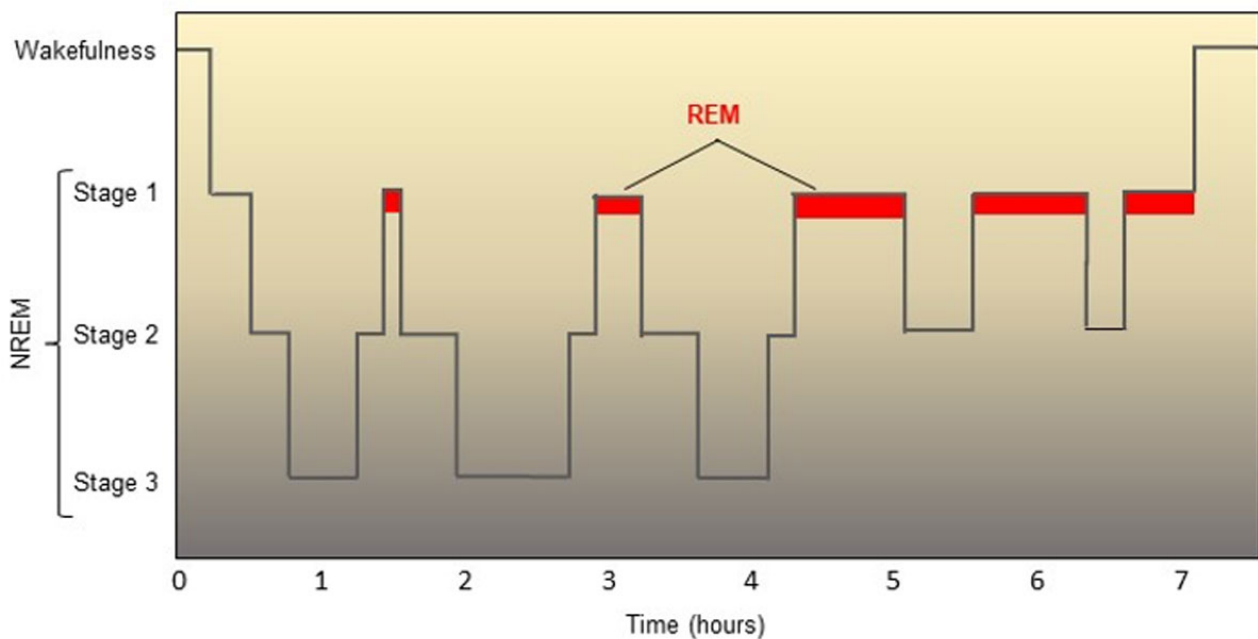


Figure 1. Every night we undergo different stages in our sleep, from wakefulness to deep sleep (Stage 3) and back a number of times. During some stages the sleeper experiences vivid dreams and rapid eye movements (REM, in red), while during other stages these phenomena are much less frequent (NREM).

Since biological rhythms are universal (even plants have them), the question is: Which factors determine them? The first possibility is that they are triggered by the cycles of nature around us. But this has not proven entirely true, since individual rhythms often persist in situations isolated from natural cycles, such when we experience extended darkness and artificial light at night, as in laboratory experiments^[1], polar regions^[2], and large cities^[3]. So, scientists have become convinced that

there are intrinsic biological clocks in our bodies and our brains that work to synchronize our rhythms with the natural cycles, especially circadian ones.

Our main biological clock is a pair of small clusters of neurons situated at the base of the brain, close to the optic nerves, called the *suprachiasmatic nuclei*. Being so close to the optic nerves, they receive fibers from both eyes, coming from retinal neurons that are sensitive to the general luminosity outside. These retinal neurons inform the suprachiasmatic nuclei about the degree of light or darkness prevalent in the environment. The neurons of the nuclei, on the other hand, have a very important property: They fire electrical impulses automatically in a cyclic manner. They are the components of our biological clock⁽⁴⁾, and synchronize their automatic firing frequency with the amount of light informed by the retinal fibers that end on them: the stronger the outside light level becomes, the faster they fire nerve impulses.

The output of these neurons is sent to other places in the brain, where sleep is regulated, together with motor activities, hormonal levels, metabolic reactions, and behavior. Some of these fibers project to a number of neuronal centers in the brain stem that control the excitability of the cerebral cortex, reducing it when it is time to go to sleep (usually at night), and returning it to a higher level when it is time to wake up and start daily activities. Other fibers from the suprachiasmatic clock project to nuclei that control hormonal levels and to others that make part of the autonomic nervous system, a set of neurons in charge of regulating the function of our digestive and circulatory systems, among others.

The result of the activity of clock neurons in the brain is to produce a slowdown of brain excitability and of body activities, making our sleep of every night possible and usually inevitable.

The biological nature of sleep and the mysterious meanings of dreams

Each one of us has his/her own particular ritual prior to sleep. Some drink water, others eat a sweet, many brush their teeth. After laying down in bed, however, all human beings go through the same stages between wakefulness and sleep (see Figure 1): The body becomes more and more relaxed, eyelids tend to close, perception of the environment becomes dizzy, and the external world is "turned off." None of these effects are permanent, as we know. After some hours, the cycle resumes.

The phenomena that occur during sleep and during the transitions between wakefulness and sleep, and vice versa, can be studied by scientists either through behavioral observations or through using devices that record heart and respiratory frequencies, muscle tone, body temperature, eye movements, and, above all, the activity of different areas of the brain. In this latter case, scientists use a technique called electroencephalography (EEG).

Taken together, these measurements indicate that heart and respiratory rates slow down during the transition to sleep, and with them blood pressure also drops somewhat. Gastrointestinal motility (movements in the gut) becomes reduced, body temperature drops one or two degrees, and the general result is a reduction of metabolic activity in most organs and tissues. In parallel, EEG shows great alterations of brain activity. During wakefulness, the brain produces a low-voltage, high-frequency, fast-wave rhythm, that is gradually replaced by a high-voltage, low-frequency, slow-wave rhythm (see Figure 2, yellow column). This transition from fast to slow rhythms in the brain—from wakefulness to sleep—is known as *synchronization*, because it suggests the simultaneous activity of neurons.

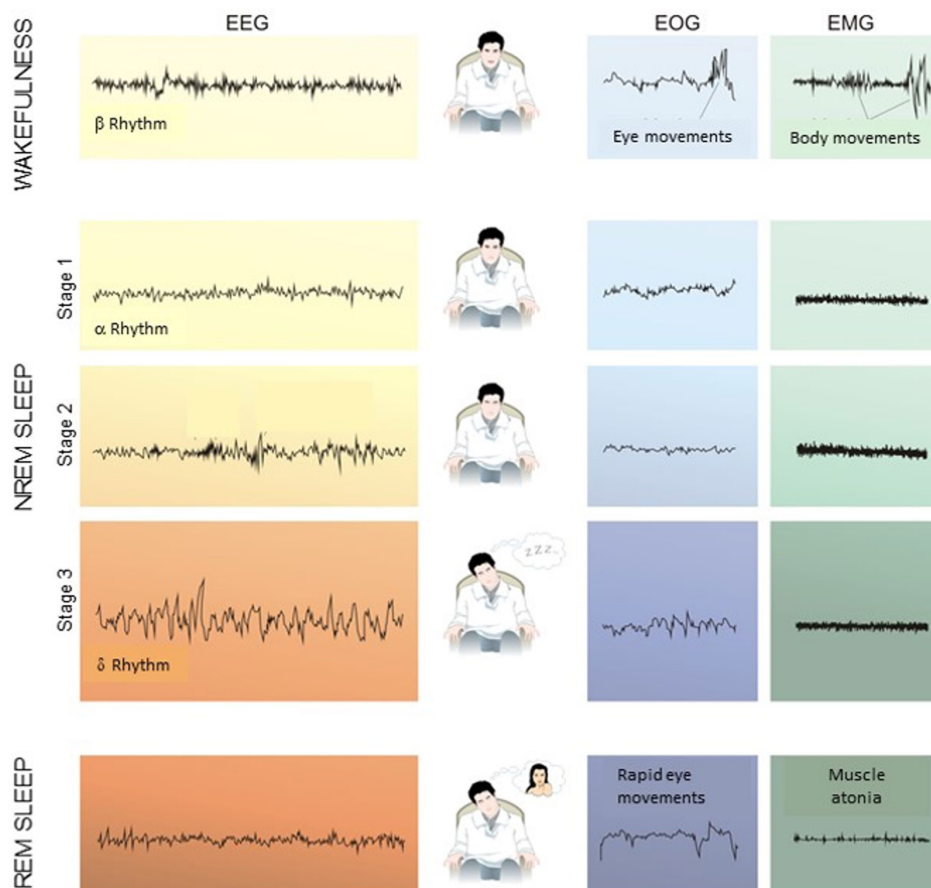


Figure 2. Brain activity during the transition from wakefulness to sleep can be observed using EEG recording, as well as by eye movements recorded by the electrooculogram (EOG), and by muscle movements detected by the electromyogram (EMG). Sleep stages can also be identified. Modified from Lent (2010) *One Hundred Billion Neurons?*¹⁶ (illustration by Simone Mendes).

At the same time, the endless eye movements of wakefulness are reduced (see Figure 2, blue column), and body movements cease to be measurable (see Figure 2, green column). During typical sleep, this gradual deceleration is, all of a sudden, substituted by episodes of rapid eye movements (REM), a return of the EEG to a “wakeful” pattern and, paradoxically, an almost complete paralysis (muscle atonia). This double pattern of sleep has come to be known as REM sleep and its opposite non-REM (NREM) sleep. The interesting thing about these two types of sleep is that if you wake up someone during REM sleep, he/she will report vivid dreams, while if you do the same during NREM sleep, reported dreams will be rarer.

Dreams are very difficult to study scientifically^[5] because any approach will depend on a verbal report by the dreamer, that is, vulnerable to influence by emotion, reasoning, and memory ability. Scientists have tried to interfere with sleep in an attempt to influence the content of dreams, but these attempts have been unsuccessful. For example, depriving someone of water during the 24 hours before sleep does not mean that the person will feel thirsty during his/her dreams. Scientists have also tried to anticipate the content of dreams based on what happened during the previous day, or even during sleep itself. However, no reliable relation between what you experience during the day and what you dream at night can be established. Also, horizontal, to-and-fro direction of the rapid eye movements during REM does not mean that you are dreaming about a tennis game. Genital erections during sleep have no relation, necessarily, with any kind of sexual content in dreams.

There is no doubt that the content of our dreams is taken from our own lived experience. This content, however, is fragmentary and distorted in a way that is apparently illogical. The meaning that can be attributed to dreams, as a channel for the emergence of unconscious feelings, perceptions, and thoughts is still, to neuroscientists, a matter for speculation and hot debate^[7]. The mystery persists.

Why sleeping is good for learning

One aspect of the scientific understanding of the nature and significance of sleep that has undergone a major advance concerns its importance for memory, and, therefore, for learning. Scientists have approached this issue both by using animal models (see Figure 3) to unravel how the mechanisms of memory are affected by sleep, and by studying people who undergo, for different reasons, sleep deprivation.

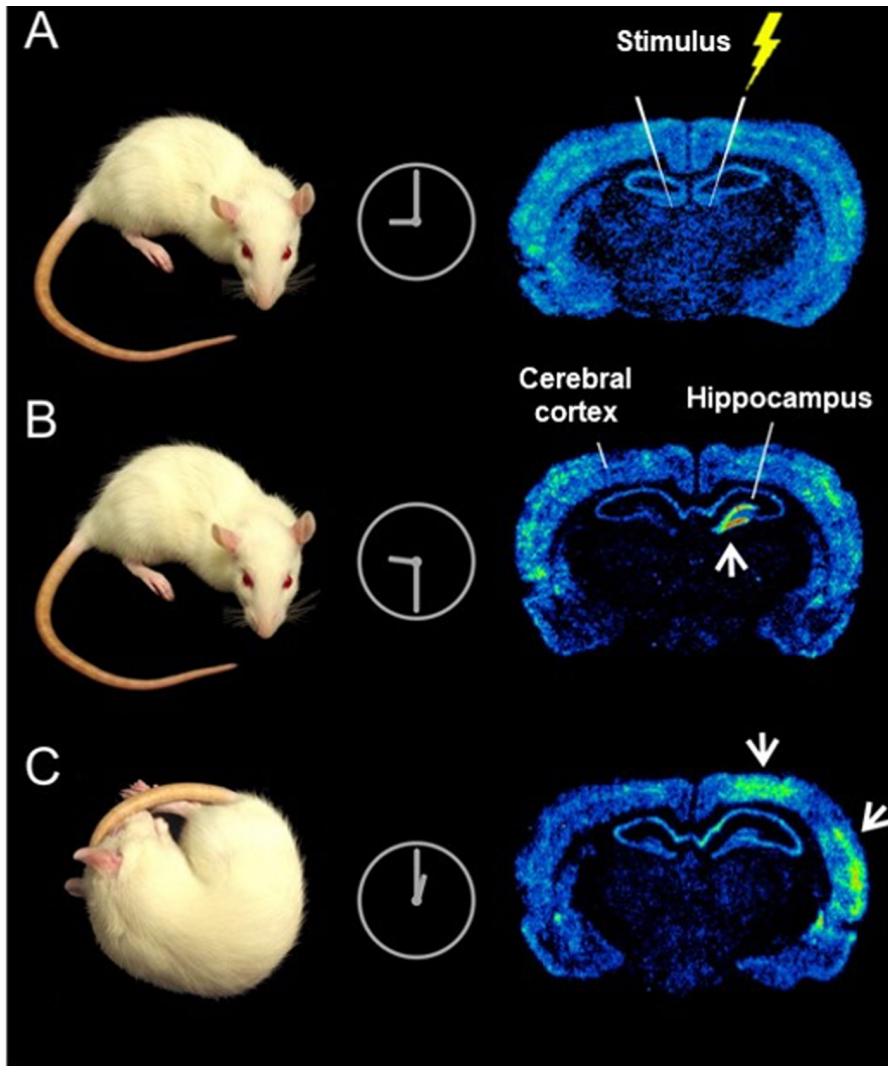


Figure 3. (A) A waking animal receives an electrical stimulation in the hippocampus. (B) Half an hour later, immediate early genes start synthesizing proteins therein, detected in the experiment. (C) Some hours later, when the animal is asleep, gene expression is transferred to the cerebral cortex. Experiment done by S. Ribeiro and collaborators^[9]. Modified from Lent^[5].

Animal work has shown that, during sleep, a number of changes in synapse morphology, synaptic transmission, and neuronal biochemistry take place in the brain. The center of attention has been the *hippocampus*^[8], a region of the brain in charge of receiving external information that includes potential traces of memory, selecting them by their importance, and addressing some to other regions that store them transiently or permanently. For instance, if a mild, high-frequency electric shock is delivered to the hippocampus of waking rats to produce a synaptic phenomenon related to memory, known as *long-term potentiation*, hippocampal neurons activate some particular genes called immediate early genes^[9] (see Figure 3). The animal goes to sleep, and after a good period of REM sleep, researchers showed that the same immediate early genes start to be expressed in the cerebral cortex. The interpretation was that the "information" contained in the electrical stimulation, whatever it means for the animal, is sent by the hippocampus to the cortex, where it is stored for longer times.

The great number of studies designed to reveal the neural mechanisms involved in memory indicates that memory is based on the remodeling of synapses and synaptic transmission. Synapses are the sites of communication between neurons, and synaptic transmission is the process by which nerve impulses from one neuron produce, modulate, or block other nerve impulses in a second neuron across the synapse. So, the synapse is a crucial site for memory acquisition and storage, and the

strengthening or weakening of its efficiency is at the core of memory and learning processes. As shown by the example above, sleep is highly influential on remodeling synapses and synaptic transmission to allow some information to be lost (forgotten), and others to be preserved (learned). Relevant information is therefore selected to be stored, while that which is irrelevant becomes discarded.

In humans, much has been discovered about the importance of sleep by observing the consequences of sleep deprivation. Our own experience is enough to convince us how important it is to have a good period of sleep every night. During early childhood, deprivation of naps may cause changes in the expression of emotions, strategies of self-regulation, and memory performance^[10]. Preadolescent children are also susceptible to sleep deprivation: one hour less of sleep during three days is enough to reduce attention and behavioral performance^[11]. The same applies to adolescents^[12]. So, neuroscientists are convinced that sleep is not simply a way to restore physical energy. Rather, it is a strong way of selecting and storing memory, and therefore a resource of utmost importance for learning.

Sleep rhythms and school routines

Direct evidence for the beneficial effect of sleep on children's performance at school has recently been obtained by a group of neuroscientists and psychologists performing a naturalistic experiment in Brazil^[13]. They worked with 24 children of about 10 years old attending the 5th grade at a state school. The experiment lasted for six weeks. Each Monday and Tuesday, children had a regular lecture on science or history and, after class, half of them had a nap supervised by their teachers. Sleeping for these children was not a problem, because they had to wake up at 5:00 a.m. to be able to start at school at 7:00 a.m. The other half of the children had other classes with no nap. On Friday, both groups were assessed for the content they had previously been taught. Results were robust: The "nap group" performed much better than the "no-nap group," revealing directly how important for learning sleep may be.

The above experiment teaches us other things besides advocating the use of post-learning naps to consolidate learning. One important issue concerns the importance of individual *chronotypes*^[14] to plan school routines. This term makes reference to the natural preference of human individuals concerning their sleep habits^[15]. Some people prefer to wake up early in the morning and go to bed early as well ("larks," as sleep researchers like to call them), while most individuals have the opposite preference ("owls"). Since this feature is influenced by genetic factors and is relatively stable throughout life, it means that a better academic result will be achieved for the majority of children—larks and owls—if school activities started later, perhaps around 9:00 a.m. each day. Although chronotype remains unchanged throughout life, sleep habits are strongly influenced by social constraints, and this is reflected very strongly after adolescence, when a phase delay takes place and pushes the sleep-wake cycle toward later times. Also, factors such as night activities and access to television and smartphones tend to accentuate these changes.

Taken together, the evidence offered by neuroscience may underpin at least two important suggestions to better organize school routines. First, during childhood, children should be given the opportunity to take a nap after lunch, at least until they are 6 years old, with an appropriate space provided for that. Of course, those who prefer to stay awake will have to be given the option to do so. This would require an interval of no more than one hour. Secondly, the start of morning activities, which is usually very early in the morning, should be displaced a little to around 9:00 a.m., to meet the needs of children with both prevalent chronotypes.

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[1] Parts of this text were based on my book *Cem Bilhões de Neurônios? Conceitos Fundamentais de Neurociência* (One Hundred Billion Neurons? Fundamental Concepts of Neuroscience, 765 pp., 2^[nd] ed.), published in 2010 by Editora Atheneu, Rio de Janeiro, Brazil.