Sleep mechanics

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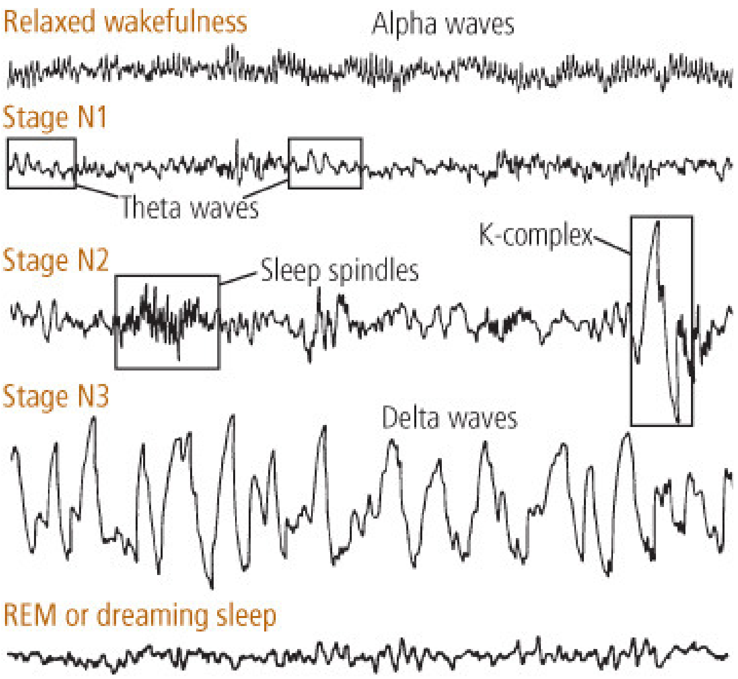
In-Depth Report

For centuries, scientists scrutinized minute aspects of human activity, but showed little interest in the time that people spent in sleep. Sleep seemed inaccessible to medical probing and was perceived as an unvarying period of inactivity — a subject best suited to poets and dream interpreters who could conjure meaning out of the void. All that changed in the 1930s, when scientists learned to place sensitive electrodes on the scalp and record the signals produced by electrical activity in the brain. These brain waves can be seen on an electroencephalogram, or EEG (see Figure 1), which today is captured on a computer screen. Since then, researchers gradually came to appreciate that sleep is a highly complex activity. Using electrodes to monitor sleepers' eye movements, muscle tone, and brain wave patterns, they identified several discrete stages of sleep. And today, researchers continue to learn how certain stages of sleep help to maintain health, growth, and functioning.

Scientists divide sleep into two major types: rapid eye movement (REM) sleep or dreaming sleep, and non-REM or quiet sleep. Surprisingly, they are as different from one another as sleeping is from waking.

Figure 1: EEG brain wave patterns during sleep



These brain waves, taken by electroencephalogram, are used by sleep experts to identify the stages of sleep. Close your eyes and your brain waves will look like the first band, "relaxed wakefulness." Theta waves indicate Stage N1 sleep. (The "N" designates non-REM sleep.) Stage N2 sleep shows brief bursts of activity as sleep spindles and K-complex waves. Deep sleep is represented by large, slow delta waves (Stage N3).

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Quiet sleep

Sleep specialists have called non-REM or quiet sleep "an idling brain in a movable body." During this phase, thinking and most physiological activities slow down, but movement can still occur, and a person often shifts position while sinking into progressively deeper stages of sleep.

To an extent, the convention of describing people "dropping" into sleep actually parallels changes in brain wave patterns at the onset of non-REM sleep. When you are awake, billions of brain cells receive and analyze sensory information, coordinate behavior, and maintain bodily functions by sending electrical impulses to one another. If you're fully awake, the EEG will record a messy, irregular scribble of activity. Once your eyes are closed and your nerve cells no longer receive visual input, brain waves settle into a steady and rhythmic pattern of about 10 cycles per second. This is the alpha-wave pattern, characteristic of calm, relaxed wakefulness.

The transition to quiet sleep is a quick one that might be likened to flipping a switch — that is, you are either awake (switch on) or asleep (switch off), according to research. Some brain centers and pathways stimulate the entire brain to wakefulness; others promote falling asleep. One chemical, hypocretin, seems to play an important role in regulating when the flip between states occurs and keeping you in the new state. Interestingly, people with narcolepsy often lack hypocretin, and they consequently flip back and forth between sleep and wakefulness frequently.

Snoozing News

While the average American adult spends about 7.5 hours a day sleeping, cats snooze about 15 hours a day. Horses sleep 3 hours a day, and bats log 20 hours.

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Three stages of quiet sleep

Unless something disturbs the process, you will soon proceed smoothly through the three stages of quiet sleep.

Stage N1. In making the transition from wakefulness into light sleep, you spend about five minutes in Stage N1 sleep. On the EEG, the predominant brain waves slow to four to seven cycles per second, a pattern called theta waves. Body temperature begins to drop, muscles relax, and eyes often move slowly from side to side. People in Stage N1 sleep lose awareness of their surroundings, but they are easily jarred awake. However, not everyone experiences Stage N1 sleep in the same way: If awakened, one person might recall being drowsy, while another might describe having been asleep.

Stage N2. This first stage of true sleep lasts 10 to 25 minutes. Your eyes are still, and your heart rate and breathing are slower than when awake. Your brain's electrical activity is irregular. Large, slow waves intermingle with brief bursts of activity called sleep spindles, when brain waves speed up for roughly half a second or longer. About every two minutes, EEG tracings show a pattern called a K-complex, which scientists think represents a sort of built-in vigilance system that keeps you poised to awaken if necessary. K-complexes can also be provoked by certain sounds or other external or internal stimuli. Whisper someone's name during Stage N2 sleep, and a K-complex will appear on the EEG. You spend about half the night in Stage N2 sleep, which leaves you moderately refreshed.

Stage N3. Eventually, large slow brain waves called delta waves become a major feature on the EEG. This is Stage N3, known as deep sleep or slow-wave sleep. During this stage, breathing becomes more regular. Blood pressure falls, and pulse rate slows to about 20% to 30% below the waking rate. The brain becomes less responsive to external stimuli, making it difficult to wake the sleeper.

Slow-wave sleep seems to be a time for your body to renew and repair itself. Blood flow is directed less toward your brain, which cools measurably. At the beginning of this stage, the pituitary gland releases a pulse of growth hormone that stimulates tissue growth and muscle repair. Researchers have also detected increased blood levels of substances that activate your immune system, raising the possibility that slow-wave sleep helps the body defend itself against infection. Normally, young people spend about 20% of their sleep time in stretches of slow-wave sleep lasting up to half an hour, but slow-wave sleep is nearly absent in most people over age 65 (see "The later years"). Someone whose slow-wave sleep is restricted will wake up feeling unrefreshed, no matter how long he or she has been in bed. When a sleep-deprived person gets some sleep, he or she will pass quickly through the lighter sleep stages into the deeper stages and spend a greater proportion of sleep time there, suggesting that slow-wave sleep fills an essential need.

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Dreaming (REM) sleep

Dreaming occurs during REM sleep, which has been described as an "active brain in a paralyzed body." Your brain races, thinking and dreaming, as your eyes dart back and forth rapidly behind closed lids. Your body temperature rises. Your blood pressure increases, and your heart rate and breathing speed up to daytime levels. The sympathetic nervous system, which creates the fight-or-flight response, is twice as active as when you're awake. Despite all this activity, your body hardly moves, except for intermittent twitches; muscles not needed for breathing or eye movement are quiet.

Just as slow-wave sleep restores your body, scientists believe that REM or dreaming sleep restores your mind, perhaps in part by helping clear out irrelevant information. Studies of students' ability to solve a complex puzzle involving abstract shapes suggest the brain processes information overnight; students who got a good night's sleep after seeing the puzzle fared much better than those asked to solve the puzzle immediately. Earlier studies found that REM sleep facilitates learning and memory. People tested to measure how well they had learned a new task improved their scores after a night's sleep. If they were roused from REM sleep, the improvements were lost. On the other hand, if they were awakened an equal number of times from slow-wave sleep, the improvements in the scores were unaffected. These findings may help explain why students who stay up all night cramming for an examination generally retain less information than classmates who get some sleep.

About three to five times a night, or about every 90 minutes, a sleeper enters REM sleep. The first such episode usually lasts only for a few minutes, but REM time increases progressively over the course of the night. The final period of REM sleep may last a half-hour. Altogether, REM sleep makes up about 25% of total sleep in young adults. If someone who has been deprived of REM sleep is left undisturbed for a night, he or she enters this stage earlier and spends a higher proportion of sleep time in it — a phenomenon called REM rebound.

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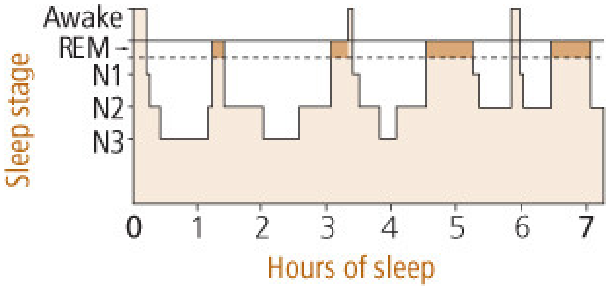
Sleep architecture

During the night, a normal sleeper moves between different sleep stages in a fairly predictable pattern, alternating between REM and non-REM sleep. When these stages are charted on a diagram, called a hypnogram (see Figure 2), the different levels resemble a drawing of a city skyline. Sleep experts call this pattern sleep architecture.

In a young adult, normal sleep architecture usually consists of four or five alternating non-REM and REM periods. Most deep sleep occurs in the first half of the night. As the night progresses, periods of REM sleep get longer and alternate with Stage N2 sleep. Later in life, the sleep skyline will change, with less Stage N3 sleep, more Stage N1 sleep, and more awakenings.

Figure 2: Sleep architecture



When experts chart sleep stages on a hypnogram, the different levels resemble a drawing of a city skyline. This pattern is known as sleep architecture. The hypnogram above shows a typical night's sleep of a healthy young adult.

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Your internal clock

Scientists have discovered that certain brain structures and chemicals produce the states of sleeping and waking.

A pacemaker-like mechanism in the brain regulates the circadian rhythm of sleeping and waking. ("Circadian" means "about a day.") This internal clock, which gradually becomes established during the first months of life, controls the daily ups and downs of biological patterns, including body temperature, blood pressure, and the release of hormones.

The circadian rhythm makes people's desire for sleep strongest between midnight and dawn, and to a lesser extent in midafternoon. In one study, researchers instructed a group of people to try to stay awake for 24 hours. Not surprisingly, many slipped into naps despite their best efforts not to. When the investigators plotted the times when the unplanned naps occurred, they found peaks between 2 a.m. and 4 a.m. and between 2 p.m. and 3 p.m.

Most Americans sleep during the night as dictated by their circadian rhythms, although many nap in the afternoon on the weekends. In societies where taking a siesta is the norm, people can respond to their bodies' daily dips in alertness with a one- to two-hour afternoon nap during the workday and a correspondingly shorter sleep at night.

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Mechanisms of your "sleep clock"

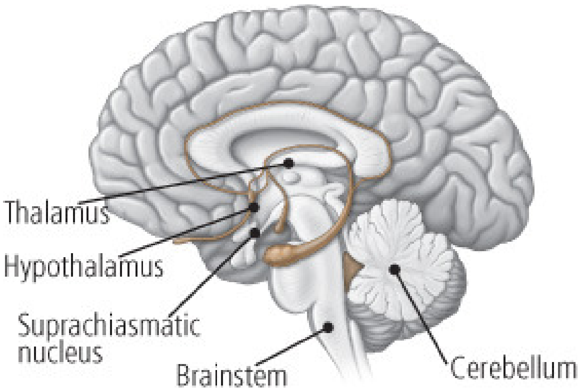
In the 1970s, studies in rats identified the suprachiasmatic nucleus as the location of the internal clock. This cluster of cells is part of the hypothalamus, the brain center that regulates appetite and other biological states (see Figure 3). When this tiny area was damaged, the sleep/wake rhythm disappeared and the rats no longer slept on a normal schedule. Although the clock is largely self-regulating, its location allows it to respond to several types of external cues to keep it set at 24 hours. Scientists call these cues "zeitgebers," a German word meaning "time givers."

Light. Light striking your eyes is the most influential zeitgeber. When researchers invited volunteers into the laboratory and exposed them to light at intervals that were at odds with the outside world, the participants unconsciously reset their biological clocks to match the new light input. The circadian rhythm disturbances and sleep problems that affect up to 90% of blind people demonstrate the importance of light to sleep/wake patterns.

Time. As a person reads clocks, follows work and train schedules, and demands that the body remain alert for certain tasks and social events, there is cognitive pressure to stay on schedule.

Melatonin. Cells in the suprachiasmatic nucleus contain receptors for melatonin, a hormone produced in a predictable daily rhythm by the pineal gland, which is located deep in the brain between the two hemispheres. Levels of melatonin begin climbing after dark and ebb after dawn. The hormone induces drowsiness in some people, and scientists believe its daily light-sensitive cycles help keep the sleep/wake cycle on track.

Figure 3: The sleep/wake control center



The pacemaker-like mechanism in your brain that regulates the circadian rhythm of sleeping and waking is thought to be located in the suprachiasmatic nucleus. This cluster of cells is part of the hypothalamus, the brain center that regulates appetite, body temperature, and other biological states.

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Your clock's hour hand

As the circadian rhythm counts off the days, another part of the brain acts like the hour hand on a watch. This timekeeper resides in a nugget of nerve cells within the brain stem, the area that controls breathing, blood pressure, and heartbeat. Fluctuating activity in the nerve cells and the chemical messengers they produce seem to coordinate the timing of wakefulness, arousal, and the 90-minute changeover between REM and non-REM sleep.

Several neurotransmitters (brain chemicals that neurons release to communicate with adjacent cells) play a role in arousal. Their actions help explain why medications that mimic or counteract their effects can influence sleep. Adenosine and gamma-aminobutyric acid (GABA) are believed to promote sleep. Acetylcholine regulates REM sleep. Norepinephrine, epinephrine, dopamine, and hypocretin stimulate wakefulness. Individuals vary greatly in their natural levels of neurotransmitters and in their sensitivity to these chemicals.

Why do we dream?

You've probably wondered whether your dreams serve any purpose. What does it mean when you arrive at your senior prom in overalls, or when you're chased through the streets of Paris by a giant turtle?

Those who have studied dreaming fall into two general camps: Those who say yes, dreams are significant, and those who say no, they're not.

Followers of the first camp trace many of their ideas to Sigmund Freud, who in 1900 proposed that dreams are meaningful representations of the unconscious mind in which we reveal our hidden conflicts, desires, and fears, albeit in disguised form. Post-Freudian theorists and psychoanalytic thinkers subsequently elaborated on and refined his ideas, focusing on how dreams help the organization of thought and the consolidation and reinforcement of long-term memory.

Other researchers, taking a physiological approach, are skeptical. Pointing to studies from the 1970s showing that dreams occur upon activation of neurotransmitters in a portion of the brain, they argue that dreams are merely aimless and chaotic images — essentially little more than the mind's attempt to make meaning out of the random chemical signals sent up from the brain stem. They also point out that we only remember a minute percentage of our dreams; if they were significant, surely we'd remember them better.

More research on the function of dreams combines the psychological and neurochemical approaches. One scientist, for example, observed that patients who sustained injuries and lesions in the brain's frontal lobe no longer dreamed. This suggests that dreaming involves parts of the brain other than the brain stem — specifically those areas in the front of the brain that are connected to urges, impulses, and appetites. Other research suggests that dreaming plays a role in helping consolidate the day's memories, attaching associations and emotions and helping to retain important events. Further research should offer important insights on why we dream and what role, if any, our dreams can play in maintaining mental health.