Why We Sleep

By Christine Gorman

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You may think it's for your body, but it's really for your brain. The latest research is full of surprises

Maybe you have a big report due first thing in the morning. Or you're trying to deliver a truckload of fish before the wholesale market opens 150 miles away. Whatever the reason, you decide to stifle that yawn and push through the night. Sure, you've been awake 16 hours, but you have a giant thermos of coffee and a few tunes to keep you going. Your body, of course, is fighting you every step of the way. Whether or not you realize it, your brain has already started to check out for the night.

That yawn was the first sign that you're not so awake as you think. After about 18 hours without sleep, your reaction time begins to slow from a quarter of a second to half a second and then longer. If you're like most people, you will start to experience bouts of microsleep--moments when you zone out for anywhere from two to 20 seconds and drift out of your lane or find that you have to keep rereading the same passage.

Your eyelids start to droop more severely, and by the 20-hour mark you begin to nod off. Your reaction time, studies show, is roughly the same as someone who has a blood-alcohol level of 0.08--high enough to get you arrested for driving under the influence in 49 states. You forget to do things like double-check the spelling of a name or set the brake when you stop on a hill.

Although you may get a second wind with the rising of the sun, the longer you stay up, the more your condition deteriorates. "By the second night, oh, my goodness, it's extremely dramatic--beyond double what it was the first night," says David Dinges, a sleep expert at the University of Pennsylvania School of Medicine. "You fall massively off the cliff."

You don't need to pull an all-nighter, work 24-hour shifts or hold down a couple of jobs to know that at some point you just have to crash. All through the animal kingdom, sleep ranks right up there with food, water and sexual intercourse for the survival of the species. Everybody does it, from fruit flies to Homo sapiens. Yet despite its clear necessity and lots of investigation, scientists still don't know precisely what sleep is for.

Is it to refresh the body? Not really. Researchers have yet to find any vital biological function that sleep restores. As far as anyone can tell, muscles don't need sleep, just intermittent periods of relaxation. The rest of the body chugs along seemingly unaware of whether the brain is asleep or awake.

Is it to refresh the mind? That's closer to the mark. The brain benefits from a good night's sleep. But there is no agreement among sleep researchers about what form that benefit takes. One theory is that sleep allows the brain to review and consolidate all the streams of information it gathered while awake. Another suggests that we sleep in order to allow the brain to stock up on fuel and flush out wastes. A third, which has been gaining currency, is that sleep operates in some mysterious way to help you master various skills, such as how to play the piano and ride a bike.

Most of the new science of sleep has emerged quite recently, as researchers supplement EEGs--the old-fashioned electroencephalograms that are a recording of the waves of electrical activity in the brain--with far more sophisticated imaging and neurological mapping techniques. With the new equipment, scientists are able to take increasingly detailed pictures of the sleeping brain, observing precisely what it is doing while it rests, down to the individual neuron. "In the past year or two, everything seemed to click together," says Dr. Giulio Tononi, a neurobiologist and psychiatrist at the University of Wisconsin at Madison. "Suddenly we have hypotheses that could explain lots of things. Whether they're right is a different story. But I feel different from a few years ago, when the thinking was, 'Who knows? Sleep could be anything.'"

THOSE SHIFTY EYES

Without a good theory of what sleep is for, scientists for many years concentrated on describing what it is--and treating conditions that interfere with it, such as anxiety, restless-leg syndrome and sleep apnea. They've learned that most mammals, with the possible exception of dolphins and whales, cycle between two distinct phases of sleep, one of which is characterized by rapid eye movement--the famous REM sleep. The other is called, straightforwardly enough, non-REM sleep. Humans generally take about 90 minutes to complete a full cycle of REM and non-REM sleep. As dawn approaches, however, we spend more and more of that time in REM sleep and less in non-REM sleep.

If you look at the EEGs of people in REM sleep, you see a pattern that shows lots of brain activity--and if you wake them up during it, they will tell you that they have just been dreaming. Any dreams in non-REM sleep usually consist of no more than a simple image or two. But despite all the mythology that surrounds dream imagery, scientists who have searched for the hidden purpose in dreams haven't had much luck. The consensus among sleep researchers today is that dreams are nothing more than random recycling of bits and pieces of the previous day's events.

EEGs taken during non-REM sleep reveal four distinct stages as we progress from light to very deep sleep. Stages 3 and 4 of non-REM sleep are characterized by distinctive low-frequency electrical waves; researchers call that slow-wave sleep. Intriguingly, humans spend much more time in slow-wave sleep during the first three hours of the night than they do in the hours just before waking. Children are champion slow-wave sleepers, which is why they sleep so soundly when being carried from the car to bed. Adults, on the other hand, get less and less slow-wave sleep as they age, which may be one of the reasons they wake up more often in the night.

For years sleep researchers focused most of their attention on REM sleep because, frankly, it seemed more interesting--all those dreams and everything. But they kept running into blank walls. Early work that tried to link REM sleep to learning foundered when scientists discovered that their test subjects could remember long lists of new words or facts whether or not they got any REM sleep. Indeed, an Israeli man with a piece of shrapnel in his brain became famous in sleep circles for not getting any REM sleep at all. Despite that, he went to law school and seems to have no trouble handling new situations. Many investigators gave up trying to figure out what sleep was for and focused their attention on treating various sleep disorders, such as insomnia and narcolepsy.

NEW TOOLS, NEW IDEAS

Two things happened in the mid-1990s, however, that revived research into the fundamental purposes of sleep. A 1994 study by scientists at the Weizmann Institute in Rehovot, Israel, suggested that researchers had been looking at the wrong kind of memory processing. And the technology for peering inside a sleeping brain got a whole lot better.

What the Weizmann researchers found was that your ability to recognize certain patterns on a computer screen is directly tied to the amount of REM sleep you get. Such skills depend on something called procedural memory, which is needed for any task that requires repetition and practice. Remembering a fact, like the name of the first U.S. President, is an example of declarative memory, a different kind of capability that apparently is not affected by REM sleep. Says Robert Stickgold, a cognitive neuroscientist at Harvard Medical School: "We were basically naive about memory."

But that changed once scientists knew which kind of memory to study. Over the past couple of years, Stickgold has teamed up with Matthew Walker at Boston's Beth Israel Deaconess Medical Center to investigate sleep's effects on procedural memory for motor skills. They asked right-handed test subjects to type a sequence of numbers (for example, 4-1-3-2-4) with their left hand over and over again as fast as they could. No matter what time of day they learned the task, their accuracy improved 60% to 70% after six minutes of practice. When subjects who learned the sequence in the morning were retested 12 hours later, they hadn't significantly improved. But when those who learned the sequence in the evening were retested following a night's sleep, they were an extra 15% to 20% faster and 30% to 40% more accurate.

Much to the researchers' surprise, the greatest improvements appeared in those who spent the most time in the second stage of non-REM sleep. Other procedural tasks that depended more heavily on visual or perceptual ability required periods of deeper sleep or both slow-wave and REM sleep. Sometimes even just an hour of shut-eye made a big difference. Other times a full night's rest was needed. "It's probably going to turn out that different types of memory tasks need different kinds of sleep," says Stickgold.

The search continues for other cognitive skills that might be linked to sleep. In January, Jan Born and his colleagues at the University of Lübeck in Germany published a clever study that shows why sleeping on a problem often brings such good results. They asked 106 test subjects to transform a string of numbers into a different string of numbers, using a simple but tedious mathematical equation. Unbeknownst to the study volunteers, there was a hidden trick to the calculations that could cut their response time dramatically. A good night's sleep between practice sessions more than doubled--from 23% to 59%--the probability that participants caught on to the trick. In other words, sleep isn't absolutely necessary to gain insight into a problem, but it can be a big help.

So can new technology, which is allowing researchers to study sleep at a microscopic level for the first time. Neuroscientists have long been able to record the firing of a single nerve cell, using a tiny electrode implanted in a laboratory animal's brain. But it's only recently that they have had electrodes small enough and computers powerful enough to record scores of individual neurons at once. The goal is to identify the changing patterns of neuronal firing during sleep. "There are days when we can record up to 500 neurons, but that's not typical," says Bruce McNaughton, a psychologist and physiologist at the University of Arizona in Tucson, who studies rats. More typically, he is able to tap between 50 and 100 neurons. That's not a lot when you consider that even a rodent's brain has 125 million neurons. But it was enough to get him started.

What McNaughton's recordings have shown is that many of the same neurons that fire during the daytime--say, when a rat is learning to navigate a maze--are reactivated during the REM stage of sleep. "Basically, the brain is reviewing its recently stored data," he says. Eventually the brain consolidates those patterns into permanent connections--or, as neuroscientists like to say, "neurons that fire together, wire together." Interestingly, says McNaughton, that process appears to happen not just during sleep but during restful states throughout the day as well.

SLOW-WAVE LEARNING

Better equipment HAS ALSO GIVEN researchers a new respect for what can be accomplished during slow-wave sleep. In a study published in July in Nature, Wisconsin's Tononi and others showed that a specific part of the brain that had been busy learning a new skill while awake needed much more slow-wave sleep in order to improve performance.

The scientists had 11 volunteers play a simple video game that required them to reach for objects on the screen with a mouse-controlled cursor. What the volunteers didn't realize was that the game sometimes introduced a slight bias to the cursor's motion, forcing them to adjust their movements. Half the group slept between sessions and the other half did not. Among the sleepers, the part of the brain that was learning to compensate for the bias while awake turned out to have the largest slow waves during sleep. "The bigger the slow waves were in that part of the brain, the better they performed the next day," Tononi says.

So far, so good. But what does it mean? Tononi speculates that instead of strengthening neural connections responsible for a given task, as appears to happen during the day or in REM sleep, slow-wave sleep actually indiscriminately weakens the connections among all nerves. The idea sounds counterintuitive, but it may simply be a matter of self-preservation. "Normally the brain takes up 20% of the energy of the entire body," Tononi explains. Most of that energy goes into sustaining the connecting points, or synapses, between neurons. The more you learn, the greater the number of synapses. "So by the end of the day, if you have synapses that are much stronger, the cost of running the brain is much higher," he says--perhaps another 20%.

It doesn't take a neuroscientist to figure out where that leads. After a few days, the number of new synapses in the brain would require more energy than the body could possibly supply. So some of those connections must be weakened--and the best guess is that it happens during slow-wave sleep.

That explanation is still hypothetical, but Tononi thinks he has evidence to back it up. "In slow-wave activity, all the neurons fire for half a second," he explains. "Then they're totally silent for half a second." For complex bioelectrical reasons, that turns out to be a perfect way for the brain to lower the strength of the connections between its neurons. Intermittent firing makes the connections leaner and more efficient and may even allow the weakest ones to drop out, clearing the mind so that it can learn something new in the morning.

A THEORY OF SLEEP

Perhaps that's what sleep really is--A series of repeated cycles of pruning and strengthening of neural connections that enables you to learn new tricks without forgetting old ones. Of course, none of that explains why you have to be unconscious for all the pruning and strengthening to occur. Maybe it's just easier to be asleep than awake while the work is going on. "When you fall asleep, it's like you're leaving your house and the workmen come in to renovate," suggests Terry Sejnowski, a computational neurobiologist at the Salk Institute in La Jolla, Calif. "You don't want to live in the house while the construction's going on because it's a mess."

It all sounds plausible enough, but that doesn't mean everyone is convinced. "It may not sound exciting, but I think sleep is essentially for rest," says Robert Vertes, a neuroscientist at Florida Atlantic University in Boca Raton. Vertes thinks most sleep scientists are overinterpreting their data because they find it so hard to believe that our brains just need to shut down for eight hours or so every night. As for what's being done during that time, the short answer, he says, is "We don't know."

Perhaps the brain just needs to restore itself. "We've all had the experience of going to bed with a problem, getting a good night's sleep and waking up in the morning, and there's a solution," says Dr. Gregory Belenky, who recently retired as head of sleep research at the Walter Reed Army Institute of Research in Silver Spring, Md., and is now at Washington State University at Spokane. But instead of thinking that extra information processing is going on during sleep, he says it makes as much sense to suggest that depleted circuits are just being rejuvenated.

The brain, like the rest of the body, runs on glucose, Belenky explains. Using computerized scanners that provide images in real time, he and his colleagues have shown that the brain's ability to use glucose drops off dramatically after being awake 24 hours, indicating a decrease in brain activity--despite the fact that there's still plenty of glucose available. The biggest drops occur in exactly those areas of the cortex that anticipate and integrate emotion and reason. After 24 hours, however, the drop-off stabilizes. "But performance doesn't level off," Belenky notes. "It continues to tank." Why? No one knows.

In addition to refueling the brain, sleep seems to detoxify it. Animals with a high metabolic rate, like field mice and bats, use a lot of calories and generate a lot of destructive molecules called free radicals. "The brain is particularly susceptible to this because neurons, by and large, don't regenerate," says Jerome Siegel, a neuroscientist at UCLA and the Veterans Affairs Medical Center in Los Angeles. Maybe sleep provides necessary downtime so that the brain can deal with all those free radicals.

Some of the most provocative sleep research doesn't have anything to do with the brain at all. A few years after researchers isolated a natural hormone they called leptin, which tells the brain that the body has enough fatty tissue, Eve Van Cauter and her colleagues at the University of Chicago began to wonder whether sleep deprivation has any effect on the amount of leptin in the blood. They soon discovered that after just a couple of days in which 12 male volunteers were allowed to get only four hours of sleep a night, their leptin levels fell sharply, signaling the brain that a lot more calories were needed. Could a hormonal imbalance, brought on by staying up too long, help tip your metabolism in favor of gaining weight? Maybe. Just last week researchers at Stanford and Wisconsin reported similar results in a study of 1,000 volunteers. But it's also true that being overweight often interferes with the quality of sleep. At any rate, "sleep is not only for the brain," says Van Cauter. "It's also for the rest of the body."

HOW MUCH IS ENOUGH?

Whatever combination of exotic or mundane things sleep turns out to be for, researchers admit they still don't know the ideal amount of it needed to keep our bodies and brains in good working order. "There's this enormous commercial push now to convince people that if they don't get eight hours of sleep a night, there's something wrong with them," Siegel says. But in fact, there's more mythology than substance to the eight-hour figure. Back in the 1980s, a survey of more than 1 million people found that those who slept more than 7 1/2 hours a night tended to die a little sooner than their more sleep-deprived counterparts. But there is a wide enough variation in the data that you can't use the results to make any blanket statements about how much any individual should sleep. Nor can you assume that you're endangering your health if you sleep longer.

Besides, the findings don't take into account the quality of sleep you get. Although surveys suggest that we get less sleep than folks did a century ago, that's not necessarily a problem. "Our sleeping environments are better than they ever have been," says Jim Horne, director of the Sleep Research Center at Loughborough University in England. In Victorian workhouses, to give just one example, folks used to sit on benches and drape themselves on long ropes, called hang-overs, to sleep. They must have got used to it, Horne says. Indeed, the sleep system can be very flexible and adapt quickly to different conditions. "It's peace of mind rather than physical comfort that counts anyway," says Horne.

So, how much sleep should you get? Most researchers take a decidedly practical stance. "If you feel sleepy the following day," says Dr. Pierre-Hervé Luppi at the University of Lyons in France, "if you have episodes of sleepiness or a feeling of major fatigue throughout the day, it means you're not sleeping enough." You don't have to know what sleep is for to know that it's good for you. --With reporting by Dan Cray/Los Angeles, Simon Crittle/New York, Helen Gibson/ London and Grant Rosenberg/ Paris