“It was literally true: I was going through life asleep. My body had no more feeling than a drowned corpse. My very existence, my life in the world, seemed like a hallucination. A strong wind would make me think my body was about to be blown to the end of the earth, to some land I had never seen or heard of, where my mind and body would separate forever.”

—From Sleep, by Haruki Murakami, 1989

Sleeping While Awake

During microsleep, the entire brain nods off so briefly that we often don’t notice it. Now research shows that individual neurons in the brain can slumber, too, especially when we are sleep-deprived.

We’ve all been there. You go to bed, close your eyes, blanket your mind and wait for consciousness to fade. A timeless interval later, you wake up, refreshed and ready to face the challenges of a new day (note how you can never catch yourself in the act of losing consciousness!). But sometimes your inner world does not turn off—your mind remains hypervigilant. You toss and turn but can’t find the blessed relief of sleep. The reasons for sleeplessness may be many, but the consequences are always the same: You are fatigued the following day, you feel sleepy, you nap. Attention wanders, your reaction time slows, you have less cognitive-emotional control. Fortunately, fatigue is reversible and disappears after a night or two of solid sleep.

We spend about one third of our lives in a state of repose, defined by relative behavioral immobility and reduced responsiveness to external stimuli. Cumu-
As slow as once every four seconds and tions, referred to as delta waves, can be storative activity. These voltage oscilla-
tude. Indeed, the deeper and more rest-
ting and falling waves of larger ampli-
non-REM sleep is marked by slowly ris-
by low-voltage, choppy, swiftly chang-
movement (REM) sleep is characterized
ceaselessly in commotion, reflecting the
surface of the sea, the electrical brain is

In one experiment attempting to ex-
plore this condition, participants had to
track a randomly moving target on a
computer monitor with a joystick for 50
minutes. While straightforward, this vi-
suomotor task demands nonstop atten-
tion that becomes difficult to sustain af-
ter a while. Indeed, on average, partici-
parts of the cortex, are the cellular hall-
mark of deep sleep.

Microsleep
My last column, “To Sleep with Half a Brain,” highlighted the growing real-
ization of sleep researchers that being awake and asleep are not all-or-none
phenomena. Just because you’re asleep doesn’t necessarily imply that your en-
tire brain is asleep. Conversely, as I will describe now, we have also learned that
even when you’re awake, your entire brain may not be awake.

A case in point for sleep intruding into wakefulness involves brief episodes of
sleep known as microsleep. These inter-
tervals can occur during any monoto-
nous task, whether driving long distanc-
es across the country, listening to a
speaker droning on or attending yet an-
other never-ending departmental meet-
ing. You’re drowsy, your eyes get
droopy, the eyelids close, your head re-
ppeatedly nods up and down and then
snaps up: your consciousness lapses.

In one experiment attempting to ex-
plor this condition, participants had to
track a randomly moving target on a
computer monitor with a joystick for 50
minutes. While straightforward, this vi-
suomotor task demands nonstop atten-
tion that becomes difficult to sustain af-
ter a while. Indeed, on average, partici-
parts had 79 microsleep episodes per
hour, lasting between 1.1 and 6.3 sec-
onds apiece, with an attendant drop in
performance. Microsleep shows up in
the EEG record by a downward shift
from activity dominated by the alpha
band (8 to 13 Hz range) to oscillations
in the theta band (4 to 7 Hz).

**MICROsleep CAN BE FATAL WHEN DRIVING OR OPERATING MACHINERY SUCH AS TRAINS OR AIRPLANES, HOUR AFTER TEDIOUS HOUR.**

Perniciously, subjects typically be-
lieve themselves to be alert all the time
during microsleep without recalling any
period of unconsciousness. This misap-
prehension can be perilous to someone
in the driver’s seat. Microsleep can be fa-\ttal when driving or operating machinery
such as trains or airplanes, hour after te-
dious hour. During a microsleep epi-

dode, the entire brain briefly falls asleep,
raising the question of whether bits and
pieces of the brain can go to sleep by
themselves, without the entire organ
succumbing to slumber.

Indeed, Italian-born neuroscientists
Chiara Cirelli and Giulio Tononi, who
study sleep and consciousness at the
University of Wisconsin–Madison, dis-
covered “sleepy neurons” in experimen-
tal animals that showed no behavioral
manifestation of sleep. In this research,
11 adult rats had microwires implanted
into their frontal motor cortex, which
controls movement. Inserted into the
cortical tissue, the sensors picked up
both the voltage called the local field po-
tential (LFP), akin to the EEG, in addi-
tion to the spiking activity of nearby
nerve cells. As expected, when awake,
the LFP was dominated by low-ampli-
tude, fast waves readily distinguishable
from the larger and slower waves char-
acteristic of non-REM deep sleep [see
box on page 23].
At the level of individual neurons, the awake animals’ cortical cells chatted away in an irregular, staccato manner over an extended period. Conversely, during deep sleep, cortical neurons experienced pronounced “on” periods of neural activity and “off” times during which they are silent. This neuronal reticence occurs simultaneously all over the cortex. It alternates with regular on periods, leading to the rising and falling brain waves that are the hallmark of deep sleep.

Knowing all this, the researchers decided to probe further. Instead of letting the rats go to sleep at their usual bedtime, the experimentalists engaged the animals in a rodent version of late-night video gaming, continuously exposing them to toys and other objects to sniff, explore, and play with. They tapped on the cage and otherwise prevented them from assuming a sleep posture or becoming drowsy. After four hours of such excitement, the rats could finally slumber. As expected from previous animal and human studies, by the end of the sleep deprivation phase, the LFP began to shift to lower frequencies, compatible with the idea that the pressure for the animals to sleep steadily built up. Closer inspection of the electrical signatures, however, revealed something unexpected: occasional, sporadic, silent periods of all or most of the neurons in the recorded brain region [see box on opposite page] without the animals showing either behavioral or EEG manifestations of micro-sleep. These short, off-like episodes were often associated with slow waves in the LFP. The opposite happened during recovery sleep, toward the end of this six-hour period, when the pressure to sleep had presumably abated. At this point, large and slow waves in the LFP became more infrequent, and neuronal activity turned more irregular, as it did during wakefulness.

It appears that when awake but sleep-deprived, neurons show signs of sleepiness, whereas after hours of solid sleep, individual neurons start waking up. Careful statistical analysis confirmed these trends: the number of off periods increased during the four hours the rats were forced to stay awake, and the opposite dynamic occurred during recovery sleep. One question was whether any one neuron fell asleep independent of any other neuron. Or was this occurrence more of a global phenomenon, whereby all neurons simultaneously transition to an off period? The answer, obtained by implanting a second array of micro-wires into a second cortical region—the parietal cortex, a quite distinct region from the motor cortex—was “yes” to both questions.

That is, sometimes neurons in both regions went off together, whereas at other times they did so independently. Yet as the sleep pressure built up, after several hours of being kept awake, neuronal activity during sleep deprivation did become more globally synchronized (as it does in deep sleep). Likewise, the longer the animal slept during the recovery period, the less likely slow waves were simultaneously detected at both cortical sites. Groups of neurons can be more easily recruited to produce the slow oscillations that constitute deep sleep when sleep pressure is high.

These results paint a more nuanced view of wakefulness and sleep than the prevailing one, in which both conditions were considered to be global, all-or-none states of consciousness. Instead these data, buttressed by single-neuron recordings from patients with implanted microelectrodes, as used occasionally in epilepsy treatment, suggest that even when the subject is awake, the individual’s neurons can become tired and occasionally check out. The heavier the sleep pressure, the more likely this will happen simultaneously at many places in cortex. Conversely, after many hours of restful sleep, some of these neurons become de-
Partially Asleep

Brain studies in animals back the notion that a person could be partially asleep on the job after a late night, with no outward signs of weariness. Local field potential measurements—summed electrical activity of large populations of nerve cells—show fast, low peaks present when an animal is awake (left panel) and slower, wider waves (center) during deep non-REM sleep (also called slow-wave sleep). But when an animal is coaxed to stay awake past its bedtime, parts of its brain can go to sleep (local sleep), with occasional sharp peaks in neural activity akin to those registered during deep sleep (right panel).

The tick marks at the bottom show the activity of six closely spaced neurons—all of which periodically switch off during slow-wave sleep. The red boxes highlight the similarity between non-REM and local sleep.

coupled from these brain-wide oscillations and begin to wake up.

But with neurons going off-line during sleep deprivation, shouldn’t there be some deterioration in performance? After all, these neurons must serve some purpose, and if they drowse, something ought to suffer. To investigate this question, Cirelli, Tononi and their collaborators trained the rats to reach with one of their front paws through a narrow opening to grasp a sugar pellet on a shelf. If done clumsily, the pellet falls off and cannot be retrieved anymore.

Learning this task engages a particular sector of the motor cortex that undergoes change as a consequence of training. Trawling for off periods while the animal reaches out for the sweets, the investigators found these gaps in neuronal firing are more likely to occur in the motor cortex a fraction of a second before a failed attempt to grasp a sugar pellet on a shelf. If done clumsily, the pellet falls off and cannot be retrieved anymore.

Learning this task engages a particular sector of the motor cortex that undergoes change as a consequence of training. Trawling for off periods while the animal reaches out for the sweets, the investigators found these gaps in neuronal firing are more likely to occur in the motor cortex a fraction of a second before a failed attempt to grasp a sugar pellet on a shelf. If done clumsily, the pellet falls off and cannot be retrieved anymore.

Extrapolating from these data, it seems plausible that as the pressure for sleep increases, the frequency of these off events and their preponderance in the cortex increase until activity in the entire brain becomes suddenly but briefly synchronized and the brain falls into deep sleep—the eyes close, and the head nods. The subject enters microsleep.

Sleep is a fascinating subject, even though we cannot knowingly experience deep sleep, because our consciousness is switched off. Sleep is a finely regulated aspect of our brain’s daily cycle as the sun rises and sets, a state whose function remains controversial.

Over the past century clinicians and neuroscientists have discovered different sleep phases (rapid eye and nonrapid eye movements) and the distinct regions of the midbrain and brain stem involved in controlling them. What is more, these researchers have demystified narcolepsy, when patients abruptly and irresistibly fall asleep, microsleep and now local sleep. What will come next?

MORE TO EXPLORE