

Chapter Seven

Sleeping and Dreaming

IT WAS 1952 AND the American military was getting panicky. Over 60 percent of the airmen captured by the Chinese army in the ongoing Korean War were confessing to bogus war crimes (such as the use of biological weapons) or were signing statements or recording messages renouncing the United States and embracing communism. These events created an enormous propaganda coup for the Chinese. The CIA and military intelligence specialists entertained a number of theories about the success of this effort, including the development of exotic “brainwashing drugs,” hypnosis, and exposure to mind-altering electric fields. The truth, revealed some years later, was much more prosaic: the Chinese were able to coerce these statements from their prisoners mainly through the use of beatings combined with prolonged sleep deprivation.

This shouldn't have been news. Throughout history it has been known that

sleep deprivation is an ideal form of torture. The ancient Romans employed sleep deprivation extensively to interrogate and punish prisoners. It leaves no physical trace and it does not result in permanent alteration of the victim's mental function: he or she is mostly back to normal after a good night's sleep or two. Indeed, of the thousands of American and United Nations prisoners of war in Korea, almost none maintained their bogus confessions or denunciations after their release. They weren't "brainwashed" at all. Their fundamental belief systems and personality had not been permanently compromised. Rather, they were temporarily rendered delusional, suggestible, and even psychotic through sleep deprivation.

In his autobiographical book *White Nights*, the Russian dissident Menachem Begin, later to become the prime minister of Israel, describes his sleep-deprivation treatment at the hands of the KGB.

In the head of the interrogated prisoner, a haze begins to form. His spirit is wearied to death, his legs are unsteady, and he has one sole desire: to sleep . . . Anyone who has experienced this desire knows that not even hunger and thirst are comparable with it.

I came across prisoners who signed what they were ordered to sign, only to get what the interrogator promised them.

He did not promise them their liberty; he did not promise them food to sate themselves. He promised them—if they signed—uninterrupted sleep! And, having signed, there was nothing in the world that could move them to risk again such nights and such days.

Begin's description highlights the effectiveness, but also the limitations, of sleep deprivation as a torture method. It is very effective as a coercive device, but torturers cannot rely upon information gleaned while a prisoner is in a se-

verely sleep-deprived state: people in this condition are often experiencing auditory and visual hallucinations as well as paranoia. They are likely to say anything if they believe they finally will be allowed to sleep. I should note that torture by sleep deprivation is a practice that is still in common use. Andrew Hogg of the Medical Foundation for the Care of Victims of Torture in the United Kingdom says, “It is such a standard form of torture that basically everybody has used it at one time or another.” Here, “everybody” includes democratic states such as the United States, the United Kingdom, India, and Israel, all of which have published recent guidelines for interrogation by the military and security services that allow for extreme sleep deprivation.

How long can a human go without sleep? The world record is presently held by Randy Gardner, who, as a 17-year-old high school student, stayed awake for 11 straight days in 1965 just for the hell of it. He did this without the use of stimulant drugs. During this period, Gardner initially became moody, clumsy, and irritable. As time progressed he showed delusions (he said that he was a famous professional football player), then visual hallucinations (he saw a path through a forest extending from his bedroom), paranoia, and a complete lack of mental focus. Remarkably, after a 15-hour sleep, almost all of these symptoms abated. Gardner appears to have suffered no lasting physical, cognitive, or emotional harm from the incident.

A grisly set of experiments with rats showed that total sleep deprivation will cause death in 3–4 weeks. Although the exact cause of death was unknown, these animals suffered from skin lesions and a gradually failing immune system. This condition ultimately allowed for the colonization of the body by otherwise benign bacteria that are usually restricted to the digestive tract. Throughout this period there is a gradual buildup of the steroid hormone cortisol, a natural immunosuppressant, and a gradual reduction in core body temperature. Human death from total sleep deprivation has not been reported in the scien-

tific literature. But there are indications of this from records of Nazi death camp experiments during World War II as well as reports of executions by sleep deprivation in China in the nineteenth century. These suggest that 3–4 weeks of sleep deprivation will kill humans as well. Or, to put it another way, 4 weeks without food may or may not kill you (depending upon your health, age, and access to medical care) but 4 weeks without sleep will.

CLEARLY, BOTH RATS and humans need sleep to live. This raises the question: what are the physiological functions of sleep that make it so important? Amazingly, we don't have a definitive answer to this simple question. One obvious idea is that sleep serves a restorative function for the entire body. Cellular growth and repair functions involving gene expression and protein synthesis seem to accelerate during sleep in both the brain and other tissues. But it is not well established that people who are physically active sleep significantly more than those who are confined to bed. Nor is it clear that a brief period of intense exercise promotes longer total sleep time (although there are some small effects on the time spent in various stages of sleep).

It has been proposed that sleep functions to conserve energy. This may be particularly relevant for warm-blooded animals (mammals and birds) that must expend a lot of energy to maintain a body temperature higher than that of their surroundings. Indeed, many small mammals living in cold climates, who lose heat easily by having an unfavorable surface area to body weight ratio, tend to sleep a lot, often in insulating burrows. Yet sleep does not appear to have evolved only in warm-blooded animals. EEG recordings from reptiles and amphibians indicate that they also sleep, and there are now strong indications of a sleep-like state in some invertebrates, such as crayfish, fruit flies, and honey bees. Also, though it is true that the overall use of energy is reduced during sleep, as compared with the active waking state, there is almost as much reduc-

tion in energy use from just resting quietly. The additional energy conservation in going from the resting state to sleep is minimal. So, an explanation for sleep based on restoration and energy conservation is unlikely to be complete.

One simple role of sleep might be to restrict an animal's activity to those times when activity is productive—when the chance of finding food is high but the chance of becoming someone else's food is low. For many species, including ours, this means sleeping at night. Others, such as many foraging rodents, bats, and owls, do the opposite, but the principle is the same: they are trying to hunt for food but avoid predators. There is some evidence to support this model: mammals at the top of the food chain such as lions and jaguars tend to sleep a lot (as much as 12 hours a day) while those that graze in the open such as deer and antelope sleep much less. Some herbivorous animals such as ground squirrels and sloths also sleep a lot (two-toed sloths sleep for 20 hours every day!), but these tend to be species that are mostly safe from predation during sleep because of their sleeping location (in underground burrows or high in trees). Nonetheless, this explanation for sleep doesn't seem entirely satisfying either. Perhaps if we look at the process of sleep in greater detail, more compelling ideas will emerge.

THE SCIENTIFIC STUDY of human sleep has a very strange beginning. In the nineteenth century, several investigators in France were very interested in the processes of sleep, but they never did the most simple, observational experiment: just stay up all night and make notes of how people's bodies move over the course of a normal night's sleep. Instead, these scientists spent their time trying to influence the dreams of their subjects. They would open a bottle of perfume under the sleeper's nose or tickle him with a feather and then wake him up a few minutes later to see if they had influenced his dreams. Not much useful information came from this line of work, and up until the 1950s the

standard model of sleep was simple and wrong. It was held that sleep is a constant, unchanging period of little body movement and low brain activity that changes only upon waking.

In 1952 Eugene Aserinsky was a graduate student in the laboratory of Nathaniel Kleitman at the University of Chicago, where EEG recordings were being made from adults as they fell asleep. These revealed that after falling asleep, the EEG gradually changed from a desynchronized, low-voltage trace to a high-voltage trace with slow, synchronized oscillations. At this point, it was assumed that deep sleep had been achieved and this status would be maintained until waking. The standard operating procedure was to record for 30–45 minutes to capture this transition and then turn the EEG recorder off to save chart paper. One night Aserinsky brought his son Armond, 8 years old, into the lab to be the subject. About 45 minutes after Armond had fallen asleep, his father was watching the pens on the EEG chart recorder register the slow oscillations of deep sleep. Then, amazingly, the EEG shifted to another rhythm that looked more like waking even though Armond was still clearly sleeping and was totally immobile. We now know that this stage of sleep is associated with rapid eye movements (REMs) and that while it usually does not occur in adults until about 90 minutes after falling asleep, in children, like Armond, it occurs sooner.

The report of these findings by Aserinsky and Kleitman in 1953 began the modern era of sleep research, and in the following years a much more detailed picture of sleep emerged. When scientists left their EEG machines on all night (piling up enormous stacks of chart paper in the process), they found an adult sleep cycle of about 90 minutes duration (Figure 7.1). This consisted of the aforementioned gradual descent into deeper and deeper sleep accompanied by gradual synchronization of the EEG. These stages of sleep are collectively called non-REM sleep and they are further subdivided into four stages ranging from

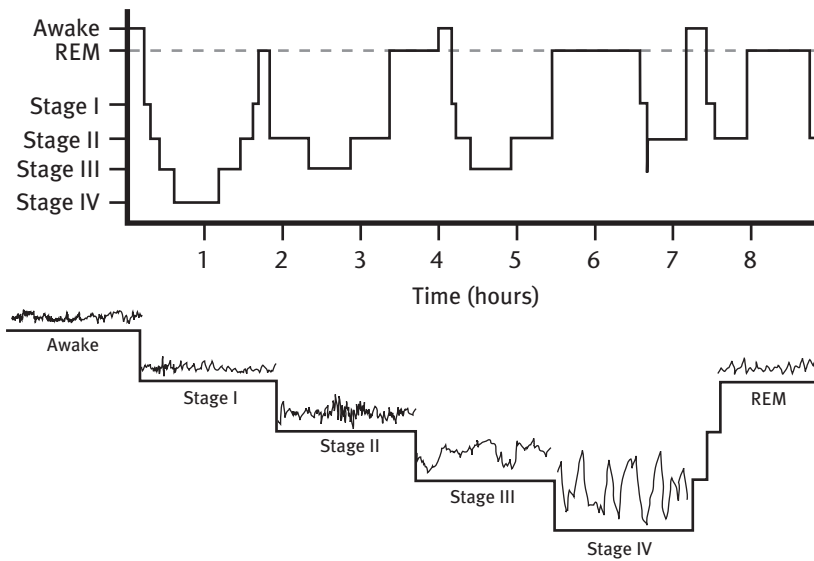


FIGURE 7.1. The stages of adult human sleep. The top panel depicts a complete night's sleep with sleep stage on the vertical axis. This graph was made by analyzing the EEG record to determine the sleep stage. It shows the main features of a normal night's sleep. There is a sleep cycle of approximately 90 minutes duration during which the sleeper gradually progresses from drowsiness (stage I) into deep sleep (stage IV), followed by a period of REM sleep. A typical night's sleep might involve 4 or 5 of these cycles. As the night progresses, a higher proportion of the sleep cycle is devoted to REM sleep with a concomitant decrease in non-REM sleep (stages I–IV). The bottom panel shows representative EEG records from each sleep stage. Note that the EEG record for REM sleep is similar to that of the waking or drowsy state. Adapted with the permission of Macmillan Publishers, Ltd., from E. F. Pace-Schott and J. A. Hobson, The neurobiology of sleep: genetics, cellular physiology, and subcortical networks, *Nature Reviews Neuroscience* 3:591–605 (2002). Joan M. K. Tycko, *illustrator*.

drowsy/nodding-off (stage I) to deep sleep (stage IV). A typical uninterrupted night's sleep will consist of 4 or 5 complete 90-minute-long cycles. What's interesting is that as the night wears on, the character of each sleep cycle changes so that there is proportionally more REM and less non-REM sleep per cycle. In the last period before waking, as much as 50 percent of the cycle may be devoted to REM sleep.

It's a testament to the occasional bone-headedness of scientists that sleep cycles were not discovered before the 1950s. You don't need an EEG recording to detect them. Simple observation of a sleeper throughout the night will show you the main features. The most obvious of these is the rapid side-to-side eye movements that are easily seen even when the eyelids are closed (owing to the bulge of the cornea indenting the eyelid). Careful observation would reveal a host of other changes during REM sleep. These include an increase in breathing rate (as well as heart rate and blood pressure) and a sexual response (penile erection in men, erection of the nipples and clitoris together with vaginal lubrication in women). Even more striking are changes in muscle tone. The typical adult sleeper will change his or her position about 40 times a night without being conscious of this action. None of these motions, however, will occur during REM sleep. In REM sleep, there is no movement at all. In fact, there is not even any muscle tone: the body goes totally limp. It is almost impossible to have REM sleep in anything other than a horizontal position. Remember this the next time you are wrapped in an airline blanket and stuffed into your coach class seat like a scrofulous burrito for a trans-Atlantic flight: even if you manage to catch some sleep in your seat, you won't be able to enter REM sleep.

REM sleep is sometimes called "paradoxical sleep" because the EEG resembles that of the waking state, yet the subject is essentially paralyzed. The story here is that the motor centers of the brain are actively sending signals to the muscles but these signals are blocked at the level of the brainstem by inhibitory

synaptic drive. This blockade affects only the outflow of motor commands down the spinal cord, not those of the cranial nerves that exit the brainstem directly to control eye and facial movements (as well as heart rate). Michel Jouvet of the University of Lyon showed that severing the inhibitory fibers that block motor outflow in cats resulted in a bizarre condition: during REM sleep the cats engaged in complex motor behaviors while keeping their eyes closed. They ran, pounced, and even seemed to eat their imagined prey. Although we can't know this for certain, they appeared to be acting out their dreams (more on this soon). A similar phenomenon is seen in a human condition called REM sleep behavior disorder, which mostly affects men over 50. This disease causes dream-enacting behaviors during the REM period of sleep, including kicking, punching, jumping, or even running. Not surprisingly, these violent behaviors can often result in injury to the patient or to his or her bedmate. In most cases, this disorder is successfully treated by a bedtime dose of the drug clonazepam (sold under the trade name Klonopin), which works by boosting the strength of synapses that use the inhibitory neurotransmitter GABA. REM sleep behavior disorder is different from conventional sleepwalking, which occurs only during non-REM sleep.

Humans show changes in sleep over the life cycle, with the proportion of the time spent in REM sleep decreasing from about 50 percent at birth to 25 percent in mid-life and 15 percent among the elderly (a decrease in REM is also seen over the lifespans of cats, dogs, and rats). If we compare our sleep with that of other mammals, we find that we are more or less in the center of the range bounded by the duck-billed platypus, which spends about 60 percent of its sleeping life in REM, and the bottlenose dolphin, which has a REM proportion of only 2 percent. There is no obvious relationship between degree of REM sleep and brain size or structure across mammalian species (Figure 7.2). Non-REM sleep appears to have evolved as early as the fly (about 500 million

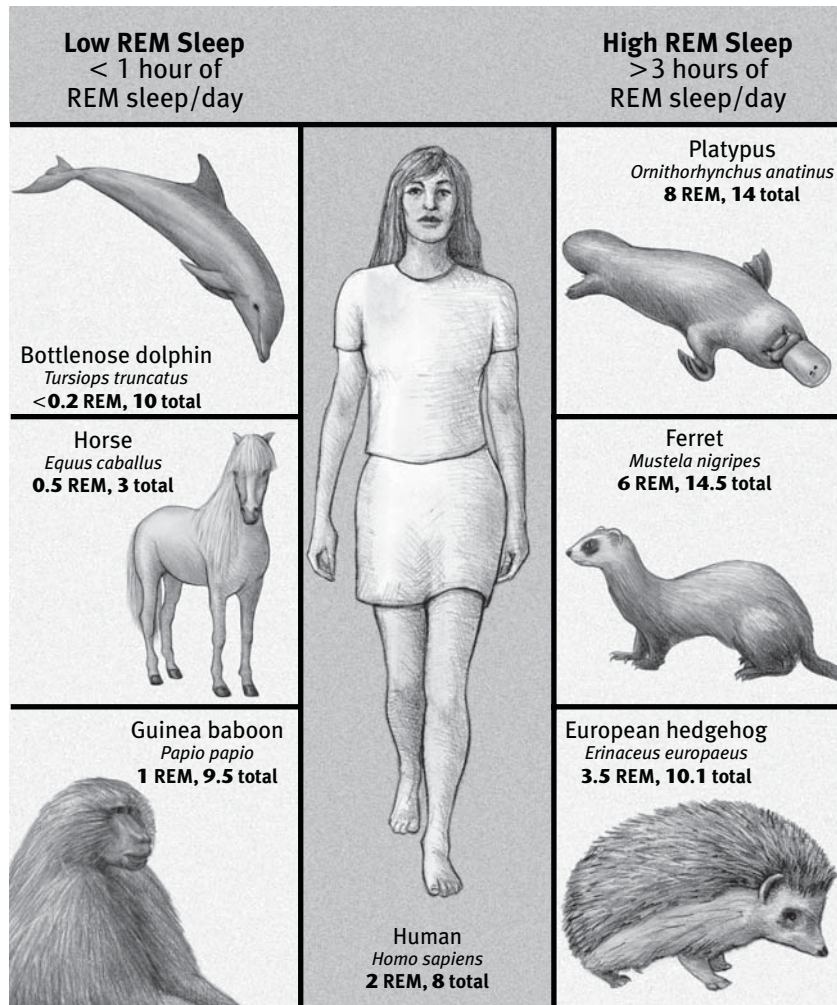


FIGURE 7.2. REM and total sleep in a gallery of representative mammals. Humans fall into the middle of the range when REM sleep is considered either as a raw value or as a proportion of total sleep. Adapted from J. M. Siegel, The REM sleep-memory consolidation hypothesis, *Science* 294:1058–1063 (2001); copyright 2001 AAAS. *Joan M. K. Tycko, illustrator.*

years ago), but true REM sleep is found only in warm-blooded species. It is present in the most primitive surviving mammals (such as the platypus and the echidna) as well as in birds, but appears to be absent in reptiles and amphibians.

So, with knowledge of sleep cycles, we can return to our main question “Why is sleep necessary?” with a bit more sophistication. Really, two separate questions are warranted: What are the key functions of sleep composed of only a non-REM period, as is found in reptiles and amphibians (and possibly some invertebrates as well)? And, what are the key functions of cycling sleep in which REM and non-REM periods alternate, as is found in mammals and birds? It may be that the previously mentioned ideas that sleep is required for restorative functions, energy conservation, and maximizing feeding efficiency while minimizing danger from predation are appropriate for non-REM sleep alone. Cycling sleep is serving some function that only emerges in mammals and birds and that is most important early in life. Let’s consider some hypotheses about what that function might be. One proposal is that cycling sleep serves a rather mundane function. It’s known that non-REM sleep tends to cool the brain, reducing its thermoregulatory set point, while REM sleep heats the brain up. Perhaps alternating bouts of REM and non-REM sleep prevent the brain from becoming too cool or too hot. This hypothesis is consistent with the first appearance of cycling sleep in warm-blooded animals but it doesn’t explain either the variation in REM across mammalian species or the decrease in REM over the lifespan.

Another idea is that cycling sleep somehow promotes the development of the brain in early life. In particular, cycling sleep may play a special role in the later, mostly postnatal, stages of development that require experience-driven plasticity. The experimental evidence in support of this idea comes from experiments in which kittens have one eye artificially closed for a brief period. This results, within a few hours, in a reduced excitation of neurons in the visual cortex by

stimuli (light pulses) delivered to the deprived eye and enhanced responses to stimulation of the open eye. When kittens are allowed to sleep following a period of monocular deprivation, this change in the responsiveness of cortical neurons is retained and even enhanced. But when kittens were either totally sleep-deprived or selectively deprived of non-REM sleep, the effects on cortical neurons of the monocular-deprivation experience were lost. Conversely, in a separate set of experiments, selective deprivation of REM sleep seemed to exaggerate the effects of monocular deprivation, producing even greater changes in the responses of visual cortex neurons.

If cycling sleep were only involved in the experience-dependent phase of brain development, then there would be no need for it to continue into adulthood. One possibility is that it is retained in adulthood but no longer has a function. But this is unlikely. Recall that the cellular mechanisms involved in the experience-dependent phases of later brain development (plasticity expressed as growth of axons and dendrites, and changes in intrinsic excitability and synaptic strength) are retained in the adult brain to store memories. Could the same be true of the sleep cycle? Perhaps alternating periods of REM and non-REM sleep initially serve to consolidate experience-driven changes in late brain development and then remain in a slightly different form to integrate and consolidate memory.

A basic hypothesis of cycling sleep and memory has been nicely articulated by Robert Stickgold of the Harvard Medical School, who writes “the unique physiology of sleep and perhaps even more so, of REM sleep, shifts the brain/mind into an altered state in which it pulls together disparate, often emotionally charged and weakly associated memories into a narrative structure and . . . this process of memory reactivation and association is, in fact, also a process of memory consolidation and integration that enhances our ability to function in the world.”

A large number of studies in both humans and rats have shown that a normal night's sleep following certain simple learning tasks results in improved performance when subjects are tested the next day. In most of these studies there is not an absolute requirement for sleep in order to consolidate memory. Some memory for the training experience is still present after 8 hours of wakefulness, and this effect is found whether the wakefulness occurs during the day or at night. But normal cycling sleep produces a noticeable improvement. In a way, these experiments prove something that is widely appreciated in folk traditions around the world: many cultures have a saying to the effect of "sleep on it and you'll have a better understanding of the problem in the morning."

Anecdotal reports of sleep-inspired insight abound. Paul McCartney of the Beatles relates that the tune for the hit song "Yesterday" came to him when he awoke from a dream. The nineteenth-century German chemist Friedrich Kekulé claimed that he solved the ring structure of benzene after being inspired by a dream in which a snake was biting its tail. The American inventor Elias Howe reported that the main innovation allowing for the first sewing machine (placing the thread hole near the tip of the needle) came to him during sleep. But do insight and revelation regularly result from sleep or are these just a coincidences that have resulted in a few good stories?

One interesting study of human learning and sleep deprivation comes from the laboratory of Jan Born at the University of Lübeck in Germany, where investigators sought to test the notion that a night's sleep can help yield insight into a previously intractable problem. To do this, a numerical problem was devised that could be solved by sequential application of simple rules. The experimenters embedded within the problem a shortcut that, if appreciated, could allow the subject to respond much more quickly than through the sequential-application method (see Figure 7.3 for the details of this task). None of the participants recognized the shortcut in the first block of trials. After a night's sleep,

though, 13 of 22 subjects had the insight to recognize the shortcut, while, in a different group of subjects, who were not allowed to sleep over a similar interval, only 5 of 22 found the shortcut. The experimenters' conclusion: sleep inspires insight.

A large number of studies have sought to interfere with REM sleep by waking humans or lab animals when an EEG recording indicates that they have entered a REM stage. Selective REM deprivation has been reported to interfere with memory consolidation for a number of learning tasks. In some cases the results have been dramatic: in one report, when humans were trained in a visual texture discrimination task, in which reaction time is taken as a measure of learning, they showed no evidence of learning whatsoever after a REM-deprived sleep but significant learning after either a normal sleep or sleep in which non-REM periods were selectively disturbed. It's important to note that REM deprivation seems to interfere specifically with the consolidation of memories for rules, skills, procedures, and subconscious associations (nondeclarative memory) but not memories of facts and events (declarative memory). Thus the people who spent a REM-deprived night following visual texture discrimination training still had clear memories of the training session (an event) but did not retain their quick reaction times in the task (a nondeclarative skill).

The timing of REM sleep also appears to be important. REM sleep must occur within 24 hours of the training experience in order for it to improve memory consolidation. People who learn a new skill or procedure during the day and then miss that night's sleep will not show any improvement following sleep on the second night. A similar effect is seen in rats, but the interval is reduced: REM sleep must occur within 4–8 hours of training to have a beneficial effect.

REM sleep also appears to be associated with “playback” of the previous day's memories. Kendall Louie and Matt Wilson of MIT used arrays of electrodes to simultaneously record from large numbers of “place cells” (Figure 5.11) in the

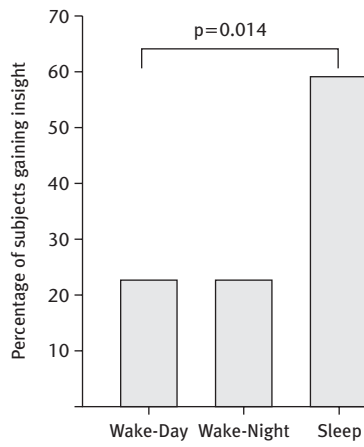
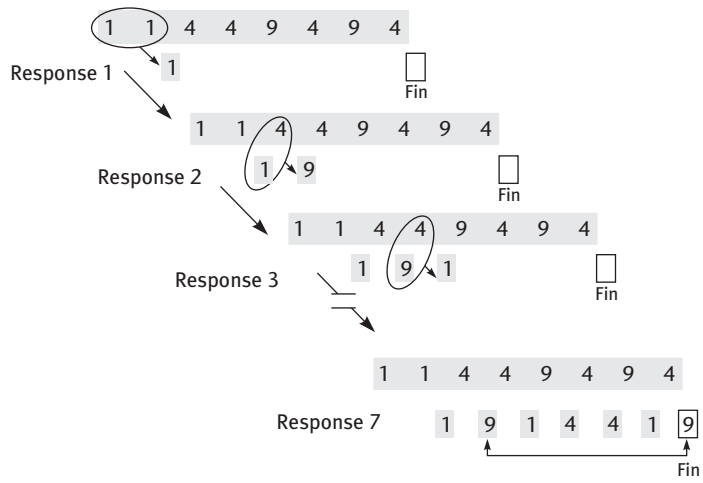


FIGURE 7.3. Sleep as a source of insight. Subjects were trained in a number-reduction task with a hidden rule and then had either intervening sleep, wakefulness during the day, or wakefulness during the night before being retested. The top panel illustrates a sample trial of the task. On each trial, a different string of eight digits was presented. Each string was composed of the digits 1, 4, and 9. For each string, subjects had to determine a digit defined as the “final solution” of the task trial (Fin). This could be achieved by sequentially processing the digits pairwise from left to right according to two simple rules. One, the “same rule,” is that the result of two identical digits is just that digit (for example, 1 and 1 results in 1, as in response 1). The other, the “different rule,” states that the result of two nonidentical digits is the remaining third digit of this three-digit system (for example, 1 and 4 results in 9, as in response 2). After the first response, comparisons are made between the preceding result and the next digit. The seventh response indicates the final solution, to be confirmed by pressing a separate key. Instructions to the subjects stated that only this final solution was to be communicated and this could be done at any time. It was not mentioned to the subjects that the strings were generated in such a way that the last three responses always mirrored the previous three responses. This implies that in each trial the second response coincided with the final solution (arrow). Subjects who gained insight into this hidden rule abruptly cut short sequential responding by pressing the solution key immediately after the second response. The bottom panel shows the percentage of subjects who gained insight into the hidden rule following sleep versus two conditions of wakefulness. Reproduced with permission of Macmillan Publishers, Ltd., from U. Wagner, S. Gais, H. Haider, R. Verleger, and J. Born, Sleep inspires insight, *Nature* 427:352–355 (2004).

hippocampus of rats as they repeatedly ran a unidirectional path in a circular track to obtain a food reward. The experimenters were able to see sequential activation of place cells coding for various locations on the circular track as the animal ran. Then recordings were continued as the animal slept after training. Amazingly, these same patterns of hippocampal place cell activation were replayed during REM sleep. The replay wasn't a perfect spike-for-spike reproduction of the waking activity. Sometimes the pattern was a bit degraded and sometimes the pattern was recognizable from the waking experience, but the overall speed of the activity had changed. Nonetheless, this study, and several others like it from different laboratories, have found statistically significant reactivation of neuronal ensemble activity during REM sleep following training. Was the replay of activity in Louie and Wilson's rats important for consolidating memory of the circular track? If so, what aspects of the experience? Were the rats dreaming of the circular track when the replay activity was recorded during REM sleep? We don't yet know the answer to these questions.

One might be tempted to conclude from this line of evidence that the relationship between REM sleep and memory consolidation is fairly solid. But a bit more investigation will reveal some cracks in the façade. For example, subsequent experiments on both rats and humans have shown that selective deprivation of non-REM sleep can also have deleterious effects on consolidation of some nondeclarative memory tasks, although these tend to be smaller than those achieved by selective REM sleep deprivation. In addition, a recent report indicates that the "playback" of neuronal firing patterns following novel experience in the rat is actually stronger in deep non-REM sleep (stages III and IV) than it is in REM sleep. Most important, it is almost impossible to produce REM sleep deprivation without also causing stress and the accompanying rise in circulating stress hormones. We know that stress can impair learning in both

humans and rats and that both stress and artificial administration of stress hormones can interfere with synaptic and morphological plasticity in rat brains.

Finally, there is a strong prediction of the REM sleep and memory consolidation hypothesis that has not been born out. Modern antidepressant drugs, including the serotonin-specific reuptake inhibitors (SSRIs, such as Prozac and its kin) and tricyclic antidepressants (such as Elavil), produce a partial reduction of REM sleep. But an earlier class of antidepressants, the monoamine oxidase inhibitors, such as phenelzine (Nardil), produce a complete blockade of REM sleep. A similar effect is seen with certain forms of traumatic brainstem damage, yet both of these cases that produce complete blockade of REM sleep (and do so without stress hormone surges) do not seem to produce significant impairment of memory. Conversely, the benzodiazepine class of anti-anxiety drugs (including Valium, Xanax, and Versed) have strong memory-blocking effects, yet leave sleep cycles unperturbed.

So, what are we to conclude? The evidence that cycling sleep has some role in the consolidation and integration of memory is fairly good. The notion that REM sleep has a privileged part in this process is somewhat weaker. My own guess is that a holistic explanation is more accurate: it's likely that something about the cycling between REM and non-REM stages throughout the night is particularly beneficial in memory consolidation and integration. Some theoretical models, involving alternating unidirectional flow of information between the hippocampus and the cerebral cortex, suggest why this might be, but I won't go into those details (interested readers are encouraged to check the Further Reading and Resources section).

So what's special about sleep? Perhaps the type of integration and cross-referencing that sleep allows is somehow different than that of the waking state. One might imagine that the reduction of external sensation during sleep

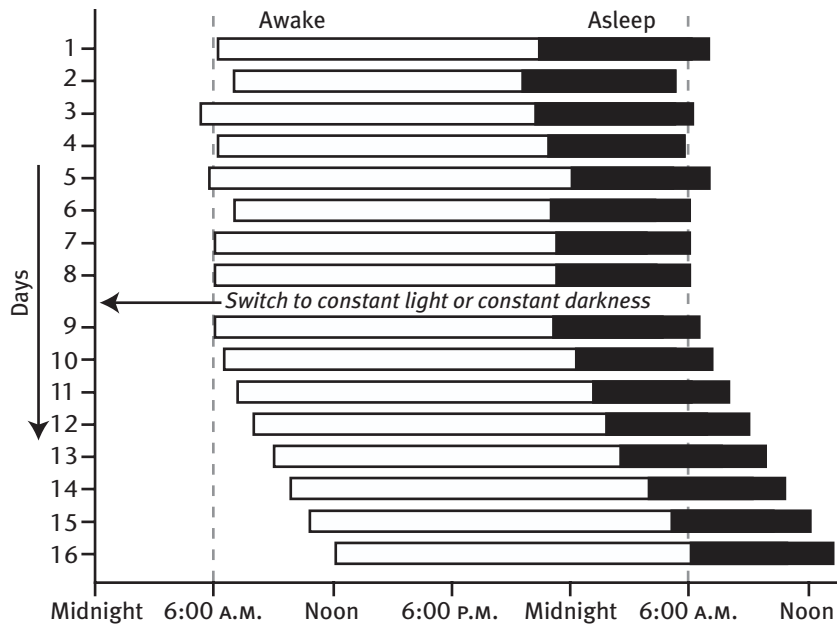


FIGURE 7.4. Changes in the human daily sleep-wake cycle in the absence of external cues. The cycle persists in the absence of cues from alternating light and darkness, but becomes gradually desynchronized to the external world. In this diagram hollow bars represent waking and filled bars indicate sleep.
Joan M. K. Tycko, Illustrator.

allows for associations between more distant and fluid aspects of memory that would be impossible during waking sensory bombardment. Let's keep this thought in the back of our minds and return to it shortly when we consider dreams.

TO THIS POINT, I have discussed the sleep-wake cycle and the stages of sleep without reference to the brain circuitry and molecular events underlying them.

Let's move in that direction by asking a very fundamental question: do daily cycles of activity such as the sleep-wake cycle require a sort of clock within the brain, or is this behavioral rhythm solely driven by external cues, such as those from sunlight? Figure 7.4 shows what happens when someone who has been living in normal conditions for 10 days, with light and dark cues, is placed into conditions where these cues are no longer present (either constant light or constant darkness). The basic daily rhythm of sleeping and waking persists with a near 24-hour-long cycle (about 24.2 hours on average), but this cycle becomes gradually desynchronized from the clock of the external world, and the time of sleep onset slowly shifts later and later. This indicates that there is indeed a clock within the brain but that it requires information to remain synchronized to the outside world.

It turns out that a tiny structure within the hypothalamus called the supra-chiasmatic nucleus (that means "above the place where the optic nerves cross" and is abbreviated SCN) is the body's master timekeeper. This cluster of about 20,000 neurons has a natural rhythm of activity that continues even if you remove it surgically (from a hamster, for example) and grow it in a lab dish filled with nutrient fluids. This activity is approximately, but not exactly, 24 hours long, hence its name, the circadian clock (from *circa* = approximately and *dia* = day). Animals that sustain damage to the SCN no longer have normal sleep-wake cycles. Rather, they have brief periods of sleep and waking distributed randomly throughout the day and night.

The way light coordinates the timing of the internal circadian clock with the external world is mostly driven by a special set of neurons in the retina. These are not the rods and cones that form the visual image, but rather a group of large, spindly cells called melanopsin-positive ganglion cells. These cells send their axons to the SCN to give information about the ambient light level. Significantly, not only are melanopsin-positive ganglion cells stimulated by strong

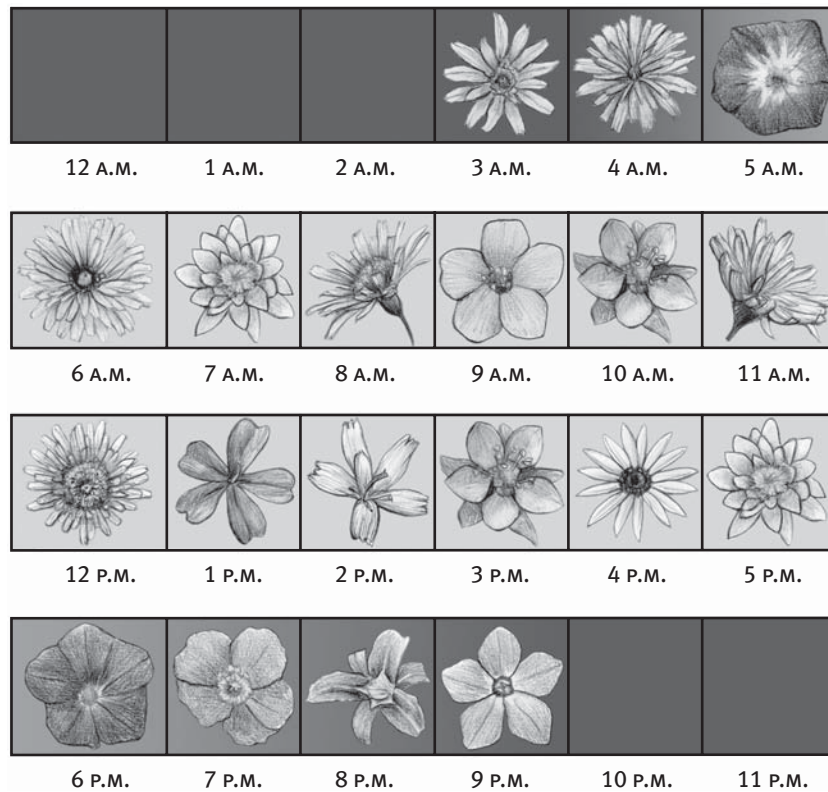


FIGURE 7.5. A rendition of Carl von Linné's flower clock, which uses the opening and closing times of European flowers to estimate time of day. *Joan M. K. Tycko, illustrator.*

sunlight, but they can also be activated by relatively weak artificial lighting. Therefore, when you stay up late under artificial light you are trying to force your internal circadian clock into a 25- or 26-hour period. The result: morning grogginess. The degree to which light can shift the internal circadian clock is limited to about a 1-hour shift per day. So, if you make a flight across 5 time

zones you are likely to need about 5 days for your internal clock to reset to the new local time. The result, as you well know: jet lag.

Is the circadian clock solely a device to drive the sleep-wake cycle? After all, many organisms have functions that are coordinated to the time of day but are independent of sleeping. Even many plants open or close their flowers at particular times of the day (Figure 7.5). This was noted by the Roman philosopher Pliny the Elder, writing in the first century A.D., and was elaborated by the eighteenth-century Swedish naturalist Carl von Linné, who proposed that it would be possible to create an accurate clock by planting a flower garden with carefully calibrated opening and closing times. It turns out that the basic biochemical scheme of the circadian clock found in the human SCN can also be found in lower animals, plants, and even fungi. Clearly, the ability to coordinate biological processes with the light-dark cycle is an important function that is likely to have predated sleeping animals by a billion years. It's most likely that circadian clocks evolved independently, at least twice: fungi have circadian clock genes that are related to ours, but cyanobacteria (as well as archaea and proteobacteria) have a set of unrelated molecules that nonetheless perform similar functions. Interestingly, these ancient bacteria are likely to have developed their circadian clock about 3.5 billion years ago when the Earth's rotation period was only about 15 hours (this is an estimate).

What is it that originally drove the evolution of the circadian clock? We don't know the answer to this question and several hypotheses have been put forward. One appealing idea, formulated by Colin Pittendrigh in the 1960s, is called the "escape from light" hypothesis. Pittendrigh and others noticed that several species of unicellular algae underwent replication of their DNA and subsequent cell division only during the night. It was known that dividing cells can be killed by the ultraviolet radiation present in daylight. Hence, Pittendrigh suggested that circadian rhythms evolved as an escape from light: to

allow sensitive cellular processes to occur in darkness. Recently, Selene Nikaido and Carl Johnson of Vanderbilt University put this to the test: They showed that the unicellular alga *Chlamydomonas reinhardtii* survives exposure to a pulse of ultraviolet light best during the day, when cell division ceases. When lab dishes of *Chlamydomonas* were placed in constant light conditions, they had a persistent circadian cycle of cell division that gradually became desynchronized with the outside world, just like the sleep-wake cycle of humans kept in constant light.

ALTHOUGH RECENT YEARS have seen an explosion of knowledge about the molecular basis of the circadian clock in the SCN and about the brain circuitry involved in the onset and various stages of sleep, the way in which the SCN affects sleep-control circuits is still poorly understood. Axons from the neurons of the SCN make synapses in several adjacent regions of the hypothalamus that in turn project to brainstem and thalamic structures. In addition, the SCN, through a complex circuit of at least three synaptic relays, stimulates the pineal gland to secrete the hormone melatonin. The levels of melatonin, widely sold in health food stores as a sort of “natural sleeping pill,” increase with nightfall and peak at about 3:00 A.M. Melatonin diffuses throughout the body, but has its major effect on sleep-control circuits in the brainstem.

One of the main circuits in the brain that affects the control of sleep is called the brainstem reticular activating system. These neurons, which use the transmitter acetylcholine (and are hence called cholinergic neurons), send their axons to sites in the thalamus, where they modulate the transmission of information between the thalamus and the cortex. Reticular cholinergic neurons are active during waking but gradually become less and less active as non-REM sleep progresses to deeper stages. Indeed, artificial electrical stimulation of the reticular activating system will wake an animal from sleep while stimulation

of its targets in the thalamus will have the opposite effect: it will induce deep non-REM sleep in a previously awake animal. When the transition from non-REM to REM sleep begins, the brainstem cholinergic neurons begin firing rapidly again, and this causes the EEG record to shift from the large-amplitude, synchronized state to the small-amplitude, desynchronized state that's typical of both REM sleep and waking. Why doesn't the animal just wake up at this point, instead of staying in REM sleep? The answer is that other brainstem systems, the serotonin-containing neurons of the dorsal raphe and the noradrenaline-containing neurons of the locus coeruleus are also involved in sleep-cycle control, and these neurons are inactive in both REM and non-REM sleep. The interaction of these three brain regions (together with some others that play a smaller role) determines how sleep stages progress through the night. The large number of neurotransmitter systems involved in sleep-cycle control means that a variety of drugs can affect sleep, producing either a desired effect (such as sleep through the use of drugs that interfere with acetylcholine receptors) or an unwanted side effect (such as the REM sleep-inhibiting properties of many antidepressants that boost serotonin).

EVERYONE LIKES TO talk about dreams. The thing about dreams is that they feel inherently meaningful. In every culture studied to date, people have elaborate ideas about the meaning and causes of dreams. In many cases, dreams are thought to be messages from divine beings or ancestors that can provide guidance or foretell the future—the Judeo-Christian Bible, the Islamic Koran, and the sacred texts of Buddhism and Hinduism all contain stories of prophetic dreams. Dreams can also be thought to represent “soul-travel” to distant locations. If you believe that dreams are meaningful, you can hold that their meanings are either rather straightforward, reflecting prior events and concerns, or are occluded and symbolic, requiring interpretation. The ancient Egyptians, by

about 1500 B.C., had elaborate temples that were specifically built for dream interpretation by trained priests. Manuscripts survive from this time that catalogue the meanings of various dream elements. Most of these are couched in terms of prophecy (“if you dream of crows, then a death will soon come to a loved one”).

Many years later, Sigmund Freud, the father of psychoanalysis, would elaborate a related theory in his famous 1900 volume entitled *The Interpretation of Dreams*. In Freud’s view, dreams arise from subconscious wishes, mostly of a sexual or aggressive nature, that the conscious mind suppresses during the day. But if these subconscious wishes were manifest in dreams in a straightforward fashion, then the dreamer would be awakened by these forbidden desires. So, instead, dreams are symbolic reflections of the dreamer’s suppressed subconscious wishes. Thus, in Freud’s view, a dream of flying represents displaced sexual desire, and a man’s dream of teeth falling out represents a fear of castration (it’s unclear what such a dream would mean for a woman). In many ways the practices of ancient Egyptian dream priests and those of present day post-Freudian psychoanalysts are not dissimilar. They have different goals in that the former are concerned with predicting the future while the latter seek to illuminate past and present events and motivations. But both rely, more or less, upon a dictionary of symbols to guide dream interpretation.

There is no question that dreams *feel* meaningful and symbolic. Indeed, various symbolic dictionaries for dream interpretation (in the basic form of “if you dream of X then it means Y”) are sold by the tens of thousands every year. Although dream interpretation is a phenomenon that is broadly cross-cultural, it is not accepted by all. There are those, mostly a subset of neurobiologists, who hold that the content of dreams has no meaning whatsoever. In their view dreams are merely the byproduct of some other important process, such as memory consolidation. Dreams are the smoke and not the fire, so to speak.

Let's try our best to address this contentious issue systematically. First, we'll consider some ideas about how patterns of activity in the brain might give rise to dreams. Then, we'll talk about the possible function or purpose of dreaming, and finally we'll attempt to ask whether the content of dreams is meaningful.

You know from your own experience that some mornings you may awaken with no recollection of any dreams at all, while at other times the night seems to be crowded with them. In general, unless you awaken during or within a few minutes of the end of a dream, you are unlikely to recall it. For many years it was thought that dreaming only occurred during REM sleep. Now we know that dreams can be reported following awakening from any stage of sleep but that their character, duration, and frequency vary with different sleep stages. Let's illustrate this with some examples from my own dream journal.

Dream 1: Shortly after falling asleep, I had the sensation of swimming underwater, as I did with my kids at the neighborhood pool yesterday.

Dream 2: I couldn't get anything done on my grant application today, and was plagued through the night with worry that I couldn't finish it before the deadline.

Dream 3: I am waltzing with a beautiful woman in a vast space. The woman is not someone I recognize but she seems to know me well. In some respects the room where we're dancing is like a large ballroom, but it's also like a shop in my home town that I visited frequently as a teenager. This shop sold musical instruments, including many unusual ones from foreign countries. My dancing partner is beaming at me, but I'm distracted by the instruments in the cases, which are complex and inviting. I long to go tinker with them, but I'm aware that my dancing partner is getting annoyed that I'm not paying enough attention to her. She grows more and more upset as she senses my distraction. Soon, she's furious and I'm running from her and the scene has

changed to a long, hot road. I jump on a bicycle and pedal quickly, which allows me to pull away from her pursuit. I can no longer see her in the road behind me. However, after a minute or so, the road grows bumpy and I realize that I'm riding over live snakes. As I pedal, the snakes snap at my feet each time they reach the lowest point in the pedal's revolution, so I put my feet up on the crossbar of the bike to avoid being bitten. Of course, I gradually lose speed and I realize that very soon, without forward momentum, I will lose my balance and fall into the snakes that now cover the road like a carpet.

Heaven knows what a psychoanalyst (such as my father!) would make of all this (is a snake, sometimes, just a snake?). These dreams are very different, but they do share two common features: I am the main character and they occur in the present. This is a general feature: the vast majority of dreams are "present-tense, first-person" experiences. Dream 1 is a typical dream from the period shortly after sleep onset. It is brief, and while it has a strong sensory component, this does not progress to form a continuing narrative. It is a scene fragment without much detail and without any particular emotional tone. It is logical, congruent with waking experience, and does not have hallucinatory properties. Significantly, sleep-onset dreams are very likely to incorporate experiences from the previous day's events. In one study, Robert Stickgold and his coworkers from Harvard Medical School had subjects play the video game "Downhill Racer II" for several hours. In the following night's sleep, more than 90 percent of the subjects reported scenes from this game, but only when they were awakened shortly after sleep onset, not in the middle or late parts of the night when deep non-REM (stages III-IV) and REM sleep predominate.

Dream 2 is a typical dream from deeper, non-REM sleep, particularly as would be found in the first half of the night. Like Dream 1, it lacks an unfolding story, but in this case, it almost completely lacks sensory experience. Ba-

sically, it's just an obsessive, emotion-laden anxious thought. The thought is logical and grounded in waking experience, but it does not trigger any form of narrative.

Dream 3 is typical of REM sleep, particularly REM episodes that occur shortly before waking. It is a narrative dream that unfolds in a story-like fashion and is rich in detail. The dream fuses together disparate locations, some specific (the music store of my youth) and others generic (a fancy ballroom I don't recognize). It incorporates elements of fantasy: in real life, I can't waltz for beans, but in the dream I do it flawlessly and without effort. There is a sense of continuous motion throughout the dream (waltzing, running, cycling). The dream narrative incorporates scene changes (from the ballroom to the road) and other events and locations that don't make sense, and yet, in the dream, I accept these phenomena as the natural course of things. There is a suspension of disbelief about otherwise illogical or bizarre experiences. There are many hallucinatory aspects to this dream but they are almost exclusively visual (as opposed to auditory or tactile). Finally, there is a growing sense of anxiety and fear that builds throughout the dream, starting with the mild social anxiety of offending my dancing partner and culminating with the acute fear of a horrible death by snakebite.

Narrative, emotion-laden dreams with illogical and bizarre scenes are the kinds of dreams we are most likely to remember and discuss, partly because they make for good stories, but also because of the structure of the sleep cycle: you are most likely to awaken, and therefore remember your dream, toward the end of the night's sleep when REM predominates. This type of dream is most frequent during REM, but we have recent evidence that people awakened from non-REM sleep during the last third of the night can sometimes recall similar narrative dreams.

There have now been many large studies in which people have kept dream

journals (either written or audio) and a much smaller sample in which people in a sleep lab or wearing a home EEG recording unit are awakened during various sleep stages to provide dream reports. What becomes clear from these studies is that, in general, dream content is very highly biased toward negative emotional states. Fear, anxiety, and aggression are the dominant emotions in about 70 percent of dreams recorded in dream journals. Only about 15 percent of these dreams are clearly emotionally positive. These results seem generally to hold cross-culturally: dreams of being chased are the most common single theme found around the world, from Amazonian hunter-gatherers to urban dwellers in Europe. Interestingly, the proportion of dreams with prominent anxiety, fear, and aggression is greater in dream journals that rely upon spontaneous waking than it is in situations where people are awakened artificially in the last third of the night (reduced from 70 percent to about 50 percent). One interpretation of this disparity is that dreams with negative emotions are more likely to awaken the sleeper, who will then remember and record them.

Given the preponderance of sexual dream interpretations by Freud, it is interesting that less than 10 percent of dreams appear to have overtly sexual content. This is similar in men and women. The previously mentioned male and female genital responses that occur during REM sleep do not seem to be correlated with sexual dreaming.

Elements of the previous day's activity, particularly those with a strong sensorimotor component, are often incorporated into brief sleep-onset dreams, but seldom in narrative dreams. In one study, less than 2 percent of narrative dreams contained autobiographical memory replay of an event from the previous day (although more incorporated a single aspect of the day's experience such as a person or a location). Some researchers have claimed that there is a time-lag effect in which experiences are most likely to appear in dreams 3 to 7

nights later. Counterintuitively, highly emotional experiences during the day seem to require a slightly longer time before showing up in dreams.

So, let's summarize the differences between the waking state and narrative dreaming. Compared to the waking state, narrative dreaming

- incorporates bizarre aspects, including fusions and abrupt changes of locations and individuals, violation of physical laws, and so on;

- is characterized by a lack of internal reflection and an acceptance of illogical events;

- often involves a heightened sense of motion, predominantly conveyed visually;

- has a higher incidence of negative emotion than waking life, particularly anxiety and fear;

- incorporates older memories to a greater degree than new ones;

- is rapidly forgotten unless interrupted by waking.

In recent years, a number of studies have used scanners to measure brain activity in people during various stages of sleep. Let's examine these findings with an eye to whether they can help explain some of the characteristics of narrative dreaming listed above. Although narrative dreams can occur during either deep non-REM sleep or REM sleep, they seem to predominate in the latter, so we'll use the REM sleep stage brain as our template for a physiological analysis of narrative dreaming. Figure 7.6 shows a simplified summary of changes in brain activity during REM sleep as compared to restful waking.

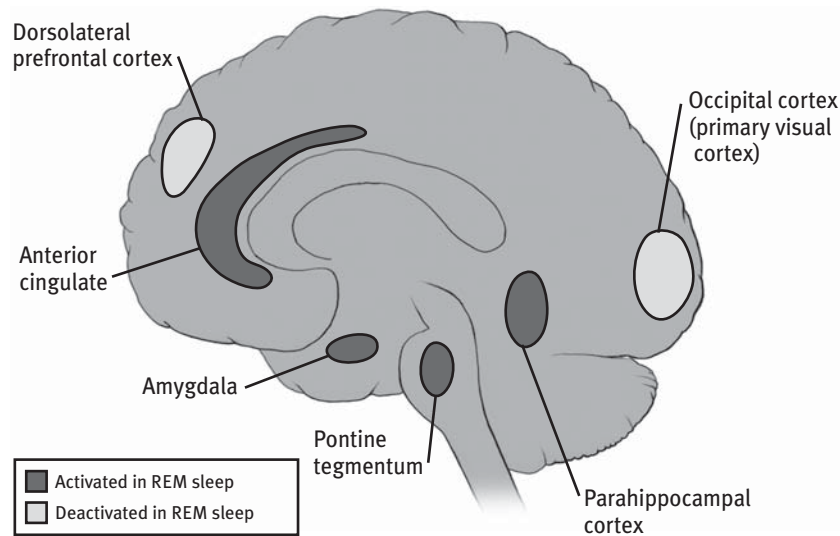


FIGURE 7.6. Some brain regions that show altered electrical function in REM sleep, as determined by PET scans. This figure is not meant to be complete. For example, in addition to the amygdala and anterior cingulate, adjacent parts of emotional circuitry are also activated during REM sleep, including the septal area and infralimbic cortex. Adapted from J. A. Hobson and E. F. Pace-Schott, The cognitive neuroscience of sleep: neuronal systems, consciousness, and learning, *Nature Reviews Neuroscience* 3:679–693 (2002). *Joan M. K. Tycko, illustrator.*

We knew from previous work in animal models that the brainstem reticular activating system is strongly active during REM sleep, and the activity of these cholinergic neurons (in a place called the pontine tegmentum) can be seen in PET scan images. One of the most striking features of the brain scans is that while narrative dreams are intensely visual, the primary visual cortex is almost completely silent during REM sleep. But areas involved in the higher-level analysis of visual scenes and the storage of visual and cross-modal memories

(such as the parahippocampal cortex) are strongly activated. This may help explain why dreams are often constructed from fragments of disparate memories, mostly long-term visual memories stored in these visual association areas.

Another striking feature of the brain in REM sleep is strong activation of regions subserving emotion. In particular, the amygdala and anterior cingulate are strongly activated and these regions appear to play a particular role in fear, anxiety, and the emotional aspects of pain as well as responses to fearful and painful stimuli. This may underlie the prevalence of fear, anxiety, and aggression in the emotional tone of narrative dreams. Finally, portions of the prefrontal cortex, in particular the dorsolateral prefrontal cortex, are deactivated in REM sleep. This is a crucial part of the brain for executive functions (judgment, logic, planning) and working memory. Its deactivation may help explain the illogical character of dreams and the dreamer's acceptance of bizarre and improbable circumstances and plotlines. Essentially, reduced dorsolateral prefrontal activation could contribute strongly to the hallucinatory properties of dreams. In this sense, it is worth mentioning that deactivation of this region is a hallmark of hallucinating schizophrenics (who, in a limited sense, have dreamlike experiences while awake).

Brain scanning with PET is a technique that gives information about the average activation of brain regions. It is very useful, but it does not convey detailed information about either the exact location of individual firing neurons or the fine temporal structure of that activity. These parameters are both critical to understanding the way information is being processed in the brain during narrative dreaming. Animal experiments using implanted recording electrodes have shown that during REM sleep the noradrenaline-containing neurons of the locus coeruleus and the serotonin-containing neurons of the dorsal raphe fall silent, while the acetylcholine neurons of the brainstem reticular activating system fire strongly. The neurons of these three modulatory systems have axons

that project widely throughout the brain, including the thalamus, limbic system, and cortex. Thus some of the regional activity changes during REM sleep, as reflected in brain scanning studies, results from turning up synaptic drive that uses acetylcholine together with turning down that which uses noradrenaline and serotonin.

The increased cholinergic drive also ultimately results in the limp muscle paralysis that characterizes REM sleep. During narrative dreams, the motor cortex and other movement control structures such as the basal ganglia and cerebellum are issuing commands to cause movements, but these commands are blocked from entering the spinal cord by an inhibitory circuit triggered by strong cholinergic drive in the brainstem. This may underlie the continual and effortless sense of movement (including flight) that is so prevalent in the experience of narrative dreams: the commands for movement are being issued but the feedback from the muscles and other sensory organs about how those movements are progressing is no longer present to ground the perception of movement in reality.

ALTHOUGH THE STORY is far from complete, we can certainly say that the pattern of brain activity during narrative dreaming can explain many of the unusual features of dream content. This level of explanation, does not, however, address either the purpose of dreams or the question of whether dream content is meaningful. So, why do we dream? The short answer, sadly, is that we don't really know. The long answer, however, suggests some avenues for investigation.

If you ask a cross section of sleep researchers why we dream, you tend to get answers that reflect that person's area of interest. In this fashion, scientists whose primary interest is emotion will tell you that the main function of dreams is to regulate mood. For example, Rosalind Cartwright, of Rush Presby-

terian—St. Luke’s Medical Center in Chicago, theorizes that dreams function as mood regulators, to allow us to process negative emotions, so we wake up feeling better than we were when we went to sleep. Some psychiatrists say that dreams are like a kind of psychotherapy. Ernest Hartmann of Tufts University has proposed that both dreams and psychotherapy largely function by allowing connections between life events to be made in a safe, insulated environment, away from the outside world.

Biologists with an interest in evolution have proposed that dreaming has developed as a time to rehearse and perfect behaviors that are crucial to survival during waking hours. They function as a kind of virtual-reality environment to simulate life-threatening scenarios in a safe place. In a way, this explanation is not too different from that offered by Hartmann. Both seek to explain the central role of fear and anxiety in dream reports, and both imagine dreaming as a protected environment in which to accomplish important mental tasks.

And, of course, I’ve already discussed the idea that cycling sleep is important for the consolidation, integration, and cross-referencing of memory, so it is a small leap to imagine that dreaming is somehow related to these memory processes. One interesting twist on this comes from Jonathan Winson of Rockefeller University, who thinks of dreams as “off-line memory processing.” In his view, the computational resources needed to integrate experience into memory, if operative only during waking, would require an even larger and ultimately untenable volume of cortex than we already have. So, in order to make the best of the brain volume we have, we run the night shift, so to speak, continuing the process of memory consolidation and integration around the clock, like a wartime munitions factory.

In considering the merits of these models for dream function we should keep several things in mind. First, these models are not necessarily mutually exclusive: for example, dreams could function *both* as regulators of mood and as a

part of memory consolidation. Second, we need to be careful to make some important distinctions between levels of analysis in dreams. On one level are the underlying processes that occur in the brain during the dreaming state. Then there is the experience of the dreaming state while it is happening, and, finally, the report of the dream that will only occur for those dreams that are interrupted or that are followed very quickly by waking.

In my view, each of the models for dream function has some strengths and weaknesses. The psychiatric explanations of dreams as mood regulators or as night therapy provides a plausible rationale for the prevalence of negative emotion in dream reports. But this model has to contend with two important observations. First, there are some people who report no dreams at all unless artificially awakened, and yet, on the average, these people have no unusual incidence of emotional or cognitive problems. Here, one might retreat a bit and posit that the therapeutic value of dreams occurs as a result of their experience during sleep, even if they are not consciously recalled. Second, many of the most emotionally salient events in life never make their way into dreams at all, even in those individuals who report dreams regularly. Some psychiatrists might respond that these events would be manifest symbolically rather than literally and would therefore not always be easy to spot.

The memory consolidation/integration model for dreams is compelling in many ways. Among other things, it provides an explanation of why items in remote memory are often dredged up in dreams: presumably these are being integrated with newer memories. Within memory consolidation/integration models there are some important distinctions. In some, the experience and/or later report of the dream are central to the process. These models, of course, must deal with the same critique leveled at the emotional models above: on average, people who fail to report dreams perform normally in a battery of memory tests. A reductionist variant of the memory model, most forcefully proposed by

J. Allen Hobson of Harvard University, states that the main purpose of cycling sleep is memory consolidation and integration and that the experiences of narrative dreams are basically what the logically impaired (inhibited dorsolateral frontal cortex) and hyperemotional (overactive amygdala, septum, and anterior cingulate) brain can stitch together into a narrative from scraps of mostly visual memory (overactive parahippocampal gyrus). In this view, the content of dreams is merely a funhouse-mirror reflection of memory consolidation and there is no need for symbolic dream interpretation in the Freudian (or ancient Egyptian) tradition.

To me, there has always been a big hole in existing memory consolidation/integration models of dreams. They fail to address why the emotional content of dreams is so negative. My own suspicion about this has been as follows: It is well known that the activation of the negative emotion circuits (fear/anxiety/aggression) in the brain will reinforce memory consolidation in the waking state. Essentially, strong activation of the brain regions subserving negative emotions is a signal that says “write this down in memory and underline it.” During memory consolidation and integration in sleep we need some mechanism to say, “OK. You’ve made this connection with something in long-term memory. Write it down now.” I suggest that that mechanism is activation of the negative emotion centers. In essence, the fear/anxiety/aggression circuitry is co-opted for use in reinforcing memories and connections between memories in the absence of relevant emotional stimuli. Your dreaming brain doesn’t know that the negative emotion circuits have been hijacked, and it integrates the activity in these centers to produce narrative dreams with negative emotional themes.

So, where do these various models leave the question of whether dream content is meaningful? To me, this has always seemed like a nonissue. Certainly, the content of dreams is of some interest under any model of dreaming. Even

diehard proponents of the memory consolidation/integration model of dreaming agree that the content of what is being written into memory and what it's being integrated with are of some value in understanding an individual's mental state. The question is how far to take it. Although there is a place for the analysis of dream content in both psychotherapy and personal growth, I have no confidence (and there is no biological basis to believe) that insight into one's mental state can be gained through analysis of dream content with arbitrary symbolic dictionaries.

The obsession with specific dream content tends to obscure what's really important about dreaming. The most useful thing about the *experience* of dreaming (as opposed to the underlying processes) is not the detailed content of dreams. It's not so crucial that you dream of a cigar rather than a shoe, or of your father rather than your mother. What's most important about dreaming is that it allows you to experience a world where the normal waking rules don't apply, where causality and rational thought and our core cognitive schemas (people don't transform or merge, places should be constant, gravity always operates, and so forth) melt away in the face of bizarre and illogical stories. And, while you dream, you accept these stories as they unfold. Essentially, the experience of narrative dreams allows you to imagine explanations and structures that exist outside of your waking perception of the natural world. In your waking life you may embrace the distorted structures of the dream world or you may be a hard-headed rationalist, or you may blend the two (as most of us do), but in all cases the experience of dreaming has thrown back the curtain and allowed you to imagine a world where fundamentally different rules apply.