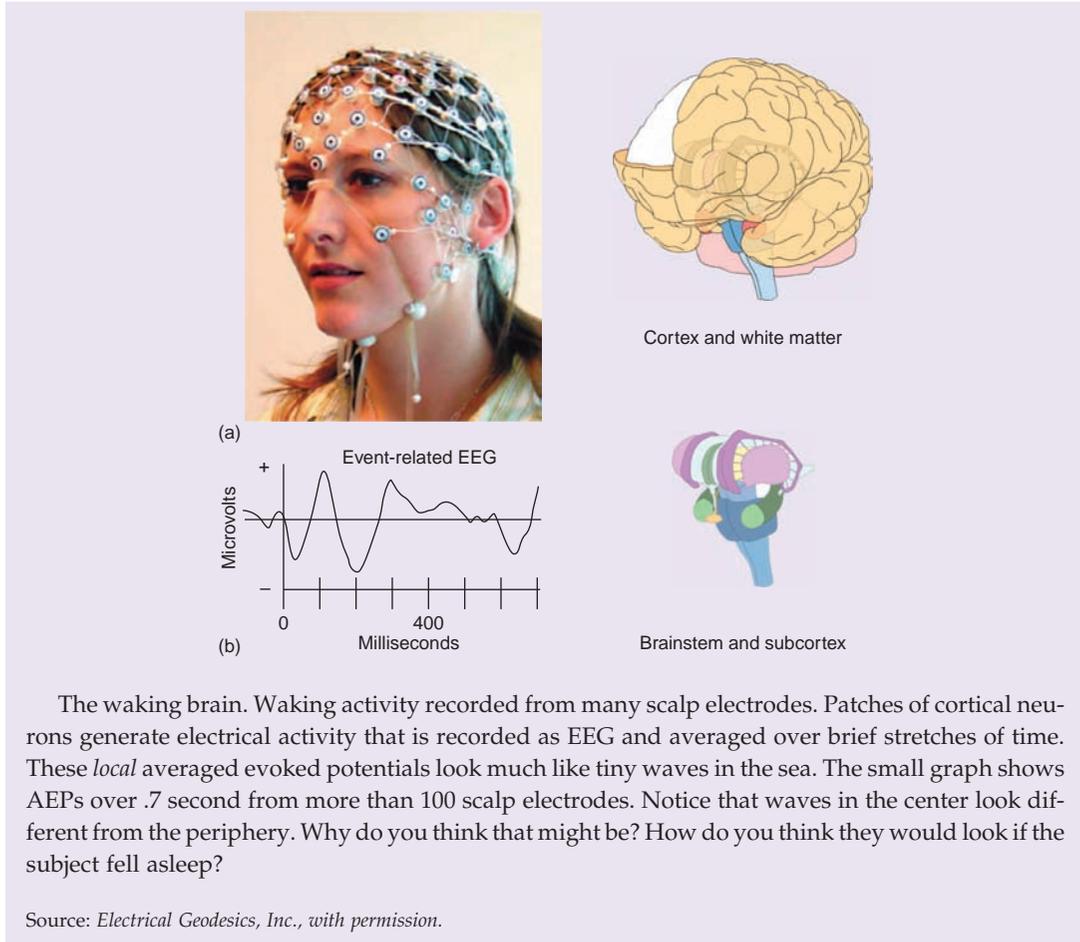


The brain is conscious

OUTLINE

1.0 Introduction	212	5.2 Nonrational thinking	243
1.1 Three global brain states	213	5.3 Working memory in dreams	243
2.0 Waking: purposeful thoughts and actions	214	5.4 Brainstem oscillations trigger dreaming	244
2.1 The stadium analogy: chattering, cheering, and chanting	216	5.5 Lucid dreaming	245
2.2 How does the chattering brain do its work?	221	6.0 Deep sleep: ups and downs	245
2.3 What we expect from conscious people	224	6.1 The need for sleep	245
2.4 Waking has conscious and unconscious threads	224	6.2 Memory replay and consolidation	246
3.0 Attention	229	7.0 Exceptional states of mind	246
3.1 Attention selects conscious events	229	7.1 Epilepsy, drugs, and psychoses	248
3.2 The Posner flanker task	230	7.2 Out-of-body experiences	248
3.3 A model of attention	231	7.3 Neurofeedback	249
3.4 Voluntary attention	238	7.4 Sensorimotor rhythm feedback	249
3.5 Synchrony enables attention	238	7.5 Rhythmic entrainment	249
4.0 Executive control	239	7.6 Hypnosis and conversion	249
4.1 Losing voluntary control	241	7.7 Meditation and yoga	250
5.0 Dreaming	241	8.0 Summary	250
5.1 Dreams are conscious	242	9.0 Study questions and drawing exercises	251
		9.1 Study questions	251
		9.2 Drawing exercise	252



1.0 INTRODUCTION

Consciousness is the water in which we swim. Like fish in the ocean, we can't jump out to see how it looks from the outside. As soon as we lose consciousness, we can no longer see anything. Ancient people knew about waking, sleep, and dreaming because they experienced those states in themselves, and they could see other people when they were sleeping and waking. Sometimes clan members would wake up from a dream and tell others about their inner journeys. All human cultures know about the three basic states.

Scientists also *combine objective evidence with subjective reports*. Scientific studies usually have ways to double-check the reports people give about their experiences. For example, we know that REM dreams show an unmistakable pattern of activity: The EEG shows low voltage, fast, and irregular waves, and the eyes move back and forth in fairly slow and large movements.

When we awaken people during REM dreams, they tend to tell us about vivid, dramatic but frequently disrupted experiences. Whenever we find both the objective signs of REM dreaming and subjective reports from people awakened during those periods, we can feel confident that we have converging evidence that people are telling us about “real” dreams.

1.1 Three global brain states

Sleep, waking, and dreaming are easy to identify based on our own experiences—and also by the electrical activity all over the brain. Steriade (1997), a leading scientist in this field, wrote, “The cerebral cortex and thalamus constitute a unified oscillatory machine displaying different spontaneous rhythms that are dependent on the behavioral state of vigilance.” We will take Steriade’s one-sentence summary as the theme of this chapter. As we will see, the cortex and thalamus work very much like an oscillatory medium, like the ocean. In addition, we know from earlier chapters that the cortex consists of flat arrays of neurons. Indeed, we can think of the cortex and its related brain regions as a huge, oscillatory array of many hundreds of arrays.

For many years the underlying mechanisms for these electrical patterns were unknown. There was debate about whether EEG was even a useful measure. However, basic research has now shown that scalp EEG reflects the fundamental “engine” of the thalamus and cortex. Although the brain’s electrical field is only a side effect of the normal working of the core brain, we can use EEG to understand how the thalamus and cortex do their work.

Figure 8.1 shows the three daily states recorded from one electrode on the scalp. One electrode is enough because states of consciousness involve *global* activities, like day and night traffic in a large city. If daytime traffic is very heavy and nighttime traffic is very light, only one observation point can show the difference.

The daily (circadian) cycle is controlled by precise biological mechanisms, stimulated by daylight and darkness, and by eating, activity patterns, sleep habits, and other factors. A small group of receptors in the retina detect daylight and darkness, signaling the suprachiasmatic (SCN) nucleus, the pineal gland, hypothalamus, and deep brain nuclei to release state-specific chemicals called neuromodulators. Melatonin is an important sleep hormone triggered by the onset of darkness.

Chemical neuromodulators spread very widely in the brain and help to trigger global states (Figures 8.2 and 8.3).

Keep in mind that the thalamus is the “gateway to the cortex.” Most thalamic nuclei are constantly signaling back and forth to corresponding parts of the cortex. The thalamus and the cortex are often considered to be one large functional “engine.” When we shift between major circadian states, the engine changes gear.

Figure 8.4 shows the neural control circuit of the thalamus and cortex, consisting of three connected cells in cortex, thalamus, and the reticular nucleus of the thalamus. The upper neuron in Figure 8.4 is a pyramidal cell in the cortex. Together this circuit works as a “pacemaker” for the major states of the circadian cycle. Signaled by neurochemicals from the brainstem, the three-neuron circuit “pumps” the giant cortico-thalamic core. There are millions of such circuits, but the simplicity of this loop is striking. Notice that the circuit is itself triggered by chemical neuromodulation from the brainstem.

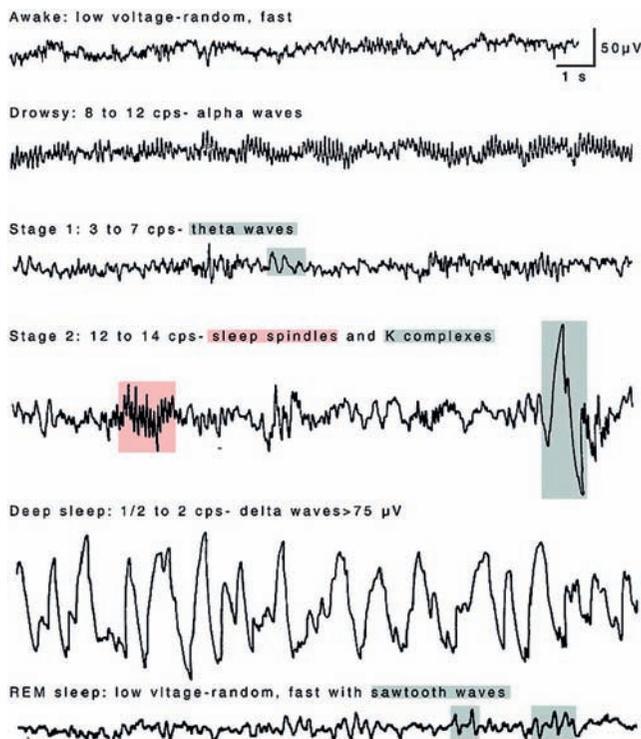


FIGURE 8.1 EEG of waking, dreaming, and deep sleep. To identify brain states, we only need one electrode on the scalp (and a reference electrode that is often attached to the ear). Global states can be identified just by looking at EEG. Waking consciousness and REM dreaming look remarkably similar, consistent with the fact that we experience a rich flow of conscious events during both waking and dreams. Deep sleep looks very different: it is high in voltage, slow, and regular. Source: *Squire, et al. 2008.*

2.0 WAKING: PURPOSEFUL THOUGHTS AND ACTIONS

Waking is our time to open up to the world around us, perceive and explore, think about ourselves and one another, learn and prepare for the future, cope with challenges, express our emotions, and advance our personal and social goals. From a biological point of view, all of our *purposeful* survival and reproductive activities take place during the conscious state.

We have used a “functional diagram” of human cognition since Chapter 2. What we haven’t said is that the waking state is *the necessary condition* for all those mental functions. That fact has many surprising consequences for our understanding of the brain. For example, the global features of the conscious state (Figures 8.1–8.4) may not be obvious, but we know they are necessary for us to have conscious sensations, working memory, and voluntary control of our muscles.

It will help to take another look at our basic functional diagram (Figure 8.5) and think about the boxes that work only in the waking state. They are generally the colorful ones. The gray boxes (long-term memories) continue to store information 24 hours per day. As we will see, conscious experiences we learn during waking periods are often consolidated in slow wave sleep.

Sensory consciousness obviously also depends on the waking state, as do the “inner senses” of verbal rehearsal (inner speech), the visuospatial sketchpad (imagery), and the like. Normal, voluntary control is mainly limited to the waking state.

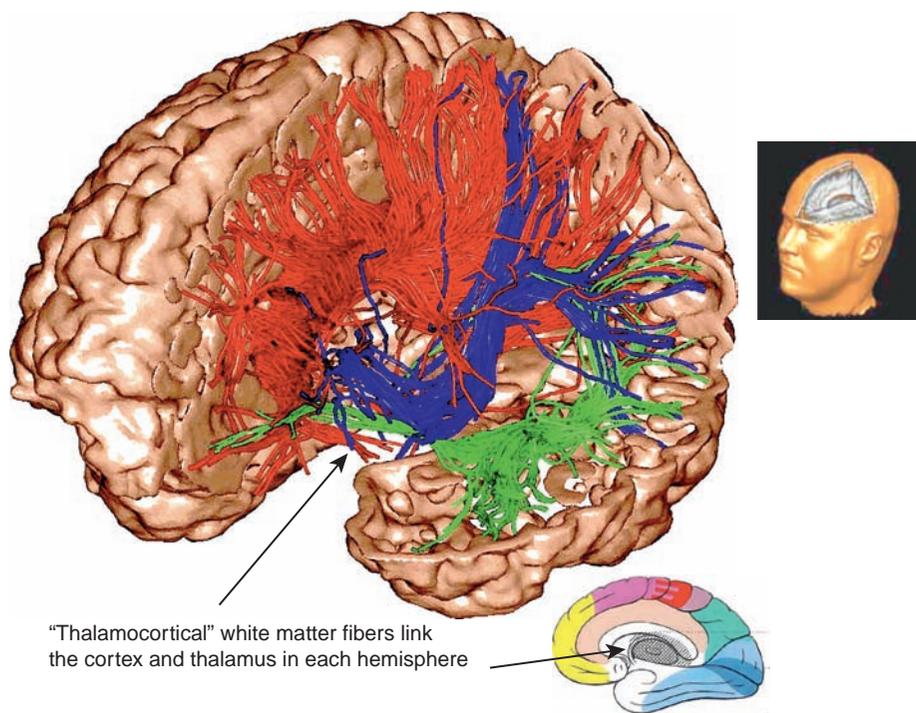


FIGURE 8.2 The cortex and thalamus make up one unified system. The massive size of axonal fiber tracts between the thalamus and the outer layers of cortex. Since axons coming from each cell body are wrapped in glial cells that are filled with lipid molecules, they appear white to the naked eye and therefore were called the “white matter” by traditional anatomists. These tracts are artificially colored in this computer-generated graphic to show the different major pathways. All the fiber tracts seem to emerge from the left thalamus from the point of view that is shown here, but at least equal numbers of axons travel from cell bodies in cortex to the corresponding nucleus of the left thalamus. Traffic is always two-way or “reentrant” in the thalamocortical system, a fundamental fact that requires explanation. Notice that there is no cross-hemisphere traffic in this image. The next figure shows equally massive cortico-cortical highways connecting the hemispheres laterally, mostly flowing across the corpus callosum. As Chapter 3 points out, it is possible to lose an entire hemisphere without losing consciousness as long as the second hemisphere is spared along with the brainstem. Source: *Izhikevich & Edelman, 2008*.

Voluntary selective attention also occurs primarily during waking. Voluntary attention is shown in Figure 8.5 as an arrow running from the central executive (roughly, the frontal lobes) to brain activities that are enhanced by attention. Spontaneous attention is not under voluntary control, but if someone yells out loud, a large dog barks unexpectedly from a few feet away, or a truck looms into your field of vision, attention will be “stimulus-driven.”

Many biologically significant events trigger attention “bottom up,” such as the smell of food when you are hungry. We spontaneously pay attention to personally significant stimuli as well, like the sounds of our own names. In the figure we symbolize stimulus-driven attention with an arrow coming from the sensory boxes of the diagram to suggest that some stimuli are inherently attention-capturing.

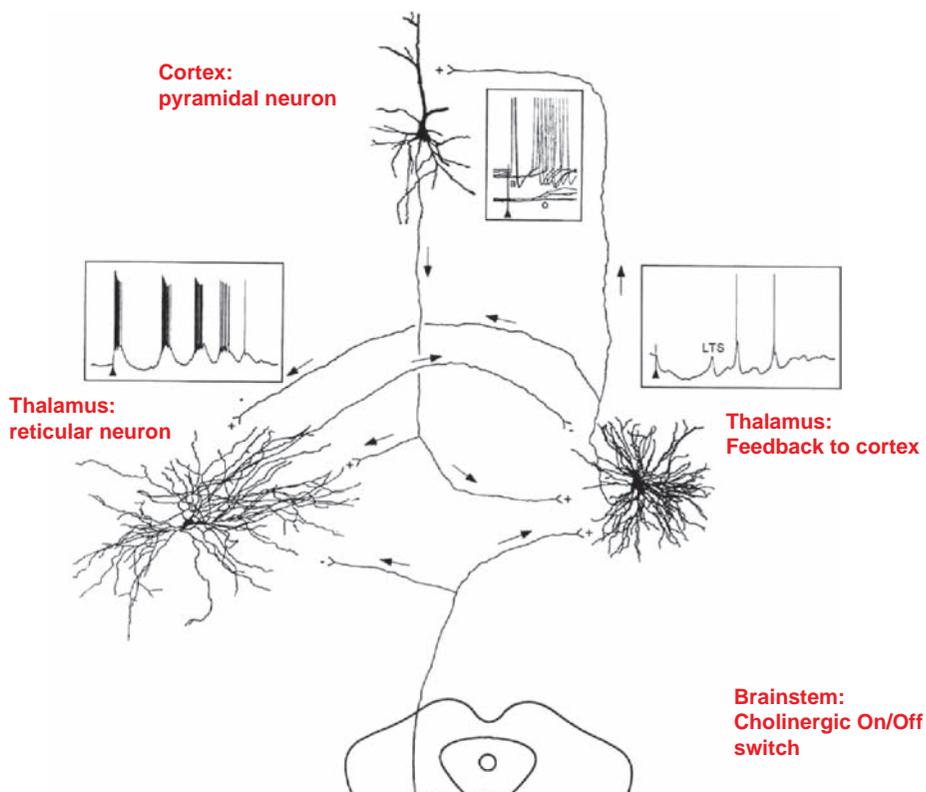


FIGURE 8.3 The state control circuit: three neurons in a thalamocortical loop. The basic rhythmic “pump” of the brain. Waking, sleep, and dreaming are driven by thalamocortical oscillations. Thalamic nuclei interact closely with corresponding regions of cortex. This core brain is shared by other mammals and birds. Source: *Adapted from Steriade, 2006.*

Later in this chapter we will see that dreaming has some features of waking consciousness, such as vivid conscious imagery and working memory. Still, the fact remains that our goal-directed actions happen during the waking state, including thinking and problem solving, food gathering, social behavior and mate seeking. It makes sense therefore that task-related signaling in the brain is mostly found in waking consciousness.

2.1 The stadium analogy: chattering, cheering, and chanting

Waking EEG has puzzled scientists since 1929, since it looks very irregular, even random, as if it’s a kind of “white noise,” such as the random noise we hear from waterfalls and ocean waves. If we record the sound of a waterfall and then average separate stretches of sound, the average will look like a flat line with zero voltage. That is because random activity is so unpredictable that it adds up to zero. The chance of a voltage at any moment being above and below zero is about equal. As we’ve seen with the averaged evoked potential in Chapter 5, we can

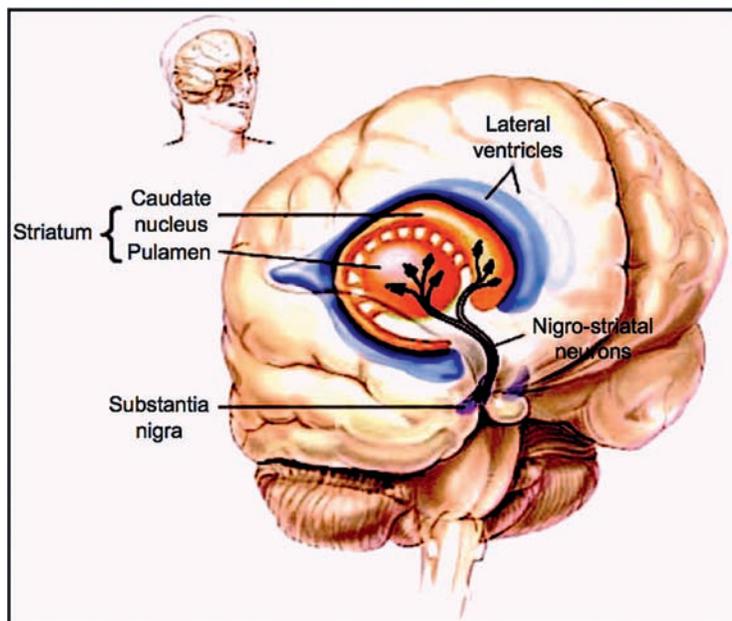


FIGURE 8.4 Chemical switching controls the state circuit. The daily states of consciousness are turned on and off by surprisingly small numbers of neurons, located at the bottom of the brain in nuclei like the substantia nigra (SN), as in the figure (dark substance). Their widespread axons spray special neurochemicals called “neuromodulators” to modify local neurotransmitters. The bundle of axons that project from the small SN in the bottom of the brain are called the nigro-striatal neurons because they start at the substantia nigra and terminate in the striatum (“striped region”) of the basal ganglia. Source: *U.S. National Institute of General Medicine*.

use that fact to obtain beautiful AEP curves that are time-locked to a stimulus. The random EEG just drops out of the averaging process.

2.1.1 Chattering in the waking brain

If we think of the brain as a huge football stadium with thousands of people just chattering with one another, the averaged sound is so irregular that it resembles white noise. However, every conversation in the stadium is very meaningful to the people doing the talking. We see *local synchrony* between two individuals in a conversation and *global randomness* because none of the conversations are linked to one another. It’s convenient to call this the “chattering” state of the football stadium.

Figure 8.6 shows that during the waking state, neurons in different parts of the cortex and hippocampus are “phase-locked” to one another. (Phase-locked simply means “synchronized with a small lag time.”)

The evidence comes from Cantero and colleagues (2005), who recorded from hundreds of neurons directly in the brain of an epileptic patient. Notice that the “Waking” column shows very high correlated activity between different parts of the cortex (top) and also between the hippocampus and neocortex. Both of those regions are very active during waking, but we now know that they are also highly correlated with each other at the single neuron level. That is analogous to spectators in the stadium talking “in sync” with one another. But like the

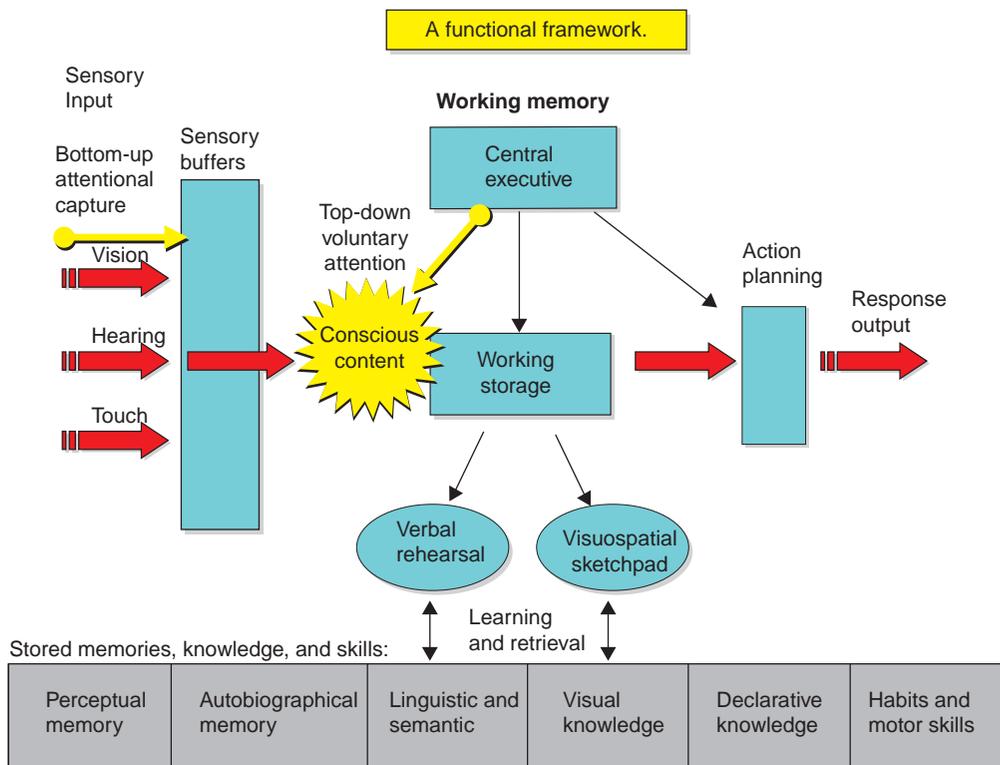


FIGURE 8.5 We are *not* conscious of all cognitive functions at the same time, but we can get rapid conscious access to all the *colored* boxes in the diagram. The *gray* boxes at the bottom are never directly conscious. However, we can *retrieve* conscious information from long-term memories. Notice that the diagram looks very different in dreams and sleep. Source: Baars, with permission.

chattering people in the stadium, their conversations are independent of one another. If we record the overall sound in the stadium, it seems random, but if we record the talk of two people in a conversation, we can see the synchronized activity.

Although the stadium analogy is not supposed to be taken literally, two people talking to each other do “dance” in synchrony with each other, so a slowed-down video of a conversation will show them “micro-dancing” with each other. We can think of Figure 8.6 as showing relatively localized synchrony between regions of the brain that are working together. During deep sleep and dreaming, that kind of synchrony breaks down, as you can see in the second and third column of the figure.

The conscious state therefore seems to support local synchrony (or phase-locking), while deep sleep and dreaming do not. As we will see next, there is very direct evidence that synchrony serves as an important coordinating rhythm for neurons that may be widely dispersed but that are supporting the same cognitive task, whether it is sensory perception, motor control, memory storage, or the other active tasks in our functional diagram (see Figure 8.5).

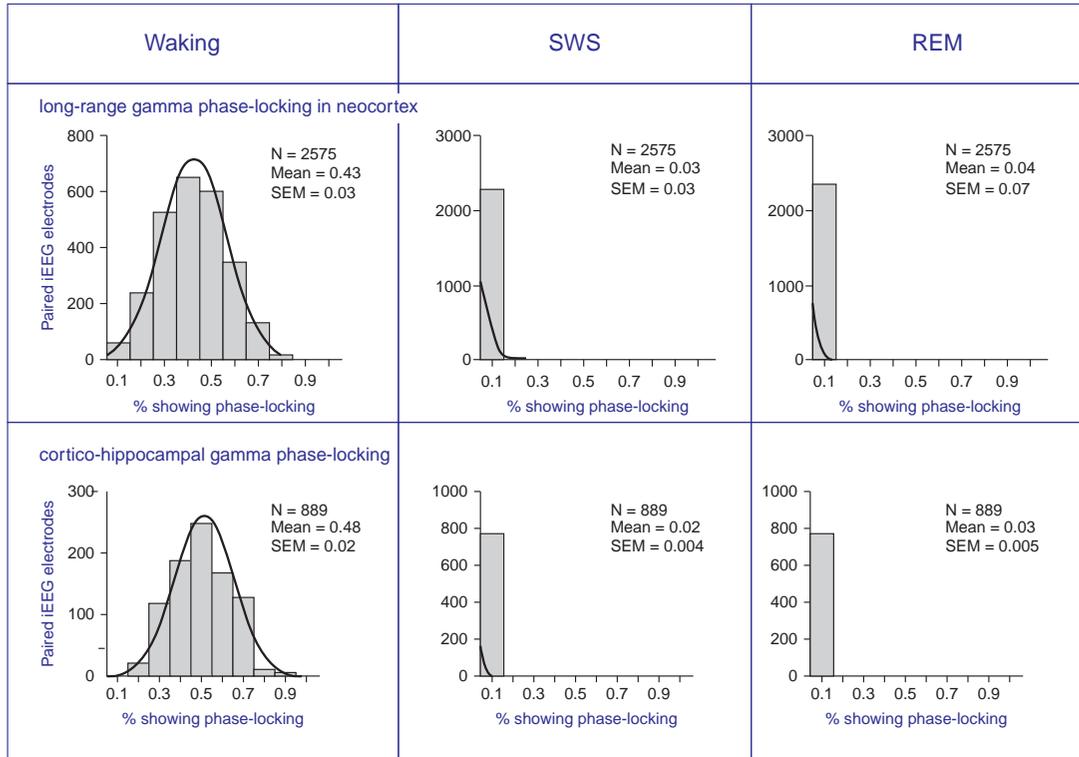


FIGURE 8.6 Synchronized “conversations” between neurons during waking. If we think of each neuron as a spectator in a large football arena, during the conscious state thousands of spectators are chattering with one another at the same time. Each dialogue synchronizes just two people, but hundreds of different conversations are happening at the same time. There is *local* synchrony but not *global* synchrony. Source: Cantero & Atienza, 2005.

2.1.2 Cheering in the waking brain

Football spectators are not always chattering to one another locally. They do at least two massively coordinated actions. One we will call *cheering*, such as when one team scores a thrilling goal. Ten thousand people suddenly applaud (or boo) out loud. Since this is an event-related cheer, it is analogous to the event-related potential. In the brain we commonly average evoked potentials over a number of triggering events, like the thrilling football play that triggers a cheer. That is the averaged evoked potential. Sending a big flash or a loud noise through the brain is very much like a simultaneous cheer going through a football stadium. Suddenly all the noisy background chat turns into a giant “hooray!”

2.1.3 Chanting in the unconscious brain

What about unconscious periods, like deep sleep (slow wave sleep)? You can see in Figure 8.1 that it consists of very large, very slow (by brain standards), and very coordinated brain activity. We know that billions of neurons are highly coordinated during SWS because

all their activity adds up during the UP state (the peak of the slow wave), and nothing seems to be happening during the DOWN swing of the slow wave.

In fact, direct brain recordings show that during the DOWN swing of the global wave most neurons in the cortex are pausing, while during the UP phase billions of neurons are firing. This is called “buzz-pause” activity, and it appears to be controlled by the neurons shown in Figure 8.3: the state control circuit. Notice that some of these neurons are located in the thalamus and others in the cortex. (The whole circuit is also controlled by small clumps of neurons in the bottom of the brain, as shown in Figure 8.4.)

The stadium analogy holds nicely for slow wave sleep, where billions of nerve cells are going “buzz-pause” over and over again, from 0.5 to 3.5 Hz (Figure 8.7). That is presumably why waking cognitive functions are largely lost during slow wave sleep.

We can get some confirmation of this hypothesis from the case of epilepsy. There are many different varieties of epilepsy, and not all involve a total loss of consciousness. But we can study cases that do lead to a temporary sleeplike state. Figure 8.8 shows the EEG of a child with epilepsy. Childhood epilepsy is usually a passing condition but one that must be treated medically.

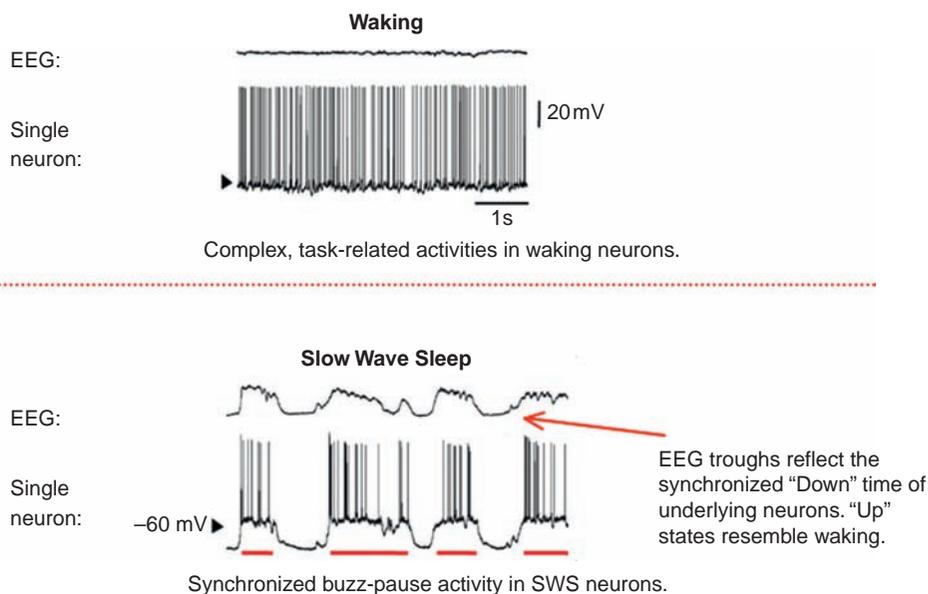


FIGURE 8.7 Chattering and chanting neurons. The waking EEG looks small, irregular, and faster than slow wave sleep. It is believed that waking (and REM dreaming) therefore involves more differentiated information processing in much the same way that a stadium full of talking people serves to process more information than the same people all chanting in unison. The unison chanting is largely redundant (you can predict the crowd chants from just one person) so the information content is lower. Because the chanting brain stops working from 0.5 to 3.5 times per second, we cannot do any cognitive work during the DOWN swings of the slow waves. Neurons can fire and even synchronize during the UP phase, but any task longer than a fraction of a second will be disrupted. You can think of it as rapidly switching a computer on and off, several times a second. The computer might be working when you turn it on, but by switching back and forth, you disrupt any long-lasting computational processes. Source: *Adapted from Steriade, 2006.*

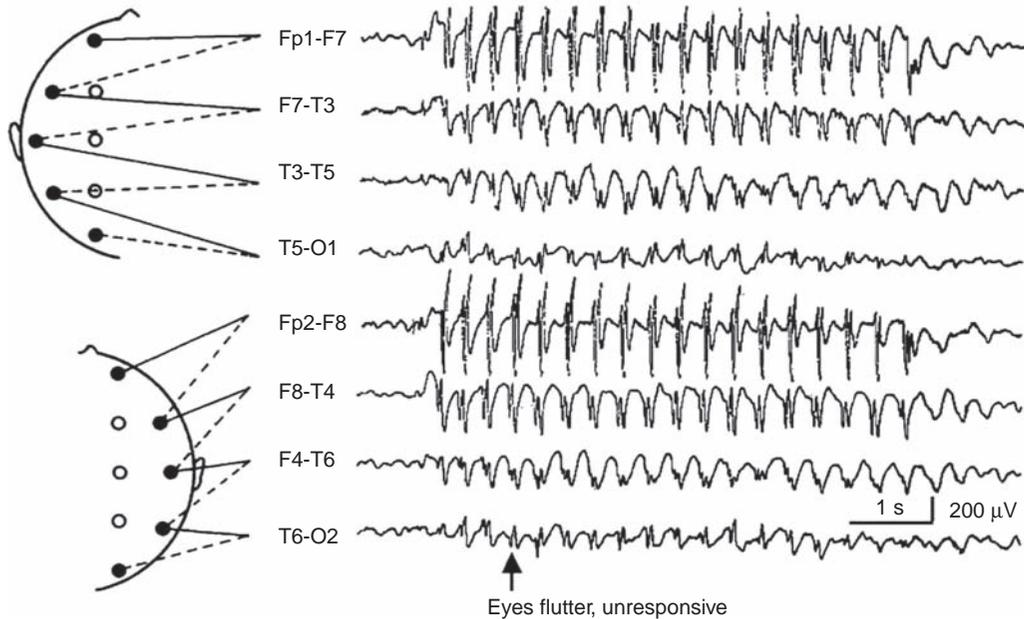


FIGURE 8.8 Slow hypersynchrony in epileptic loss of consciousness. The surface EEG of a 7-year-old girl during an epileptic seizure with loss of consciousness. Epileptic loss of consciousness shows slow, hypersynchronized global EEG similar to deep sleep but characteristically more jagged. Other unconscious states, like coma and general anesthesia, also show slow, high-voltage, and synchronized waves spreading over the cortex, suggesting that synchrony by itself is not the marker of consciousness. Tonic-clonic seizures are cortical. Source: *Blemenfeld, 2005*.

Other unconscious states also show slow EEG waves, except for deep coma, which may show a very low voltage level so that peak waves simply drop out. However, scalp EEG sometimes fails to pick up EEG activity deep in the brain, so a low overall level of the EEG does not necessarily mean there is no consciousness at all. It is important to remember that scalp EEG only picks up 0.1 percent of the voltage level at the cortex. It is therefore possible to miss brain activity if we only look at scalp EEG.

In some cases, patients have been wrongly diagnosed as being in an irreversible coma when closer observations showed signs of consciousness (Laureys et al., 2002). Medical scientists have therefore proposed a new diagnosis called the *minimally conscious state* (MCS) for conditions that may look like coma on the outside but that may actually involve patients who have conscious periods.

2.2 How does the chattering brain do its work?

If the stadium analogy is right, most cognitive tasks happen during chattering states. That includes both waking and dreaming (see Figure 8.1). Waking and dreaming EEGs look irregular and low in voltage because there is no global synchrony. However, we expect there to be local synchrony (technically, local phase-locking).

We will discuss dreaming later in this chapter. Here we will only deal with the conscious waking state. The question is, how does a brain full of randomly chattering neurons do its work? After all, the waking brain does all the purposeful work we need to survive and propagate the species. The answer is now clear. In the giant stadium of the brain there are many *synchronized* conversations taking place between neurons “talking to” one another to get things done. There is nothing to evoke a global cheer in the stadium.

If we then compare the same patient during deep sleep and dreaming, there is no significant correlation between the same neurons. This evidence is what we would expect on the stadium analogy. Waking EEG is so irregular that different periods sum up to zero. The same thing would happen if we recorded random conversations in a football stadium. “White noise” is the technical word for random sounds, like the sound of a waterfall or a buzz of talking in a large auditorium.

What seems to be happening in conscious states is that the overall activity looks random, but all kinds of purposeful tasks are going on using local synchrony.¹ In dreams, much the same irregular EEG can be observed, except that we cannot perform survival tasks. The function of dreaming is therefore still unclear. We know, however, that executive brain functions are strongly inhibited and that sensory input is generally blocked as well. (Voluntary attention is not possible during sleep and only rarely during dreams.)

Deep sleep shows global synchrony (see Figure 8.1). In “slow wave sleep” (SWS), massive numbers of neurons show broadly synchronized *bursts* and *pauses* one to four times per second, adding up to slow, high-amplitude EEG waves. This is the least conscious state of the daily cycle, as measured by the arousal threshold—by playing louder and louder sounds until the subject wakes up.

The stadium analogy for deep sleep is tens of thousands of people chanting in unison. The total sound in the stadium therefore goes up and down in slow synchrony. Notice that because everybody is chanting the same words, the information flow inside the stadium is small. If everyone were carrying on separate conversations, much more information would be transmitted between people. SWS therefore looks like a state of *high redundancy* and *low information flow*.

In summary, in SWS billions of neurons “buzz” together and “pause” together. Waking shows much more differentiated and task-specific signaling. The difference between sleep and waking is not just behavioral and subjective, but it’s also in our ability to execute life-relevant tasks. The functional role of the conscious waking state has now clarified. Slow wave sleep has at least one known function, as we will see. However, we still do not know why we dream, though many ideas have been offered. Biological adaptations often have multiple functions. Our lungs are necessary for taking in oxygen and expelling CO₂, but they are also used to control speech, singing, shouting, whispering, and playing the flute. Lungs evolved when vertebrates began to populate the land, while human speech built on that ancient biological foundation only about 100,000 years ago.

¹ For example, the lower ventral stream of vision yields reportable conscious object representations, like visual coffee cups or a kitchen chair. The upper dorsal stream of the visual brain represents body space and controls actions like manual reaching, but its contents are not reportable as conscious (Milner & Goodale, 2008). Yet both the dorsal and ventral streams require the state of waking consciousness to work.

In the same way, the brain's circadian states are likely to have more than one function. The onsets of both waking and sleep trigger gene expression in hundreds of different neural genes. In waking we have easy access to a vast repertoire of skills and capacities. One of these is voluntary attention; we can decide to pay attention to this book or to yesterday's notes. Consciousness and attention are intimately related but are not identical. When we selectively attend to one thing over another, we become conscious of the attended object. Those conscious moments may then trigger further attentional selection, and so on. We cycle between experiencing things (consciousness) and deciding what we want to experience next (selective attention).

Figure 8.2 is a reminder of waking state functions, including selective attention. With 100 billion neurons firing about ten times per second, and excitatory neurons triggering off other excitatory neurons, you can imagine what an ocean of mutually pushing waves and troughs we have oscillating in our brains every second. Fortunately, most excitatory neurons are controlled by inhibitory neurons so the brain can regulate its state of excitation. Otherwise we might get epileptic seizures, with giant waves of excitation constantly triggering new waves so the cortex goes into overdrive. Like all the organs of your body, the activity of the brain is under careful homeostatic control.

TABLE 8.1 Major Features of the Conscious State

-
1. A very wide range of conscious contents
 2. Widespread brain effects beyond the specific contents of consciousness
 3. Informative conscious contents
 4. Rapid adaptation (learning and coping)
 5. The "fleeting present" of a few seconds
 6. Internal consistency
 7. Limited capacity and seriality
 8. Sensory binding
 9. Self-attribution
 10. Accurate reportability
 11. Subjectivity
 12. Focus-fringe structure
 13. Consciousness facilitates learning
 14. Stability of conscious contents
 15. Object and event-centered
 16. Consciousness is useful for voluntary decision making
 17. Involvement of the thalamocortical core
-

Source: *Modified from Seth & Baars, 2008.*

During waking consciousness, the thalamocortical system reveals a constant flow of signal traffic, with thousands of messages going back and forth. Figure 8.3 shows a large-scale simulation of the known neurons and synaptic signal flow in the thalamocortical system (Izhikevich et al., 2004, 2008).

Waking consciousness resembles the back-and-forth flow of traffic in a busy city. At night, street traffic might dwindle to a few cars, but during the rush hour, vehicles are constantly going from any location to any other. It is that ability to go anywhere, guided by local goals, that makes cars useful. Waking tasks serve a huge variety of functions with great flexibility.

Humans have access to a remarkable range of conscious events—the sight of a single star on a dark night, the difference between the sounds “ba” and “pa,” and the goal of studying for an exam. All sensory systems do a great deal of unconscious processing, leading to conscious, reportable sights, sounds, and feelings.

Recalling an autobiographical memory also results in conscious experiences, like your memory of seeing this book for the first time. Inner speech and imagery have conscious aspects. Asking someone to rehearse a list of words usually results in conscious inner speech. People vary in the vividness of their visual images, but dreams are generally reported to have vivid imagery (Stickgold et al., 2001). Finally, action planning can have conscious components, especially when we have to make choices about our actions (Lau et al., 2004a, b). Normally, we may not have to think much about the action of walking, but if we injure a leg, even standing up and walking can become a consciously planned process (Sacks, 1984).

2.3 What we expect from conscious people

Table 8.1 presents 17 properties of consciousness that are generally recognized in scientific and medical literature. (Of course, the humanities, arts, philosophy, and religion have a long history of exploring consciousness, too.) People with head injuries are often given a mental status examination, which tests for abilities we expect normal, conscious people to have (McDougall, 1990). The test includes the following:

1. Orientation to time, place, and person: “What day of the week, date, and season is it?” “Where are you now?” “Who are you?” “Who am I?” (asked by the examiner)
2. Simple working memory: “Remember these three objects. . . .”
3. Attention and calculation: “Count down by sevens starting from 100.” (100, 93, 86, 79, 72 . . .)
4. Intermediate recall: “What were the three objects I asked you to remember a few minutes ago?”
5. Language: Asking the patient to identify a wristwatch and a pencil, to repeat a sentence, to follow three simple commands, to read and understand a simple sentence, and to write their own sentence.
6. A basic visuomotor skill: Asking the patient to copy a drawing of a line pentagon.

The mental status exam gives a broad overview of normal mind and brain functions. Some disorders involve disorientation, others affect short-term memory, and still others impair visual and motor coordination.

We also expect healthy, conscious adults to do *realistic thinking*. While dreams are unrealistic, waking consciousness has been believed to be necessary for logical, mature, and reality-oriented thought. Nevertheless, we routinely experience waking fantasies, unfocused states, daydreams, emotional thinking, and mind wandering.

2.4 Waking has conscious and unconscious threads

It is important to keep in mind that waking cognition is woven of *both* conscious and unconscious threads, constantly weaving back and forth. For example, the process of reading *these words* is only partly conscious. You are a highly practiced reader, and you have learned over

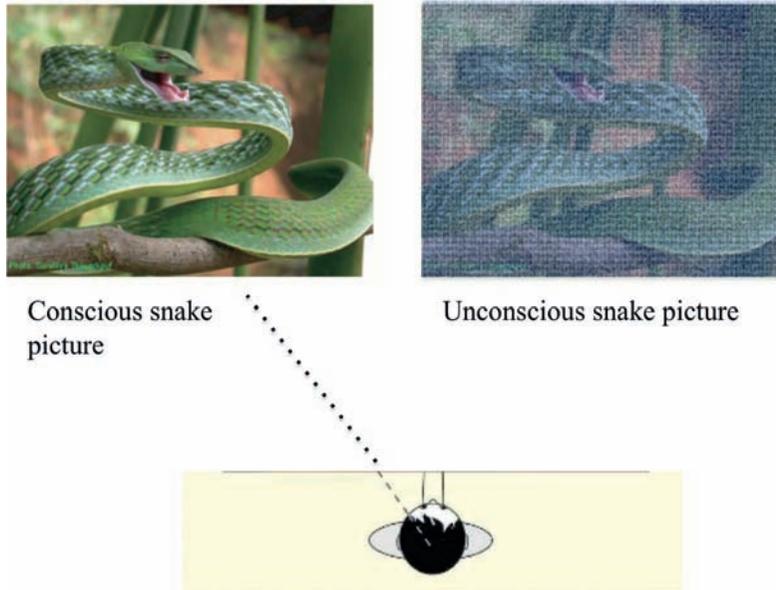


FIGURE 8.9 Comparing conscious versus unconscious events during the waking state. The subject can report the snake on the left side but not on the right side, even though the experimental stimulus is identical. This can be done using binocular rivalry, for example. In this experiment the emotional brain (the amygdala) can recognize the unconscious snake. Humans evolved in environments where deadly snakes were not unusual. Source: *Ohman et al., 2007*.

many hours of practice to automatically convert *these tiny marks on paper* into your own inner speech and then into unconscious processes like word recognition, grammar, and meaning.

We do not become conscious of every mental step in reading a sentence. In fact, there is a great deal of scientific evidence today that all cognitive tasks have many conscious and unconscious components. Figure 8.9 shows an example of unconscious detection of the picture of a snake. Human beings are attuned to detecting some things unconsciously, it seems, including snakes and even facial expressions, which are processed through the visual system, and trigger the fear-sensitive amygdala, a major subcortical center for processing emotions.

One can imagine how that ability may have evolved, since humans (and our ancestors) lived for millions of years in environments where snakes were an everyday, deadly threat. Human beings learn a vast amount of information from other people, such as the danger of crossing busy streets without looking. We are not innately attuned to cars rushing through a street, although we may be afraid of “looming” objects like a fast-approaching elephant.

Until recently, however, the evidence was still hotly debated on whether humans respond to genuinely unconscious stimuli. Studies like this one seem to prove the point convincingly (see Figure 8.9) (Ohman et al., 2007).

Even conscious sensory percepts have stages of unconscious processing (Figure 8.10). We have both psychological and brain evidence to that effect. Social psychologists like Banaji and Greenwald (1995) have found evidence that social perception and inference seem to have unconscious properties as well.

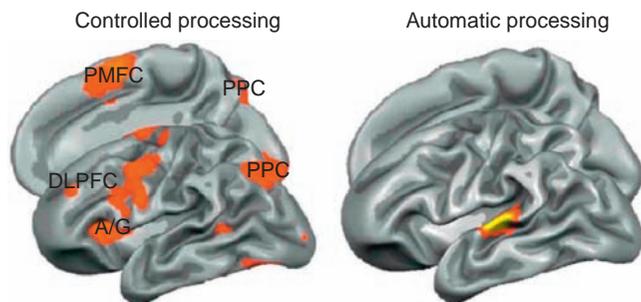


FIGURE 8.10 Voluntary and automatic skills. The brain images show cortical activity during two identical behavioral tasks. The difference is that the left-side task is novel and therefore requires more conscious and voluntary control (labeled “controlled processing”). The red-orange regions indicate fMRI peak activity mainly in the prefrontal and parietal lobes. The brain images on the right only show activity in the auditory cortex, probably because the specific auditory stimulus is never entirely predictable. Just like riding a bicycle, the most predictable parts of a practiced task tend to fade from consciousness. Instead of controlling every movement, we control higher levels, like which direction to steer. PMFC = premotor frontal cortex; PPC = posterior parietal cortex; DLPFC = dorso-lateral prefrontal cortex; A/G = anterior gyrus. Source: Scheider, 2009.

Almost all cognitive tasks we know take place during the waking state and have both conscious (reportable) and unconscious (nonreportable) components. Most cognitive tasks we know are therefore *consciously mediated*. Working memory, for example, has both conscious and unconscious components. If you rehearse seven numbers, you will notice that some are conscious at any moment, but others are not. The instructions to rehearse and remember are obviously conscious and so is the set of items as you see or hear them. But we are not aware of the nonrehearsed items at any moment, of the important role of the basal ganglia in controlling inner speech, or of the automatic (habitual) components of any task. There are no completely conscious cognitive tasks, as far as we know, and there may be no completely unconscious ones (Baars & Franklin, 2003). (Franklin has suggested the term “consciously mediated” for cognitive tasks that have a consciousness but are otherwise unconscious.)

The basal ganglia and cerebellum are very large brain structures that are believed to function without supporting moment-to-moment conscious contents, even in the waking state. The cerebellum can actually be lesioned on both sides and people will continue to behave much as before but without the ability to control fine motor movements. In humans those structures have many other cognitive roles but without direct conscious contents.

What can we do completely unconsciously? We still do not know the answer, because it is difficult to do careful studies on sleepwalking, sleep movement disorders, epileptic “automatic behaviors,” and other “zombie states” (Crick & Koch, 2003). There are many reports about automatic behaviors from individuals with sleep disorders and epilepsy. To verify those reports we need brain recordings that are difficult to obtain in freely moving people. It is also possible that epileptic behavioral automatisms, for example, reflect momentary conscious “flashes” that are known to exist (Kranczioch et al., 2006). It is therefore hard to test whether there are complex but entirely unconscious behaviors, in part because we simply do not know the distinctive brain correlates of consciousness as yet (but see Gaillard et al.,

2009; Revonsuo, 2006). We do not know yet what difference enables consciousness of the ventral but not the dorsal stream of the visual cortex. There are, however, ongoing efforts to answer those questions (Laureys & Tononi, 2008).

Most cognitive tasks we know are therefore consciously mediated. *Problem incubation* is a famous example of unconscious mental processing.

2.4.1 Task-related signaling between linked neurons

Because new findings about brain rhythms for cognitive functions are constantly appearing, it helps to use just three ranges: slow, midrange, and fast. Slow oscillations include the delta waves of deep sleep (less than 4 Hz). Delta waves are important for consolidating temporary memories into long-term memories. (In addition, a slower rhythm has been discovered that continues throughout the 24-hour cycle (Steriade, 1997).) There is no certainty yet about their role in waking tasks.

Delta waves occur during sleep and drowsy states, and similar slow waves occur during light anesthesia and in epileptic loss of consciousness. These are unconscious states. Faster waves occur during waking and dreaming.

MID-RANGE AND FAST WAVES

Cognitive tasks during waking are known to involve both midrange and faster waves. Until the evidence settles down, therefore, it is useful to talk about two frequency ranges for waking cognition.

ALPHA AND THETA RHYTHMS

Midrange oscillations include theta and alpha waves. Alpha rhythms of 8 to 12 Hz were first observed over the occipital cortex when human subjects were relaxed or closed their eyes. However, alpha and theta (4–7 Hz) are now known to be involved in many different waking tasks in many parts of the brain. In many cases these near-10 Hz waves seem to coordinate faster oscillations. In a very broad sense, near-10 Hz waves may function as a widespread “system clock” for many parts of the brain. For example, theta waves are known to facilitate encoding of temporary episodic memories into long-term episodic memory. In the motor cortex alpha-like rhythms have been reported to be involved in the inhibition of planned actions. In the frontal lobe, alpha-like waves are involved in momentary memory storage, and some researchers find that both synchrony and desynchrony of alpha waves may play a role in cognitive processes. Even the boundary between theta and alpha is not necessarily clear, and some researchers believe that these waves are not necessarily stable in their conventional range.

Scientific periods of rapid discovery often seem confusing until they settle into some stable pattern of evidence. Because empirical science is unpredictable, we do not know at this time whether the brain wave spectrum will be divided up neatly into frequency ranges or whether different brain locations will turn out to have quite different oscillations.

There is reasonable agreement, however, that alpha/theta oscillations near 10 Hz interact with faster oscillations. One proposal is that brain waves resemble the radio spectrum, with “carrier frequencies” being modulated (by amplitude, as in AM radio), or by frequency (FM). In the case of radio waves, broadcasting stations generate electromagnetic radiation at specific tuning frequencies (as you can see on your AM or FM dial). Radio receivers can be

tuned to the major frequencies. Since speech and music involve faster oscillations, these are “carried” by the standard tuning frequencies.

In the case of the brain, it is believed that theta waves sometimes work as carrier waves and that individual neurons can tune their own firing patterns relative to some widespread theta wave (Canolty et al., 2006). Since these are open issues on the scientific frontiers, we simply do not know precisely how they will settle over the longer term.

There is no agreement currently on the range of faster oscillations, often called beta and gamma. Functional rhythms have been reported up to 200 Hz and even (briefly) 600 Hz. Because new findings are constantly appearing, it makes more sense to describe three frequency ranges (see Figure 8.1). Midrange oscillations include classical alpha and theta, near 10 Hz. The pace of new findings is now so rapid that we can expect to see much greater clarification on these issues.

A range of frequencies have now been observed for sensory processing, attentional enhancement of sensory input, and both working and long-term memory. Synchrony is both natural and useful for signaling in an oscillatory system like the brain. Sometimes perfect synchrony is not attainable, so there is a brief time lag between the peak of the wave in one place (like the hippocampus) and another place (like the frontal lobe). In those cases, the better term is *phase locking* or *phase coherence*, a little bit like a syncopated “off-beat” rhythm in music. It is synchrony with a time lag.

Individual neurons have a temporal integration time of about 10 ms, the period when dendritic inputs can add up to increase the probability of a single axonal output spike (see Chapter 3). A group of interconnected neurons can strengthen one another’s firing rates between 30 and 100 Hz by supplying synaptic inputs within the 10 ms window. If two excitatory neurons are signaling each other at a rate of 50 Hz, for example, it is possible to sustain an excitatory feedback loop, because converging signals can arrive within the critical 10 ms period. However, neuronal firing rates below 30 Hz may not be integrated by target neurons because different spikes may arrive too late to have additive effects. It is therefore believed that a group of neurons firing in the beta-gamma range will exert a stronger drive to downstream neurons than lower frequencies. Obviously, real brain networks are more complex and have inhibitory as well as excitatory elements. Nevertheless, these basic points apply to neurons in general and have gained a good deal of direct empirical support.

Radio transmission has some similarities to oscillatory synchrony in the brain. The existence of AM and FM radio suggests at least two ways in which brain rhythms may process information in the brain. But there are many more coding schemes. Brain rhythms could serve as clocks, and they can use single pulses or a series of pulses like Morse code. Different neurons may use signals in different ways, perhaps in combination with different molecules and synapses.

Television is an example of a spatiotemporal code, in which the broadcast signal scans across every line of the screen from top to bottom. Computer screens use similar spatiotemporal coding. Brain rhythms are also likely to coordinate visuotopic maps, somatotopic maps, and motor maps. As we have mentioned, the brain is rich in topographical maps, which represent sensory input arrays or neuromuscular maps at various levels of abstraction (see Chapter 5).

Evolution has exploited the rhythmic properties of neurons over hundreds of millions of years. For that reason, we should not expect to find only a single neural code. What we do know is that brain rhythms are very widespread and that they are associated with known functions.

Finally, waves can also interfere with one another. When you place a radio receiver next to a computer, you will hear a burst of noise whenever you press the keyboard. That is because each key press triggers an electromagnetic signal that radiates into the surrounding space. Wave interference is a fundamental phenomenon in the physics of radiation. Interference may have important uses in the brain, but it might also degrade neural information processing. We are only beginning to understand the role of brain rhythms, but it is likely that wave interference will turn out to have effects as well.

3.0 ATTENTION

Common sense makes a distinction between attention and consciousness. The word *attention* seems to imply an ability to bring something to mind. If you can't remember a word in this book, for example, you might try to "pay more attention." What trying to pay more attention comes down to is allowing the forgotten word to be in consciousness for a longer time. So we rehearse the forgotten word (consciously), or we make a note about it (making it conscious again), or we write a definition about it (same thing). The traditional "law of effect" about learning states that the more we make something conscious, the more we will learn it. When we call someone's attention to a speeding car, we expect him or her to become conscious of it.

In everyday language, "consciousness" refers to an experience—of reading this sentence, for example, or conscious sensory perception, conscious thoughts, feelings, and images. Those are the experiences we can talk about to one another. Selective attention implies a selection among possible conscious events. When we make an attentional selection, we expect to become conscious of what we've chosen to experience.

With careful studies we can separate the phenomena of attention and consciousness. To focus on conscious events "as such," we typically study them experimentally in contrast with closely matched unconscious events, as we have seen in previous chapters (see Chapters 1, 3, 6, and 7). By contrast, experiments on attention typically ask subjects to select one of two alternative stimuli. "Attention" is therefore concerned with the process of selection and consciousness, with reportable experiences themselves. Some key questions for cognitive neuroscience are: What is distinctive about conscious events in the brain? What does it really mean for someone to be conscious? How does the brain basis of attentional selection relate to our private, conscious experiences of the world?

3.1 Attention selects conscious events

Attention has two aspects: the source of attentional control, which decides what to pay attention to, and the target of attention, which is selected for additional processing. Consider the case of a college student sitting in a lecture room, with many sensory inputs at the same time and many simultaneous tasks to perform. The student must stay alert, orient to the visual and auditory input, keep track of the lecture, take notes, and more. In fact, students are always multitasking, and as we know, that is inherently difficult. That is why it is important to review lectures. Live lectures can easily overwhelm our attentional capacities.

3.2 The Posner flanker task

Michael Posner and colleagues devised a simple method called the “flanker task.” They ask subjects to pay attention to a stimulus at a known location on the right or left side of the fixation point (marked with a dot or a plus sign) (Figure 8.11). Because humans have a very limited foveal “keyhole” through which they fixate a small part of the visual field at any single moment, it is possible to control the exact information that is available to a subject. (We see only about 3–6 degrees of visual arc when the eyes are fixed on a point. Try it!

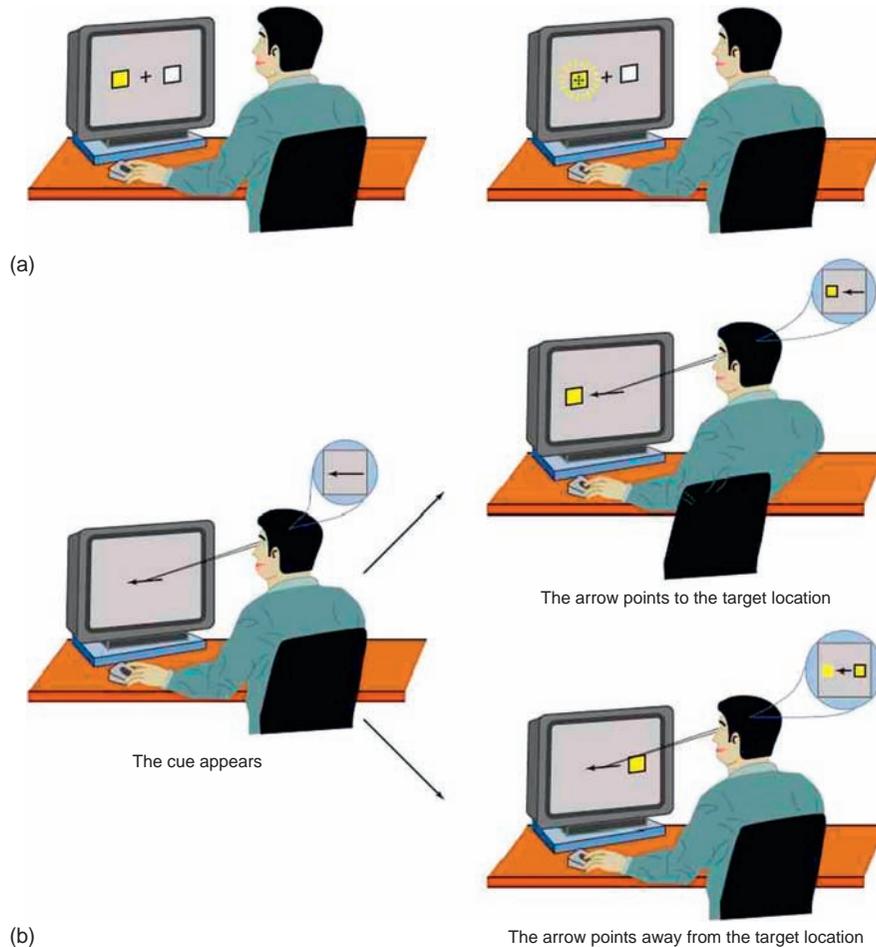


FIGURE 8.11 The flanker task for studying attention. The Posner flanker task has long been used to assess visual attention and its brain bases. The subject looks only at a fixation point in the center of the screen (a) Directional cues such as an arrow (b) draw attention to the left or right flank (side) of the fixation point, but no eye movements are allowed. It is the subject’s attention that is cued to one or the other side of the screen, not the eyes. Source: *Reynolds et al., 2003*.

The flanker task is simple, effective, and adaptable. For example, the target stimuli can be emotional faces, allowing us to explore how the brain pays attention to emotional events (Fan et al., 2002; Posner & Petersen, 1990).

Subjects keep their gaze on the fixation point. When flanking stimuli appear on the right or left side, they can be detected even when the eyes are kept fixed on the crosshairs. In Figure 8.11, the target is flashed in the expected location for a fraction of a second. Subjects respond as quickly as possible. When their cued expectations are correct, their reaction times and accuracy are optimal.

The flanker task allows for testing of both voluntary and nonvoluntary attention, by giving subjects either correct or incorrect information about the flank on which the stimulus will appear. The task is simple enough to administer in an fMRI scanner in a half hour or so, and the resulting brain scans provide separate information about expectation-driven trials and unexpected trials. By subtracting the “unexpected attention” brain activity from the “expected attention” scans, Posner and colleagues were able to obtain a relatively pure measure of the brain regions involved in voluntary visual attention.

3.3 A model of attention

Itti and Koch (2001) developed a model of attention that combines a number of important features. It shows a simplified layered concept of the visual system, with multiple topographic visual maps. The visual maps show line orientation, stimulus intensity (contrast), color, and salience. *Saliency* is defined in terms of feature contrast in any visual map. In light-sensitive regions, it is the contrast between light and dark patches on the map. In motion-sensitive areas, like area MT, it may be a stable object against the background of a waterfall. A combined saliency map may combine all the contrasting features into a single saliency map, one that reflects the unusual, unexpected, or noteworthy features of a visual scene at any level of analysis. A “winner-take-all” computation selects the most salient location on a combined map and inhibits competing locations. Obviously, salience can also be misleading; for example, when you are watching a visually exciting music video that contains a variety of attention-driving features, you may want to think about something else. You may have to *override* what is most salient at any moment.

Visuotopic neurons respond to optical stimuli at different levels of analysis (see Chapter 6). Figure 8.12 gives us a convenient overview. Each layer of the pictured model by Itti and Koch responds to a particular feature of the stimulus: color, line orientation, contrast, and object identity. This is a simplification of the visual brain, which is far more complex and flexible and that must deal with complications such as the constant motion of the eyes and the head, the very narrow limits on foveal vision, and much more. But Figure 8.12 helps to clarify our question.

Each visuotopic map is a two-dimensional mosaic of neurons with rather narrow receptive fields (see Chapter 6). We can therefore ask a more focused question: Does attention to some event or location enhance signal processing in the correct receptive field? If the watcher in Figure 8.12 is hot and thirsty while wandering in the Sahara Desert, will his or her attentional system enhance visual processing for ice-cold mugs of beer located on the left side of his visual field? This question is much more specific and testable.

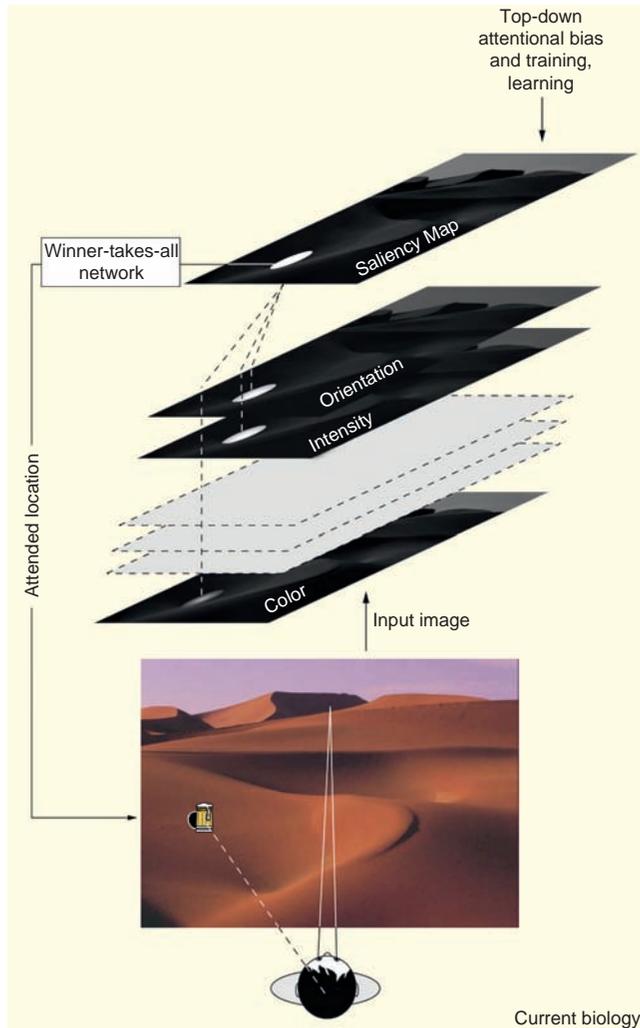


FIGURE 8.12 How attention might activate sensory maps. Multiple visuotopic maps support our conscious experiences of beer mugs and deserts. Notice that the person at the bottom seems to be looking for a cold drink on a hot day in the Sahara. How do our brains select the cold beer? What do we become conscious of? Source: Thier *et al.*, 2002; figure adapted from Itti & Koch, 2001.

The concept of a saliency map reflects significance, motivational relevance, and vividness of the input. Many topographical maps in the visual brain are sensitive to motivation and relevance. The man at the bottom of the figure is imagined standing in a hot desert with a cold mug of beer on the far left side of his visual field—just outside of his direct visual field. Selective attention allows significant stimuli like the cold beer to emerge into consciousness. These can be expressed as “top-down attentional biases” that alter the saliency map on top of the stack. Prior learning also is input into the saliency map. All the topographical maps resonate together in synchrony and jointly make decisions in cases where the corresponding points on the majority of maps lead to the same overall result. The output may be an eye movement, allowing the viewer to see the cold beer mug, or it may be a covert shift in attention to the left, again allowing

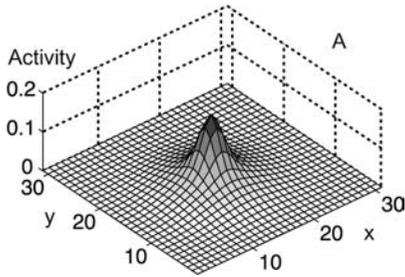


FIGURE 8.13 A winner-take-all (WTA) network, in which the most activated point in the horizontal plane inhibits all the surrounding points. The vertical axis is labeled *activity* and may represent the summed activity of multiple visuotopic maps. WTA networks are very common in decision-making neural nets. In the brain, both selective attention and conscious perception may make their final “decisions” using a WTA mechanism. In the case of ambiguous stimuli, the brain makes one of two competing interpretations conscious. Source: *Standage et al., 2005*.

the beer stein to come to visual consciousness. Again, it is possible that the man may want to override the perception of the cold beer and focus attention on crossing the desert instead. There are potentially competing decisions in this multilayered network.

An important aspect is the “winner-take-all” (WTA) network (Figure 8.13). WTA networks essentially allow the most active point on the joint topographical maps to “win,” input from saliency, which represents such things as motivation, hunger, and thirst; learning about relevance; and so on. WTA also suggests an explanation for conscious experiences of ambiguous figures. Conscious experiences are marked by internal consistency, even when sensory inputs are not. Most of the words in the English lexicon are highly ambiguous, for example, but in context (as in this sentence), ambiguous words are consciously experienced in terms of just one interpretation. Thus, a WTA network may be involved in an attentional system, as shown in Figure 8.12, but they are also a very powerful feature of conscious perception. Indeed, we can consider conscious perception to be the outcome of many attentional acts. In reality, there may be no difference in the brain between those two mechanisms.

The term *attention* is used most intuitively when there is a clear voluntary or executive aspect. We ask people to pay attention to things, which implies they can choose to do so or not, depending on some decision-making processes. Voluntary attention is the kind that is studied most often, and as you might guess from the other chapters, it is likely to use prefrontal cortex in humans (see Chapter 12).

Corbetta and colleagues (2002) recently wrote that voluntary attention “is involved in preparing and applying goal-directed (top-down) selection for stimuli and responses.” Automatic attention, on the other hand, “is not involved in top-down selection. Instead, this system is specialized for the detection of behaviorally relevant stimuli, particularly when they are salient or unexpected.” When we hear a sudden loud noise, our attention is “captured,” even without executive guidance. As you might expect, visual attention can be captured by human faces, emotional expressions, and bodies, when compared with neutral stimuli. Intense or sudden stimuli, or unexpected events generate larger brain responses than control stimuli. Thus we can talk about “bottom-up” capture of selective attention, driven by stimuli.

In the real world, voluntary and automatic types of attention are generally mixed. We can train ourselves to pay attention to the sound of the telephone ringing. When it rings and we suddenly pay attention to it, is that voluntary or automatic? Well, it began being voluntary and became more automatic. The dimension of voluntary versus automatic attention is therefore a continuum. Perhaps the strongest case of voluntary attention is the one where we must exert intense mental effort over a period of time. A clear example of the opposite pole of the

continuum might be a case of a loud sound or a biologically important event like a crying baby, which is hard *not* to pay attention to.

Therefore, attention is defined here as the ability to select information for cognitive purposes. Selection may be shaped by emotion, motivation, and salience, and it is at least partly under executive control. Thus selective attention works closely with all the other components of our framework diagram (see the chapter opening figure). Without flexible, voluntary access control, human beings could not deal with unexpected emergencies or opportunities. We would be unable to resist automatic tendencies when they became outdated or change attentional habits to take advantage of new opportunities.

As Figure 8.14 shows, attention is a selective capacity, either under voluntary control or driven by a stimulus. The result of selective attention is to enhance the quality of the selected information or at least try to do so. What is the evidence for attentional enhancement?

Figure 8.15 shows a current set of hypotheses about specific brain regions involved in voluntary attention to a visual location or stimulus. Notice that voluntary control of attention is attributed to the prefrontal cortex. Top-down activity descends to visual maps related to eye movements (prefrontal eye field, parietal eye field, and superior colliculus) and visuotopical feature maps (V1-IT). The pulvinar nucleus of the thalamus also contains a visuotopical map and is hypothesized to bring together saliency cues, basically representing contrasting features and their locations in all the sensory feature maps. Notice that this brain model lacks a WTA mechanism, as postulated by the abstract model shown in Figure 8.13.

Top-down attention is driven by expectations, and in the delay interval (see Figure 8.16a) subjects know where to look, but the stimulus has not yet appeared. Yet visuotopical synchrony still occurs in motion-sensitive areas and the posterior intra-parietal sulcus (pIPS) on the right hemisphere. During this period of attentional expectancy there is significant coupling between MT and IPS. After the delay, the stimulus is presented to one side of the visual field, so its first effect will occur on the *opposite* side of the stimulus. If subjects know when to expect a visual stimulus, anticipatory synchrony occurs (Figure 8.16).

Figure 8.17 shows that visual maps often synchronize, but that they synchronize differently in different tasks. Sometimes the frontal eye fields (FEF) are not in sync with other visual maps. You can imagine a rock band with players who are in sync some of the time, but not all the time. The vocalist might rest for a while and let other instruments take over, or different instruments might play in syncopation.

How is it that you can learn the material in this book? What we do in daily life is simply pay attention to new and interesting things—exploring them with our senses, rehearsing them mentally, and repeatedly directing our attention to them—and, magically, learning seems to occur. The next day, we suddenly realize that yesterday's new information seems more familiar. We must have learned it. Orienting tasks are important to enable learning. Mere exposure to information is often enough to enable recognition memory. In cognitive science jargon, most of our everyday learning is *incidental*.

What we generally do is just pay attention to new material, even if it seems hard to understand. The biggest challenge is paying attention to new and difficult information and be patient enough to allow our brains to wonder, ask questions, and, ultimately, comprehend any new material. Once we perceive and comprehend something new, learning seems to occur. Brain evidence indicates that spontaneous attention to some sensory content also activates the hippocampal complex (Stark & Okado, 2003). Though there is reliable evidence for

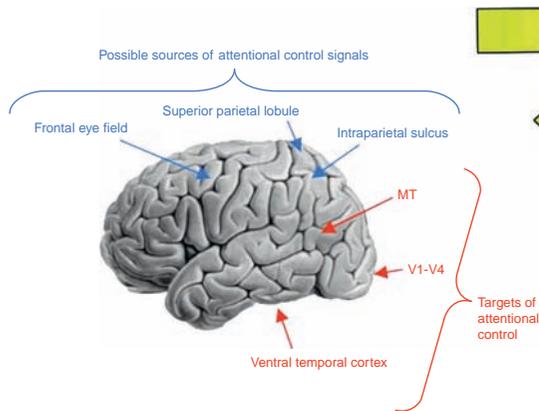


FIGURE 8.14 Voluntary attention. From frontoparietal to sensory cortex. Voluntary attention in perception is directed to sensory cortex by frontal and parietal regions. Parietal regions are believed to be involved in spatially directed attention. Visual regions (in red) are enhanced by attentional mechanisms, such as gamma synchrony among multiple visuotopic maps for the selected spatial location and visual features. Source: Yantis, 2008.

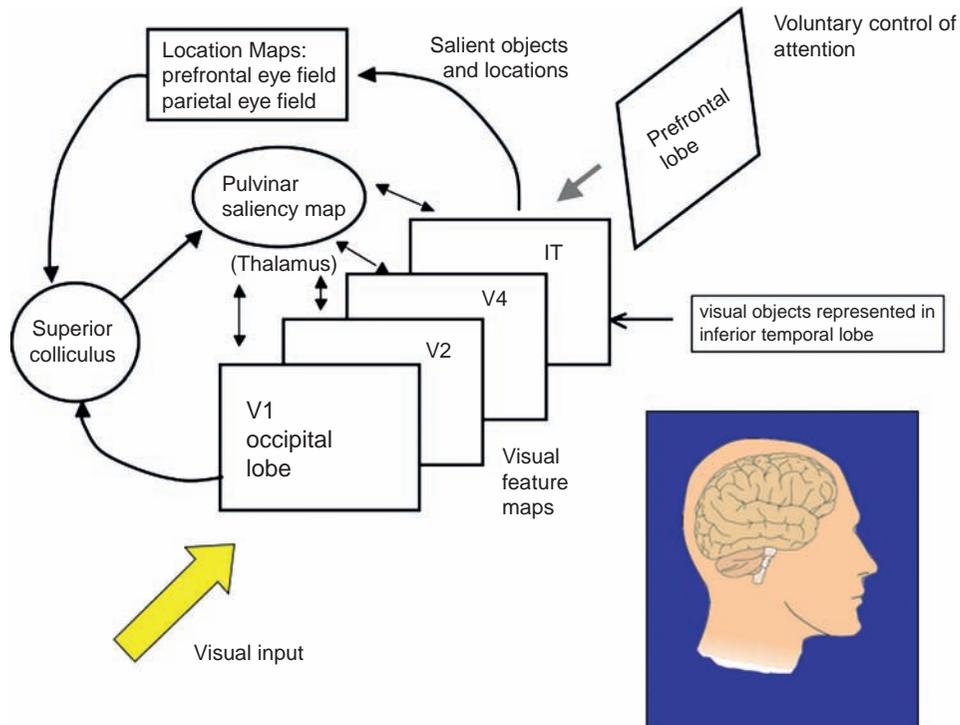


FIGURE 8.15 A brain model for visual attention. Shipp (2005) explores a number of brain models of visual attention. Notice that in addition to cortical maps, two subcortical maplike regions are shown. They are the pulvinar nucleus of the thalamus and the superior colliculus. Many of these same regions are involved in the control of overt eye movements, raising the possibility that in evolution visuospatial attention may have emerged on the prior basis of selective eye movements. Source: Adapted from Shipp, 2005.

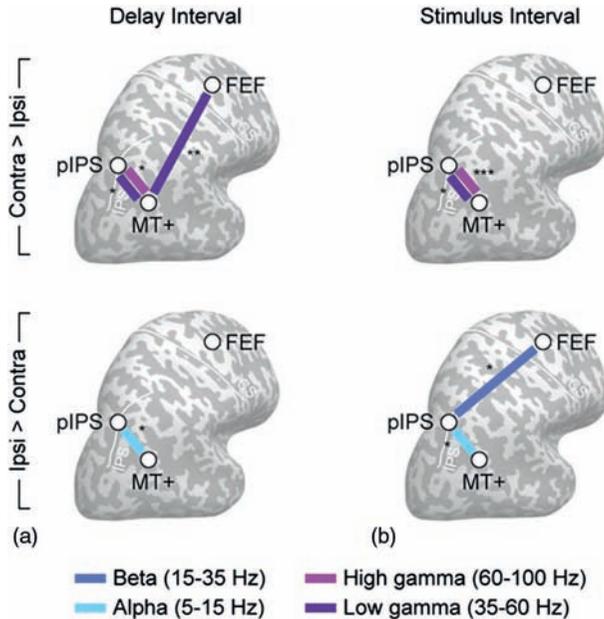


FIGURE 8.16 Attention works by synchronizing multiple visual maps. Here the MEG signal shows high synchrony in the right hemisphere. The cortex has been mathematically “puffed up” to make its hidden valleys (sulci) visible. Source: Siegel et al., 2008.

subliminal perception and learning, we will limit this discussion to episodic and declarative memory of conscious events.

Cognitive neuroscientists believe that declarative and episodic learning occurs something like this (Seitz & Watanabe, 2005): We pay attention to new information so that it tends to become conscious. As soon as we experience the new information with enough clarity, our brains are able to store it. Repeated attention to new or difficult material often is needed before we get a sense of clarity. By using sensitive measures of episodic and declarative (conscious) memory, like recognition measures, we can show that humans learn very quickly after clear conscious experiences of new information. There is reliable evidence for subliminal learning, but here we will focus on learning of conscious events.

That does not mean we can recall all memories on cue. It does mean that we can recognize consciously experienced events far above chance.

For example, you may recognize a scene in a movie you may have seen ten years ago. It wasn't necessary to memorize the movie scene. All you had to do was to watch it once—consciously—and then see it again ten years later. Consciousness of an event seems to be enough to establish it in memory. Much the same is true of recognizing yearbook photos of high school classmates, news photos, headlines from years ago, and the like.

Unfortunately, academic exams rarely use recognition tests. Rather, exams test associative recall by asking questions like “What is the capital of France?” College exams would be easier if they gave us a part of the answer, like the partial recognition item “Par__ is the capital of France.”

Associative recall tests give much lower memories than recognition tests. That is why academic exams are difficult. It is not our stored memories that are at fault but our ability to retrieve them on demand. By analogy, you can file a book randomly in a giant library. The book (the memory) is somewhere in there, but you cannot retrieve it on demand unless

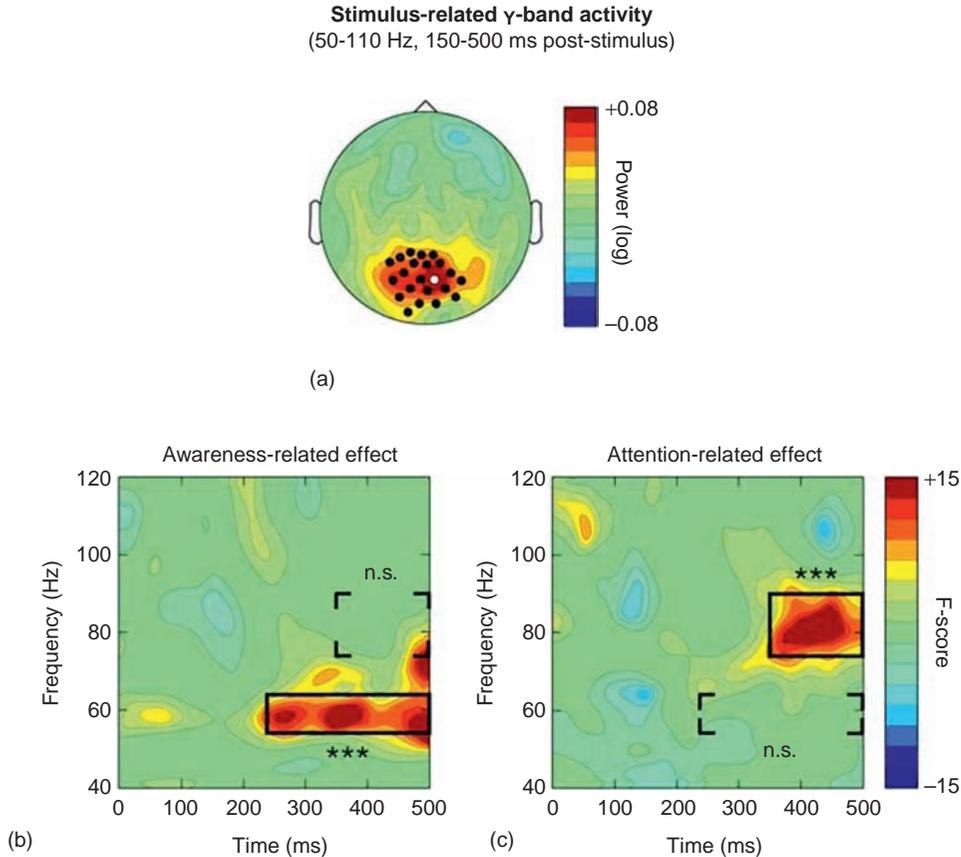


FIGURE 8.17 Separate brain correlates of attention and awareness. Wyart and Tallon-Baudry (2008) were able to dissociate the effect of visual awareness and selective attention. (a) MEG activity in the back of the brain (occipital) is shown in a simplified cartoon of the brain, as seen from above. The color bar shown on the right side indicates the intensity of the MEG signal. (b) Awareness has a different effect from selective attention. This figure shows MEG frequency on the vertical axis, with time on the horizontal axis. The zero point of time corresponds to the onset of the stimulus. We can see a burst of intense MEG activity around 60 Hz, starting 230 ms after the stimulus, and going on for several hundred milliseconds. In panel (c) we can see a separate attention effect at a higher frequency and starting a little later. Awareness and attention therefore seem like two different processes. Source: *Wyart & Tallon-Baudry, 2008*.

you have a very good retrieval system, like a search engine or a card catalog. Otherwise, the book might as well be lost forever.

Paying attention does not always make things conscious. For example, we can pay attention to an ambiguous figure without seeing interpretations (see Chapter 1). Learning a complicated subject like brain science is often like learning an ambiguous stimulus. At first, new material may seem vague, hard to understand, or confusing. Then we may spend some time thinking about it, paying attention to it, trying to draw it by hand, or answering questions about it. Over time, a clearer sense of meaning tends to come. At the point when we become clearly conscious of the information, learning tends to follow quickly. Most of our effort in studying new material is therefore devoted to the task of comprehension. Once we understand things clearly, memory tends to come along.

In sum, paying attention may be a means toward conscious clarity, which in turn enables learning. The hippocampal complex is believed to turn conscious experiences into memories. At first, hippocampal memory is believed to be unstable. Consolidation serves to make long-lasting changes to the neocortex. Theta oscillations play a role in local hippocampal functions and in long-range coordination between the hippocampus and neocortex.

3.4 Voluntary attention

Voluntary selective attention is controlled by the frontal lobes (executive functions) and parietal regions (for spatial localization, which is often needed for paying attention). The network of cortical and other areas has been called the *cognitive control network*. In the case of vision, many of these areas overlap with the control of eye movements.

If we want to pay attention to a spoken word in a stream of words, we may want to increase the sensitivity of our auditory and speech perception cortex to words that sound like “cognitive control network.” If we are reading, we want to do the same thing to visual word recognition areas. In general, therefore, we can think of the control of attention and the targets of attention.

One way to increase the signal strength in cortical area is to synchronize it. (See Chapter 2 on neural synchrony.) The idea is similar to volume control on a loudspeaker. Because the brain can be viewed as a very large collection of topographical arrays that oscillate together with other topographical arrays, selective attention may simply “dance together” with attentional target arrays.

For example, the attentional network discovered by Posner and colleagues may dance to the same beat as face-selective visual maps of the temporal lobe (Figure 8.18a-d). Figure 8.18b shows that the attentional influences could work by adding to the overall synchrony strengthens the red face signal and decreases the blue face activity by breaking up its synchronous activity. Finally, in Figure 8.18c, a synchronous population can respond to a stimulus and may keep running for some seconds or minutes after the stimulus has ended. Synchronous wave activity can therefore store a temporary memory, but it may fade fairly quickly and may also be vulnerable to interference from other stimuli.

These are only some of the coding possibilities of synchronous neurons and populations. Obviously, these hypotheses require evidence, as we will see.

3.5 Synchrony enables attention

Gamma synchrony may amplify neuronal population amplitude because synchronized neurons can add to one another’s activity. Synchrony tends to increase the size of the signal in much the same way a microphone that picks up sounds from a loudspeaker will tend to amplify the signal over and over again. In biological systems, such self-amplifying feedback can never be allowed to run out of control for the same reason that sound systems can’t allow infinite self-amplification. Audio systems have control circuits to prevent amplifier feedback from overloading the speakers, not to mention the ears of the listeners. Epileptic seizures may actually represent the wrong kind of self-amplification of slow rhythms, interfering with normal brain functions and even leading to a loss of consciousness.

The raw EEG shows only the surface waves of a deep and turbulent ocean. Underneath the visible EEG there are multiple oscillatory streams interacting over a wide range of

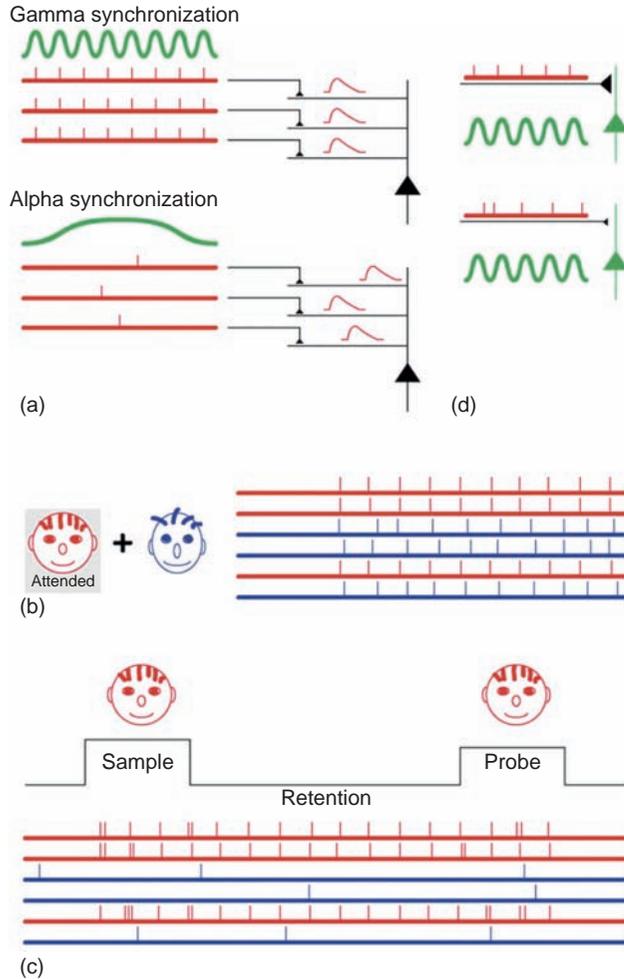


FIGURE 8.18 Synchrony in perception, attention, and memory. (a) Shows how several neurons firing at the same time can add up to a gamma wave in the electrical field. Gamma synchrony allows for finer temporal resolution than alpha. (b) Shows how attention might selectively drive target neurons at gamma rates. If you are looking at the red face on a sheet of white paper, neurons that are sensitive to the difference between red and white, those that fire to high visual contrast, and those that pick up faces will tend to fire in synchrony to enable the brain to encode the red face. If you then decide to pay attention to the red face, your brain can add to the activity of those sensory populations by firing additional cells in synchrony with the red face-sensitive populations. The blue face will not receive these additional pulses of activity. (c) Shows how synchronized neurons may retain a dynamic memory of a visual stimulus for seconds or minutes. The sample face triggers feature-sensitive neurons that fire in synchrony. When the sample face is removed, some of those neurons continue to fire for seconds or minutes. When the recognition probe is presented, the relevant neurons are already primed to respond to the recognized stimulus. There is direct evidence for such short-term memory mechanisms. (d) Shows how synchrony between single neuron firing and group oscillations can work to strengthen each other. Source: *Jensen et al., 2007*.

frequencies (0.01–1,000 Hz have been observed). Some of these under-the-surface waves are phase-locked. The metaphor of a turbulent ocean is a useful first approximation, but unlike the ocean there are many functional activities going on all the time. Knowledge about brain rhythms is building at remarkable speed.

4.0 EXECUTIVE CONTROL

The waking state supports an endless set of adaptive functions. One of the most important is executive control (see Chapter 12).

Intuitively most of us believe that conscious experiences involve an “experiencing I”—a personal viewpoint on the world that may be supported by parietal and prefrontal areas

of the cortex (Baars et al., 2003) (see Chapter 12). In daily life we use phrases like “I’m awake,” “I see the coffee cup,” “I lost consciousness,” “I couldn’t control myself,” and so on.

For many years the “observing I” was criticized as “the homunculus fallacy” (from the Latin word for “little man”). The problem, according to the critics, is that to make sense of the observing self, a little observer would have to sit in the brain, looking at the sensory inflow. But to make sense of the little observer, it would also need another little observer inside of it, and so on ad infinitum. Such an infinite regress does not explain anything. It just moves the burden of explanation to another level.

However, not all versions of an observing self lead to an infinite regress (Baars, 1988). For example, executive programs are routinely needed in robots, without leading to an infinite set of control routines. Similarly, it is possible to have an executive capability in the frontal and parietal lobes to interpret self-relevant information, such as “Is this new information good for me? If not, will it hurt? How much? Should I run away? Would I feel embarrassed if I did?” The emotions are generally believed to process self-relevant information, but even body movement requires the visual system to interpret a flow of visual vistas in these terms. Watching a visual flow while sitting still (in a car or in a theater) is not the same as actively walking or driving. Moving one’s eyes spontaneously is different from pushing the eyeball from the outside, as Helmholtz pointed out in a famous demonstration. The weight of scientific opinion may now be swinging back to the idea of an executive “I.”

There is a great deal of evidence for an executive network in the human brain (see Chapter 12). The brain areas in the cognitive control network (CCN) are shown in Figure 8.19, with connections—fiber tracts—that form the neural basis for the CCN. For example, certain kinds of brain damage seem to damage executive functions without necessarily impairing conscious perception. The classic case of Phineas Gage involved a radical change in personality and impaired self-control. The sense of agency in voluntary control is also

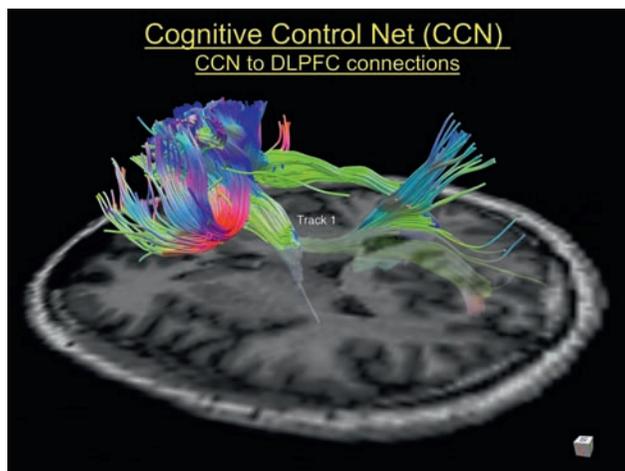


FIGURE 8.19 The Cognitive Control Network proposed by Cole and Schneider. The colored tracts are white matter fibers densely connected in the frontal lobes (on the left), and making parietal connections (on the right). The tractography images are in very high resolution. Source: W. Schneider, *personal communication*, 2009.

dependent on the frontal regions, and the right parietal region is a crucial area for “perspective of the self” in the neurological condition of parietal neglect (Baars, 2002; Baars et al., 2003).

4.1 Losing voluntary control

The outer muscles of the body and head are inhibited during sleep. Sleep-related muscle inhibition is easy to notice when your head starts to drop down when you feel drowsy. In your brain, a small circuit in the brainstem simply switches to its sleeping mode. It is now inhibiting body muscles. When you are awake, the same circuit maintains your upright posture and normal muscle tone. Muscle inhibition in sleep probably evolved to avoid sleepwalking or acting out one’s dreams.

5.0 DREAMING

Hobson and colleagues (2000) define dreams as:

Mental activity occurring in sleep characterized by vivid sensorimotor imagery that is experienced as waking reality, despite such distinctive cognitive features as impossibility or improbability of time, place, person, and actions; emotions, especially fear, elation, and anger predominate over sadness, shame, and guilt and sometimes reach sufficient strength to cause awakening; memory for even very vivid dreams is evanescent and tends to fade quickly upon awakening unless special steps are taken to retain it.

In a sense, dreaming is our most creative state. In normal waking we could never spin out the flow of visual scenes, dramatic characters, or strange plots we constantly make up in our dreams. It is almost as if we are creating a running movie but we can’t recall the storyline from one scene to the next. Spontaneous waking thoughts tend to be about our current concerns, and dream contents may refer to those concerns in a more visually symbolic way.

Both sensory input and muscular output are blocked during REM dreaming, so the brain is talking only to itself (Figure 8.20). The existence of muscular inhibition may give rise to some “paralysis dreams,” in which we feel paralyzed or want to move but feel we cannot. This can

TABLE 8.2 What Makes Dreams Different

-
1. Hallucinations—especially visual and motoric, but occasionally in any and all sensory modalities
 2. Bizarreness—incongruity (imagery is strange, unusual, or impossible; discontinuity (imagery and plot can change, appear or disappear rapidly); uncertainty (persons, places, and events often bizarrely uncertain by waking standards)
 3. Delusion—we are consistently duped into believing that we are awake (unless we cultivate lucidity)
 4. Self-reflection absent or greatly reduced—relative to waking
 5. Lack of orientational stability—people, times, and places are fused, plastic, incongruous, and discontinuous
 6. Narrative story lines—explain and integrate all the dream elements in a confabulatory manner
 7. Emotions increased—intensified and predominated by fear-anxiety
 8. Instinctual programs—(especially fight/flight) often incorporated
 9. Volitional control—greatly attenuated
 10. Memory deficits—across dream-wake, wake-dream, and dream-dream transitions
-

Source: *Hobson in Squire et al., 2008.*

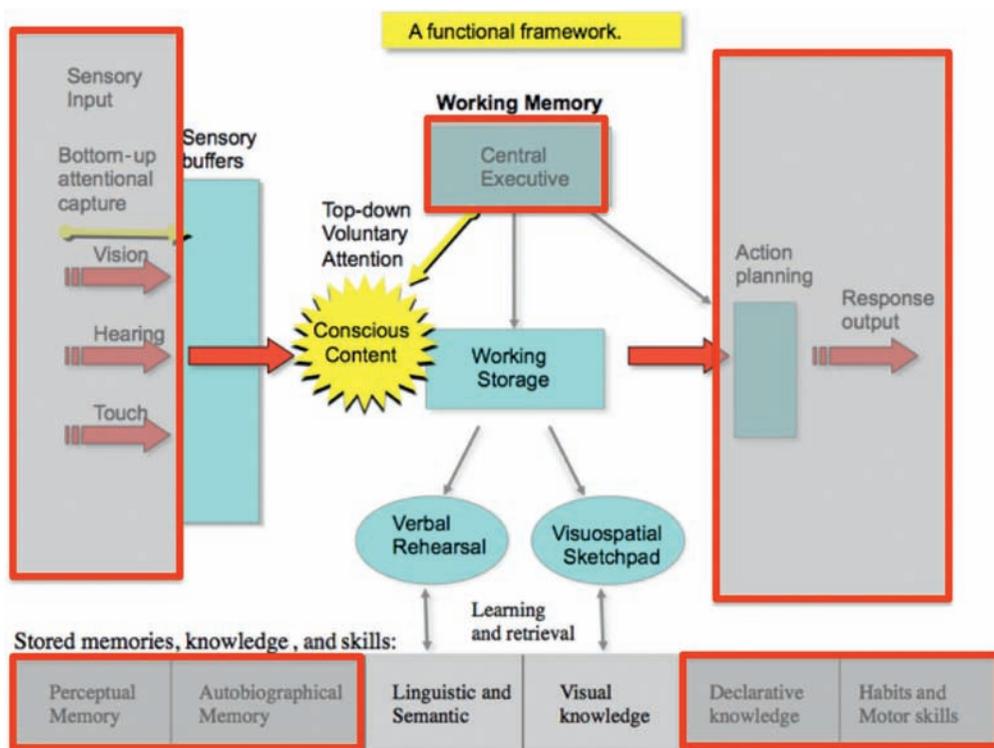


FIGURE 8.20 The grayed-out boxes show impaired functions, including sensory and motor flow, executive functions, and some kinds of memory. Dreams are conscious states, but voluntary control is lost. Visual imagery is unusually vivid. Source: *Baars, with permission.*

lead to unpleasant “locked-in” feelings during dreaming if we become aware of being unable to move. But muscular inhibition is an entirely normal part of dreaming. It keeps us from acting out our dreams.

Memory is also impaired during rapid eye movement (REM) dreaming. When dreamers are woken up from REM, they may report vivid visual memories, but they tend to fade in seconds unless we make a special effort to rehearse them. Even people with good dream recall are likely to remember only a tiny fraction of their nightly 90 to 120 minutes of REM (Figure 8.21).

5.1 Dreams are conscious

Dreams are reported as conscious experiences when people are woken up during REM. The EEG of REM dreaming is strikingly similar to wakefulness. It therefore seems that we actually have two daily conscious states: waking and REM dreaming. The activity of waking and dreaming reflects a similar operating style by the thalamocortical system. During dreams, the EEG looks very much like waking consciousness (see Figure 8.1). The function of dreams is still debated, but similar physiological states are found in many mammals.

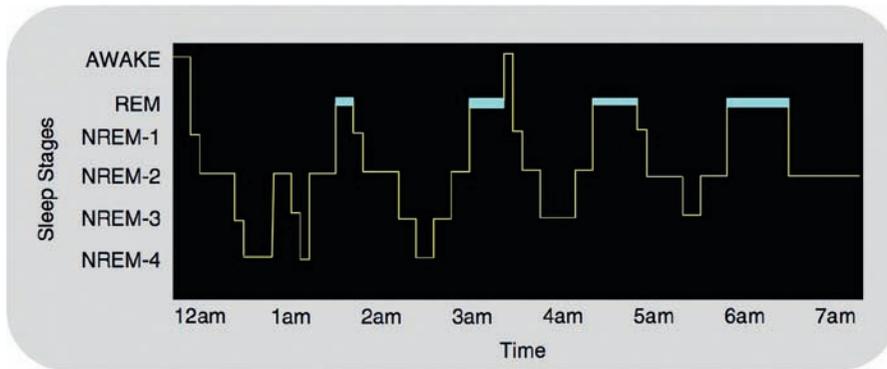


FIGURE 8.21 The architecture of sleep. The thalamocortical core changes dramatically in sleep. In deep sleep, the low, irregular oscillations of waking EEG change to high, slow, and regular activity, called *delta* waves. The four levels of arousability (Stages 1–4) show increasing delta waves, until Stage 4 of Non-REM (NREM-4) is almost all delta. Every 90 minutes or so, sleepers show rapid eye movements (REM) as the eyes swing back and forth. At the same time the EEG shows striking waking-like activity in the EEG: fast, irregular, and low in amplitude. People who are awoken from REM tend to report vivid, narrative dreams, whereas SWS sleepers may report waking-like inner speech. REM periods become longer in the second half of the night. Source: *Stickgold & Walker, 2007*.

Dreaming is therefore likely to have an evolutionary function. However, it is important to keep in mind that there are important differences during REM as well, such as sensory and motor blocking, a high level of emotional activity, and a low level of executive (frontal lobe) control.

5.2 Nonrational thinking

The surreal and nonrational nature of dreams may reflect this lower level of executive control. Dreaming is a “hypofrontal” state, like drowsiness, alcohol inebriation, delirium, and other states of lowered self-reflection and self-control (Dietrich, 2003). In addition, the limbic regions of the brain, which are involved with emotions, show higher fMRI activity than in the waking state (Figure 8.22).

5.3 Working memory in dreams

In dreams we can unexpectedly jump from one imagined scene to another, and dream characters can change their identities, as if the brain is constantly trying to reinterpret the flow of imagined experiences from moment to moment. Waking events tend to be much more coherent.

One possibility is that dreams overload our immediate memory with their creative flow of emotions, images, and imaginary encounters. If we tried to spin dreamlike fantasies during the waking state, we would certainly lose track of our narrative, just because it’s hard to remember all the details. Story writers work for hours and days to imagine what all of us experience from minute to minute during sleep. The jumpy transitions in dreams may reflect moments when we simply lose track of the plot.

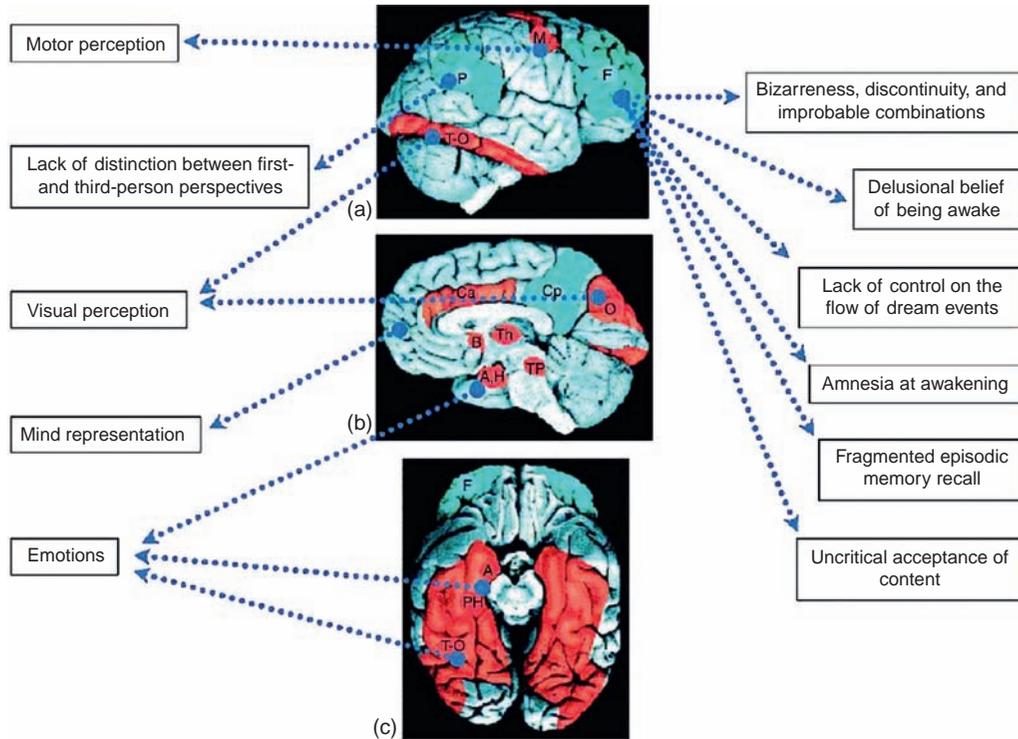


FIGURE 8.22 Functional brain imaging of REM dreams. Red areas represent increased blood oxygen–related activity—for example, in emotion areas. Blue areas correspond to below-baseline activity during dreaming, as in the frontal lobes. Higher activity in occipital regions may reflect vivid visual dream imagery. Low frontal lobe metabolism may also explain the delusional beliefs, bizarreness, and sudden discontinuities of dreams, such as rapid changes in scenes, dream characters, and narrative coherence. Low frontal lobe functioning is consistent with amnesia for dreams upon awakening and low levels of voluntary control. Source: *Dang-Vu et al., 2005*.

5.4 Brainstem oscillations trigger dreaming

REM dreaming is triggered by “PGO waves”—pons-geniculate-occipital activation—along with neuromodulation. Sharp bursts of neuronal spikes come from the pons (P), activate the lateral geniculate nucleus of the thalamus (G), and then trigger visual experiences by way of the occipital cortex (O). Hobson and McCarley (1977), who advanced the early PGO hypothesis, called this the “activation-synthesis hypothesis,” with the emphasis on the activation burst from the pons and its conscious interpretation or “synthesis” by the cortex (see Figure 8.22). Pace-Schott and Hobson (2002) write that REM sleep is also triggered by changes in major brain modulators, especially norepinephrine, acetylcholine, serotonin (5-HT), and glutamine.

However, the PGO theory does not explain the *content* of dreams. It only suggests that the cortex tries to make a coherent story out of meaningless brainstem signals. What determines dream contents remains a puzzle. Valli & Revonsuo (2006) proposed a “threat simulation” theory of dreams, an evolutionary hypothesis based on the fact that the REM state is widely observed in mammals and birds and therefore may have an important evolutionary function.

Valli & Revonsuo (2006) suggests that dreams allow us to mentally rehearse threatening situations. Traumatized individuals may re-experience events related to the trauma (in some cases even during the waking state). Consistent with their theory, Valli & Revonsuo (2006) found that traumatized children from a war zone had significantly more threatening dreams than controls. Other major life events, such as loss of a loved one, or even normal stressful events, might also be reflected in dream contents.

5.5 Lucid dreaming

Some people can learn to experience their dreams *knowing* they are dreaming, and even with some voluntary control over dream events. LaBerge and colleagues (1986) made a case for such “lucid dreaming” in the sleep laboratory by showing that some dreamers could learn to voluntarily move their eyes back and forth three times in a row, on cue, when given an auditory signal. Some lucid dreamers could also count to ten in the dream and then show the experimenters that they had done so by repeating the triple eye movement to signal the end of the ten-second period. Lucid dreamers in this experiment had to recall and carry out their task instructions learned during the waking period before going to sleep. Thus lucid dreaming required executive functions and semantic memory retrieval, as well as linguistic and auditory processing. Lucid dreamers may therefore be able to control some of the cognitive functions that usually are impaired in the REM state.

6.0 DEEP SLEEP: UPS AND DOWNS

Deep sleep is the least conscious state of the daily cycle. It is also called “slow wave sleep” (SWS) because of the predominance of slow EEG waves over the cortex during this time. (see Figure 8.2). In slow EEG, billions of neurons in the cortex and thalamus turn on and off in unison at the rate of the delta wave (about 2–4 Hz). The flow of signals is forced to screech to a halt every half second, then start again, stop again, and so on. The fast and flexible flow of signaling is therefore constantly disrupted. Unconsciousness is the state where we cannot perform our normal, waking activities because the engine of consciousness cannot maintain continuity.

Why do we sleep and dream for a third of the day? We only know a few of the answers. Deep sleep is the best time for consolidating what we learn during conscious periods into long-term memories. Sleep and dreaming probably have other functions. We know that hundreds of neuronal genes turn on and off whenever we fall asleep or we wake up. But there is no scientific agreement on the functions of our “offline” states.

Waking consciousness is the best time for learning, but learned material is “consolidated” during the next deep sleep period. If you study for an exam, it’s good to “sleep on it” and then refresh your memory in the morning. Much of yesterday’s learning will then be stabilized.

6.1 The need for sleep

Sleep-deprived rats die after only three weeks. We know therefore that sleep is needed for survival in rats and very likely in other mammals. Sleep duration is under precise biological regulation. We tend to make up for lost sleep by sleeping longer. Sleep-deprived individuals show

“microsleeps”—moments of “dropping off”—that can seriously interfere with actions like driving. In a second or two, your neck muscles can lose tone, and your head will tend to drop forward.

As a major biological adaptation, sleep presumably does things that help us to survive and reproduce as a species. Many of its functions are programmed genetically, causing DNA-controlled proteins to build new synapses to consolidate learning. And yet, sleeping animals are also more vulnerable to predators. Animals seek shelter before going to sleep, in trees, in earth hollows, or in dense bushes that are hard for predators to penetrate. Some animals rely on large colonies that sleep together so they can warn one another about predators. Nevertheless, sleep is still a period of special danger because animals cannot run, flee, fight, or engage in mate selection and reproduction.

Our nightly eight hours of unconsciousness must therefore have some compensatory advantages. We know that sleep seems to enable memory consolidation, converting new and unstable memories into lasting ones. The function of dreaming is still debated. Because the sleep-waking cycle is a very widely conservative feature among animals, it is likely to have multiple functions.

Surprisingly, a single night of sleep deprivation can also improve depression. Staying up for one night therefore has been suggested as a safe, inexpensive, and effective treatment. But chronic (long-lasting) sleep deprivation is stressful and degrades normal conscious functioning.

6.2 Memory replay and consolidation

SWS is more common in the first half of the night, whereas REM predominates in the second half. Researchers therefore have studied memory consolidation after “SWS-rich” and “REM-rich” periods of sleep. In general, SWS-rich periods appear to strengthen explicit memories, and REM-rich periods strengthen procedural tasks and perhaps implicit memories. Increased SWS has been observed after intensive episodic learning, and increased REM is seen after procedural training.

Episodic memories are thought to be transferred from the hippocampus to the neocortex for memories to become enduring. The hippocampus plays a major role in place learning and navigation, and it has been possible to pinpoint hippocampal “place cells” that fire when the animal passes a particular point in the maze. As the rat runs the learned maze, place cells fire in sequence. Afterward the same pattern of cell firing is observed during slow wave sleep, activating other parts of the brain, like the thalamus, neocortex, and basal ganglia (Figures 8.23 and 8.24).

In rats, we can actually record neurons when the animals are exploring locations in sequence and observe that the brain *replays* a learned spatial sequence during SWS. The theta rhythm appears to be a major rhythm for the hippocampal-neocortical dialogue that leads to memory consolidation (Buzsaki, 2006; Jensen & Colgin, 2007).

7.0 EXCEPTIONAL STATES OF MIND

To achieve altered states, humans have used a huge variety of methods: taking psychoactive plants, fasting, drinking alcohol, special exercises, visualization, disorientation, hypoxia, self-mutilation, sexual practices, dramatic rites, lucid dreaming, dancing, whirling, chanting and music, suggestion, trauma, sleep deprivation, and social isolation. Traditions like

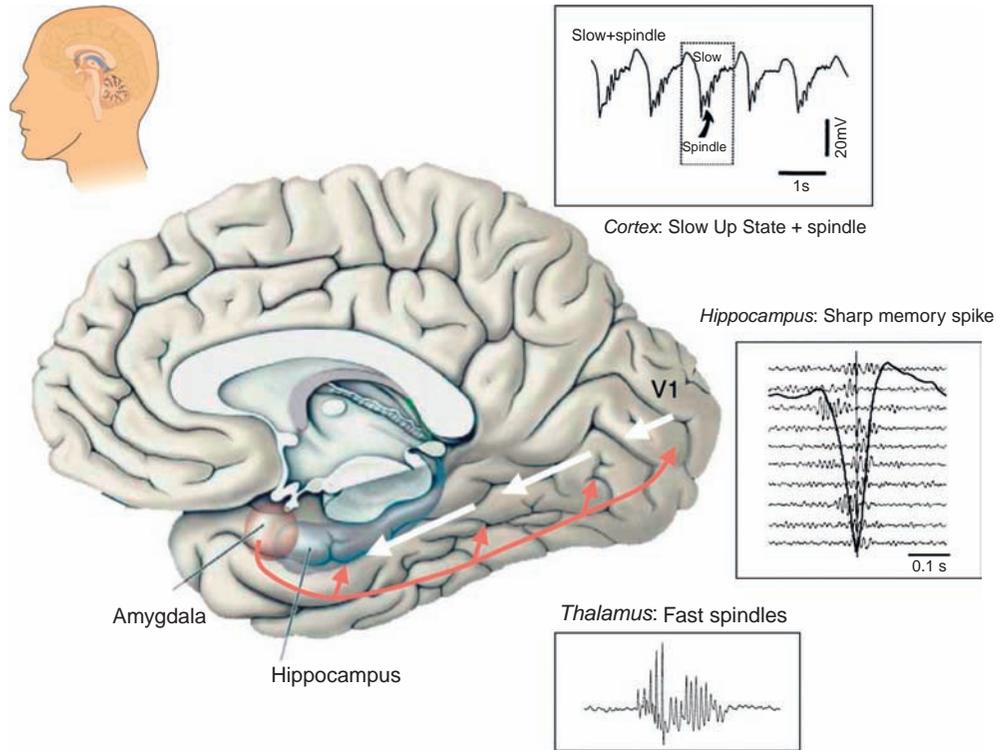


FIGURE 8.23 Slow wave sleep enables memory consolidation during “up states.” Three brain regions work together: early episodic learning during the waking state encodes unstable hippocampal and neocortical memory traces. During slow wave sleep, thalamic spindles ignite, which triggers hippocampal sharp spikes, which are believed to activate synchronized memory traces in the hippocampus. Thus thalamic spindle activity helps to trigger the next up state, as shown by cortical iEEG. These regions act in concert to reactivate recent memory traces. During the following down state of slow wave sleep, the activated neurons are believed to express proteins that lead to synaptic plasticity for more enduring memory coding. *Source: Adapted from Steriade, 2000.*

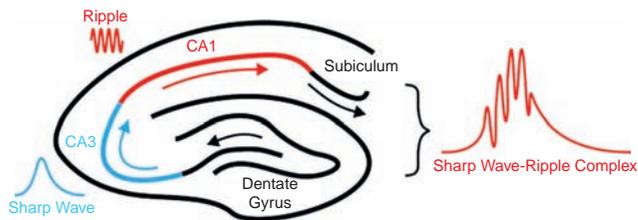


FIGURE 8.24 Hippocampal sharp and ripple waves. A cartoon of the hippocampus shows its basic arrays of neurons, which generate sharp waves and ripple complexes in activating retrieval and neocortical consolidation during slow wave sleep. *Source: Beenhakker & Huguenard, 2009.*

Buddhism and Vedanta Hinduism believe that humans should change their states of consciousness and self. That belief can be found in many times and places.

Simply asking people whether some practice makes them happier does not make for convincing evidence. Brain evidence may be more convincing. We cannot alter our EEG or fMRI scans to prove a favorite hypothesis. Decreased metabolism in the frontal lobes may be a

common theme for altered states. Dietrich (2003) argues that lowered frontal metabolism is a shared feature of hypnotizability, “runner’s high,” “flow,” and other unusual states of mind.

7.1 Epilepsy, drugs, and psychoses

Some mystical experiences are associated with epilepsy. Epileptic patients sometimes describe altered states as their EEG begins to show slow synchrony, even without visible seizures (see Figure 8.8). Since epileptic synchrony alters the workings of the thalamocortical core, there could be a link between altered subjective states and brain rhythms.

Psychedelic drugs have been compared to dreams, often showing vivid visual hallucinations, delusions, dreamlike actions, emotional encounters, time loss, and discontinuities. Similar experiences are described with some psychedelic drugs. The LSD molecule resembles serotonin, which is involved in REM dreaming. “Recreational drugs” by definition are taken with the goal of having unusual experiences. In the psychoses, delusions and hallucinations are often extremely upsetting, frightening, and unwanted. They occur at unexpected times, interfere with normal life, and can develop into painful persecutory voices and distressing beliefs. The degree to which these experiences are unwanted is one major difference between psychedelic drugs and psychotic experiences. Mental disorders are not a matter of choice, and people who suffer from them cannot stop at will.

7.2 Out-of-body experiences

Direct stimulation of the right posterior parietal cortex (PPC) can evoke dramatic changes in experienced body space (Figure 8.25), including out-of-body experiences (OBEs). Some of the most reliable results come from studies of OBEs, the experience of looking at one’s own body from the outside. Some epileptics experience alterations in body space, perhaps because of hypersynchronous activity affecting the parietal cortex. The parietal cortex plays a role in several unusual states.

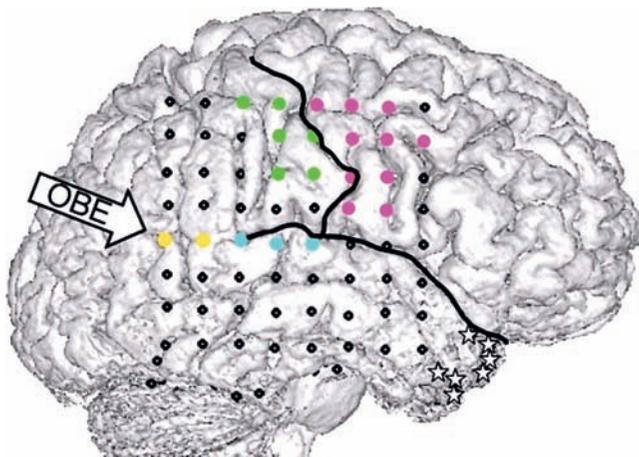


FIGURE 8.25 Electrical stimulation of the colored locations on the right parietal cortex and evoke out-of-body experiences. Source: Tong, 2003, after Blanke et al, 2002.

7.3 Neurofeedback

Neurofeedback training is defined as learning to control brain events by giving sensory (conscious) feedback, contingent on the event. Simply by holding a thermometer one can learn to increase warmth, for example, which seems to help people relax and lower blood pressure. Neurofeedback studies of animals have shown positive results over several decades. In a brain with billions of neurons, simple sensory feedback can allow training of voluntary control over otherwise involuntary neuronal firing.

EEG neurofeedback show significant results, but long-term studies are often lacking. Because neurofeedback may work in cases where other medical treatments have failed, long-term trials would seem to be vitally important.

7.4 Sensorimotor rhythm feedback

The sensorimotor response (SMR) is an alpha-like EEG pattern found over the motor cortex when people voluntarily suppress some planned action. SMR feedback training has been shown to be an effective treatment in cases of human epilepsy, ADHD, and impulse control disorders (Serman, 2006). On average, 80 percent of patients trained to enhance SMR had significant improvements.

Drug treatments for epilepsy do not always work, and having another treatment is helpful for many patients. Scientifically, because epilepsy shows slow, synchronous, and high waves in the EEG, the ability to modify it by training reveals an interesting fact about the voluntary control of brain rhythms.

7.5 Rhythmic entrainment

If brain rhythms constitute a basic neural code, it would be interesting to know if we can drive rhythms externally. If we listen to a 10-Hz auditory stream, will alpha waves increase? Brain wave entrainment has been described with TMS (transcranial magnetic stimulation) and tACS (transcranial alternating current). However, although there are many popular claims about the effects of auditory entrainment, they have not been demonstrated to work by demanding medical and scientific standards so far.

7.6 Hypnosis and conversion

About one-fourth of the normal population is highly hypnotizable, as assessed by standard hypnotic procedures. Hypnotic suggestions can change brain events, as in reducing the averaged evoked potential (AEP) to a flashing light simply by “hallucinating” a cardboard box covering the stimulus (Spiegel, 2003). We do not know how hypnotic induction works. About 5 percent of the population are said to be “hypnotic prodigies,” who can hallucinate perceptual events, such as the buzzing of a fly; they can also enter into dissociated identity states (Hilgard, 1977). fMRI studies show that hypnotically suggested pain activates some of the same brain regions as real pain. Hypnotic procedures can alleviate chronic pain (Spiegel, 2003).

Hypnosis may involve a dissociation between voluntary control (dorsolateral prefrontal cortex, DL-PFC) and the ability to monitor errors (the anterior cingulate cortex, ACC). Egner and colleagues (2005) reported an fMRI-EEG study of hypnosis in the Stroop task showing that “hypnosis decouples cognitive control from conflict monitoring processes of the frontal lobe.”

Mild conversion symptoms are quite common in medicine. Medical students who are studying serious diseases may become worried when they seem to notice “real” symptoms in themselves. “Medical student syndrome” is common and generally fades over time. Conversion disorders might be a result of the general human tendency toward autosuggestion. The placebo effect is a positive version of autosuggestion.

7.7 Meditation and yoga

The term *meditation* covers many mental techniques. One is silent repetition of a word called a “mantra.” Asian and other traditions describe mantra meditation as a method for changing mind states, as taught in Vedanta, Buddhism, and Chinese medicine. It has also been widely practiced in Europe and the Middle East.

Meditation methods have been reported to increase coherence (synchrony), especially in theta, alpha, and beta-gamma EEG. Frontal-lobe coherence is also reported, as well as improved attentional functioning (Lazar et al., 2000; Lutz et al., 2004; Tang et al., 2007).

One of the surprises with mantra repetition is a significant drop in metabolic activity, reflected in “breath suspensions”—spontaneous stopping of the breath without compensatory breathing afterward. This is different from holding our breath voluntarily. In swimming, for example, we may take a deep breath before diving and then feel the need to take some extra breaths after coming up for air. The lack of compensatory breathing suggests that energy demand has indeed dropped more than an ordinary resting state, as has been demonstrated by measuring O₂/CO₂ exchange (Benson et al., 1975).

Herbert Benson and colleagues (1975) proposed that these results represent a “relaxation response,” like other physiological reflexes. Spontaneous breath suspensions are reported to be associated with reports of periods of “pure consciousness,” defined as relaxed alertness without any specific mental contents. Converging evidence has come from measures of metabolism, sympathetic nervous system tone and, recently, large-scale changes in gene expression. Because the exact functions of “relaxation-related” genes are not yet clear, this promising direction requires additional studies (Dusek et al., 2006; Jacobs et al., 1996).

A different procedure is called “mindfulness meditation.” Cahn and Polich (2006, 2009) describe it as “allowing any thoughts, feelings, or sensations to arise while maintaining a specific attentional stance: awareness of the phenomenal field as an attentive and nonattached observer without judgment or analysis.” Mindfulness meditation has been shown to improve depression and even suicidal thinking.

8.0 SUMMARY

Consciousness has intrigued human beings since the beginning of history. With improved scientific tools we have seen considerable progress in recent years. Attention and consciousness can be considered complementary processes (see Figure 8.5). Conscious contents often

are thought to involve the widespread distribution of focal contents, like the sight of a rabbit. As soon as we see a rabbit (consciously), we can also judge whether it's real or if it's somebody's pet. We can laugh or scream for fear of being bitten and try to remember if rabbits carry rabies. The point is that a great variety of brain events can be evoked by a conscious object, including a great variety of unconscious processes.

Conversely, we can *select* a source of information to focus on. Selective attention allows us to choose what we will be conscious of. In order to learn about the brain, we direct attention to it over and over again. Learning a difficult subject involves allocating attentional resources over time.

Consciousness typically involves a small amount of focal contents at any given moment, like the sight of coffee cup at a distance, which then may recruit and mobilize many unconscious brain functions. In attention, major functions like motivation, planning, emotional needs, and the like all interact with consciousness of a specific object in the world. Episodic and declarative types of learning seem to occur automatically as a function of conscious contents, which in turn may be guided by voluntary attention.

The three major brain states of the circadian cycle show different operating styles. A major function of slow wave sleep is to consolidate the memory of events that were initially learned in the waking state. Waking consciousness is by far the most active state in terms of survival and reproduction, the two essential activities of any species. Food seeking, infant protection, fight or flight, tracking, hunting and gathering, social interactions, mate seeking—all these goal-directed activities require the conscious state. It follows that the brain (particularly the cortex and its great input hub, the thalamus) must be able to organize itself around many different goal-directed actions during waking.

REM dreaming looks similar to waking as measured by EEG. We can remember the last 10 or 20 seconds of a dream as a conscious drama. The contents of dreams are hallucinatory, visually vivid, and often emotionally dramatic. Dream contents come from the brain itself, triggered by brainstem (PGO).

Deep sleep (slow wave sleep) appears to be unconscious, but people can remember some content when they are woken up from SWS. Slow delta waves occur at 2 to 4 Hz, and it has been suggested that we are only truly unconscious during the valleys of the slow waves, the "down" cycle of the slow wave. At those times billions of neurons pause at the same time, making it impossible for neurons to signal one another. However, SWS is not inactive. Rather, it is the best time to convert learning into permanent synaptic changes.

9.0 STUDY QUESTIONS AND DRAWING EXERCISES

9.1 Study questions

1. What brain region triggers the circadian rhythm of waking, sleep and dreaming?
2. What is the function of slow wave sleep? Of waking? Of dreaming? (If no function is established, say so.)
3. When you learn to ride a bicycle really well, what happens to your cortical activity for sensorimotor control?
4. How might two brain areas that represent the visual field be coordinated?
5. What are the physiological signs of dreaming?

6. What are the main effects of selective attention? What part of the brain appears to control voluntary, selective attention?
7. What's meant by the "architecture of sleep"? Describe its features and timing.
8. What are some hypotheses about deep or slow-wave sleep? What kind of function might it have?
9. What are the features of the conscious waking state? What kind of cortical waveforms seem to occur?
10. Describe the up state and the down state of slow-wave sleep. What are the implications for brain processing?
11. Describe neurofeedback training. What is it useful for?
12. Is there convincing evidence that hypnosis reflects a brain state?
13. What are the pros and cons of surface (scalp) EEG compared to intracranial EEG (iEEG)?
14. Meditation methods have been described for thousands of years. What are some common features? What evidence do we have pro or con?

9.2 Drawing exercise

In Figure 8.26, indicate how dreams differ from waking. (Hint: What capacities are available during dreaming but not waking? During waking but not dreaming?)

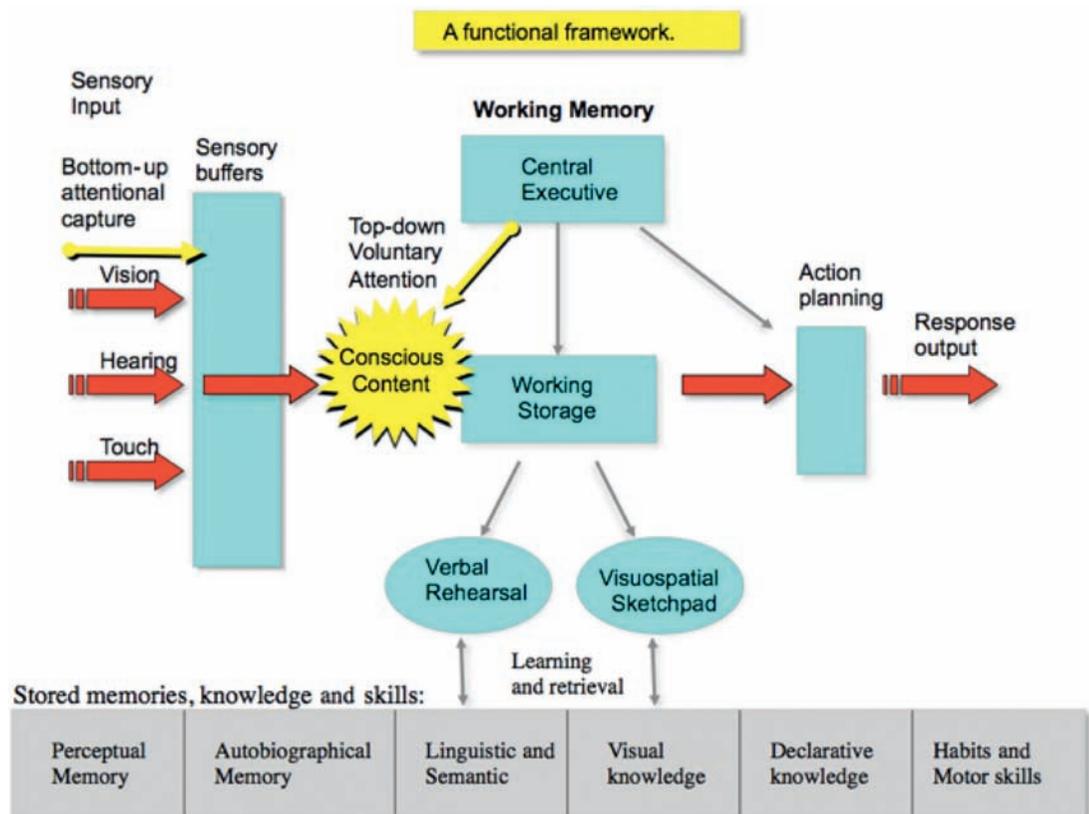


FIGURE 8.26 Source: Baars, with permission.