CHAPTER

8

Sleep and Dreaming

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OUTLINE

ABSTRACT

Sleep brings about the most dramatic change in consciousness we are all familiar with. Consciousness nearly fades during deep sleep early in the night, and returns later on in the form of dreams despite our virtual disconnections from the outside world. Meanwhile, the brain goes through an orderly progression of changes in neural activity, epitomized by the occurrence of slow oscillations and spindles. There are also local changes in the activation of many brain regions, as indicated by imaging studies. This chapter considers sleep stages and cycles, brain centers regulating wakefulness and sleep, the neural correlates of wakefulness and sleep including changes in spontaneous neural activity and in metabolism, as well as changes in responsiveness to stimuli. Next, it reviews changes in the level of consciousness during sleep, and considers recent findings concerning the underlying mechanisms. Finally, the chapter examines how consciousness changes during dreaming and discusses the underlying neuropsychology, possible neurocognitive models, as well as the development of dreams. This overview ends with a consideration of dissociated states such as daydreaming, lucid dreaming, sleepwalking, REM sleep behavioral disorders and narcolepsy.

Studying mental activity during sleep offers a unique opportunity to find out how changes in consciousness are associated with changes in brain activity. Indeed, sleep brings about at once the most common and the most dramatic change in consciousness that healthy subjects are likely to witness – from the near-fading of all experience to the bizarre hallucinations of dreams. At the same time, the brain goes through an orderly progression of sleep stages, which can be identified by recording the electroencephalogram (EEG), eye movements (EOG, electroculogram), and muscle tone (EMG, electromyogram), and which indicate that major changes in brain activity are taking place. Within each sleep stage, there are frequent, short-lasting EEG phenomena, such as slow oscillations and spindles, which indicate precise times at which brain activity undergoes important fluctuations. There are also orderly spatial changes in the activation of many brain regions, as indicated by imaging studies. All of this happens spontaneously and reliably every night. Moreover, similar changes occur in animals, which have spearheaded detailed studies of the underlying neural mechanisms.

This chapter will first examine how sleep is traditionally subdivided into different stages that alternate in the course of the night, and consider the brain centres that determine whether we are asleep or awake. The chapter will then discuss how brain activity changes between sleep and wakefulness, and consider how this leads to the characteristic modifications of consciousness.

SLEEP STAGES AND CYCLES

In the course of the night, the EEG, EOG, and EMG patterns undergo coordinated changes that are used to distinguish among different sleep stages (Figure 8.1).

Wakefulness. During wakefulness, the EEG is characterized by waves of low amplitude and high frequency. This kind of EEG pattern is known as *low-voltage fast-activity* or *activated*. When eyes close in preparation for sleep, EEG alpha activity (8–13 Hz) becomes prominent, particularly in occipital regions. Such alpha activity is thought to correspond to an 'idling' rhythm in visual areas. The waking EOG reveals frequent voluntary eye movements and eye blinks. The EMG reveals tonic muscle activity with additional phasic activity related to voluntary movements.

Falling asleep: Stage N1. Falling asleep is a gradual phenomenon of progressive disconnection from the environment. Sleep is usually entered through a transitional state, stage 1, characterized by loss of alpha activity and the appearance of a low-voltage mixed-frequency EEG pattern with prominent theta activity (3–7 Hz). Eye movements become slow and rolling, and muscle tone relaxes. Although there is decreased awareness of sensory stimuli, a subject in stage N1 may deny that he was asleep. Motor activity may persist for a number of seconds during stage N1. Occasionally individuals experience sudden muscle contractions (hypnic jerks), sometimes accompanied by a sense of

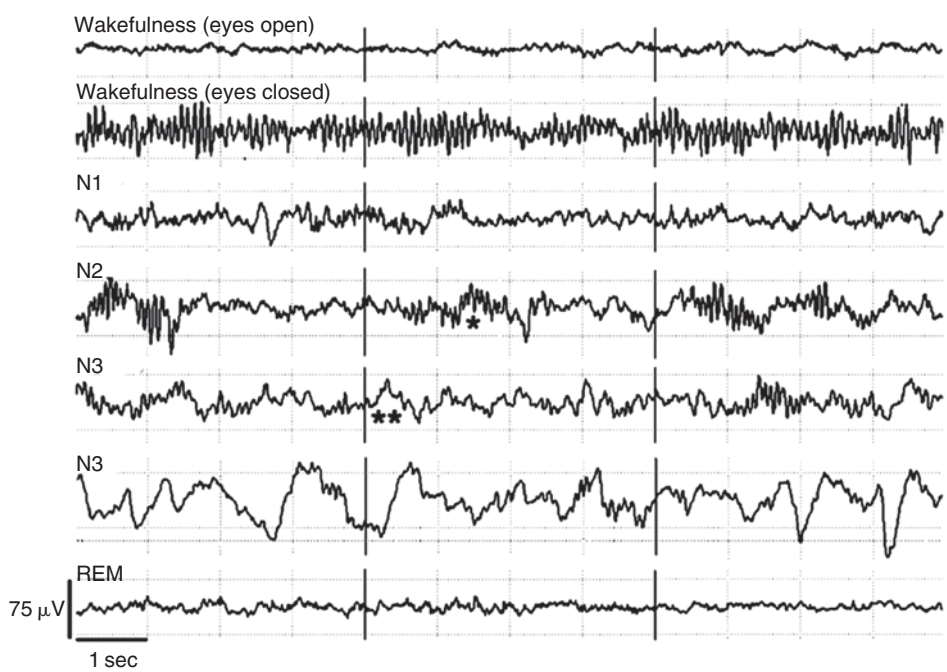

FIGURE 8.1 The human EEG during wakefulness and the different stages of sleep (*, sleep spindles; **, slow wave).

falling and dream-like imagery. Individuals deprived of sleep often have 'microsleep' episodes that consist of brief (5–10 seconds) bouts of stage 1 sleep; these episodes can have serious consequences in situations that demand constant attention, such as driving a car.

Sleep is traditionally categorized into non-rapid eye movement (NREM) sleep and REM sleep. Human NREM sleep, in turn, is divided into stages N2 and N3.

NREM sleep: Stage N2. After a few minutes in stage N1, people usually progress to stage N2 sleep. Stage N2 is heralded in the EEG by the appearance of K-complexes and sleep spindles, which are especially evident over central regions. K-complexes are made up of a high-amplitude negative sharp wave followed by a positive slow wave, and are often triggered by external stimuli. Sleep spindles are waxing and waning oscillations at around 12–15 Hz that last about 1 second and occur 5–10 times a minute. Eye movements and muscle tone are much reduced. Stage N2 qualifies fully as sleep because people are partially disconnected from the environment, meaning that they do not respond to the events around them – their *arousal threshold* is increased. If stimuli are strong enough to wake them up, people in stage N2 will confirm that they were asleep.

NREM sleep: Stage N3. Stage N2 is followed, especially at the beginning of the night, by a period called stage N3, during which the EEG shows prominent slow waves in the delta range (<2 Hz, >75 μV in humans). Eye movements cease during stage N3 and EMG activity decreases further. Stage N3 is also referred to as *slow wave sleep*, *delta sleep*, or *deep sleep*, since the threshold for arousal is higher than in stage N2. The process of awakening from slow wave sleep is drawn out, and subjects often remain confused for some time.

REM sleep. After deepening through stages N2 to N3, NREM sleep lightens and returns to stage N2, after which the sleeper enters REM sleep [1, 2] also referred to as *paradoxical sleep* [3–5] because the EEG during REM sleep is similar to the activated EEG of waking or of stage N1. Indeed, the EEG of REM sleep is characterized by low-voltage fast-activity, often with increased power in the theta band (3–7 Hz). REM sleep is not subdivided into stages, but is rather described in terms of tonic and phasic components. Tonic aspects of REM sleep include the activated EEG and a generalized loss of muscle tone, except for the extraocular muscles and the diaphragm. REM sleep is also accompanied by penile erections. Phasic features of REM include irregular bursts of REM and muscle twitches. Behaviourally, REM sleep is deep sleep, with an arousal threshold that is as high as in slow wave sleep.

The sleep cycle. The succession of NREM sleep stages followed by an episode of REM sleep is called a sleep cycle, and lasts approximately 90–110 minutes in humans. As shown in Figure 8.2, there are a total of 4–5 cycles every night. Slow wave sleep is prominent early in the night, especially during the first sleep cycle, and diminishes as the night progresses. As slow wave sleep wanes, periods of REM sleep lengthen and show greater phasic activity. The proportion of time spent in each stage and the pattern of stages across the night is fairly consistent in normal adults. A healthy young adult will typically spend about 5% of the sleep period in stage N1, about 50% in stage N2, 20–25% in stage N3 (slow wave sleep), and 20–25% in REM sleep.

Sleep during the lifespan. Sleep patterns change markedly across the lifespan [6–10]. Newborn infants spend 16–18 hours per day sleeping, with an early version of REM sleep, called active sleep, occupying about half of their sleep time. At approximately 3–4 months of age, when sleep starts to become consolidated during the night, the sleep EEG shows more mature waveforms characteristic of NREM and REM sleep. During early childhood, total sleep time decreases and REM sleep proportion drops to adult levels. The proportion of NREM sleep spent in slow wave sleep increases during the first year of life, reaches a peak, declines during adolescence and adulthood and may disappear entirely by age 60.

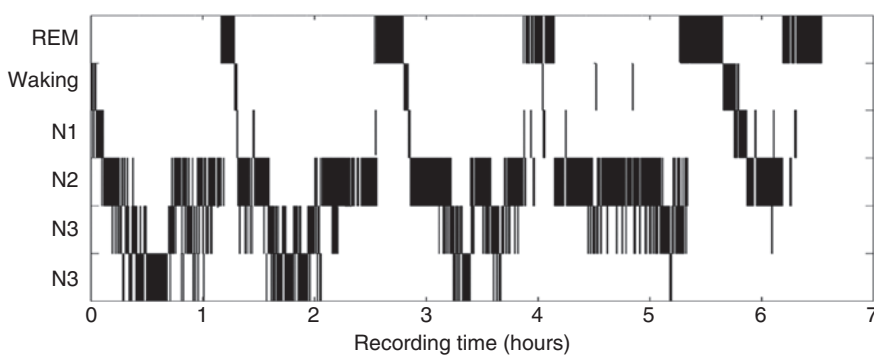

FIGURE 8.2 Hypnogram for an all-night recording in a young man. Note the occurrence of five sleep cycles, the predominance of slow wave sleep (stage N3 – the two of N3 rows correspond to stages 3 and 4 of the previous staging convention) early in the night and the increasing length of REM sleep episodes later in the night.

BRAIN CENTRES REGULATING WAKEFULNESS AND SLEEP

Wakefulness system. Maintenance of wakefulness is dependent on several heterogeneous cell groups extending from the upper pons and midbrain (the so-called *reticular activating system*, RAS [11, 12]), to the posterior hypothalamus and basal forebrain. These cell groups are strategically placed so that they can release, over wide regions of the brain, neuromodulators and neurotransmitters that produce EEG activation, such as acetylcholine, histamine, norepinephrine, glutamate, and hypocretin (Figure 8.3, red). Cholinergic cells are located in the basal forebrain and in two small nuclei in the pons: the *pedunculopontine tegmental* and *lateral dorsal tegmental* nuclei (*PPT/LDT*). Both basal forebrain and pontine cholinergic cells fire at high rates in wakefulness and REM sleep, and decrease or stop firing during NREM sleep [13–15]. Pontine cholinergic cells project to the thalamus, where they help depolarize specific and intralaminar thalamic nuclei. The latter, which are dispersed throughout the thalamus and project diffusely to the cortex, fire at very high frequencies during both wakefulness and REM sleep and help to synchronize cortical firing in the gamma (>28 Hz) range [16–18]. Cholinergic cells in the dorsal brainstem and nearby non-cholinergic cells also project to other cholinergic and non-cholinergic cells (many of them glutamatergic) in the basal forebrain, which in turn provide an excitatory input to the entire cortex [18–20].

Cholinergic neurons in the pons also project to the posterior hypothalamus, where histaminergic neurons are located in the *tuberomammillary nucleus* [21]. Histaminergic neurons, which project throughout the cortex, fire at the highest rates during wakefulness and are inhibited during both NREM and REM sleep [22]. Probably the largest contingent of the wakefulness-promoting system is made up by cells dispersed throughout the brainstem reticular formation and the basal forebrain that do not release conventional neuromodulators, but rather the ubiquitous neurotransmitter glutamate. By binding to metabotropic receptors, glutamate can act as a neuromodulator and influence the excitability of target cells. The firing patterns of these glutamatergic cells are not well characterized [18–20]. Noradrenergic cells are concentrated in the *locus coeruleus* in the upper pons, from where they project throughout the brain [23–27]. They fire tonically during wakefulness, and emit short, phasic bursts of activity during behavioural choices or salient events [13, 23–27]. By contrast, locus coeruleus neurons decrease their firing during NREM sleep, and cease firing altogether during REM sleep. Serotoninergic cells from the *dorsal raphe* nucleus also project widely throughout the brain and, like noradrenergic neurons, fire at higher levels in waking, lower levels in NREM sleep, and fall silent during REM sleep. However, in contrast to noradrenergic neurons, serotoninergic neurons are inactivated when animals make behavioural choices or orient to salient stimuli, and are activated instead during repetitive motor activity such as locomoting, grooming, or feeding [28, 29]. Dopamine-containing neurons located in the substantia nigra and ventral tegmental area, which innervate the frontal cortex, basal forebrain, and limbic structures [30], do not appear to change their firing rate depending on behavioural state, though blocking dopamine reuptake is known to promote arousal [30]. Finally, the peptide hypocretin (also known as orexin) is produced by cells in the posterior hypothalamus that provide excitatory input to all components of the waking system [31, 32]. These cells, too, are most active during waking, especially in relation to motor activity and exploratory behaviour, and almost stop firing during both NREM and REM sleep [33, 34].

Altogether, the main mechanism by which these neuromodulators and neurotransmitters produce cortical activation is by closing leakage potassium channels on the cell membrane of cortical and thalamic neurons, thus keeping cells depolarized and ready to fire.

Sleep system. At sleep onset, wakefulness-promoting neuronal groups are actively inhibited by antagonistic neuronal populations located in the hypothalamus and basal forebrain (Figure 8.3, green). Decreasing levels of acetylcholine and other waking-promoting neuromodulators and neurotransmitters lead to the opening of leak potassium channels in cortical and thalamic neurons, which become hyperpolarized

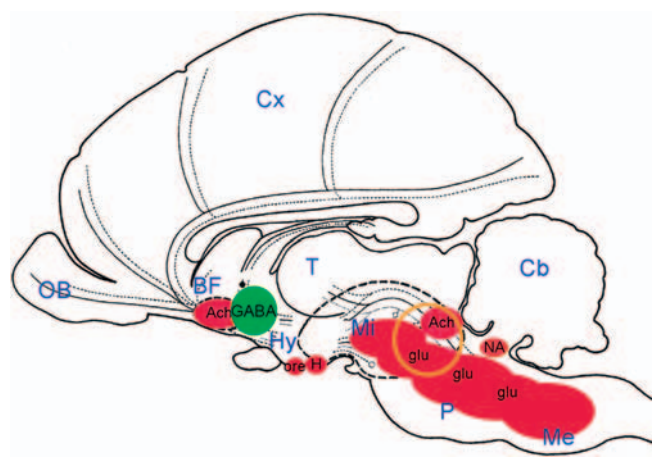

FIGURE 8.3 The major brain areas involved in initiating and maintaining wakefulness (red), NREM sleep (green), and REM sleep (orange). OB, olfactory bulb; Cx, cerebral cortex; Cb, cerebellum; T, thalamus; BF, basal forebrain; Hy, hypothalamus; Mi, midbrain; P, pons; Me, medulla oblongata; Ach, acetylcholine; glu, glutamate; NA, norepinephrine; H, histamine; ore, orexin/hypocretin.

and begin oscillating at low frequencies. Cell groups scattered within the anterior hypothalamus, including the ventrolateral preoptic area (VLPO [35, 36]) and the median preoptic nucleus [37], as well as in the basal forebrain, are involved in the initiation and maintenance of sleep. These neurons tend to fire during sleep and stop firing during wakefulness. When they are active, many of them release GABA and the peptide galanin, and inhibit most waking-promoting areas, including cholinergic, noradrenergic, histaminergic, hypocretinergic, and serotonergic cells. In turn, the latter inhibit several sleep-promoting neuronal groups [38–41]. This reciprocal inhibition provides state stability, in that each state reinforces itself as well as inhibits the opponent state.

REM sleep generator. This consists of pontine cholinergic cell groups (LDT and PPT) that are part of the wakefulness system, and nearby cell groups in the medial pontine reticular formation and medulla [3, 13, 42, 43]. Lesions in these areas eliminate REM sleep without significantly disrupting NREM sleep. Pontine cholinergic neurons produce EEG activation by releasing acetylcholine to the thalamus and to cholinergic and glutamatergic basal forebrain neurons that in turn activate the limbic system and cortex. However, while during wakefulness other waking-promoting neuronal groups, such as noradrenergic, histaminergic, hypocretinergic, and serotonergic neurons, are also active, they are inhibited during REM sleep. Other REM active neurons in the dorsal pons are responsible for the tonic inhibition of muscle tone during REM sleep. Finally, neurons in the medial pontine reticular formation fire in bursts and produce phasic events of REM sleep, such as REM and muscle twitches.

NEURAL CORRELATES OF WAKEFULNESS AND SLEEP

Wakefulness, NREM and REM sleep are accompanied by changes in spontaneous neural activity, metabolism, and responsiveness to stimuli.

Spontaneous Neural Activity

Wakefulness. The waking EEG, characterized by the presence of low-voltage fast-activity, is known as *activated* because most cortical neurons are steadily depolarized close to their firing threshold (Figure 8.4, left), and are thus ready to respond to the slightest change in their inputs. The readiness to respond of cortical and thalamic neurons enables fast and effective interactions among distributed regions of the thalamocortical system, resulting in a continuously changing sequence of specific firing patterns. Superimposed on the low-voltage fast-activity background of wakefulness one frequently observes rhythmic oscillatory episodes within the alpha (8–13 Hz), beta (14–28 Hz), and gamma (>28 Hz) range, which are usually localized to specific cortical areas. These waking rhythms are due to the activation of oscillatory mechanisms intrinsic to each cell as well as to the entrainment of oscillatory circuits among excitatory and inhibitory neurons.

NREM sleep. The EEG of NREM sleep differs markedly from that of wakefulness because of the occurrence of slow waves (<2 Hz in humans), K-complexes, and sleep spindles. The opening of leakage potassium channels due to the reduced levels of acetylcholine and other neuromodulators draws cortical and thalamic cells towards hyperpolarization and triggers a series of membrane currents that produce the *slow oscillation* (Figure 8.4, centre) [45]. As shown by intracellular recordings, the slow oscillation is made up of a hyperpolarization phase or *down-state*, which lasts a few hundreds of milliseconds, and a slightly longer depolarization phase or *up-state*. The down-state is associated with the virtual absence of synaptic activity within cortical networks. During the up-state, by contrast, cortical cells fire at rates that are as high or even higher than those seen in waking, and may even show periods of fast oscillatory activity in the gamma range.

The slow oscillation is found in virtually every cortical neuron, and is synchronized across much of the cortical mantle by cortico-cortical and thalamo-cortical

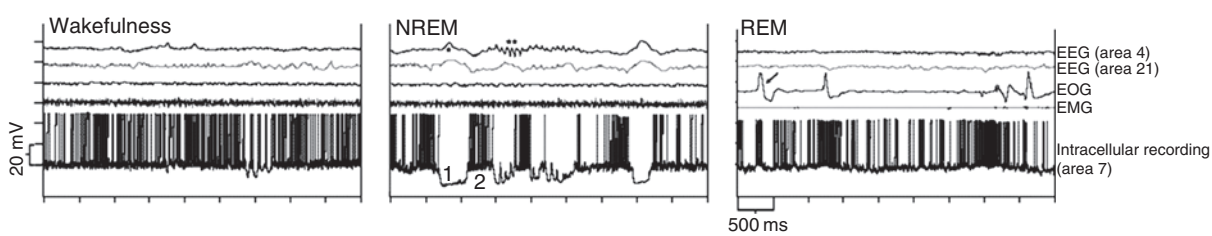

FIGURE 8.4 Simultaneous EEG, EOG, EMG, and intracellular cortical recording in a cat. During NREM sleep, the EEG trace shows slow waves (*) and sleep spindles (**), while the intracellular trace reveals the occurrence of slow oscillations in membrane potential (1 and 2 indicate down-state and up-state, respectively). During REM sleep note the absence of muscle tone and the presence of REM (arrow). *Source*: Modified from [44].

connections, which is why the EEG records high-voltage, low-frequency waves. Human EEG recordings using 256 channels have revealed that EEG slow waves behave as travelling waves that sweep across a large portion of the cerebral cortex [46]. Most of the time, the sweep starts in the very front of the brain and propagates front to back. These sweeps occur very infrequently during stage N1, around 5 times a minute during stage N2, more than 10 times a minute in stage N3. Thus, a wave of depolarization and intense synaptic activity, followed by a wave of hyperpolarization and synaptic silence, sweeps across the brain more and more frequently just as NREM sleep becomes deeper. Slow waves can originate at short intervals at multiple cortical sites, in which case they superimpose or interfere, leading to EEG waves that are shorter and more fractured. Topographically, slow waves are especially prominent over dorsolateral prefrontal cortex. *K-complexes*, which are usually triggered by external stimuli and appear particularly prominent because they are not immediately preceded or followed by other slow waves, are most likely the EEG correlate of global slow oscillations due to the near-synchronous activation of the cortical mantle by the RAS (as opposed to a single cortical source).

Sleep spindles occur during the depolarized phase of the slow oscillation and are generated in thalamic circuits as a consequence of cortical firing. When the cortex enters an up-state, strong cortical firing excites GABAergic neurons in the reticular nucleus of the thalamus. These in turn strongly inhibit thalamocortical neurons, triggering intrinsic currents that produce a rebound burst of action potentials. These bursts percolate within local thalamoreticular circuits and produce oscillatory firing at around 12–15 Hz. Thalamic spindle sequences reach back to the cortex and are globally synchronized by corticothalamic circuits, where they appear in the EEG as sleep spindles.

REM sleep. During REM sleep, the EEG returns to an activated, low-voltage fast-activity pattern that is similar to that of quiet wakefulness or stage 1 (Figure 8.4, right). As in wakefulness, the tonic depolarization of cortical and thalamic neurons is caused by the closure of leakage potassium channels. In fact, during REM sleep acetylcholine and other neuromodulators are released again at high levels, just as in wakefulness, and neuronal firing rates in several brain areas tend to be higher.

Metabolism and Blood Flow

Recently, the data obtained by recording the activity of individual neurons have been complemented by imaging studies that provide a simultaneous picture of synaptic activity over the entire brain, although at much lower resolution.

NREM sleep. Positron emission tomography (PET) studies show that metabolic activity and blood flow are globally reduced in NREM sleep compared to resting wakefulness [47, 48]. During slow wave sleep metabolic activity can be reduced by as much as 40%. Metabolic activity is mostly due to the energetic requirements of synaptic transmission, and its reduction during NREM sleep is thus most likely due the hyperpolarized phase of the slow oscillation, during which synaptic activity is essentially abolished. At a regional level, activation is especially reduced in the thalamus, due to its profound hyperpolarization during NREM sleep. In the cerebral cortex, activation is reduced in dorsolateral prefrontal cortex, orbitofrontal and anterior cingulate cortex. This deactivation is to be expected given that slow waves are especially prominent in these areas. Parietal cortex, precuneus and posterior cingulate cortex, as well as medial temporal cortex also show relative deactivations. As discussed in other chapters, the deactivation of thalamus and associated frontoparietal networks is seen in other conditions characterized by reduced consciousness, such as coma, vegetative states, and anaesthesia. By contrast, primary sensory cortices are not deactivated compared to resting wakefulness. Basal ganglia and cerebellum are also deactivated, probably because of the reduced inflow from cortical areas.

REM sleep. During REM sleep absolute levels of blood flow and metabolic activity are high, reaching levels similar to those seen during wakefulness, as would be expected based on the tonic depolarization and high firing rates of neurons. There are, however, interesting regional differences [48, 49]. Some brain areas are more active in REM sleep than in wakefulness. For example, there is a strong activation of limbic areas, including the amygdala and the parahippocampal cortex. Cerebral cortical areas that receive strong inputs from the amygdala, such as the anterior cingulate and the parietal lobule, are also activated, as are extrastriate areas. By contrast, the rest of parietal cortex, precuneus and posterior cingulate, and dorsolateral prefrontal cortex are relatively deactivated. As will be mentioned below, these regional activations and inactivations are consistent with the differences in mental state between sleep and wakefulness.

Upon awakening, blood flow is rapidly re-established in brainstem and thalamus, as well as in the anterior cingulate cortex [50]. However, it can take up to 20 minutes for blood flow to be fully re-established in other brain areas, notably dorsolateral prefrontal cortex. It is likely that this sluggish reactivation

is responsible for the phenomenon of *sleep inertia* – a post-awakening deficit in alertness and performance that can last for tens of minutes.

Responsiveness to Stimuli

The most striking behavioural consequence of falling asleep is a progressive disconnection from the environment: the threshold for responding to peripheral stimuli gradually increases with the succession of NREM sleep stages N1 to N3, and remains high during REM sleep. Since cortical neurons continue to fire actively during sleep, how does this disconnection come about?

NREM sleep. Due to the progressive, intermittent hyperpolarization of thalamocortical neurons, sensory stimuli that normally would be relayed to the cortex often fail to do so because they do not manage to fire thalamocortical cells. In addition, the rhythmic hyperpolarization during sleep spindles is especially effective in blocking incoming stimuli, since it imposes an intrinsic oscillatory rhythm that effectively decouples inputs from outputs. Thus, the 'thalamic gate' to the cerebral cortex is partially closed [51]. However, sensory stimuli in various modalities can still elicit evoked potentials from the cerebral cortex, and neuroimaging studies show that primary cortical areas are still being activated [52]. As suggested by studies using transcranial magnetic stimulation (TMS) in conjunction with high-density EEG [53], it is likely that during NREM sleep the activation of primary sensory areas is not followed by the activation of higher-order areas because of a breakdown in cortical effective connectivity.

REM sleep. With the transition from NREM to REM sleep, neurons return to be steadily depolarized much as they are during quiet wakefulness, yet sensory stimuli are still ignored, as if the brain were focusing on its internal activities rather than on the environment [54], not unlike states of intense absorption. While the underlying mechanisms are not clear, the prefrontal and parietal cortical areas that are deactivated in REM sleep are important for directing and sustaining attention to sensory cortices. Sensory inputs reaching primary cortices would then find themselves to be systematically unattended. It is likely that the reduced activity in these cortical regions is a direct consequence of changes in the neuromodulatory milieu during REM sleep. Specifically, the reduction of serotonin release during REM sleep may favour a dissociative–hallucinogenic state, as seen with certain psychoactive compounds. Nevertheless, in contrast to a person in a coma or a vegetative state, a sleeping person can always be awakened if stimuli are strong enough, or especially meaningful. For example, it is well known that the sound of one's name, or the wailing of a baby, is among the most effective signals for awakening.

CONSCIOUSNESS IN SLEEP

There are two main lessons to be learned from the study of consciousness in sleep. The first is that, during certain phases of sleep, the level of consciousness can decrease and at times nearly vanish, despite the fact that neural activity in the thalamocortical system is relatively stable. The second is that, during other phases of sleep, vivid conscious experience is possible despite the sensory and motor disconnection from the environment and the loss of self-reflective thought.

Changes in the Level of Consciousness

Studying mental activity during sleep offers a unique opportunity to find out how changes in brain activity are associated with changes in consciousness [55]. When REM sleep was discovered, it was immediately noticed that, if subjects were awakened from that stage of sleep and asked whether they had a dream, they would say so at least 80% of the time. Subjects invariably reported dreams that were vivid, with characteristically intricate plots and changes of scene. Awakenings from NREM sleep, instead, yielded dreams 20% of the time or less. These findings led to the approximate equation of a physiological state, REM sleep, with a cognitive state, dreams. This equation was encouraged by the remarkable similarity between the EEG of REM sleep with that of wakefulness, as opposed to that of NREM sleep. It seemed natural to infer that the activated (low voltage, fast activity) EEG of waking and REM sleep would support vivid conscious experience, while the deactivated (high voltage, slow activity) EEG of NREM sleep would not.

However, later studies have shown that the relationship between consciousness and sleep stages is more complicated. By just changing the question from 'tell me if you had a dream' to 'tell me anything that was going through your mind just before you woke up', the percentages of recalls from NREM sleep reaches as high as 60%. It is now clear that reports indicative of conscious experience, including dream-like experiences, can be elicited during any stage of sleep [56, 57].

Sleep onset. Reports from sleep stage 1 are very frequent (80–90% of the time) but also very short. Usually people report hallucinatory experiences, so-called

hypnagogic hallucinations (Greek for 'leading into sleep'). In contrast to typical dreams, hypnagogic hallucinations are often static, similar to single snapshots or a short sequence of still frames. For instance a subject may report: '… *I could feel myself moving just the way the sea moves our boat when I was out fishing today*'. This and the following examples are taken from [56, 58].

NREM sleep. A substantial number of awakenings from NREM sleep yield no report whatsoever, especially early in the night when stage N3 is prevalent. Thus, early slow wave sleep is the only phase of adult life during which healthy human subjects may deny that they were experiencing anything at all. On the other hand, between 60% and 80% of the time, awakenings from NREM sleep yield reports with experiential content. The length of NREM reports is widely distributed. Their median length is similar to that of reports from sleep onset. However, there are many very short reports early in the night and much longer reports later in the night [59], considerably longer than those typically obtained at sleep onset or even during quiet wakefulness. Reports from NREM sleep, especially early in the night, are often thought-like, for example: '*I kept thinking about my upcoming exam and about the subject matter that it will contain…*' Later in the night, they can be much more hallucinatory and, generally speaking, more dream-like.

REM sleep. Awakenings from REM sleep yield reports 80–90% of the time, a percentage similar to that obtained at sleep onset. Especially in the morning hours, the percentage is close to 100%, which is of course the report rate for wakefulness. Most REM reports have the characteristics of typical dreams: complex, temporally unfolding hallucinatory episodes that can be as vivid as waking experience. For example, as reported by Allan Hobson [58]: '*As the climbing party rounds the trail to the right, I am suddenly on a bicycle, which I steer through the group of climbers. It becomes clear that I make a complete circuit of the peak (at this level) by staying on the grass. There is, in fact, a manicured lawn surface continuing between the rocks and the crags … Then the scene changes to Martha's Vineyard Island (though I was still on the same bicycle) … and then to a shopping centre, a restaurant, a dance, and a meeting of faculty colleagues … one of my colleague's wives is seen as a blonde when, in reality, she is a brunette. The sense of movement, which is continuous, becomes particularly delightful when I become practically weightless and glide along a golf fairway. At the dance there is a Baltic group wearing embroidered peasant garb and stamping the floor to a loud band (I can hear the drums especially)*'. Remarkably, the median word count of REM sleep reports is even higher than that of wakefulness reports, whether quiet or active. This finding seems to fit with the notion that dreams are single-minded, and thus less frequently interrupted by extraneous thoughts, than waking consciousness. Also, the average length of REM reports increases with the duration of the REM sleep episode. By contrast, there is no such relationship for NREM sleep reports [59].

What are the processes underlying the systematic changes in the level of consciousness during different phases of sleep? At first, it was assumed that the fading of consciousness during certain phases of sleep was due to the brain shutting down. However, while metabolism is reduced, the thalamocortical system remains active also during stage N3, with mean firing rates during the up-state of the slow oscillation that are comparable to those of quiet wakefulness [51]. Indeed, most other aspects of neural activity during the up-state of the sleep slow oscillation, including gamma activity, resemble those observed during wakefulness [60]. Why, then, does consciousness fade during certain phases of sleep and return during others?

An intriguing possibility is that the level of consciousness during sleep may be related to the degree of bistability of thalamocortical networks. Even though the level of activation of cortical neurons during the up-state of NREM slow oscillations is as high as in wakefulness and REM sleep, the up-state of NREM sleep is intrinsically unstable, in that it is inexorably terminated by the occurrence of a down-state – a generalized, stereotypical cessation of activity that can last for a tenth of a second or more. The transition from up- to down-states appears to be due to depolarization-dependent potassium currents and to short-term synaptic depression, both of which increase with the amount of prior activation [51]. Indeed, during NREM sleep the stimulation of cortical neurons typically precipitates a down-state, and even spontaneous activity cannot last for long before a down-state is triggered.

From this perspective, the incidence of spontaneous slow waves can provide a telling indicator of the degree of bistability in thalamocortical networks. Thus, during stage N1, at the transition between wakefulness and sleep, the cortex enjoys periods of activation that can last up to a minute before a large slow wave sweeps through, which is consistent with reports of short, hallucinatory sequences upon awakening. In stage N2 early in the night, the EEG is similar to that of stage N1, but the intervals between large slow waves are much shorter, on average 12 seconds. Accordingly, reports are not only short, but also thought-like in character. In stage N2 later in the morning, the intervals between large slow waves are longer, and reports are correspondingly longer and more dream-like. The hallmark of slow wave sleep, which is prevalent early in the night, are the large slow

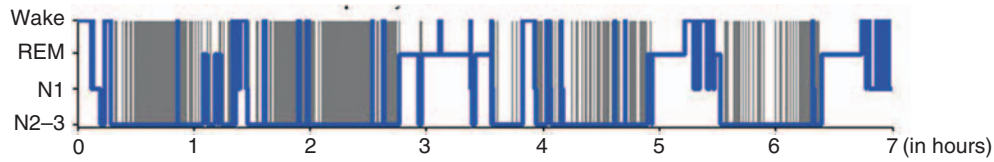

FIGURE 8.5 Incidence of large slow waves depending on sleep stage and time of night.

waves that sweep through the cortex more than 10 times a minute in stage N3 (Figure 8.5), suggesting an extreme degree of bistability. Correspondingly, reports are usually of short duration and often thought-like; at times, no experiential content is reported. In stark contrast, during REM sleep, which predominates later in the night, the EEG is tonically activated and there are no slow waves sweeping the cortex. Accordingly, REM reports are on average much longer, 2–7 times more than in NREM sleep, and usually yield vivid, prototypical dreams.

Why would the level of consciousness reflect the degree of bistability of thalamocortical networks? A possible answer is offered by the integrated information theory of consciousness [61], which states that the level or quantity of consciousness is given by a system's capacity to generate integrated information. According to the theory, the brain substrate of consciousness is a complex of neural elements within the thalamocortical system that has a large repertoire of available states (*information*), yet cannot be decomposed into a collection of causally independent subsystems (*integration*). In this view, integrated information would be high during wakefulness because thalamocortical networks have a large repertoire of global firing patterns that are continuously available on a background of tonic depolarization. During early NREM sleep, by contrast, the ensuing bistability would reduce this global repertoire through two mechanisms. First, a local activation would cause a local down-state preventing effective interactions with other brain areas. As a consequence, the main thalamocortical complex would break down into causally independent modules (loss of integration). Second, to the extent that global activation patterns can still occur, they too would be rapidly followed by a global, stereotypical down-state, thereby greatly reducing the repertoire of available states (loss of information).

To test these predictions, it is not sufficient to observe activity levels or patterns of temporal correlations among distant brain regions (*functional connectivity*), but it is crucial to employ a perturbational or causal approach (*effective connectivity*). For this purpose, TMS-evoked brain responses were recorded using a high-density EEG system to investigate to what extent cortical regions can interact causally (*integration*) and produce differentiated responses (*information*) [53]. As shown in Figure 8.6A, TMS applied to various cortical regions during wakefulness induced a sustained response made of changing patterns of activity. Specifically, a sequence of time-locked, high-frequency (20–35 Hz) oscillations occurred in the first 100 ms and was followed by a few slower (8–12 Hz) components that persisted until 300 ms. Source modelling revealed that the initial response to TMS was followed by spatially and temporally differentiated patterns of activation presumably mediated by long-range ipsilateral and transcallosal connections.

As soon as the subjects transitioned into stage N1, the TMS-evoked response grew stronger at early latencies but became shorter in duration due to dampening of later fast waves. With the onset of NREM sleep, the brain response to TMS changed markedly. The initial wave doubled in amplitude and became slower. Following this large wave, no further TMS-locked activity could be detected, except for a negative rebound between 80 and 140 ms. Specifically, fast waves, still visible during stage N1, were completely obliterated, and all TMS-evoked activity had ceased by 150 ms. Moreover, as shown in Figure 8.6B left, the activity evoked by TMS remained localized to the site of stimulation and did not propagate to connected brain regions, presumably because of the induction of a local down-state. This finding indicates that during early NREM sleep, when the level of consciousness is reduced, effective connectivity among cortical regions breaks down, implying a corresponding breakdown of cortical integration.

In subsequent experiments, it was found that, when applied to a median centroparietal region, each TMS pulse would trigger a full-fledged, high-amplitude slow wave that closely resembled spontaneous ones and that travelled through much of the cortex [62]. Spatially, the TMS-evoked slow wave was associated with a broad and stereotypical response: cortical currents spread, like an oil-spot, from the stimulated site to the rest of the brain. The large negative peak evoked by the TMS pulse, corresponding to a global cortical down-state, demonstrates that during early NREM sleep activation is inevitably followed by deactivation, suggesting that the repertoire of possible firing patterns (information) is drastically reduced

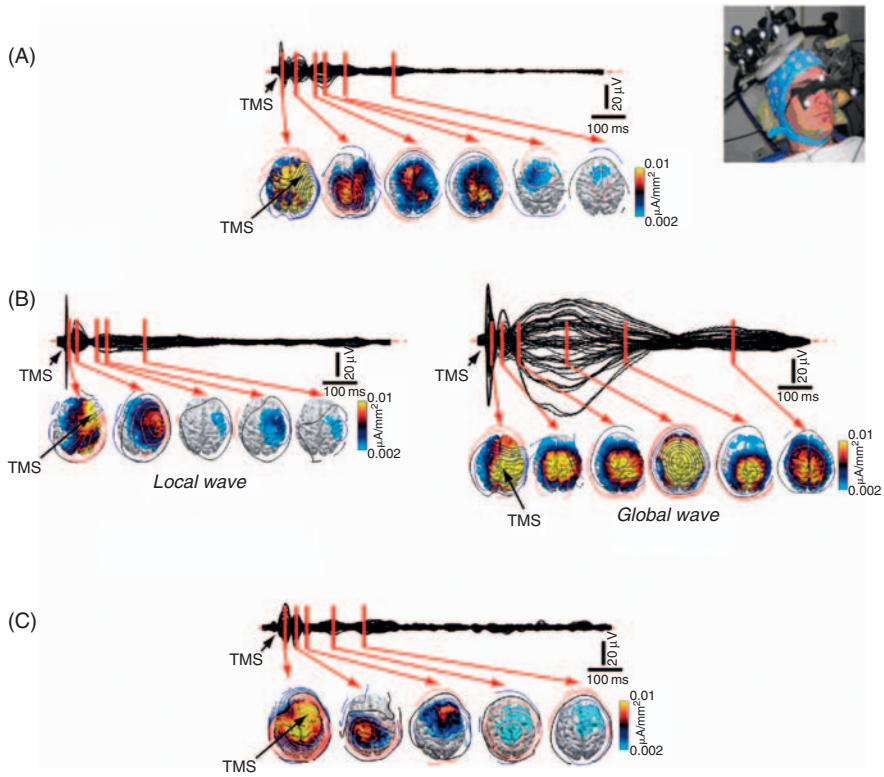

FIGURE 8.6 Spatiotemporal cortical current maps of TMS-induced activity during (A) wakefulness, (B) NREM, and (C) REM sleep. On the top right is the setup for TMS/EEG. From the EEG data, current sources corresponding to periods of significant activations were plotted on the subject's MRI. Note for TMS during wakefulness the rapidly changing patterns of activation, lasting up to 300 ms and involving several different areas (right premotor cortex stimulation is shown, but similar results are observed for other stimulation sites, including midline centroparietal regions); for TMS during NREM sleep either a brief activation that remains localized to the area of stimulation (right premotor cortex stimulation) or a global wave of activation that affects indiscriminately and stereotypically the entire cortex (midline centroparietal stimulation); and for TMS during REM sleep, an intermediate pattern of activation. *Source*: From [53, 62] and Tononi and Massimini, unpublished data).

(Figure 8.6B, right). Importantly, such stereotypical responses could be induced even when, for the preceding seconds, there were no slow waves in the spontaneous EEG, indicating that perturbations can reveal the potential bistability of a system irrespective of its observed state.

By contrast, during REM sleep late in the night, when dreams become long and vivid and the level of consciousness returns to levels close to those of wakefulness, the responses to TMS also recovers and comes to resemble more closely those observed during wakefulness: as shown in Figure 8.6C, evoked patterns of activity become more complex and spatially differentiated, although some late components are still missing. Altogether, these TMS–EEG measurements suggest that the sleeping brain, despite being active and reactive, changes dramatically in its capacity to generate integrated information: it either breaks down in causally independent modules, or it bursts into a global, stereotypical response, in line with the predictions of the integrated information theory [61]. Importantly, the use of a perturbational approach (TMS–EEG) reveals that during NREM sleep cortical circuits may be intrinsic bistable even during periods of stable ongoing EEG with no overt slow waves.

Dreams: Consciousness in the Absence of Sensory Inputs and Self-reflection

Just as striking as the near-loss of consciousness during certain phases of sleep is its remarkable preservation during other phases. This is especially true of REM sleep awakenings, which yield almost without exception reports of vivid dreams. Perhaps the most remarkable property of dreams is how similar they can be to waking consciousness, to the point that the dreamer may be uncertain whether he is awake or asleep. This means that the sleeping brain, disconnected from the real world, is capable of generating an imagined world, a virtual reality, which is fairly similar to the real one and is indeed experienced as real (Box 8.1).

BOX 8.1

NEUROCOGNITIVE MODELS OF DREAMING

Building on the cognitive model of Foulkes [63] and on the work of Hall on content analysis of dreams [64], William Domhoff has recently attempted a synthesis that he calls the neurocognitive model of dreaming [65, 66]. Domhoff proposes that dreaming is what the mature brain does when (1) primary sensory cortices are relatively inactivated, thus enforcing a partial disconnection from the external world; (2) dorsolateral prefrontal cortices are relatively inactivated, thus reducing our ability to exercise reflection and decision making; and (3) a subsystem of brain regions, comprising limbic and paralimbic structures as well as several association areas at the temporo-parieto-occipital junction, is at a sufficient level of activation. According to Domhoff's model, dream-like experiences can occur not only in NREM sleep, but also during wakefulness, provided sensory and prefrontal cortices are sufficiently quiet.

Like Foulkes, Domhoff emphasizes that the dreaming subsystem, when activated, is drawing on memory schemas and general knowledge to produce a kind of dramatized version of the world, and that these dramatizations are an active act of imagination, rather than a mere reaction to random activation. More specifically, Domhoff argues that the system of scripts and schemas activated in dreams is nothing else but the organizational basis for all human knowledge and beliefs. Basic-level categories, which can be represented by a single image, reflect distinctions among types of animals, such as cats and dogs, types of social interactions, such as friendly and aggressive, or types of actions, such as walking and running. Spatial relations categories are, for example, 'up', 'down', 'in front of', and 'in back of'. Finally, sensorimotor categories are based on experiences related to temperature, motion, and touch. The systematic occurrence of basic experiential categories in dreams is confirmed by the analysis of thousands of dreams from all over the world according to the Hall/van de Castle system [64].

Dreams may also build upon figurative thinking: conceptual metaphors, metonymies, ironies, and conceptual blends. As pointed out by Lakoff and Johnson [67], hundreds of primary conceptual metaphors actually map common experiential categories. For example, basic experiences like warmth and motion are used to understand more difficult concepts like friendship (they have a warm relationship) and time (time flies by). Just as in waking thought, figurative thinking may be used in dreams when it expresses a conception better and more succinctly than an experiential concept does. To this extent, some dreams may indeed be symbolic.

Finally, based on content analysis, Domhoff concludes that most dreams deal with personal concerns – typical ones are being inappropriately dressed, being lost, or being late for an examination. Personal concerns are very stable over the years, as well as across cultures, which may explain why dreams themes are stable across life across individuals, and around the world. Such personal concerns are also the subject of recurrent dreams, and of the repetitive nightmares experienced by people suffering from post-traumatic stress disorder (generally in stage N2). Curiously, personal concerns in dreams are often stuck in the past, in a way that fits with the persistence of negative memories stored in the amygdala and other limbic circuits that are part of the brain's fear system.

Perceptual modalities and submodalities that are experienced in wakefulness are represented in dreams: dreams are highly visual, in full colour, rich of different shapes and movements, but they also have sound, tactile feelings, smells, and tastes, as well as pleasure and pain [56]. The categories that are the stuff of dreams are the same as those that constitute the fabric of wakefulness – objects, animals, people, faces, places, and so on. Dream experiences are not necessarily all vivid and perceptual – there are also faint ideas, just as in wakefulness, and various kinds of thoughts. Dreams are also rich in emotion: in fact, emotions are often very intense, especially fear and anxiety. Hearing speech or conversation is also extremely frequent, and speech patterns are as grammatically correct as in waking life. Finally, there is a good correlation between our waking and dreaming selves with respect to mood, imaginativeness, and predominant concerns. For example, people dream most often about the individuals and interests that preoccupy them in waking life, and they show aggression in dreams towards the same people with whom they are in conflict in waking life.

Despite the remarkable similarities between waking and dreaming consciousness, dreaming consciousness often presents some distinctive features. These include: (1) disconnection from the environment; (2) internal generation of a world-analogue; (3) reduction of voluntary control and reflective thought; (4) amnesia; and (5) high emotional involvement.

Disconnection. The most obvious difference between dreaming and waking consciousness is the profound disconnection of the dreamer from his current environment. Only occasionally do external stimuli manage to be incorporated in dreams, the most effective being a spray of water or pressure on the limbs. The disconnection is so effective that even the regular erections occurring during REM sleep dreams almost never make it into the dream's content. It is also difficult to influence dream content with pre-sleep stimuli, even strong ones such as viewing a horror movie just before going to bed. Instead, all sensory experiences in dreams are generated internally: they are, strictly speaking, hallucinations. The disconnection is also evident on the motor side. For example, a feeling of weightlessness is commonplace in dreams, as are the experience of floating or flying. It is possible that the peculiar, effortless nature of motor activities in dreams has something to do with the activation of motor programmes in the absence of proprioceptive feedback signalling. As would be expected, the sensory and motor disconnection of dreams are neatly reflected in the reduced activation of primary sensory and motor areas in PET studies of REM sleep [68].

Internal generation of a world-analogue. Given the sleeper's disconnection from the external world, all dream consciousness is generated internally. Dreams, rather than being at the mercy of bottom-up signals and events from the environment, take a top-down approach by following a narrative script and using a set of well-rehearsed formulas: if waking consciousness is like watching a news broadcast, dreaming is more like watching a movie produced by an imaginative director (rather than by a camera bouncing around at random). In selecting scenes, the dream director is not particularly choosey: any actor, dress, means of transportation, or food item that is readily available will do. Indeed, as in some B-movies, characters and objects seem to be chosen for their role in each scene, with little regard for factual truth or plausibility, and without caring about the mixing of incongruent characteristics, or inconsistencies between one scene and the other. Thus, chimerical creatures, sudden transformations, and physically impossible objects are not infrequent. While the ability to dream requires the ability to imagine, dream images are generally more vivid, presumably because they do not have to compete with external signals. Also, in dreams there is a strong tendency for a single train of related thoughts and images to persist for extended periods without disruption or competition from other thoughts or images ('*single-mindedness*' [69]). From a neuroimaging perspective, the internal generation of a world-analogue is consistent with the strong activation of temporo-occipital and parahippocampal association areas that is observed in REM sleep [48, 49].

Reduced voluntary control and reflective thought. During dreaming there is a prominent reduction of voluntary control, whether of action, thought, or attention. With the exception of lucid dreaming (see below), the dreamer has no control on what he is going to dream, and is largely a passive spectator. Reflective thought processes are also impaired in characteristic ways. Again with exception of lucid dreams, dreaming is almost always delusional, in the sense that events and characters in the dream are taken for real. While the dreamer experiences thoughts, there is a severe impairment of the ability to pursue goals effectively, to analyse situations intelligently, to question assumptions, to reason properly, and to make appropriate decisions. For example, holding contradictory beliefs is quite common in dreams, and a dreamer easily accepts impossible events or situations, such as flying. There is often uncertainty about orientation in space (where one is in the dream), about time (when the dream is taking place in personal history), and person (confusion about the gender, age, and identity of dream characters). When dreaming, one cannot stop and reflect rationally on what one should be doing, nor imagine other scenarios (after all, one is already imagining the dream). Once again, these characteristics of dreaming consciousness are consistent with neuroimaging findings: dorsolateral prefrontal cortex, which is involved in volitional control and self-monitoring, is especially deactivated during REM sleep [48, 49].

Amnesia. Memory is drastically impaired both within the dream and for the dream. Working memory is not working well, as it is extremely difficult to hold anything in mind during a dream. Episodic memory is also not functioning properly. Remarkably little makes it into dreams of recent episodes of the dreamer's life. While individual items from waking experience sometimes are incorporated into a dream, they do so in new and unrelated contexts, and true declarative memories for wakening episodes are found in a very small percentage of dreams. For example, in a study where subjects had intensively played the computer game Tetris, there was no episodic memory in subsequent dreams that the subject had indeed played Tetris. In

fact, dreams of healthy subjects were indistinguishable from those of profoundly amnesic subjects, who could not remember having played Tetris whether they were dreaming or awake. In contrast, both normal and amnesic subjects often reported perceptual fragments, such as falling blocks on a computer screen, especially at sleep onset, but there were no episodic memories associated with these fragments [70]. Even previous events within a dream are soon forgotten and do not appear to influence the subsequent evolution of dream experiences. Instead, dreams are characterized by what has been called '*hyperassociativity*', as if the network of association were much wider and less constricted than in wakefulness. Finally, dreams themselves are extremely fleeting: if the dreamer does not wake up, they are forever lost, and even upon awakening they vanish extremely rapidly unless they are written down or recorded. This is true even of the most intense dreams, even if they are accompanied by great emotion. It is not clear why the dreaming brain is so profoundly amnestic since, for example, parahippocampal and limbic circuits are highly active during REM sleep ([48, 49], although prefrontal cortex, which also plays a role in episodic memory, is deactivated). As is the case with daydreaming (see below), the source and structure of experienced events (external, highly constrained, vs. internal, less constrained) is a crucial determinant of recall. Perhaps changes in neuromodulators also play a role, specifically the silence of noradrenergic neurons whose activity is involved in the conversion of neural activity into neural plasticity [71].

Hyperemotionality. Many dreams are characterized by a high degree of emotional involvement, especially fear and anxiety, to a degree rare in waking life. This has led to the suggestion that the initial impetus for constructing dream narratives may originate in perceived threats or conflicts. Whether or not this interpretation has merits, REM sleep is in fact associated with a marked activation of limbic and paralimbic structures such as the amygdala, the anterior cingulate cortex, the insula, and medial orbitofrontal cortex.

In summary, there are many aspects of dreaming consciousness that can be found in textbooks of psychopathology, including hallucinations, delusions, reduced orientation and attention, impaired memory, loss of voluntary control and reflective thought. Since hallucinations and delusions are the hallmark of psychosis, it is not surprising that a connection between dreams and madness has often been suggested. However, the closest psychiatric conditions are not the major psychoses, but the so-called acute confusional state or delirium, which is often due to withdrawal from alcohol and drugs and is characterized by many of the same symptoms as dreams – hallucinations and delusions, impaired orientation and attention, intense emotions, loss of directed thought and self-reflection, frequent confabulations, as well as by a reduced responsiveness to the external world [72]. The remarkable regional differences in activation during REM sleep are probably responsible for many of the differences between waking and dreaming consciousness [56]. It is still unclear what is responsible in turn for these regional differences, although once again it is likely that neuromodulatory systems may be involved. For example, since monoaminergic systems are silent during REM sleep, acetylcholine is alone in maintaining brain activation. Consistent with imaging results, cholinergic innervation is especially strong in limbic and paralimbic areas and much weaker in dorsolateral prefrontal cortex.

Neuropsychology of Dreaming

The analysis of patients with brain lesions indicates that the ability to dream depends on specific forebrain regions rather than on the brainstem REM sleep generator [73, 74]. In most cases of global cessation of dreaming, there is damage to the parieto-temporo-occipital junction (uni- or bilaterally), while the brainstem and the polygraphic features of REM sleep are preserved. The parieto-temporo-occipital junction is important for mental imagery, for spatial cognition (on the right side) and for symbolic cognition (on the left side), all central features of dreaming. More restricted lesions produce the cessation of visual dreaming. In all these patients, these functions were at least partially impaired during wakefulness. Thus, the ability to dream seems to go hand in hand with the ability to imagine and with visuospatial skills. Indeed, these areas are among those that are most activated during REM sleep, although it is unknown to what extent they may be activated during NREM dreaming.

The close relationship between dream generation and waking imagery is borne out by longitudinal studies of dreaming in children, which show that dreaming progresses in parallel with the child's waking ability to imagine and his visuospatial skills (Box 8.2). Thus, children of age 2–3, although they obviously can see and even speak of everyday people, objects, and events, cannot imagine them, nor can they dream of them. Similarly, if people are blind from birth, they cannot construct visual images during wakefulness, nor can they dream visually (dreams of blind people are otherwise just as vivid as those of sighted subjects). However, if people become blind after the age of

BOX 8.2

THE DEVELOPMENT OF DREAMS

When do children start dreaming, and what kind of dreams do they have? These questions have been addressed in a series of studies by David Foulkes in children between the ages of 3 and 15 years [77]. Foulkes's laboratory studies showed that children under the age of 7 awakened from REM sleep recall dreaming only 20% of the time, compared with 80–90% in adults. NREM sleep awakenings before age 7 produced some recall only 6% of the time. For both REM and NREM sleep awakenings, recall came first from awakenings late in the night.

Preschoolers' dreams are often static and plain, such as seeing an animal, thinking about eating or sleeping – 'they are more like a slide than a movie'. There are no characters that move, no social interactions, very little feeling of any sort, and they do not include the dreamer as an active character. There are also no autobiographic, episodic memories, and Foulkes suggests that the paucity of childrens' dreams is closely related to infantile amnesia: both would be due to the inability of preschoolers to exercise conscious episodic recollection. Children's dreams are more positive than adult dreams: preschoolers never reported fear in dreams, and there are few aggressions, misfortunes, and negative emotions. Note that children who have *night terrors*, in which they awaken early in the night from slow wave sleep and display intense fear and agitation, are terrorized not by any dream, but by disorientation due to incomplete awakening.

Between ages 5 and 7 dream reports become longer, although still infrequent. Dreams may contain short sequences of events in which characters move about and interact, but the dream narratives are not very well developed. At around age 7, dream reports become longer and more frequent, the child's self becomes an actual participant in the dream, with thoughts and even feelings, and dreams begin to acquire a narrative structure and to reflect autobiographic, episodic memories.

Foulkes also found that recall frequency was best correlated with the ability to produce waking mental imagery, and not with language ability. If childrens' dreams seem rare and not well developed, then, it is not because of an inability to report dreams. Instead, the frequency of dream reporting in young children is correlated with their visuospatial skills. Visuospatial skills are known to depend on the parietal lobes, which are not fully myelinated until age 7. Recall that blind adults have visual imagination and dreaming only if they lost their sight after age 7. These data suggest that dreaming is a gradual cognitive development that is tightly linked to the development of visual imagination. According to Foulkes, studying the development of dreams is tantamount to studying the development of consciousness.

seven, they generally can still construct visual images, and they do have visual dreams [75, 76].

Global cessation of dreaming can also be produced by bilateral lesions of white matter tracts underlying ventromedial prefrontal cortex [74]. White matter tracts in this region are the ones that used to be severed in prefrontal leucotomy, once performed on many schizophrenic patients. Most leucotomized patients complained of global cessation of dreaming as well as of lack in initiative, curiosity, and fantasy in waking life. Many of the nerve fibers travelling in the ventromedial white matter originate or end in limbic areas. In addition, the ventromedial white matter contains dopaminergic projections to the frontal lobe. Once again, these lesion data are consistent with imaging results since limbic areas are highly active during REM sleep. By contrast, lesions of forebrain areas that are deactivated during REM sleep, such as the dorsolateral prefrontal cortex, sensorimotor cortex, and primary visual cortex, do not affect the ability to dream. Also, many patients with brainstem lesions are able to dream, though it is unclear whether REM sleep was preserved. However, it is well known that certain antidepressant treatments that suppress REM sleep do not eliminate dreaming.

DISSOCIATED STATES

This last section will consider a series of conditions that lie as it were in between waking and sleep: they partake of some features typical of waking consciousness as well as of some characteristics of consciousness in sleep – that is, they represent dissociated states [78]. Some of these conditions, such as daydreaming

and lucid dreaming, are perfectly normal, and can even be learned; others occur in the context of certain sleep disorders. Other conditions, known as *parasomnias*, include some of the most remarkable examples of pathological dissociation between consciousness, awareness of the environment, reflective consciousness, and behaviour.

Daydreaming

A common definition of daydreaming is 'a dream-like musing or fantasy while awake, especially of the fulfilment of wishes or hopes'. For experimental purposes, daydreaming can be defined as 'stimulus-independent mentation', that is, as waking images and thoughts that are independent of the task at hand [79]. Daydreaming is extremely common. Indeed, no matter how hard one concentrates on the task at hand, a surprising amount of time is spent drifting off into fantasies and interior monologues of one kind or another. If subjects are periodically interrupted for thought sampling during a signal-detection task, they report stimulus independent mentation at least 35% of the time, even under heavy processing loads. Their reports also indicate discontinuities and scene changes that are more frequent that in REM sleep. There have been attempts at further categorizing waking mental activities and validating such categories using questionnaires and factor analysis. Relevant dimensions are (1) directed or operant vs. non-directed or respondent thought (the former voluntarily directed towards accomplishing a task); (2) stimulus bound vs. stimulus independent; (3) realistic vs. fanciful; (4) well-integrated (orderly, connected, coherent) vs. degenerated; and (5) vivid vs. non-vivid. A prototypical daydream would be non-directed, stimulus-independent, fanciful, and non-integrated. Recall of waking images and thoughts experienced while daydreaming can be as poor as dream recall, possibly because, just as dream images, daydreaming images cannot be referenced by external events.

The neural circuits involved in daydreaming are beginning to be studied. For instance, using both thought sampling and brain imaging [80], a recent study showed that mind wandering is associated with activity in the same default network of cortical regions that are active when the brain is not actively engaged in a task [81]. Regions of the default network that exhibited greater activity during mind wandering included bilateral medial prefrontal cortex, anterior cingulate, posterior cingulate, precuneus, insula, left angular gyrus, as well as superior temporal cortex. In addition, individuals' reports of the tendency of their minds to wander were correlated with activity in this network [80]. Based on these results, however, it would seem that the circuits activated during daydreaming may actually be different from those involved in dreaming, given that, for instance, posterior cingulate, precuneus, and lateral parietal cortex are relatively deactivated during REM sleep [48, 49, 82].

Lucid Dreaming

Dreams usually involve loss of self-reflection and of reality testing. Hallucinations and delusions in dreams are typically thought to be real rather than dreamt up. Sometimes, however, a dreamer can become aware that he is dreaming [83–86]. Under such circumstances, the dreamer is able to remember the circumstances of waking life, to think clearly, and to act deliberately upon reflection, all while experiencing a dream world that seems vividly real. Lucid dreaming can be cultivated, typically by a pre-sleep autosuggestion procedure: the key is to remember that, if one is experiencing something bizarre, such as floating in space, it must be a dream rather than a waking experience. In fact, lucid dreamers often attempt to fly: if they succeed, they know they are probably dreaming. Lucid dreaming has been extensively studied in the laboratory by asking trained subjects to carry out distinctive patterns of voluntary eye movements when they realize they are dreaming. The prearranged eye movement signals appear on the polygraph records during REM sleep, proving that the subjects had indeed been lucid during uninterrupted REM sleep. This strategy has been used to demonstrate that time intervals estimated in lucid dreams are very close to actual clock time, that dreamed breathing corresponds to actual respiration, and that dreamed movements result in corresponding patterns of muscle twitching. Stable lucid dreams apparently only occur during REM sleep, especially in the early morning, when REM sleep is accompanied by intense phasic phenomena. It is plausible, but not proven, that the deactivation of dorsolateral prefrontal cortex that is generally observed during REM sleep may not occur during lucid dreams.

Sleepwalking

Sleepwalking refers to various complex motor behaviours, including walking, that are initiated during deep NREM sleep, typically during stage N3 (see also Chapter 9). Some episodes may be limited to sitting up, fumbling, picking at bedclothes, and mumbling. Patients usually stand up and walk around quietly and aimlessly.

Sleepwalkers walk around with open eyes and sometimes speak, though slowly and often inarticulately. They behave as if they were wide awake though their awareness of their actions is very restricted. Occasionally, sleepwalkers become agitated, with thrashing about, screaming, running, and aggressive behaviour. A highly publicized case is that of Ken Parks, a sleepwalker who, after falling asleep at home, arose to drive to his in-laws, strangled his father-in-law into unconsciousness, and stabbed his mother-in-law to her death.

Sleepwalking is frequent in children, but it can persist in up to 1% of adults. In predisposed individuals, attacks can be precipitated by forced arousals, for example by placing the subject afoot. Sleepwalking is regarded as a disorder of arousal with frequent but incomplete awakening from slow wave sleep. If awakened during an episode, sleepwalkers typically do not report any dream-like mental activity, although in a few cases hallucinations have been reported. There is almost never any memory of the behaviours carried out while sleepwalking. The episodes begin while the EEG shows high-amplitude slow waves. During the episodes, the EEG decreases in amplitude and increases in frequency, usually leading to the appearance of mixed-frequency patterns typical of stage N1. There may also be rhythms resembling the alpha rhythm of waking, but slower by 1–2 Hz and not abolished by eye opening or visual stimulation. During short episodes of sitting up with eyes open and moving around, the EEG may show slow waves throughout – providing a clear-cut dissociation between observable behaviour, brain activity and consciousness.

A recent study has succeeded in performing neuroimaging during a sleepwalking episode using single photon emission computed tomography, a variant of PET [87] (Chapter 9). The patient, a 16-year-old man, stood up with his eyes open and a scared facial expression. After a few seconds, he sat down, pulled on the EEG leads and spoke a few unintelligible words. The EEG showed diffuse, high-voltage rhythmic slow wave activity. Compared to waking, regional cerebral blood flow was decreased during sleepwalking in frontoparietal associative cortices, just as it is in slow wave sleep. This deactivation of prefrontal cortices during normal sleep and sleepwalking is consistent with the lack of self-reflective consciousness and recall that characterize both conditions. However, blood flow was higher during sleepwalking than in slow wave sleep in the posterior cingulate cortex and anterior cerebellum, and the thalamus was not deactivated as it is during normal slow wave sleep. Thus, at least in this patient, sleepwalking seems to arise from the selective activation of thalamo-cingulate circuits and the persisting deactivation of other thalamocortical systems. Normally, the entire forebrain is either awake or asleep. Sleepwalking thus appears to constitute a dissociated state where some brain areas are 'awake' while others are 'asleep'. It is likely that, in different patients or at different times in the same patient, different areas may be awake or asleep.

Sleeptalking is a more frequent occurrence than sleepwalking, and it can occur both in NREM and REM sleep. The majority of sleep speeches contain at least a few words, but they range from a single, mumbled utterance to several minutes of perfectly intelligible talk, the latter more frequently associated with REM sleep. Sometimes sleeptalk is clearly a soliloquy, at other times it may resemble telephone conversation. While there is some correspondence between sleeptalking and dream content, more often one has the impression of multiple, concurrent stream of mental activity that occur independently and in parallel. Such instances suggest that the speech-production system may be active in relative isolation from dream consciousness, thereby constituting another example of dissociation.

REM Sleep Behaviour Disorder

This disorder, which affects mostly elderly males, is characterized by vigorous, often violent episodes of dream enactment, with punching, kicking, and leaping from bed [78]. Patients often injure themselves or their spouses. For example, a male subject would dream of defending his wife, but in enacting his dream he would actually forcefully strike her in bed. In rare cases there can be well-articulated speech. Polysomnographic recordings demonstrate that such episodes occur during REM sleep. Unlike sleepwalkers, who usually have no recollection of what they were thinking or dreaming at the time of their actions, people with REM sleep behaviour disorder can usually recall their dreams in detail. Conscious experience during an episode is extremely vivid, as in the most animated dreams, and is fully consistent with the motor activity displayed.

Much before the clinical syndrome was recognized in humans, sleep researchers had observed that, if certain regions of the pons that are normally responsible for inhibiting muscle tone and motor programmes during REM sleep are lesioned, cats seem to 'enact their dreams' of raging, attacking, fleeing, or eating while not responding to external stimuli [88–90]. In humans, the disorder most often occurs without an

obvious cause, but it is sometimes associated with neurological conditions. It may indeed result from minute lesions in the pons, it may anticipate the development of Parkinson's disorder, and it may be triggered acutely by certain drugs (certain antidepressants) or by withdrawal (ethanol).

Narcolepsy and Cataplexy

Narcolepsy is characterized by daytime sleepiness (sleep attacks), cataplexy (muscle weakness attacks), hypnagogic hallucinations and sleep paralysis [78]. Narcolepsy usually begins with excessive sleepiness and unintentional naps in the teens and twenties. Sleepiness is especially strong during periods of inactivity and may be relieved by short naps. When narcoleptics fall asleep, they usually go straight into REM sleep. Not surprisingly, patients complain that they have a short attention span, have poor memory, and sometimes behave in an automatic, uncontrolled way. The sleepiness seems to be due to a problem staying awake rather than to an increased need for sleep, since narcoleptics generally get enough sleep at night. In more than half of the cases, narcolepsy is accompanied by cataplexy. This is a sudden loss of muscle tone, typically brought on by strong emotions such as laughter or anger. The sudden weakness may be generalized and force the patient to collapse to the ground, or it may be localized to the voice, the chin, or a limb. Each episode generally lasts only a few minutes. Consciousness and awareness of the environment are preserved during cataplectic attacks, unless sleep intervenes. Hypnagogic hallucinations are dream-like hallucinations, mostly visual, that occur at sleep onset or when drowsy. Sleep paralysis is a frightening feeling of being fully conscious but unable to move, which may occur on awakening or falling asleep, like a temporary version of the locked-in syndrome (see Chapter 15). Healthy individuals can experience hypnagogic hallucinations, especially when sleep deprived, and may also experience sleep paralysis. However, while laughter and other emotional stimuli can produce muscle relaxation in normals, cataplexy is definitely an abnormal phenomenon. Sleep paralysis and cataplexy are probably due to the inappropriate activation of the brainstem mechanisms responsible for abolishing muscle tone during REM sleep. Narcolepsy–cataplexy are known to be associated with a defect in the hypocretin–orexin system [91]. Narcoleptic dogs and mice have a mutation in the gene for hypocretin or its receptors and, in the brain of narcoleptic patients, there is a loss of hypocretin cell groups in the posterior hypothalamus.

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