Chapter 2
What is Sleep and How it is Scientifically Measured

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If we want to scientifically study sleep, we need to know when a person is asleep and when awake. How do we know if a person is asleep? We might be able with great certainty to determine that the person is awake using criteria such as eyes open, interactive with their surroundings, physically active, and appears alert. So, the presence of the opposite signs—little movement, steady breathing, eyes closed, not interacting with surroundings, and typical sleep posture—might indicate that the person is asleep. But, a person displaying all of these could be awake; we cannot be sure. Another way is to ask whether they were asleep after they were awakened. Two problems arise here. First, we cannot be certain that the answer is reliable, and second, the person is no longer in the state of sleep that we wish to study. It was not until the middle of the twentieth century that scientists devised more objective ways of determining whether a person was in a state of sleep using technological advances enabling the recording of brain waves and other bodily functions. To their surprise, they also discovered that there are several types of sleep called stages.

Specific references to statements in this chapter that can be found in multiple, widely available sources are not included in the text. A selection of these sources is listed below and can also be consulted for verification or more detail. (Kryger et al. 2011; Lee-Chiong, Somnology 2011; Amlaner and Fuller, Basics of Sleep 2009).

W. H. Moorcroft, *Understanding Sleep and Dreaming*,
DOI: 10.1007/978-1-4614-6467-9_2,

2.1 Polysomnography[1]

It was not long before these methods, called *polysomnography*, became refined and universally accepted. Today, the determination of states of sleep and wakefulness is reliable and valid. Polysomnography involves the recording of three things—brain waves, eye movements, and neck muscle tension. Polysomnography works because many organs of the body generate small amounts of electrical energy as they perform their functions. Sensors placed near these organs can pick up some of this energy and transmit it via wires to powerful amplifiers whose output is permanently recorded as ink lines on paper or, more recently, as lines on a computer screen and stored in computer memory. (Sensors being applied are shown in a segment of http://www.youtube.com/watch?v=9nmVzXxdUeU&NR=1&feature=endscreen from time 12:44 to 13:18). Brain waves or EEG, short for electroencephalogram, are visualizations of the waveform and intensity in microvolts of electrical activities of large groups of brain cells. For sleep recording, standard procedure calls for the EEG sensor to be placed on the scalp about 8 cm above the right or left ear. EEGs are the most important of all things recorded for the determination of stages of sleep. The shape of the EEG waves, their frequency, and their intensity or amplitude are the key components.

Eye movement recordings or *EOG*, short for electrooculogram, are possible because the front of the eye is electrically positive. As the eyeballs move, the distance of their positive poles change relative to sensors placed near the outer corner of each eye. Typically, the movements of each eye are recorded on a separate line on the polysomnogram. It is important to note the presence or absence of any eye movements as well as their shape and frequency when they are present.

For neck muscle tension or EMG, short for electromyogram, pairs of sensors are placed in the region of the chin or jaw. When nearby muscles contract, they generate some electrical activity whose strength is in proportion to the degree of the contraction or tension. The sensors can detect this electrical activity. The thickness of the EMG line is what is accessed; the thicker the tracing the greater the muscle tension.

At a minimum, a polysomnogram contains two rows of EOG, one of EMG, and one of EEG (see Fig. 2.1). It is becoming more common to also include two additional rows of EEG—one from the posterior brain region (the right or left occipital cortex) and another from the anterior brain region (the frontal cortex). These additional placements can better indicate the brain waves characteristic of different types, called stages, of sleep. Additional recordings from brain and other body organs may also be made, and although not essential to determine sleep, may be useful for determination of what else is going on during sleep (see Chap. 13).

Polysomnographic stages are designated as follows:

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1 The primary source for the material in this section is Carden 2009.

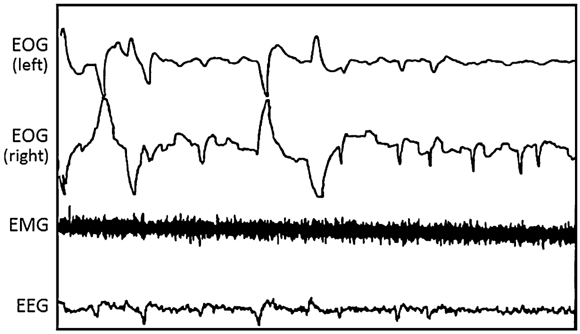


Fig. 2.1 A typical polysomnogram page of 30-s duration showing wake. Note the sharp eye movements that resemble mirror images of each other, the high thickness of the EMG tracing, and the not very intense but fast-frequency beta waves in the EEG

- alert wakefulness
- drowsy wakefulness
- stages *N1*, *N2*, and *N3* (pronounced N1 sleep, N2 sleep, and N3 sleep)
- N1, N2, and N3 are collectively referred to as non-REM sleep (*NREMS* pronounced "NREM sleep").
- plus rapid eye movement sleep (abbreviated *REMS* but pronounced "REM sleep").

Prior to 2007, N1 was known as stage 1, and N2 as stage 2. N3 is a combination of what was formerly known as stage 3 plus the more intense stage 4. N3 is also known as slow-wave sleep (abbreviated SWS, pronounced "slow-wave sleep") because of the presence of slower-frequency delta waves.

2.1.1 The Stages of Sleep

Figure 2.2 shows the criteria for the stages of sleep. The components most critical for determining each stage are in bold. Beta waves are irregular, low intensity, and fast frequency (>13 Hz) that typically occur in an awake, active brain. Alpha waves are regular, moderate intensity, and intermediate frequency (8–13 Hz) that typically occur in an awake but relaxed or drowsy brain. Theta waves are moderate to low intensity and intermediate frequency (4–7 Hz). Delta waves have high amplitude and low frequency (<4 Hz). A K-complex lasts at least ½ s and is a large, slow peak followed by a smaller valley. A spindle is an obvious, moderately intense, and moderately fast (12–14 Hz) rhythmic oscillation for ½–1½ s. Sawtooth waves have relatively low intensity and mixed frequency that often have a notched appearance. Left eye movement recordings look like approximate mirror images of the right eye movement recordings. Waking eye movements tend to be relatively constant and have mainly sharp peaks and valleys with some smaller peaks and rounded peaks mixed in. So called "slow rolling eye movements" are associated with sleep onset; they are mostly large with rounded peaks. The eye movements of REMS usually have sharp peaks and come in bursts of a few

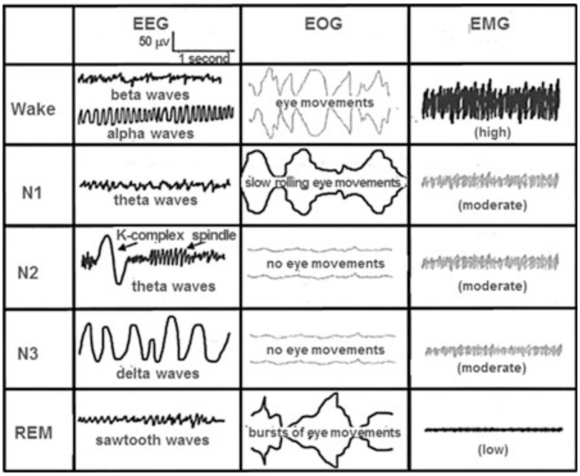


Fig. 2.2 EEG, EOG, and EMG characteristics of waking and each stage of sleep. The most important aspects for determination of each stage are shown darker than the less important aspects

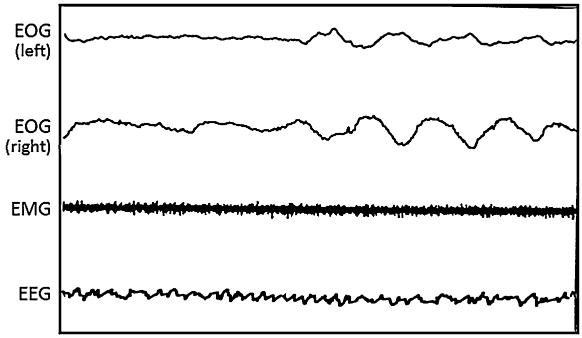


Fig. 2.3 A typical 30-s polysomnogram page showing N1. Note the slow eye movements, moderate thickness of the EMG, and theta waves in the EEG

seconds each with intervening quiet periods of a few to 10 s. The thickness of the EMG line is the key indicator of the amount of muscle tension.

Figures 2.1 and 2.3, 2.4, 2.5, and 2.6 show typical 30-s polysomnogram pages for each stage.

Although not important for the distinguishing of the stages of sleep and waking, during the 1990s, the importance of 20–50 Hz gamma waves became apparent. These waves are present during waking and REMS. They are thought to be important in synthesizing[2] various aspects of sensory-motor inputs (e.g., size of an object with its color and shape) and/or cognitive processes.

Accurately determining the times of first falling asleep and final awakening is also of great importance. The time between these transitions is called the sleep period. Awakening is easier to determine; it is the sudden shift from a sleep stage

[2] Our brain uses sensory and other information to put together our awareness of our external world in a process called synthesis.

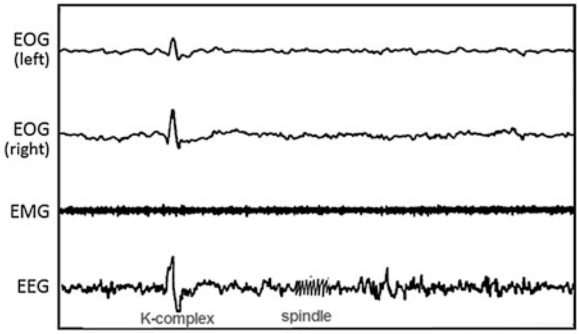


Fig. 2.4 A typical 30-s polysomnogram page showing N2. Note the absence of eye movements (the upward spikes early in the record are not eye movements since the one on the first line is not a mirror image of that on the second line), moderate EMG intensity, and theta waves in the EMG with occasional K-complexes and spindles

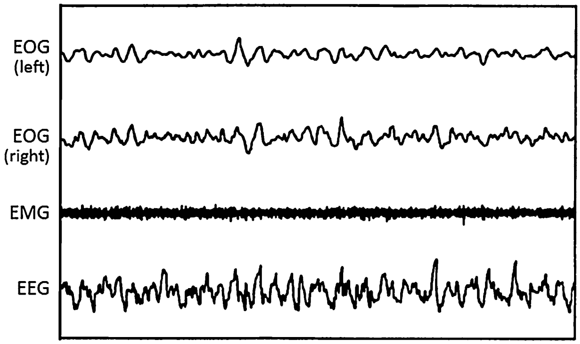
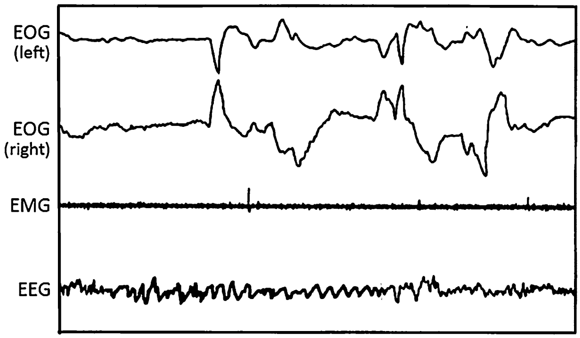


Fig. 2.5 A typical 30-s polysomnogram page showing N3. Note the moderately intense EMG, the intense but slow EEG activity, and the absence of eye movements. The peaks and valleys that appear in the EOG records during N3 are not from eye movements since they are not mirror images. Rather, they are produced by the strong slow-wave electrical activity of the brain near the eyeballs

Fig. 2.6 A typical 30-s polysomnogram page showing REMS. Note the bursts of eye movements, the low EMG (but with occasional brief muscle twitches), and the fast-frequency, low-intensity "sawtooth" pattern of the EEG



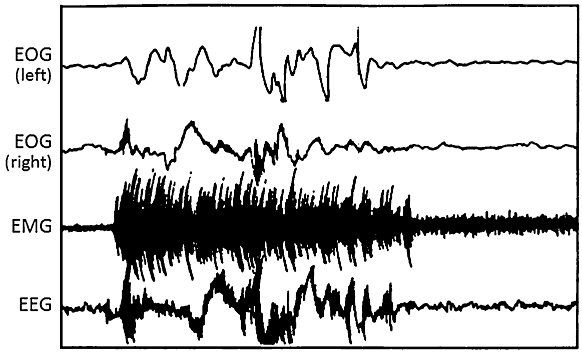


Fig. 2.7 A typical 30-s polysomnogram page showing movement artifact. Note the very thick EMG and obliterated EEG and partially obliterated EOG

to active wake, usually accompanied by many seconds of movement artifact composed of intense, very high frequency registrations in the EEG, EOG, and EMG recordings (see Fig. 2.7). Sleep onset is more difficult to determine, because we do not suddenly fall asleep. Instead, the transition from wake to sleep is a complex succession of changes beginning with relaxed drowsiness, going through N1, and ending in the first couple of minutes of N2. While this succession may occur very rapidly, it is usually more gradual and a person may briefly dip in and out of sleep several times before maintaining it. Different sets of criteria are used to pinpoint the time of sleep onset, but most involve the replacement of drowsy waking EEG (alpha waves) with sustained theta waves plus the indicators of N1 or N2. In practice, the time of sleep onset can usually be determined within a range of several seconds.

As can be seen in Figs. 2.2 and 2.6, REMS is a very unique state. The EEG very closely resembles that of wakefulness, yet it is clear from behavioral criteria (see Sect. 2.2) and subsequent subjective reports from the person that they are asleep. At one time, REMS was called paradoxical sleep because in some ways, the person showed characteristics of both sleep and wake. Furthermore, during REMS, the muscles controlling body movements are paralyzed into a very relaxed state as shown by the very low EMG level. During REMS, the EOG shows bursts of rapid eye movements with seconds of quiescence between bursts. This phenomenon can be observed even without the aid of a polysomnograph by looking at the bulge of the eyeballs moving under the eyelids in a sleeping person early in the morning. Just be sure the person knows that they will be observed, as they may awaken only to be startled with a face a few inches away! Actually, this exercise is easier to do with a baby.

It is useful to distinguish between the components of REMS that are tonic and those that are phasic. The tonic components are those that are constant, such as the EEG and the muscle paralysis. The phasic components are the relatively short-lived clusters of events, such as the rapid eye movements and a number of changes in the body discussed in Sect. 2.1.1 and Chap. 6.

NREMS is what most people think sleep is and ought to be. The brain waves, especially in N3, are those of a brain that is idling. At the same time, the body is relaxed but capable of movement.

Let us put all this together now by following a typical young adult, Rita, as she sleeps through the night. Shortly after she turns out the lights and closes her eyes with the intention of going to sleep, her EOG is flat and her EEG begins to show fewer beta waves and more alpha waves, while her EMG thickness gets smaller as her muscles are relaxing. A few minutes later, she begins to show signs of N1—slow eye movements appear on her EOG, while her EEG alpha waves are replaced by theta waves mixed with other low-voltage fast waves. However, the alpha waves reemerge a few times before disappearing completely. At this point, if we were to ask, she would quickly say that she was not quite asleep but less conscious, maybe experiencing something like floating. On other occasions, she might say she had had a simple, short dream.

A short time later, usually less than 10 min, we see the first sign of N2—a K-complex or perhaps spindle in her EEG. If we now were to ask whether she was asleep yet, it would take longer to get a response, and she would seem a bit groggy at that, but her reply would be affirmative. The slow eye movements shortly after that disappear. After another 20 or so minutes go by, we begin to see large, slow delta waves that quickly begin to dominate the EEG. We now know she is in N3. Awakening her now would be more difficult and result in obvious grogginess. A good half hour later, the delta waves diminish and signs of N2 reemerge for about another 10 min.

It is now about 80 min since the onset of Rita's sleep and we notice that the EMG has become almost a thin, flat line. Shortly thereafter, there are sawtooth waves in the EEG, and suddenly the EOG dances with a burst of rapid eye movements signaling the appearance of REMS. We could have awakened her at this point more easily than when she was in N3 but less easily then N1. If asked, after being awakened from REMS, she probably would have said she was dreaming.

After only a couple of minutes of REMS, the lines on the polysomnography computer get very intense and scrambled. Rita has moved. Around 30 s later, she settles down again but is no longer in REMS. A brief interval of N1 is followed by solid N2 followed by a bit more N3 before again entering REMS.

This sequence continues throughout the night with the interval between REMS periods gradually increasing to closer to 100 min, the indicators of REMS on the polysomnogram getting more obvious, and the duration of each successive REMS period increasing until the last one is a half hour or more. As changes are taking place, the amount of N3 quickly diminishes such that it is hardly visible in the latter half of the night. From this point on, her NREMS is N2 with some periods of N1 and brief arousals, counted as awakenings only if lasting more than 30 s, mixed in. She has moved, often at the point of stage change, about 50 times during the 8 h sleep period.

2.1.2 Other Sleep Brainwave Patterns

There are other brainwave patterns that occur during sleep that are not a part of discerning the stages of sleep. They are associated with poor sleep or outright sleep disorders. Two of them are fast-wave intrusions during N3 and the cyclic alternating pattern (CAP).

Many years ago, some people were observed to have fast waves riding on their slow waves during N3. That is, the slow waves on the EEG were not relatively smooth lines but more like a spring that was stretched on the slow waves. At first, this was called an alpha-delta pattern because the fast waves are in the alpha-wave frequency range. However, research I and colleagues did at the Rush Medical College Sleep Disorders Center and later confirmed in other laboratories, suggested that they are not true alpha waves (Weber et al. 1983). They are more like sleep spindles because of their frequency characteristics and the fact that they originate from the anterior of the brain rather than the posterior. Although what this indicates is not clear-cut, the presence of this EEG pattern is often associated with light and unrefreshing sleep. More recently, fast waves have been sometimes noted in other stages of NREMS, so now the term alpha EEG sleep rather than alpha-delta sleep is used. Alpha EEG sleep is associated with pain and fatigue syndromes such as rheumatoid arthritis and some sleep disorders.

The term cyclic alternating pattern (CAP) designates the occurrence of bursts of a repetitive, transient, dramatic 2–60 s change in the EEG during NREMS (Parrino et al. 2012). The presence of CAP indicates unstable sleep that compromises the restorative aspect of sleep. CAP has sometimes been noted to occur in patients with pain but also occurs in others without pain.

2.2 Definition of Sleep

In spite of all of this description of scientific measurement and the stages of sleep, we have not yet defined sleep. Polysomnograms are a convenient way to measure sleep accurately but say little about what sleep is. For centuries, most people seemed to accept the intuitive notion of sleep: it is a passive phenomenon with the body, including the brain, slowed down or even stopped. Science has shown that this belief is wrong. For example, the discovery that there are different stages of sleep that alternate in a lawful way showed that an active process produces sleep. Today the accepted definition is that *sleep is simply a reversible behavioral state of low attention to the environment typically accompanied by a relaxed posture and minimal movement.*

Other than intense, discomforting, or especially meaningful stimuli can cause a sudden awakening, the sleeping person is much less aware of their surroundings and makes little response to it. This finding has been verified in experiments like the following. Sleepy subjects in a quiet environment were asked to continue doing

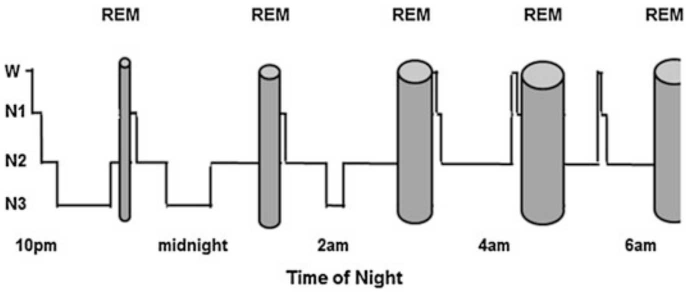


Fig. 2.8 Idealized sequence of sleep stages through the sleep period in an average young adult. Note that the first REM sleep period comes after about 80 min and then NREM and REM sleep alternate about every 100 min thereafter. Also note that SWS occurs mainly early in the night and REMS gets longer as sleep progresses

a simple behavioral task, such as alternating tapping or attending to words, visual patterns, or sound patterns. They began to falter greatly at the time the polysomnogram showed clear N1 patterns. For example, Ogilvie (e.g., Ogilvie et al. 1989) had people press a button each time they heard a sound. When awake, they performed at or near 100 % accuracy but only at about 5 % when in N2 and at 0 % in N3 and REMS. Importantly, as soon as they showed signs of N1, they averaged about 60 % (ranging from 0 to 75 %). In contrast to these behavioral observations, people are not always aware that they have just fallen asleep even when the polysomnogram shows they have.

Not only are there several states of sleep rather than a unitary state, as our intuitive experience would have us believe, the states also alternate in a pattern. NREMS is replaced with REMS about every 90–110 min. The first REMS period of the night lasts only a few minutes. This time gradually increases with each successive REMS period such that the last one is 30 or so minutes in duration. Additionally, there are changes in NREMS as the night progresses. Early in the night, there is considerable N3 (in the neighborhood of 60 min) but as the sleep period progresses, it rapidly diminishes in time and intensity in an exponential fashion such that there is little to be seen in the second half of the night. N1 sleep occupies only about 5 % of the sleep period and, other than at sleep onset, mostly follows the two to three 1 min awakenings scattered during the sleep period. Overall N2 sleep occupies around 50 % of the sleep period, but there is less of it early in the sleep period and more as N3 diminishes. N3 is typically around 20 %, but less as we get older. About 25 % of sleep is REMS. Figure 2.8 and Table 2.1 summarize these and other facts.

Three other important terms are *sleep period*, *sleep efficiency*, and *sleep latency*. The sleep period is the time from when a person first falls asleep through last awakening. Sleep efficiency is the proportion of sleep period spent asleep rather than awake. Sleep latency is the time it takes to get to sleep.

Table 2.1 Average sleep characteristics in the typical young adult

Stage	Percent	Range
W	1	0–3
N1	5	1–10
N2	50	40–60
N3	20	10–35
REM	25	15–35
Stage shifts		35 (about)
Efficiency		0.96
Sleep latency		10 min
Time in bed		7 h and 20 min
Total sleep time		7 h
Number of awakenings		2
Latency to REM		100
NREM–REM cycle		90 min
Number of REM periods		4–5

One other factor needs to be mentioned. We sometimes talk about deep sleep. In one sense, this term usually means our sleep was relatively uninterrupted, and we awakened feeling refreshed. Yet, in another sense, it is not very meaningful. It is a holdover from the notion of deep sleep being furthest away from wakefulness. In fact, neither REMS nor NREMS are quantitatively deeper sleep. Rather, they are qualitatively different kinds of sleep. Instead of thinking of sleep as being toward the lower end of a ramp leading from waking, we should think of it as being like different rooms in a house. Just as a kitchen differs from a family room and both differ from a bedroom, so too does wake differ from NREMS, and both differ from REMS. Yet, we can accurately talk about the depth or quality of sleep in general. For one thing, it is harder to awaken someone when they are in N3 than in other stages of sleep. Also, depth of sleep is measured by such things as greater intensity of delta waves, less stage one, and fewer arousals. Research has shown that sleep punctuated by arousals lasting 3–15 s that occur more frequently than every 20 min fragment sleep enough to reduce its quality resulting in sleepiness the next waking period. Arousals are indicated by bursts of faster-frequency EEG or alpha waves sometimes accompanied by increases in EMG. Typically, these arousals do not result in awakening but leave the perception that sleep was not deep.

2.3 Sleep Changes with Age

What we have been describing pertains to the sleep in the "average young adult" who is approximately between 20 and 50 years of age. Most average young adults, as carefully done studies have shown, need between 7.5 and 8.5 h of sleep each night. However, as will be pointed out in Chap. 3, not all young adults are average in this regard. This amount of sleep and the way it is patterned as just reviewed forms the basis from which comparisons can be made to different ages and to unusual sleep. It is convenient to contrast sleep in average young adults with that of newborns and infants, children, teenagers, and the elderly. (The interactive website http://healthysleep.med.harvard.edu/interactive/sleep_lab enables you to see the sleep characteristics of sleep in an average young adult. It also compares this to sleep in a newborn and an elderly person as well as some sleep problems).

2.3.1 Sleep in Newborns and Infants

Sleep in newborns and infants is markedly different from that of the average young adult. Newborn sleep does not fit the polysomnographic criteria used at other ages, because the newborn brain is too immature to produce the kinds of brain waves we have just reviewed. They are so different that the stages have their own names. *Quiet sleep* (*QS*) is characterized by EEG similar to that of N3 in adults, no eye movements, high EMG, plus the absence of body movements. *Active sleep* (*AS*) is characterized by low-voltage, irregular brain waves, eye movements, low EMG, plus the observation of body and facial movements and occasional vocalizations. The term *indeterminate sleep* (*IS*) is used when there is a mixture of indications of both quiet and active sleep. Newborns sleep 16–18 h of every nychthemeron[3] of which 50 % is AS. AS constitutes as much as 75 % of the sleep of late term fetuses and premature newborns. QS and AS alternate in a 50 min cycle that gradually lengthens to about 100 min by school age, and for the first several months of age, infants frequently go directly into AS. In a relatively short period of time during infancy, AS comes to resemble REMS more and more (it can be called REMS at 12 weeks of age), and QS morphs into NREMS by 6 months. This process is similar to the maturation of the coos and babbling of infants into adult language; the coos and babbling are not adult speech but are the important, immature precursors of it. Furthermore, the amount of REMS per nychthemeron drops to adult level by about 2 years of age. N3 as a percent of total sleep is as high as it ever will be in early childhood then gradually declines by around 50 % by preadolescence. REMS is also very high during childhood and shows a decline with maturation.

Another difference at this age is the distribution of sleep and wake across the nychthemeron. Rather than the characteristic adult pattern of a long period of sleep, typically at night, alternating with a long period of wake every nychthemeron plus maybe an afternoon nap, newborns alternate between sleep and wake many times during a nychthemeron. After a few weeks of age, longer periods of sleep and wake are seen with greater and greater amounts of sleep seen during the night. During the first 4 months, infant sleep rapidly merges into fewer periods

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[3] A nychthemeron (nick-**them**-er-on) is a full period of a night and a day or 24 h. In everyday use, “day” can mean 24 h or the portion of every 24 h that is light. In science, we need to be more precise, so we eliminate ambiguity when we use nychthemeron to refer to a 24 h cycle and reserve the term “day” to refer to the light portion of this cycle.

(Henderson et al. 2010). Eventually—typically between 2 to 3 months of age, but the sooner the better in the view of the parents—most infants are "sleeping through the night" (Henderson et al. 2010) supplemented by a couple of daytime naps. By 5 months of age, over half of infants are sleeping during the same period as their parents (Henderson et al. 2010). The total sleep time drops to 14–15 h per nychthemeron by 16 weeks of age and gradually continues to drop to 10–12 h between ages 3–5. Also about this time, daytime napping ceases. However, these are averages and individuals may need more or less sleep than this. Short sleepers remain this way until adolescence, as do long sleepers. There are similar individual differences in circadian sleep phase preferences with some individuals being evening types ("night owls"), others morning types ("morning larks"), and others neither type (see Sect. 4.4 for discussion of circadian sleep phase preference). Napping diminishes until there is typically one per nychthemeron and then none by age 3–5.

Toddlers and preschool-aged children have a NREM–REM sleep cycle averaging 60 min. When they first fall asleep, they quickly (within 10 min) go into deep N3 sleep from which it is difficult to awaken them. They often stay in this stage for about an hour at which point the child's brain waves shift into a mixture of sleep and arousal. Children may change positions and show other movements such as stroking their face, vocalizing, blinking. They may even awaken briefly. Although there may be initial signs of REMS at this time, frequently the first REMS period is "skipped." Usually within a minute or two, they are back in NREMS, mainly N3. The initial REMS period lasts about 10–20 min with the duration of subsequent REMS periods increasing to around 35 min in the middle of the sleep period, gradually decreasing to 20–25 min. There may be some increase in NREMS toward the end of the sleep period.

During the rest of childhood, the changes in sleep continue but more slowly. By grade school, the NREM–REM sleep cycle is at adult levels, and by age 10, the sleep stage proportions begin to assume adult levels, but the total sleep time remains higher at about 10 h. It appears that the sleep of older children is the most intense of any other age. It is easy for children of this age to fall asleep, and they have fewer awakenings. Also, it is very difficult to awaken a preteen child from NREMS.

2.3.2 Sleep in Teens

The sleep of teenagers also differs from that of the average young adult. Although the need for sleep per nychthemeron remains higher than that of the adult, averaging 9.25 h (but some do well with 8.5 h), teens in the Western world typically get much less than this amount, especially males. Let us look at the source and implications of these statements more closely.

For several years beginning in 1976, Bill Dement (physician and one of the long time, most active, and most influential sleep researchers, now retired from the Stanford University sleep research labs) and Mary Carskadon (PhD, former student and then colleague of Dement at Stanford and now Director of Sleep and Chronobiology Research at E.P. Bradley Hospital and Professor of Psychiatry and Human Behavior at the Brown University School of Medicine) did a series of experiments with teens at what they called summer "sleep camp" (e.g., Carskadon et al. 1980). The campers were monitored with the polysomnograph while required to spend 10 h in bed every night. They were then tested for alertness and behavioral functioning in various ways during the day. It was found that, separately from the amount of sleep obtained, daytime sleepiness gradually increased from the onset to the middle of puberty then stayed level through the rest of the teen years. When given the opportunity, teens consistently slept more than the average young adult. In subsequent studies at this camp, the amount of time in bed was shortened by varying degrees. When sleep was restricted to less than the amount needed, increased signs of fatigue and drops in behavioral abilities resulted during the day, especially in the morning (see Sects. 3.1.2–3.1.4 and 12.1.2 for more on the effects of sleep deprivation).

Subsequent research showed that the amount of sleep teens were getting in their home situations was found to be considerably less than the amount the campers demonstrated was actually needed. One survey showed that about a quarter of high school students in the United States regularly sleep less than 6.5 h on school nights, while only 15 of every 100 sleep 8.5 h or more. To make up for lost sleep, teenagers tend to sleep for an additional couple of hours on weekend mornings (Wolfson and Carskadon 1998). Similar patterns in teen sleep have been noted worldwide (Gradisar et al. 2011).

So, we know that Western teens need much more sleep than they think they need and actually get. The drop in obtained sleep begins in the early teenage years. On the average, there are 2½ h less sleep than needed on school nights and over one hour less on non-school nights. Another drop of an additional ½ h occurs in college freshmen. It is not known for certain what happens to the sleep of like-aged teens who do not go on to college, but it is thought that they too under sleep to some degree. The net results of teenagers sleeping less than really needed are signs of sleep deprivation including daytime sleepiness resulting in automobile accidents, decline in grades, moodiness, and impulsivity (see Sect. 4.5 and Box 12.2). Further complicating matters is the irregularity of sleep schedules in those teens who often go to bed later on weekends and holidays, then "sleep in" the next morning. Napping returns for many adolescent and college students as schedules permit. For example, in one study about 1/3 of older adolescents averaged 4 naps per week, usually around 4 pm (Gradisar et al. 2008). To round matters out, during the rest of the college years, there is a gradual drift toward the average young adult patterns (Moorcroft, unpublished data).

These changes in the sleep of adolescents appear to be the result of several factors. Adolescents seem to be less sensitive to sleep loss and more tolerant to sleep pressure. Additionally, there is a shift of the circadian influence on sleep to later clock hours.

2.3.3 Sleep in the Elderly

Sleep in the elderly is best characterized as fraying (Webb 1975), like the way the ends of a rope can unravel with time. In a similar way, the tightly defined sleep of the average young adult may come apart with age. For some older adults, sleep frays a lot, and for others, the changes are minimal. As a consequence, there are great individual differences in the sleep of the elderly. These changes actually begin during mid- to late middle age but become more intense and noticeable in the elderly.

The amount of sleep needed may not decline with age. Both self-reports and polysomnographic studies agree that older people tend to sleep less at night (averaging 6–7 h) than when younger. However, if naps are included in the count, then it appears that there is much less difference per nychthemeron. Also, an objective test for daytime sleepiness, the MSLT (see Sect. 3.1.1.2), and other data suggest that the elderly are sleepier during the day than when they were younger. This finding can be interpreted to mean they are not getting enough sleep at night. A contrasting interpretation is that the elderly need just as much sleep as they did when younger but more evenly distributed throughout the nychthemeron. Supporting this latter conclusion are studies with elderly animals that also show a more even distribution of sleep per nychthemeron. On the other hand, the negative consequences of the loss of sleep (see Sects. 3.1.2–3.1.4) are less in elderly people than they are in younger people, suggesting less of a need for sleep. Certainly, the elderly's sleep/wake pattern changes, and the intensity of both sleep and wakefulness lessens, but the meaning of these facts is not obvious.

Sleep onset is often reported to be more difficult and it is fragmented by more and sometimes longer awakenings. The sleep of the elderly tends to be more easily interrupted by noises and other stimuli. In sum, sleep efficiency gradually declines by about 3 % per decade starting at about age 30, going from 0.96 to the low 0.80 s.

The amount of N3 sleep gradually diminishes up to 60 years of age and then remains relatively constant at only 5–10 % (or even less in males). However, some authorities say that N3 sleep does not drop that much; delta waves still occur but many do not have enough amplitude to be counted. But even if the amplitude criterion for delta waves is lowered, the amount of N3 is still a bit lower than that of the average young adult.

There is some decrease in the total amount of REMS, but the decrease in the number of rapid eye movements during REMS is even greater. Additionally, there is more REMS earlier in the night and the duration of the REMS periods may not change much as the night progresses. Accompanying these changes is a proportional increase in N1 sleep. As a result of all these changes, the elderly frequently report that their sleep is less satisfying and less restorative than when they were younger.

Other changes are common in addition to these changes. The timing of the sleep–wake cycle, which is called the circadian rhythm (see Sect. 3.2) shifts; older adults become sleepy earlier in the evening and awaken earlier in the morning. Additionally, sleep often is more fragmented because of the emergence of sleep disorders (see Part V) and illnesses common in the elderly, plus medications often used by this population can contribute to complaints of insomnia.

Box 2.1 Sleep in Other Cultures and Eras

Most of what we know about sleep is from the study of sleep in the Western industrialized world where people typically sleep at somewhat regular times, in night clothes, alone or in pairs in a bed with a comfortable mattress, and in isolated, quiet, climate-controlled indoor bedrooms. We tend to accept this as the only acceptable way to sleep. In contrast, for much of human existence, things were much different (Horne 2006; Bed 2012; Worsley 2012). People have slept in what they had been wearing for many days and between animal skins on a pile of straw, mats, wooden platforms, o the ground with a pillow made of rolled up animal skin with the fur on the inside. Eventually, carpets or rugs that lay on the floor were used to sleep on.

An improvement was to raise the sleeping surface of the floor or to place it on a bench against the wall or in a shallow chest. Even today in the non-Western world, sleep occurs on horsehair or cotton mattresses that are not placed on springs. In Persia almost 4,000 years ago, waterbeds made by filling several goat skins were in use. What we now know of as a bed with linen sheets evolved over time in some parts of the world. By the seventeenth century in the United States and Europe, a bed was most likely rope or leather stretched out on a simple wood frame with a bag containing straw or wool on top. A step up was a mattress made of sailcloth with grommets along the edges that were fastened to pegs in the frame. During the nineteenth century, mattresses that were tufted or buttoned and placed on coiled bedsprings made their appearance. It was not until the mid-twentieth century that latex mattresses began to be used.

For most of history, sleep occurred in shared spaces with constant noise and great variations in heat and cold and humidity. This is true even today in many places. These communal sleeping spaces could be malodorous and sweaty, yet they were often better and more secure than sleeping out-of-doors. Before recent times, it was typical for members of a family to even share a bed. Even colleagues from work might share the bedroom. In fact, it was not unusual for strangers to do the same in an inn. It was not until recently that people felt the need to sleep by themselves. Before this, isolated was not possible because there were not enough rooms in dwellings for this purpose. And the sleeping room might also be used for cooking, washing, and working as well as a place to eat meals and interact with others socially. One extreme example of sleeping arrangements was among the poor in Victorian England living in workhouses. They slept in a line on benches with their arms hanging over a chest high tightrope, referred to as a “hangover.” And they were charged by the hour for this sleeping arrangement.

Darkness of night tended to determine bedtimes, but sleep may not have been consolidated. Western Europeans of 200–500 years ago are reported to have slept in two phases at night. "First sleep" lasting several hours was followed by a "watching period" before the "second or morning sleep." During the watching period, people often stayed in bed to contemplate, pray, converse with one another, have sex, or simply just let their wandering minds enjoy this semiconscious state. Additionally, they awakened after each REMS period. In order to explore this a bit more, Thomas A Wehr, psychiatrist at the National Institute of Mental Health in Bethesda, Maryland, had subjects spend weeks of 14-h nights during which time they had to be in bed. They soon settled into a pattern of taking a long time to fall asleep, sleeping for 2–5 h, lying quietly in bed for 1–3 h, then sleeping for 2–5 h (e.g., People in traditional societies sleep in eye-opening ways 1999).
Sleep patterns are affected by cultural beliefs, what is thought to be the function of sleep, and how important it is believed to be for things like health and social relationships (Owens 2008). For example, in some cultures, sleep is seen as something done communally with people sleeping together regardless of age. For more on fascinating cross-cultural differences of sleep in children, see Judith Owens' paper entitled Socio-Cultural Considerations and Sleep Practices in the Pediatric Population (2008).

2.4 Sleep in Animals

To this point, we have been focusing on sleep in humans. However, as far as we know, all mammals and many other animals have some form of sleep. There are no reported occurrences of sleepless animals. Sleep in over 90 species of mammals has been studied, extensively in a few species like the cat, rat, mouse, and of course human, but otherwise slightly studied in only a very small proportion of all the animals alive today. As a result, there are large gaps in our knowledge of animal sleep, and often what we can conclude is based on broad inferences from scant data. However, at least a few representatives from each of the 17 mammalian orders have been studied. There are enough data available to make some observations about sleep in animals.

There are great variations in the sleep of animals. Those animals closer to us on the evolutionary tree have sleep that more closely resembles ours, but the amount of sleep per nychthemeron varies greatly as does the proportion of sleep spent in REMS and NREMS. For example, the length of sleep per nychthemeron ranges from 1.9 h in the giraffe to 19.9 h in the little brown bat. Other examples include Asiatic elephants at 3.1 h, baboons at 9.4 h, lions at 13.5 h, and eastern chipmunks at 19.9 h. Hairy armadillos spend 16 h per nychthemeron in NREMS, but horses only 2 h, and Virginia opossums are in REMS for 7 h per nychthemeron, but sheep only ½ of an hour. The amount of sleep per nychthemeron bares no affinity to the degree of relatedness between species. Cows, sheep, deer, and other grazing animals sleep only up to 2 h per nychthemeron and even that is divided into multiple occasions. Dogs may sleep for 8 h. Cats and mice spend about 13 h asleep divided into several periods. Possums, baboons, and bats may sleep close to 20 h per nychthemeron. It appears that several factors interact to influence sleep length in mammals with some factors being more important than others for individual species. These factors are thought to be as follows:

- *The degree to which the species is predator or prey* the more likely an animal is to be preyed upon, the less it can afford to sleep. However, this factor is controversial because it is hard to measure.
- *The quality, quantity, and availability of the food supply that the species typically eats* animals that do not have an abundant supply of highly nutritious food need to spend more time awake finding and consuming food.
- *The type of sleeping habitat the species has* an animal with a safe sleeping place can safely sleep more than one that does not.
- *If the species is warm- or cold-blooded,* cold-blooded animals may use sleep as a time to avoid becoming too warm or too cold.
- *The degree to which the brain is developed at birth in the species* REMS seems to facilitate brain development (see Sect. 11.1.1.1). Thus, animals relatively immature at birth need to spend more time in this state.
- *The body size of the species* large animals are at less risk for losing or gaining too much body heat during sleep, thus can sleep for longer periods at a time.
- *Events and activities* sleep increases around the time of situations like brooding, hibernation, injury, and copulation.

The distribution of sleep in the nychthemeron varies greatly among species, too. Diurnal animals, such as humans, sleep mainly at night, while nocturnal animals do the opposite. Other animals sleep during both the day and night. Even within these patterns, there are variations. Some animals, like humans, generally have a single, consolidated period or two of sleep. Others have many small periods of sleep per nychthemeron. Then, there is the crepuscular pattern of sleep like that of the bat—asleep except at dawn and dusk.

The habits, places, and postures of animal sleep likewise vary greatly. Some animals, such as rabbits, sleep in burrows; some animals, such as gorillas, make nests to sleep in; while others, such as zebras, sleep in the open. Horses sometimes sleep standing up; some birds can apparently sleep while flying; foxes sleep curled up. Some humans have even been observed to sleep sitting at a desk in a classroom! You can probably add to the list other varieties of animal (and student) sleep habits.

All of the mammals (except possibly the sea-dwelling dolphins, porpoises, and whales) and birds so far investigated cycle between REMS and NREMS. Only a small percent of the sleep of most birds is REMS, but avian predators (e.g., eagles, hawks) have a much larger percent of sleep. For a while it appeared that the Australian spiny ant eater, echidna, did not manifest REMS. This observation was of considerable theoretical interest, because this animal is an egg-laying mammal of very ancient origin. It was thought to give a clue of how sleep developed over the ages, specifically that REMS is a newer type of sleep than NREMS. However, careful study in the 1990s by neurophysiologist Jerry Siegel (of UCLA and the VA Center in Sepulveda Medical Center in California) and colleagues using newer kinds of techniques revealed that the echidna shows signs of rudimentary REMS mixed in with its NREMS (Siegel 1997). They also found that another ancient egg-laying mammal, the platypus, has copious amounts of obvious REMS.

Smaller animals generally sleep longer than larger ones and have a shorter NREM–REM sleep cycle. Birds have much less REMS in their sleep than do mammals. Most primates have the same three NREM stages of sleep that humans have. Non-primate mammals seem to have two or just one stage of NREMS. Not all animals show all of the signs of REMS that are seen in humans. Some animals such as rabbits, dogs, and most birds do not show complete muscle paralysis. Rapid eye movements are absent in or minimal in animals such as moles, opossums, and owls that do not move their eyes when awake. Yet, in all of these animals, there is some kind of regular cycling between NREM and REMS. All mammals and birds that have REMS have more of it early in life.

Some mammals and birds show patterns of sleep not seen in humans. Some carnivores, ungulates, and insectivores spend part of their nychthemeron somewhere between sleep and wake in what is called dozing (also called drowsiness, but not to be confused with human drowsiness as discussed in Chap. 3). This state is characterized by relaxed body position, partially closed eyes, slightly less responsiveness to stimuli, and a mixture of activated EEG waves and slow waves. You may have noticed cats spending a lot of time in this state, but contrary to appearances in class, college students have not been documented to exhibit this kind of drowsiness.

Mammals that live in the sea and birds that migrate over oceans have a problem. They cannot settle down to rest while sleeping. The sea mammals need to surface periodically to breathe, and the migrating birds have no place to stop. One way some of these animals have solved the problem is to sleep half of their brain at a time. Bottlenose dolphins and porpoises have been most studied by the Russian scientist L. M. Mukhametov of the Severtsov Institute of Evolution, Morphology and Ecology of Animals in Moscow. He and his colleagues have found that both sides of the brain in these animals may simultaneously show a small amount of N2-like sleep, with the animal surfacing to breathe without awakening, but such complex continuously coordinated activity is not seen during N3. Rather, EEGs show that while one half of the brain sleeps, the other half is awake. When in this state, the eye on the opposite side of the head remains open allowing the animal to monitor their surroundings. Further, the wake half enables the animal to surface periodically and then take a breath. This pattern can persist for over an hour at a time followed by awakening before the other half takes its turn to sleep. However, the total amount of sleep that each side of the brain gets is seldom equal. Additionally, studies have shown that each side has its own quota of sleep each nychthemeron and that one half cannot sleep for the other half. Note, however, that such one-sided sleep has not been observed during REMS in these animals. Other sea mammals compensate differently; they hold their breath while sleeping for up to ½ h at a time, then awaken to surface and breathe before returning to sleep.

Many species of birds have also been found have NREMS half a brain at a time with one eye open. The riskier the environment the more they do this. Additionally, several other variants of sleep are found in birds. Vigilant sleep found in birds is an intermediate combination of NREMS and REMS. Gaze wake in birds is sleep with low-voltage fast EEG and reduced muscle tone but with open eyes manifesting slow, unique eye movements. Pigeons and other birds sometimes peep, something like a reverse blink, while sleeping. The frequency of blinks in individual pigeons is increased by predators being nearby but decreased by the presence of other pigeons or by sleep deprivation.

Even less is known about the sleep of lower animals, but of those that have been studied, the signs of sleep are even more different from those found in humans and other mammals due to their more primitive brains. In most cases, behavioral criteria are relied upon to study sleep in these animals. These criteria include: (1) periods of quiescence in a typical posture that are easily reversed by intense or sensory stimuli indicating a potential threat and (2) a compensatory increase in this state following a period of its deprivation. These indicators of sleep have been shown in at least some representatives from all orders, including lower vertebrates (e.g., reptiles, amphibians, and fish) and invertebrates (e.g., scorpions, cockroaches, and fruit flies). However, no signs of sleep have been found in other representatives of these orders.

Sleep has been clearly seen in many but not all reptiles that have been studied. Some amphibians appear to have some form of sleep, but others apparently do not. Some fish and some invertebrates have clearly been shown to have states resembling sleep. Interesting animal sleep research has been done by biological sciences Dr. Ida Karmanova, Professor and retired Director of the Laboratory of Wake-Sleep Evolution at the I.M. Sechenov Institute of Evolutionary Physiology and Biochemistry in St. Petersburg, Russia (Karmanova 1982; Karmanova and Oganesyan 1999). This research has not been widely attended to in the West. She and her associates have data that strongly suggest that reptiles have two kinds of sleep that are forerunners of NREMS and REMS in more advanced animals. Even lower vertebrates demonstrate wakefulness plus three other states of immobility or "protosleeps" according to these Russian researchers. These states are not sleep per se, but sleep as seen in higher vertebrates developed out of one of these (e.g., Karmanova and Oganesyan 1999).

Hibernation and torpor seem in some ways to be related to sleep and in other ways to differ from it. Hibernation is an extended period of quiescence, while the body temperature and metabolic rate are greatly lowered with periodic bouts every several days to every several weeks of increases in muscle tension, more than a few deep breaths, and other activity. Torpor is a similar state but not as intense and only lasting part of a day. EEG, body temperature, and arousability all line up in a continuum from quiet wake to sleep to torpor to hibernation. Torpor consists mainly of low-amplitude N3, but there are no recordable brain waves during hibernation. However, hibernation is usually achieved by going through N3 and eliminating REMS and then through torpor. During sleep, there is typically a slight drop in body temperature, a moderate one during torpor, and a great drop during hibernation. Arousal is slower from torpor than from sleep and even slower yet from hibernation. On the other hand, when animals come out of torpor or hibernation, they sleep for a long time with an increase in SWS as if they are sleep deprived. The longer the duration of the hibernation, the longer the subsequent sleep, and the greater the amount of SWS.

(Interesting research program on sleep in fruit flies can be seen at http://www.pbs.org/wgbh/nova/body/sleep.html from 0:39 to 2:05.)

2.5 Conclusion

Sleep is not as simple as it seems. Prior to the scientific study of sleep, people believed that sleep was a passive phenomenon. Our brains and bodies simply seemed to reduce their levels of functioning as we went to sleep. Indeed it seems that way, because things like noises, pains, or thoughts that keep our minds or bodies aroused can keep us from sleeping. Also, in spite of dreaming, it was believed that not much is going on mentally when we sleep. The discovery of REMS in the middle of the twentieth century changed all that. The existence of more than one kind of sleep and the regular cycling between the stages of sleep showed that there must be active mechanisms controlling sleep as well as wakefulness. Also, REMS is anything but an inactive state. The EEG shows the brain is very activated. The only reason we remain quietly in bed during REMS is because our muscles of movement are paralyzed.

Along with the change in the notion of what sleep is came a whole new scientific attitude toward it. New questions were asked that no one ever thought to ask before. More interest, especially in REMS, was generated. More scientists turned their research attention to sleep. More research money became available. More sleep research was done. With this, increase in research came even more surprise discoveries about sleep—and even more understanding of how much more there is to learn. Much of the rest of this book is filled with the knowledge and understanding, much of it surprising and some counterintuitive, gained as a result of the new attitude and understanding about sleep since the mid-twentieth century.

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