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Excerpt
More Information

PART I

Sleep

CHAPTER 1

What Is Sleep?

Learning Objectives

- Identify the homeostatic nature of sleep
- Evaluate the key elements in the scientific definition of sleep
- Evaluate the evidence for the social nature of sleep
- Distinguish biologic characteristics of reptilian, avian, mammalian, nonhuman primate sleep, and human sleep

1.1 Introduction

What happens if you do not get enough sleep? You become easily distractible, your tolerance for other's foibles declines, you are less able to think clearly, and you act as if you are drunk during social interactions. If you go without sleep for more than just a single night you find that social interactions become difficult; you find it harder to control your emotions, you get irritable with others very easily, your self-control declines; your primary drives for food, aggression and sex increase; you become more susceptible to viral infection, especially for things like cold and flu; minor aches and pains get amplified into major pains, and you just want to get some sleep.

But if you go without sleep for more than a couple of nights, things go from bad to worse: You find it harder to regulate your internal body temperature, you feel weak, you walk through the day like a zombie, you may even start to hallucinate all kinds of weird visions, and you may begin to develop paranoid delusions that people are out to get you. Admittedly, the paranoid delusions are rare after prolonged sleep loss, but thinking problems are not; nor is it rare to experience subtle visual hallucinations after sleep loss. These visual effects may be due to intrusion of dreams into waking consciousness. In any case, the thing that happens invariably, without fail and most insistently and prominently when you do not get enough sleep is that you become extremely sleepy. You will get more and more sleepy until one of two things happen: Either you die or you eventually succumb to sleep. Sleep, therefore, is a biological need for human beings. We need it and we therefore need to understand it. Increasing evidence also suggests that dreams are vital for normal human cognitive and social functioning. Thus, the purpose of this book is to help all of us to better understand sleep and dreams.

More than sixty million Americans, or approximately one in three adults, experience inadequate sleep that can interfere with daily activities. Sleep loss has been linked with several leading causes of death in the United States, including cardiovascular disease, cancer, stroke, diabetes, and hypertension (Kochanek et al., 2014). Sleep loss not only adversely affects our health, it also costs us and the economy. Lack of sleep can lead to traffic accidents, industrial accidents (e.g., Exxon Valdez oil spill, etc.), medical errors, and loss of work time (Pack et al., 1995).

Employers should be worried about sleep-deprived employees. Workers who sleep less than six hours per day call in sick more often than workers who get a regular night's sleep. A worker sleeping less than six hours a night loses around six working days per year, *more* than a worker sleeping seven to nine hours. On an annual basis, the United States loses an equivalent of about 1.23 million working days due to insufficient sleep (Hafner et al., 2016).

Chronic sleep loss is not limited to the fast paced, highly industrialized economies of the North. People in the global South, especially those in poor countries, are also complaining that they do not get enough sleep. Stranges et al. (2017) surveyed large numbers of people from eight countries across Africa and Asia participating in the INDEPTH WHO-SAGE multicenter study during 2006–2007. The participating sites included rural populations in Ghana, Tanzania, South Africa, India, Bangladesh, Vietnam, and Indonesia, and an urban area in Kenya. There were 24,434 women and 19,501 men age fifty years and older. Two measures of sleep quality, over the past thirty days, were assessed alongside a number of sociodemographic variables, measures of quality of life, and health disorders. Overall, 16.6 percent of participants reported severe/extreme sleep problems. When the authors attempted to identify causes of sleep loss in this group of people, several social factors emerged as leading culprits: Being a solitary sleeper (not living in partnership), poorer self-rated overall quality of life, and feelings of depression and anxiety were consistently strong, independent predictors of sleep problems.

Why are so many people, both in rich and poor countries, so sleep-deprived? Social conditions seem to be a major contributing factor to sleep loss. When we worry, we lose sleep and we worry most often due to social problems: A fight with a friend, inability to pay the rent or to adequately feed your kids, pressing job deadlines or no luck in finding a job, neighborhood crime, or even neighborhood noise can all lead to sleep loss. People who live in poor neighborhoods are more vulnerable than others to many of these sorts of worries and sleep-loss-inducing stressors. Recent community surveys have found that upwards of 53 percent of non-Hispanic African Americans living in poor neighborhoods sleep less than six hours a night (Durrence and Lichstein, 2006).

While insufficient sleep can have detrimental impacts on all age cohorts, regardless of socioeconomic status, sleep deprivation among children and adolescents across economic classes may trigger irreversible long-term consequences. For instance, there is strong evidence for the association of quality and quantity of sleep with school performance and cognitive ability among school-aged children and adolescents (DeWald et al., 2010). In addition, according to a National Sleep Foundation (2014) survey, over half (58 percent) of fifteen- to seventeen-year-olds sleep seven hours or less per night and only 10 percent sleep nine hours or more. Among six to eleven year olds, 8 percent sleep seven hours or less per night and 23 percent sleep only eight hours per night. Smartphones and TVs are disrupting sleep of children. Eighty-nine percent of adults and 75 percent of children have at least one electronic device in their bedrooms; 68 percent of parents and 51 percent of children had two or more devices in their bedroom at night. Use of smartphone apps, such as addicting game apps, at bedtime by children as young as four- or five-years-old is not uncommon and is severely disruptive to sleep. More than 10 percent of children awaken during the night to send or read a text message; again this is very disruptive for sleep. At the other end of the age spectrum, over half of the thirty-three million adults over sixty-five years of age in the USA have some chronic sleep complaint which contributes to personal discomfort and illness, to caregiver burden, and to overall health care costs.

In short, there appears to be a global epidemic of sleep loss. This is despite the fact that some simple behavioral habits can often restore adequate sleep times and sleep quality (see Table 1.1). For all these reasons we need a better understanding of sleep.

The first step one needs to take to study sleep effectively is to define sleep.

1.2 What Is Sleep?

Here is a definition I propose for human sleep (Table 1.2): Sleep is a restorative process that is brain state–regulated, reversible, homeostatic,

Table 1.1 Sleep hygiene

1. Establish a regular and consistent bedtime routine. Set a consistent wake-up time.
2. Get adequate exposure to natural light during daytime and reduce exposure to light from all sources including electronic devices before bedtime.
3. Limit the consumption of stimulants like caffeine, soda, alcohol and nicotine which may impair sleep quality.
4. Exercise. As little as 10 minutes of aerobic exercise during the daytime can improve sleep.
5. Limit daytime napping.
6. Practice some form of mental and physical relaxation routine before bedtime in order to quiet socially related anxieties and ruminations at bedtime.

Table 1.2 Definition of sleep

Sleep is a restorative process that is brain state-regulated, reversible, homeostatic, embedded in a circadian and social–physiologic organization and involving a species-specific quiescent posture, some amount of perceptual disengagement, and elevated arousal thresholds.

- Restorative process indicates that one feels refreshed after high quality sleep.
- Reversible means that once we fall asleep we can easily return to wake if aroused sufficiently via noise, shaking, etc. There is no quick reversibility in other quiescent states like coma.
- Homeostatic means that if we go without sleep we need to at least partially make up for that lost sleep.
- Brain state–regulated indicates that the brain is what triggers and maintains sleep and that different forms of sleep are associated with distinctive patterns of brain activation and deactivation; we will see in later chapters that the "social brain" is particularly important for sleep and vice versa.
- Circadian and social-physiologic organization refers to the fact that sleep occurs every 24 hours and is entrained to social cues in the environment such that interactions with conspecifics are optimized.
- Quiescent posture indicates that for most animals sleep is associated with a relatively motionless posture – most often recumbency (lying down).
- Perceptual disengagement indicates that the sleeper exhibits reduced responsiveness to normal environmental stimuli.
- Elevated threshold means that it takes a sufficiently loud noise or hard shake to wake us up.

embedded in both a circadian and social–physiologic organization and involving a species-specific quiescent posture, some amount of perceptual disengagement, and elevated arousal thresholds. Admittedly, that is a mouthful. But I assure you there is a good reason for including every single element in that long definition. We will define and discuss each of these terms shortly. This definition best captures human sleep but it can encompass sleep of other organisms if we allow relaxation of some of the components of the definition. For example, even organisms as genetically and neurally simple as the worm *Caenorhabditis elegans*, exhibits a regularly occurring period of inactivity or quiescence. Other simple organisms like the fruit fly and some insects also display regularly occurring periods of quiescence and some evidence of compensatory "sleep" rebound or homeostatically regulated periods of quiescence. The role of brain state–regulated transitions between different phases of activity and inactivity becomes more prominent in organisms with more complex nervous systems like animals and humans. Thus, the definition is broad enough to capture the essentials of sleep expression from the simplest to the most complex of organisms. To fill out this definition in more detail we need to quickly identify some common traits or characteristics normally associated with sleep in animals and in humans.

Sleep can be thought of as composed of behavioral, functional, physiologic, and electrophysiological traits (see Table 1.3). For most animals, sleep can only be identified via measurement of its behavioral and functional sleep traits, as their nervous systems do not support what has become known as full polygraphic sleep or sleep that can be measured with an electroencephalograph or EEG machine that records brain waves through the skull.

Full polygraphic sleep refers to electrophysiologic measures of both REM (rapid eye movement) and NREM (non-rapid eye movement) sleep stages N1, N2, and N3, identified via the electroencephalogram or EEG. It has become common however to use the term "full polygraphic sleep" to refer to an animal who exhibits most or all of the other three major components of sleep in addition to the electrophysiologic measures. When an animal exhibits all four major components of sleep including the behavioral, electrophysiologic, physiologic, and functional components of sleep, then it is said that the animal exhibits full polygraphic sleep. Full polygraphic sleep, in this sense, has so far only been documented in primates (including humans). In humans and other mammals (and perhaps some reptiles) sleep comes in two forms or phases: REM (rapid eye movement) and NREM (non-REM) sleep. While REM and NREM phases of sleep have been identified in a large

Table 1.3 Sleep traits

1. Behavioral
   - Typical usually quiescent body posture.
   - Specific sleeping site.
   - Behavioral rituals before sleep (e.g., circling, yawning).
   - Physical quiescence.
   - Elevated threshold for arousal and reactivity.
   - Rapid state reversibility.
   - Circadian organization of rest–activity cycles.
   - Entrained to and sensitive to social cues and to activities of conspecifics.
   - Different from hibernation/torpor.
2. Electrophysiological
   EEG
   NREM: high voltage slow waves, Delta power (quiet sleep).
   - Spindles in some animals.
   - K-complexes in some primates.

   REM: low voltage fast waves (REM, Paradoxical sleep or AS [active sleep]).
   - Hippocampal theta; PGO waves.

   Electro-oculogram (EOG)
   NREM: absence of eye movements or presence of slow rolling eye movements.
   REM: rapid eye movements.
   EMG
   - Progressive loss of muscle tone from Wake ➔ NREM ➔ REM.
3. Physiological
   - REM: instabilities in heart-rate, breathing, body temperature, etc. Other: penile tumesence.
   - NREM: reduction in physiologic/metabolic processes; reduction of about 2C in core body temperature.
4. Functional
   Compensation of sleep deficit: (homeostatic regulation)
   - Enhancement of sleep time after sleep deprivation.
   - Intensification of the sleep process (e.g., enhanced EEG power in the Delta range).

number of mammalian species, NREM in most of these species cannot be differentiated into distinct substages as it is in several primate species.

Behavioral traits of sleep include a species-specific body posture that typically involves a recumbent non-moving animal (quiescence), though some animals can engage in some limited sleep while standing (e.g., cows). There is also typically a species-specific sleeping site that is constructed to conserve warmth and to protect the sleeping animal from predators. Before relaxing into the sleep site an animal usually engages in behavioral rituals such as circling the nest and yawning before laying down to sleep. It is unclear why these behavioral rituals are needed before sleep. Other behavioral indicators of sleep include reduced muscle tone, reduction in neck/nuchal muscle tone, paralysis of the antigravity muscles in some species, increased arousal threshold, and rapid reversibility to wakefulness. Physiologic indices of sleep include significant reductions in core body temperature and metabolism during NREM and significant lability in the autonomic nervous system activity (ANS), as well as cardiovascular and respiratory measures during REM. Electrophysiologic measures of REM include low voltage fast waves, rapid eye movements, theta rhythms in the hippocampus, and pontine-geniculo-occipital or PGO waves. PGO waves are electrical discharges in all the visual centers (from the pons to the occipital cortex) of the brain. Electrophysiologic measures of NREM include high voltage slow waves, spindles, and k-complexes. Functional indices of sleep include increased amounts of sleep after sleep deprivation and increased sleep intensity after sleep deprivation.

We say that ***sleep is a restorative process that is brain state–regulated, reversible, homeostatic, embedded in a circadian and social-physiologic organization and involving a species-specific quiescent posture, some amount of perceptual disengagement, and elevated arousal thresholds.***

1.3 What Do Each of These Terms Mean?

1.3.1 Restorative Process

When you have a night of high quality sleep you wake up feeling refreshed and no longer tired. Sleep, therefore, reverses some process that makes you feel worn, ragged, socially inept, and tired. That process is the waking state. Since both the waking state and sleep are mediated by the brain, we need neuroscience to understand sleep. Genetic and neurochemical analyses of the sleep state reveal that housekeeping, metabolic, and energy-related genes are differentially expressed during sleep and there is cumulative evidence that sleep restores glycogen (the fuel for the brain) levels in the brain.

1.3.2 Reversible State

By reversible state we mean that when you go to sleep, you are not stuck there as may be the case with an irreversible coma; with appropriate forms of stimulation such as a loud noise and a vigorous shaking you can return to wakefulness. Typically the brain spontaneously shifts itself out of sleep and back into waking after about five to eight hours in adult human beings.

1.3.3 Homeostatic

By homeostatically regulated we mean that the *amount* and *intensity* of sleep you experience is controlled by a kind of internal thermostat. If you get too little sleep you cumulate a sleep debt that needs to eventually be paid back or made up. To make up for lost sleep time you sleep a bit longer and a bit more intensely on subsequent nights. In short, you sleep in proportion to wake time. The longer the wake time (or the greater the amount of sleep deprivation), the greater the subsequent sleep time and intensity. Lots of people sleep little during the work week and then sleep in (or sleep longer) during the weekend. In other words, we make up for lost sleep time during the work week by sleeping more on the weekends.

If we use an electroencephalograph or EEG (to be discussed more fully later and in the Appendix) to record brain waves during catch-up sleep, we see that the brain exhibits a lot of so-called *delta power*. The longer the wake time before sleep, the stronger or higher the delta power during sleep. Once you go to sleep, however, delta power begins to decline across the night, indicating that delta signal's "need for sleep," or the intensity with which you sleep during catch-up sleep. The greater the delta power the more intense the catch-up sleep. When delta power is high at the beginning of the night and declines across the night, people report high-quality sleep. So it is not so much the amount of sleep but the intensity of sleep that counts in catch-up sleep. The more intense the sleep as measured by delta power, the more refreshing the sleep. Thus, we can pay back a sleep deficit by sleeping more intensely as well as by sleeping longer.

The phenomenon of catch-up sleep suggests that something, some chemical process within the body or the brain perhaps, builds up during wake and is discharged during sleep. Delta activity (during slow wave sleep; N3) indexes the efficiency with which this wake-related chemical process, call it Process S, is discharged. Delta power is doing something that reverses whatever Process S induces during wake. For example, if Process S is some sort of fuel for body and brain that gets depleted during waking, then delta power would presumably index some sort of manufacturing process that produces some chemical that would refuel the body and brain. If we could identify the physical factor responsible