Why We Sleep

UNLOCKING THE POWER OF SLEEP AND DREAMS

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To Dacher Keltner, for inspiring me to write.

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PART 1

This Thing Called Sleep

CHAPTER 1

To Sleep . . .

Do you think you got enough sleep this past week? Can you recall the last time you woke up without an alarm clock feeling refreshed, not needing caffeine? If the answer to either of these questions is "no," you are not alone. More than a third of adults in many developed nations fail to obtain the recommended seven to nine hours of nightly sleep.*

I doubt you are surprised by this fact, but you may be surprised by the consequences. Routinely sleeping less than six hours a night weakens your immune system, substantially increasing your risk of certain forms of cancer. Insufficient sleep appears to be a key lifestyle factor linked to your risk of developing Alzheimer's disease. Inadequate sleep—even moderate reductions for just one week—disrupts blood sugar levels so profoundly that you would be classified as pre-diabetic. Short sleeping increases the likelihood of your coronary arteries becoming blocked and brittle, setting you on a path toward cardiovascular disease, stroke, and congestive heart failure. Fitting Charlotte Brontë's prophetic wisdom that "a ruffled mind makes a restless pillow," sleep disruption further contributes to all major psychiatric conditions, including depression, anxiety, and suicidality.

Perhaps you have also noticed a desire to eat more when you're tired? This is no coincidence. Too little sleep swells concentrations of a hormone that makes you feel hungry while suppressing a companion hormone that otherwise signals food satisfaction. Despite

*The Centers for Disease Control (CDC) stipulates that adults need seven hours of sleep or more per twenty-four hours.

being full, you still want to eat more. It's a proven recipe for weight gain in sleep-deficient adults and children alike. Worse, should you attempt to diet but don't get enough sleep while doing so, it is futile, since most of the weight you lose will come from lean body mass, not fat.

Add the above health consequences up, and a proven link becomes easier to accept: relative to the recommended seven to nine hours, the shorter your sleep, the shorter your life span. The old maxim "I'll sleep when I'm dead" is therefore unfortunate. Adopt this mind-set, and it is possible that you will be dead sooner and the quality of that (shorter) life will be worse. The elastic band of sleep deprivation can stretch only so far before it snaps. Sadly, human beings are in fact the only species that will deliberately deprive themselves of sleep without legitimate gain. Numerous components of wellness, and countless seams of societal fabric, are being eroded by our costly state of sleep neglect: human and financial alike. So much so that the Centers for Disease Control declared insufficient sleep as a public health epidemic. It may not be a coincidence that countries where sleep time has declined most dramatically over the past century, such as the US, the UK, Japan, and South Korea, and several in western Europe, are also those suffering the greatest increase in rates of the aforementioned physical diseases and mental disorders.

Scientists such as myself have even started lobbying doctors to start "prescribing" sleep. As medical advice goes, it's perhaps the most painless and enjoyable to follow. Do not, however, mistake this as a plea to doctors to start prescribing more sleeping *pills*—quite the opposite, in fact, considering the evidence surrounding the deleterious health consequences of these drugs.

But can we go so far as to say that a lack of sleep can kill you outright? Quite posssibly—on at least two counts. First, there is a very rare genetic disorder that starts with a progressive insomnia, emerging in midlife. Several months into the disease course, the patient stops sleeping altogether. By this stage, they have started to lose many basic brain and body functions. Few drugs that we currently have will help the patient sleep. After twelve to eighteen months of no sleep, the patient will die.

Second is the deadly circumstance of getting behind the wheel of a

motor vehicle without having had sufficient sleep. Drowsy driving is the cause of hundreds of thousands of traffic accidents and fatalities each year. And here, it is not only the life of the sleep-deprived individuals that is at risk, but the lives of those around them. Tragically, one person dies in a traffic accident every hour in the United States due to a fatigue-related error.

Society's apathy toward sleep has, in part, been caused by the historic failure of science to explain why we need it. Sleep remained one of the last great biological mysteries. All of the mighty problem-solving methods in science—genetics, molecular biology, and high-powered digital technology—have been unable to unlock the stubborn vault of sleep. Minds of the most stringent kind, including Nobel Prize–winner Francis Crick, who deduced the twisted-ladder structure of DNA, famed Roman educator and rhetorician Quintilian, and even Sigmund Freud had all tried their hand at deciphering sleep's enigmatic code, all in vain.

To better frame this state of prior scientific ignorance, imagine the birth of your first child. At the hospital, the doctor enters the room and says, "Congratulations, it's a healthy baby boy. We've completed all of the preliminary tests and everything looks good." She smiles reassuringly and starts walking toward the door. However, before exiting the room she turns around and says, "There is just one thing. From this moment forth, and for the rest of your child's entire life, he will repeatedly and routinely lapse into a state of apparent coma. It might even resemble death at times. And while his body lies still his mind will often be filled with stunning, bizarre hallucinations. This state will consume one-third of his life and I have absolutely no idea why he'll do it, or what it is for. Good luck!"

Astonishing, but until very recently, this was reality: doctors and scientists could not give you a consistent or complete answer as to why we sleep. Consider that we have known the functions of the three other basic drives in life—to eat, to drink, and to reproduce—for many tens if not hundreds of years now. Yet the fourth main biological drive, common across the animal kingdom—the drive to sleep—has continued to elude science for millennia.

Addressing the question of why we sleep from an evolutionary per-

spective only compounds the mystery. No matter what vantage point you take, sleep would appear to be the most foolish of biological phenomena. When you are asleep, you cannot gather food. You cannot socialize. You cannot find a mate and reproduce. You cannot nurture or protect your offspring. Worse still, sleep leaves you vulnerable to predation. Sleep is surely one of the most puzzling of all human behaviors.

On any one of these grounds—never mind all of them in combination—there ought to have been a strong evolutionary pressure to *prevent* the emergence of sleep or anything remotely like it. As one sleep scientist has said, "If sleep does not serve an absolutely vital function, then it is the biggest mistake the evolutionary process has ever made."*

Yet sleep has persisted. Heroically so. Indeed, every animal species carefully studied to date sleeps.† This suggests that sleep evolved with—or very soon after—life itself on our planet. Moreover, the subsequent perseverance of sleep throughout evolution means there must be tremendous benefits that far outweigh all of the obvious hazards and detriments.

Ultimately, asking "Why do we sleep?" was the wrong question. It implied there was a single function, one holy grail of a reason that we slept, and we went in search of it. Theories ranged from the logical (a time for conserving energy), to the peculiar (an opportunity for eyeball oxygenation), to the psychoanalytic (a non-conscious state in which we fulfill repressed wishes).

This book will reveal a very different truth: sleep is infinitely more complex, profoundly more interesting, and strikingly health-relevant. We sleep for a rich litany of function*s*, plural—an abundant constellation of nighttime benefits that service both our brains and our bodies. There does not seem to be one major organ within the body, or process within the brain, that isn't optimally enhanced by sleep (and detrimentally impaired when we don't get enough). That we receive such a bounty of health benefits each night should not be surprising. After

*Dr. Allan Rechtschaffen.

†Cirelli, C., and Tononi, G. (2008). "Is sleep essential?" *PLoS Biology*. 6, e216.

all, we are *awake* for two-thirds of our lives, and we don't just achieve one useful thing during that stretch of time. We accomplish myriad undertakings that promote our own well-being and survival. Why, then, would we expect sleep—and the twenty-five to thirty years, on average, it takes from our lives—to offer one function only?

Through an explosion of discoveries over the past twenty years, we have come to realize that evolution did not make a spectacular blunder in conceiving of sleep. Sleep dispenses a multitude of health-ensuring benefits, yours to pick up in repeat prescription every twenty-four hours, should you choose.

Within the brain, sleep enriches a diversity of functions, including our ability to learn, memorize, and make logical decisions and choices. Benevolently servicing our psychological health, sleep recalibrates our emotional brain circuits, allowing us to navigate next-day social and psychological challenges with cool-headed composure. We are even beginning to understand the most impervious and controversial of all conscious experiences: the dream. Dreaming provides a unique suite of benefits to all species fortunate enough to experience it, humans included. Among these gifts are a consoling neurochemical bath that mollifies painful memories and a virtual reality space in which the brain melds past and present knowledge, inspiring creativity.

Downstairs in the body, sleep restocks the armory of our immune system, preventing infection and warding off all manner of sickness. Sleep reforms the body's metabolic state by fine-tuning the balance of insulin and circulating glucose. Sleep further regulates our appetite, helping control body weight through healthy food selection rather than rash impulsivity. Plentiful sleep maintains a flourishing microbiome within your gut from which we know so much of our nutritional health begins. Adequate sleep is intimately tied to the fitness of our cardiovascular system, lowering blood pressure while helping keep our hearts in fine condition.

A balanced diet and exercise are of vital importance, yes. But we now see sleep as a preeminent force in this health trinity. The physical and mental impairments caused by one night of bad sleep dwarf those caused by an equivalent absence of food or exercise. It is difficult to imagine any other state—natural or medically manipulated—that

affords a more powerful redressing of physical and mental health at every level of analysis.

Based on a rich, new scientific understanding of sleep, we no longer have to ask what sleep is good for. Instead, we are now forced to wonder whether there are any biological functions that do *not* benefit by a good night's sleep.

Emerging from this research renaissance is an unequivocal message: sleep is the single most effective thing we can do to reset our brain and body health each day—Mother Nature's best effort yet at contra-death. Unfortunately, the real evidence that makes clear all of the dangers that befall individuals and societies when sleep becomes short have not been clearly telegraphed to the public. It is perhaps the most glaring omission in the contemporary health conversation. In response, this book is intended to help address this unmet need, and provide what I hope is a fascinating journey of discoveries. It aims to revise our cultural appreciation of sleep, and reverse our neglect of it.

Personally, I should note that I am rather in love with sleep (not just my own, though I do give myself a non-negotiable eight-hour sleep opportunity each night). I am in love with everything sleep is and does. I am in love with discovering all that remains unknown about it. I am in love with communicating the relevance of it to the public. I am in love with finding any and all methods for reuniting humanity with the sleep it so desperately needs. This love affair has now spanned a twenty-plus-year research career that began when I was a professor of psychiatry at Harvard Medical School and continues now that I am a professor of neuroscience and psychology at the University of California, Berkeley.

It was not, however, love at first sight. I am an accidental sleep researcher. It was never my intent to inhabit this esoteric outer territory of science. At age eighteen I went to study at the Queen's Medical Center in England: a prodigious institute in Nottingham boasting a wonderful band of brain scientists on its faculty. Ultimately, medicine wasn't for me, as it seemed more concerned with answers, whereas I was always more enthralled by questions. For me, answers

were simply a way to get to the next question. I decided to study neuroscience, and after graduating, obtained my PhD in neurophysiology supported by a fellowship from England's Medical Research Council, London.

It was during my PhD work, conducted mostly at Newcastle University, that I began making my first scientific contributions in the field of sleep research. I was examining patterns of electrical brainwave activity in older adults in the early stages of dementia. Counter to common belief, there isn't just one type of dementia. Alzheimer's disease is the most common, but is only one of many types. For a number of treatment reasons, it is critical to know which type of dementia an individual is suffering from as soon as possible.

I began assessing brainwave activity from my patients during wake and sleep. My hypothesis: there was a unique and specific electrical brain signature that could forecast which dementia subtype each individual was progressing toward. Measurements taken during the day were ambiguous, with no clear signature of difference to be found. Only in the nighttime ocean of *sleeping* brainwaves did the recordings speak out a clear labeling of my patients' saddening disease fate. The discovery proved that sleep could potentially be used as a new early diagnostic litmus test to understand which type of dementia an individual would develop.

Sleep became my obsession. The answer it had provided me, like all good answers, only led to more fascinating questions, among them: Was the disruption of sleep in my patients actually contributing to the diseases they were suffering from, and even causing some of their terrible symptoms, such as memory loss, aggression, hallucinations, delusions? I read all I could. A scarcely believable truth began to emerge—nobody actually knew the clear reason why we needed sleep, and what it does. I could not answer my own question about dementia if this fundamental first question remained unanswered. I decided I would try to crack the code of sleep.

I halted my research in dementia and, for a post-doctoral position that took me across the Atlantic Ocean to Harvard, set about addressing one of the most enigmatic puzzles of humanity—one that had eluded some of the best scientists in history: Why do we sleep? With

genuine naïveté, not hubris, I believed I would find the answer within two years. That was twenty years ago. Hard problems care little about what motivates their interrogators; they meter out their lessons of difficulty all the same.

Now, after two decades of my own research efforts, combined with thousands of studies from other laboratories around the world, we have many of the answers. These discoveries have taken me on wonderful, privileged, and unexpected journeys inside and outside of academia—from being a sleep consultant for the NBA, NFL, and British Premier League football teams; to Pixar Animation, government agencies, and well-known technology and financial companies. These sleep revelations, together with many similar discoveries from my fellow sleep scientists, will offer proof about the vital importance of sleep.

A final comment on the structure of this book. The chapters are written in a logical order, traversing a narrative arc in four main parts.

Part 1 demystifies this beguiling thing called sleep: what it is, what it isn't, who sleeps, how much they sleep, how human beings should sleep (but are not), and how sleep changes across your life span or that of your child, for better and for worse.

Part 2 details the good, the bad, and the deathly of sleep and sleep loss. We will explore all of the astonishing benefits of sleep for brain and for body, affirming what a remarkable Swiss Army knife of health and wellness sleep truly is. Then we turn to how and why a lack of sufficient sleep leads to a quagmire of ill health, disease, and untimely death—a wakeup call to sleep if ever there was one.

Part 3 offers safe passage from sleep to the fantastical world of dreams scientifically explained. From peering into the brains of dreaming individuals, and precisely how dreams inspire Nobel Prize–winning ideas that transform the world, to whether or not dream control really is possible, and if such a thing is even wise—all will be revealed.

Part 4 seats us first at the bedside, explaining numerous sleep disorders, including insomnia. I will unpack the obvious and not-so-obvious reasons for why so many of us find it difficult to get a good night's sleep,

night after night. A discussion of sleeping pills then follows, based on scientific and clinical data. Details of new, safer, and more effective non-drug therapies for better sleep will then be described. Transitioning from bedside up to the level of sleep in society, we will subsequently learn of the sobering impact that insufficient sleep has in education, in medicine and health care, and in business. The evidence shatters beliefs about the usefulness of long waking hours with little sleep in effectively, safely, profitably, and ethically accomplishing the goals of each of these disciplines. Concluding the book with genuine optimistic hope, I lay out a road map of ideas that can reconnect humanity with the sleep it remains so bereft of—a new vision for sleep in the twenty-first century.

I should note that you need not read this book in this progressive, four-part narrative arc. Each chapter can, for the most part, be read individually, and out of order, without losing too much of its significance. I therefore invite you to consume the book in whole or in part, buffet-style or in order, all according to your personal taste.

It is worthwhile pointing out that this book is not designed to be a self-help guide. It is not written to target or treat sleep disorders, including insomnia. There are books that do this, and many of them will recommend speaking to a doctor if you suspect you have a sleep disorder. I am also very understanding of, and sympathetic to, those people who struggle with sleep and are most anxious about it. For these individuals, it is possible that their anxiety may increase when reading about the impact of insufficient sleep, including information contained in the book. I therefore want to alert the reader to this possibility, allowing for reader discretion on this matter.

In closing, I offer a disclaimer. Should you feel drowsy and fall asleep while reading the book, unlike most authors, I will not be disheartened. Indeed, based on the topic and content of this book, I am actively going to encourage that kind of behavior from you. Knowing what I know about the relationship between sleep and memory, it is the greatest form of flattery for me to know that you, the reader, cannot resist the urge to strengthen and thus remember what I am telling you by falling asleep. So please, feel free to ebb and flow into and out of consciousness during this entire book. I will take absolutely no offense. On the contrary, I would be delighted.

CHAPTER 2

Caffeine, Jet Lag, and Melatonin

Losing and Gaining Control of Your Sleep Rhythm

How does your body know when it's time to sleep? Why do you suffer from jet lag after arriving in a new time zone? How do you overcome jet lag? Why does that acclimatization cause you yet more jet lag upon returning home? Why do some people use melatonin to combat these issues? Why (and how) does a cup of coffee keep you awake? Perhaps most importantly, how do you know if you're getting enough sleep?

There are two main factors that determine when you want to sleep and when you want to be awake. As you read these very words, both factors are powerfully influencing your mind and body. The first factor is a signal beamed out from your internal twenty-four-hour clock located deep within your brain. The clock creates a cycling, day-night rhythm that makes you feel tired or alert at regular times of night and day, respectively. The second factor is a chemical substance that builds up in your brain and creates a "sleep pressure." The longer you've been awake, the more that chemical sleep pressure accumulates, and consequentially, the sleepier you feel. It is the balance between these two factors that dictates how alert and attentive you are during the day, when you will feel tired and ready for bed at night, and, in part, how well you will sleep.

GOT RHYTHM?

Central to many of the questions in the opening paragraph is the powerful sculpting force of your twenty-four-hour rhythm, also known as your circadian rhythm. Everyone generates a circadian rhythm (*circa*,

meaning "around," and *dian*, derivative of *diam*, meaning "day"). Indeed, most living creatures on the planet with a life span of more than several days generate this natural cycle. The internal twenty-four-hour clock within your brain communicates its daily circadian rhythm signal to every other region of your brain and every organ in your body.

Your twenty-four-hour tempo helps to determine when you want to be awake and when you want to be asleep. But it controls other rhythmic patterns, too. These include your timed preferences for eating and drinking, your moods and emotions, the amount of urine you produce,* your core body temperature, your metabolic rate, and the release of numerous hormones. It is no coincidence that the likelihood of breaking an Olympic record has been clearly tied to time of day, being maximal at the natural peak of the human circadian rhythm in the early afternoon. Even the timing of births and deaths demonstrates circadian rhythmicity due to the marked swings in key life-dependent metabolic, cardiovascular, temperature, and hormonal processes that this pacemaker controls.

Long before we discovered this biological pacemaker, an ingenious experiment did something utterly remarkable: stopped time—at least, for a plant. It was in 1729 when French geophysicist Jean-Jacques d'Ortous de Mairan discovered the very first evidence that plants generate their own internal time.

De Mairan was studying the leaf movements of a species that displayed heliotropism: when a plant's leaves or flowers track the trajectory of the sun as it moves across the sky during the day. De Mairan was intrigued by one plant in particular, called *Mimosa pudica.*† Not only do the leaves of this plant trace the arching daytime passage of the sun across the sky's face, but at night, they collapse down, almost as though they had wilted. Then, at the start of the following day, the leaves pop

*I should note, from personal experience, that this is a winning fact to dispense at dinner parties, family gatherings, or other such social occasions. It will almost guarantee nobody will approach or speak to you again for the rest of the evening, and you'll also never be invited back.

†The word *pudica* is from the Latin meaning "shy" or "bashful," since the leaves will also collapse down if you touch or stroke them.

open once again like an umbrella, healthy as ever. This behavior repeats each and every morning and evening, and it caused the famous evolutionary biologist Charles Darwin to call them "sleeping leaves."

Prior to de Mairan's experiment, many believed that the expanding and retracting behavior of the plant was solely determined by the corresponding rising and setting of the sun. It was a logical assumption: daylight (even on cloudy days) triggered the leaves to open wide, while ensuing darkness instructed the leaves to shut up shop, close for business, and fold away. That assumption was shattered by de Mairan. First, he took the plant and placed it out in the open, exposing it to the signals of light and dark associated with day and night. As expected, the leaves expanded during the light of day and retracted with the dark of night.

Then came the genius twist. De Mairan placed the plant in a sealed box for the next twenty-four-hour period, plunging it into total dark for both day and night. During these twenty-four hours of blackness, he would occasionally take a peek at the plant in controlled darkness, observing the state of the leaves. Despite being cut off from the influence of light during the day, the plant still behaved as though it were being bathed in sunlight; its leaves were proudly expanded. Then, it retracted its leaves as if on cue at the end of the day, even without the sun's setting signal, and they stayed collapsed throughout the entire night.

It was a revolutionary discovery: de Mairan had shown that a living organism kept its own time, and was not, in fact, slave to the sun's rhythmic commands. Somewhere within the plant was a twenty-four-hour rhythm generator that could track time without any cues from the outside world, such as daylight. The plant didn't just have a circadian rhythm, it had an "endogenous," or self-generated, rhythm. It is much like your heart drumming out its own self-generating beat. The difference is simply that your heart's pacemaker rhythm is far faster, usually beating at least once a second, rather than once every twenty-four-hour period like the circadian clock.

Surprisingly, it took another two hundred years to prove that we humans have a similar, internally generated circadian rhythm. But this experiment added something rather unexpected to our understanding of internal timekeeping. It was 1938, and Professor Nathaniel Kleitman

at the University of Chicago, accompanied by his research assistant Bruce Richardson, were to perform an even more radical scientific study. It required a type of dedication that is arguably without match or comparison to this day.

Kleitman and Richardson were to be their own experimental guinea pigs. Loaded with food and water for six weeks and a pair of dismantled, high-standing hospital beds, they took a trip into Mammoth Cave in Kentucky, one of the deepest caverns on the planet—so deep, in fact, that no detectable sunlight penetrates its farthest reaches. It was from this darkness that Kleitman and Richardson were to illuminate a striking scientific finding that would define our biological rhythm as being *approximately* one day (circadian), and not *precisely* one day.

In addition to food and water, the two men brought a host of measuring devices to assess their body temperatures, as well as their waking and sleeping rhythms. This recording area formed the heart of their living space, flanked either side by their beds. The tall bed legs were each seated in a bucket of water, castle-moat style, to discourage the innumerable small (and not so small) creatures lurking in the depths of Mammoth Cave from joining them in bed.

The experimental question facing Kleitman and Richardson was simple: When cut off from the daily cycle of light and dark, would their biological rhythms of sleep and wakefulness, together with body temperature, become completely erratic, or would they stay the same as those individuals in the outside world exposed to rhythmic daylight? In total, they lasted thirty-two days in complete darkness. Not only did they aggregate some impressive facial hair, but they made two groundbreaking discoveries in the process. The first was that humans, like de Mairan's heliotrope plants, generated their own endogenous circadian rhythm in the absence of external light from the sun. That is, neither Kleitman nor Richardson descended into random spurts of wake and sleep, but instead expressed a predictable and repeating pattern of prolonged wakefulness (about fifteen hours), paired with consolidated bouts of about nine hours of sleep.

The second unexpected—and more profound—result was that their reliably repeating cycles of wake and sleep were not precisely twenty-four hours in length, but consistently and undeniably longer than

twenty-four hours. Richardson, in his twenties, developed a sleep-wake cycle of between twenty-six and twenty-eight hours in length. That of Kleitman, in his forties, was a little closer to, but still longer than, twenty-four hours. Therefore, when removed from the external influence of daylight, the internally generated "day" of each man was not exactly twenty-four hours, but a little more than that. Like an inaccurate wristwatch whose time runs long, with each passing (real) day in the outside world, Kleitman and Richardson began to add time based on their longer, internally generated chronometry.

Since our innate biological rhythm is not precisely twenty-four hours, but thereabouts, a new nomenclature was required: the *circa*dian rhythm—that is, one that is *approximately*, or around, one day in length, and not precisely one day.* In the seventy-plus years since Kleitman and Richardson's seminal experiment, we have now determined that the average duration of a human adult's endogenous circadian clock runs around twenty-four hours and fifteen minutes in length. Not too far off the twenty-four-hour rotation of the Earth, but not the precise timing that any self-respecting Swiss watchmaker would ever accept.

Thankfully, most of us don't live in Mammoth Cave, or the constant darkness it imposes. We routinely experience light from the sun that comes to the rescue of our imprecise, overrunning internal circadian clock. Sunlight acts like a manipulating finger and thumb on the side-dial of an imprecise wristwatch. The light of the sun methodically resets our inaccurate internal timepiece each and every day, "winding" us back to precisely, not approximately, twenty-four hours.†

It is no coincidence that the brain uses daylight for this resetting purpose. Daylight is the most reliable, repeating signal that we have in our environment. Since the birth of our planet, and every single day thereafter without fail, the sun has always risen in the morning and set in the evening. Indeed, the reason most living species likely

*This phenomenon of an imprecise internal biological clock has now been consistently observed in many different species. However, it is not consistently long in all species, as it is in humans. For some, the endogenous circadian rhythm runs short, being less than twenty-four hours when placed in total darkness, such as hamsters or squirrels. For others, such as humans, it is longer than twenty-four hours.

†Even sunlight coming through thick cloud on a rainy day is powerful enough to help reset our biological clocks.

adopted a circadian rhythm is to synchronize themselves and their activities, both internal (e.g., temperature) and external (e.g., feeding), with the daily orbital mechanics of planet Earth spinning on its axis, resulting in regular phases of light (sun facing) and dark (sun hiding).

Yet daylight isn't the only signal that the brain can latch on to for the purpose of biological clock resetting, though it is the principal and preferential signal, when present. So long as they are reliably repeating, the brain can also use other external cues, such as food, exercise, temperature fluctuations, and even regularly timed social interaction. All of these events have the ability to reset the biological clock, allowing it to strike a precise twenty-four-hour note. It is the reason that individuals with certain forms of blindness do not entirely lose their circadian rhythm. Despite not receiving light cues due to their blindness, other phenomena act as their resetting triggers. Any signal that the brain uses for the purpose of clock resetting is termed a zeitgeber, from the German "time giver" or "synchronizer." Thus, while light is the most reliable and thus the primary zeitgeber, there are many factors that can be used in addition to, or in the absence of, daylight.

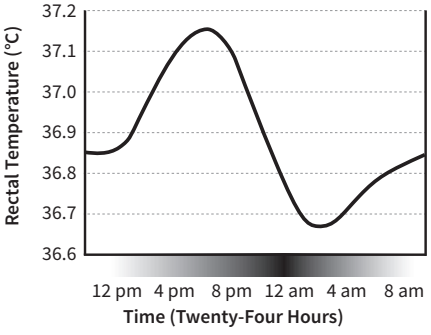
The twenty-four-hour biological clock sitting in the middle of your brain is called the suprachiasmatic (pronounced *soo-pra-kai-as-MAT-ik*) nucleus. As with much of anatomical language, the name, while far from easy to pronounce, is instructional: *supra*, meaning above, and *chiasm*, meaning a crossing point. The crossing point is that of the optic nerves coming from your eyeballs. Those nerves meet in the middle of your brain, and then effectively switch sides. The suprachiasmatic nucleus is located just above this intersection for a good reason. It "samples" the light signal being sent from each eye along the optic nerves as they head toward the back of the brain for visual processing. The suprachiasmatic nucleus uses this reliable light information to reset its inherent time inaccuracy to a crisp twenty-four-hour cycle, preventing any drift.

When I tell you that the suprachiasmatic nucleus is composed of 20,000 brain cells, or neurons, you might assume it is enormous, consuming a vast amount of your cranial space, but actually it is tiny. The

brain is composed of approximately 100 billion neurons, making the suprachiasmatic nucleus minuscule in the relative scheme of cerebral matter. Yet despite its stature, the influence of the suprachiasmatic nucleus on the rest of the brain and the body is anything but meek. This tiny clock is the central conductor of life's biological rhythmic symphony—yours and every other living species. The suprachiasmatic nucleus controls a vast array of behaviors, including our focus in this chapter: when you want to be awake and asleep.

For diurnal species that are active during the day, such as humans, the circadian rhythm activates many brain and body mechanisms in the brain and body during daylight hours that are designed to keep you awake and alert. These processes are then ratcheted down at nighttime, removing that alerting influence. Figure 1 shows one such example of a circadian rhythm—that of your body temperature. It represents average core body temperature (rectal, no less) of a group of human adults. Starting at "12 pm" on the far left, body temperature begins to rise, peaking late in the afternoon. The trajectory then changes. Temperature begins to decline again, dropping below that of the midday start-point as bedtime approaches.

Figure 1: Typical Twenty-Four-Hour Circadian Rhythm (Core Body Temperature)



Your biological circadian rhythm coordinates a drop in core body temperature as you near typical bedtime (figure 1), reaching its nadir, or low point, about two hours after sleep onset. However, this temperature rhythm is not dependent upon whether you are actually

asleep. If I were to keep you awake all night, your core body temperature would still show the same pattern. Although the temperature drop helps to initiate sleep, the temperature change itself will rise and fall across the twenty-four-hour period regardless of whether you are awake or asleep. It is a classic demonstration of a preprogrammed circadian rhythm that will repeat over and over without fail, like a metronome. Temperature is just one of many twenty-four-hour rhythms that the suprachiasmatic nucleus governs. Wakefulness and sleep are another. Wakefulness and sleep are therefore under the control of the circadian rhythm, and not the other way around. That is, your circadian rhythm will march up and down every twenty-four hours irrespective of whether you have slept or not. Your circadian rhythm is unwavering in this regard. But look across individuals, and you discover that not everyone's circadian timing is the same.

MY RHYTHM IS NOT YOUR RHYTHM

Although human beings display an unyielding twenty-four-hour pattern, the respective peak and trough points are strikingly different from one individual to the next. For some people, their peak of wakefulness arrives early in the day, and their sleepiness trough arrives early at night. These are "morning types," and make up about 40 percent of the populace. They prefer to wake at or around dawn, are happy to do so, and function optimally at this time of day. Others are "evening types," and account for approximately 30 percent of the population. They naturally prefer going to bed late and subsequently wake up late the following morning, or even in the afternoon. The remaining 30 percent of people lie somewhere in between morning and evening types, with a slight leaning toward eveningness, like myself.

You may colloquially know these two types of people as "morning larks" and "night owls," respectively. Unlike morning larks, night owls are frequently incapable of falling asleep early at night, no matter how hard they try. It is only in the early-morning hours that owls can drift off. Having not fallen asleep until late, owls of course strongly dislike waking up early. They are unable to function well at this time, one

cause of which is that, despite being "awake," their brain remains in a more sleep-like state throughout the early morning. This is especially true of a region called the prefrontal cortex, which sits above the eyes, and can be thought of as the head office of the brain. The prefrontal cortex controls high-level thought and logical reasoning, and helps keep our emotions in check. When a night owl is forced to wake up too early, their prefrontal cortex remains in a disabled, "offline" state. Like a cold engine after an early-morning start, it takes a long time before it warms up to operating temperature, and before that will not function efficiently.

An adult's owlness or larkness, also known as their chronotype, is strongly determined by genetics. If you are a night owl, it's likely that one (or both) of your parents is a night owl. Sadly, society treats night owls rather unfairly on two counts. First is the label of being lazy, based on a night owl's wont to wake up later in the day, due to the fact that they did not fall asleep until the early-morning hours. Others (usually morning larks) will chastise night owls on the erroneous assumption that such preferences are a choice, and if they were not so slovenly, they could easily wake up early. However, night owls are not owls by choice. They are bound to a delayed schedule by unavoidable DNA hardwiring. It is not their *conscious* fault, but rather their *genetic* fate.

Second is the engrained, un-level playing field of society's work scheduling, which is strongly biased toward early start times that punish owls and favor larks. Although the situation is improving, standard employment schedules force owls into an unnatural sleep-wake rhythm. Consequently, job performance of owls as a whole is far less optimal in the mornings, and they are further prevented from expressing their true performance potential in the late afternoon and early evening as standard work hours end prior to its arrival. Most unfortunately, owls are more chronically sleep-deprived, having to wake up with the larks, but not being able to fall asleep until far later in the evening. Owls are thus often forced to burn the proverbial candle at both ends. Greater ill health caused by a lack of sleep therefore befalls owls, including higher rates of depression, anxiety, diabetes, cancer, heart attack, and stroke.

In this regard, a societal change is needed, offering accommodations not dissimilar to those we make for other physically determined differences (e.g., sight impaired). We require more supple work schedules that better adapt to all chronotypes, and not just one in its extreme.

You may be wondering why Mother Nature would program this variability across people. As a social species, should we not all be synchronized and therefore awake at the same time to promote maximal human interactions? Perhaps not. As we'll discover later in this book, humans likely evolved to co-sleep as families or even whole tribes, not alone or as couples. Appreciating this evolutionary context, the benefits of such genetically programmed variation in sleep/wake timing preferences can be understood. The night owls in the group would not be going to sleep until one or two a.m., and not waking until nine or ten a.m. The morning larks, on the other hand, would have retired for the night at nine p.m. and woken at five a.m. Consequently, the group as a whole is only collectively vulnerable (i.e., every person asleep) for just four rather than eight hours, despite everyone still getting the chance for eight hours of sleep. That's potentially a 50 percent increase in survival fitness. Mother Nature would never pass on a biological trait—here, the useful variability in when individuals within a collective tribe go to sleep and wake up—that could enhance the survival safety and thus fitness of a species by this amount. And so she hasn't.

MELATONIN

Your suprachiasmatic nucleus communicates its repeating signal of night and day to your brain and body using a circulating messenger called melatonin. Melatonin has other names, too. These include "the hormone of darkness" and "the vampire hormone." Not because it is sinister, but simply because melatonin is released at night. Instructed by the suprachiasmatic nucleus, the rise in melatonin begins soon after dusk, being released into the bloodstream from the pineal gland, an area situated deep in the back of your brain. Melatonin acts like a powerful bullhorn, shouting out a clear message to the brain and body: "It's dark, it's dark!" At this moment, we have been served a writ

of nightime, and with it, a biological command for the timing of sleep onset.*

In this way, melatonin helps regulate the *timing* of when sleep occurs by systemically signaling darkness throughout the organism. But melatonin has little influence on the *generation* of sleep itself: a mistaken assumption that many people hold. To make clear this distinction, think of sleep as the Olympic 100-meter race. Melatonin is the voice of the timing official that says "Runners, on your mark," and then fires the starting pistol that triggers the race. That *timing* official (melatonin) governs when the race (sleep) begins, but does not participate in the race. In this analogy, the sprinters themselves are other brain regions and processes that actively *generate* sleep. Melatonin corrals these sleep-generating regions of the brain to the starting line of bedtime. Melatonin simply provides the official instruction to commence the event of sleep, but does not participate in the sleep race itself.

For these reasons, melatonin is not a powerful sleeping aid in and of itself, at least not for healthy, non-jet-lagged individuals (we'll explore jet lag—and how melatonin can be helpful—in a moment). There may be little, if any, quality melatonin in the pill. That said, there is a significant sleep placebo effect of melatonin, which should not be underestimated: the placebo effect is, after all, the most reliable effect in all of pharmacology. Equally important to realize is the fact that over-the-counter melatonin is not commonly regulated by governing bodies around the world, such as the US Food and Drug Administration (FDA). Scientific evaluations of over-the-counter brands have found melatonin concentrations that range from 83 percent less than that claimed on the label, to 478 percent more than that stated.†

Once sleep is under way, melatonin slowly decreases in concentration across the night and into the morning hours. With dawn, as sunlight enters the brain through the eyes (even through the closed lids), a brake pedal is applied to the pineal gland, thereby shutting off the release of melatonin. The absence of circulating melatonin now informs the brain

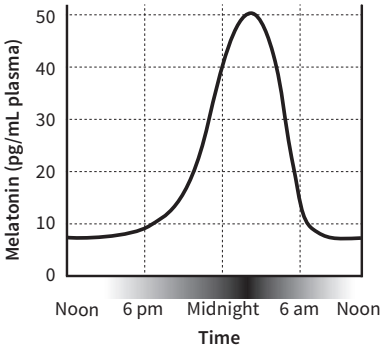
*For nocturnal species like bats, crickets, fireflies, or foxes, this call happens in the morning.

† L. A. Erland and P. K. Saxena, "Melatonin natural health products and supplements: presence of serotonin and significant variability of melatonin content," *Journal of Clinical Sleep Medicine* 2017; 13(2): 275–81.

and body that the finish line of sleep has been reached. It is time to call the race of sleep over and allow active wakefulness to return for the rest of the day. In this regard, we human beings are "solar powered." Then, as light fades, so, too, does the solar brake pedal blocking melatonin. As melatonin rises, another phase of darkness is signaled and another sleep event is called to the starting line.

You can see a typical profile of melatonin release in figure 2. It starts a few hours after dusk. Then it rapidly rises, peaking around four a.m. Thereafter, it begins to drop as dawn approaches, falling to levels that are undetectable by early to midmorning.

Figure 2: The Cycle of Melatonin



HAVE RHYTHM, WON'T TRAVEL

The advent of the jet engine was a revolution for the mass transit of human beings around the planet. However, it created an unforeseen biological calamity: jet planes offered the ability to speed through time zones faster than our twenty-four-hour internal clocks could ever keep up with or adjust to. Those jets caused a biological time lag: jet lag. As a result, we feel tired and sleepy during the day in a distant time zone because our internal clock still thinks it is nighttime. It hasn't yet caught up. If that were not bad enough, at night, we are frequently unable to initiate or maintain sleep because our internal clock now believes it to be daytime.

Take the example of my recent flight home to England from San Francisco. London is eight hours ahead of San Francisco. When I arrive

in England, despite the digital clock in London's Heathrow Airport telling me it is nine a.m., my internal circadian clock is registering a very different time—California time, which is one a.m. I should be fast asleep. I will drag my time-lagged brain and body through the London day in a state of deep lethargy. Every aspect of my biology is demanding sleep; sleep that most people back in California are being swaddled in at this time.

The worst, however, is yet to come. By midnight London time, I am in bed, tired and wanting to fall asleep. But unlike most people in London, I can't seem to drift off. Though it is midnight in London, my internal biological clock believes it to be four p.m., which it is in California. I would normally be wide awake, and so I am, lying in bed in London. It will be five or six hours before my natural tendency to fall asleep arrives . . . just as London is starting to wake up, and I have to give a public lecture. What a mess.

This is jet lag: you feel tired and sleepy during the day in the new time zone because your body clock and associated biology still "think" it is nighttime. At night, you are frequently unable to sleep solidly because your biological rhythm still believes it to be daytime.

Fortunately, my brain and body will not stay in this mismatched limbo forever. I will acclimatize to London time by way of the sunlight signals in the new location. But it's a slow process. For every day you are in a different time zone, your suprachiasmatic nucleus can only readjust by about one hour. It therefore took me about eight days to readjust to London time after having been in San Francisco, since London is eight hours ahead of San Francisco. Sadly, after such epic efforts by my suprachiasmatic nucleus's twenty-four-hour clock to drag itself forward in time and get settled in London, it faces some depressing news: I now have to fly back to San Francisco after nine days. My poor biological clock has to suffer this struggle all over again in the reverse direction!

You may have noticed that it feels harder to acclimate to a new time zone when traveling eastward than when flying westward. There are at least two reasons for this. First, the eastward direction requires that you fall asleep earlier than you would normally, which is a tall biological order for the mind to simply will into action. In contrast, the westward direction requires you to stay up later, which is a consciously and prag-

matically easier prospect. Second, you will remember that when shut off from any outside world influences, our natural circadian rhythm is innately longer than one day—about twenty-four hours and fifteen minutes. Modest as this may be, this makes it somewhat easier for you to artificially stretch a day than shrink it. When you travel westward—in the direction of your innately longer internal clock—that "day" is longer than twenty-four hours for you and why it feels a little easier to accommodate to. Eastward travel, however, which involves a "day" that is shorter in length for you than twenty-four hours, goes against the grain of your innately long internal rhythm to start with, which is why it is rather harder to do.

West or east, jet lag still places a torturous physiological strain on the brain, and a deep biological stress upon the cells, organs, and major systems of the body. And there are consequences. Scientists have studied airplane cabin crews who frequently fly on long-haul routes and have little chance to recover. Two alarming results have emerged. First, parts of their brains—specifically those related to learning and memory—had physically shrunk, suggesting the destruction of brain cells caused by the biological stress of time-zone travel. Second, their short-term memory was significantly impaired. They were considerably more forgetful than individuals of similar age and background who did not frequently travel through time zones. Other studies of pilots, cabin crew members, and shift workers have reported additionally disquieting consequences, including far higher rates of cancer and type 2 diabetes than the general population—or even carefully controlled match individuals who do not travel as much.

Based on these deleterious effects, you can appreciate why some people faced with frequent jet lag, including airline pilots and cabin crew, would want to limit such misery. Often, they choose to take melatonin pills in an attempt to help with the problem. Recall my flight from San Francisco to London. After arriving that day, I had real difficulty getting to sleep and staying asleep that night. In part, this was because melatonin was not being released during my nighttime in London. My melatonin rise was still many hours away, back on California time. But let's imagine that I was going to use a legitimate compound of melatonin after arriving in London. Here's how it works: at around seven to

eight p.m. London time I would take a melatonin pill, triggering an artificial rise in circulating melatonin that mimics the natural melatonin spike currently occurring in most of the people in London. As a consequence, my brain is fooled into believing it's nighttime, and with that chemically induced trick comes the signaled timing of the sleep race. It will still be a struggle to generate the event of sleep itself at this irregular time (for me), but the timing signal does significantly increase the likelihood of sleep in this jet-lagged context.

SLEEP PRESSURE AND CAFFEINE

Your twenty-four-hour circadian rhythm is the first of the two factors determining wake and sleep. The second is sleep pressure. At this very moment, a chemical called adenosine is building up in your brain. It will continue to increase in concentration with every waking minute that elapses. The longer you are awake, the more adenosine will accumulate. Think of adenosine as a chemical barometer that continuously registers the amount of elapsed time since you woke up this morning.

One consequence of increasing adenosine in the brain is an increasing desire to sleep. This is known as sleep pressure, and it is the second force that will determine when you feel sleepy, and thus should go to bed. Using a clever dual-action effect, high concentrations of adenosine simultaneously turn down the "volume" of wake-promoting regions in the brain and turn up the dial on sleep-inducing regions. As a result of that chemical sleep pressure, when adenosine concentrations peak, an irresistible urge for slumber will take hold.* It happens to most people after twelve to sixteen hours of being awake.

You can, however, artificially mute the sleep signal of adenosine by using a chemical that makes you feel more alert and awake: caffeine. Caffeine is not a food supplement. Rather, caffeine is the most widely used (and abused) psychoactive stimulant in the world. It is the second most traded commodity on the planet, after oil. The consumption of caffeine represents one of the longest and largest unsupervised drug

*Assuming you have a stable circadian rhythm, and have not recently experienced jet travel through numerous time zones, in which case you can still have difficulty falling asleep even if you have been awake for sixteen hours.

studies ever conducted on the human race, perhaps rivaled only by alcohol, and it continues to this day.

Caffeine works by successfully battling with adenosine for the privilege of latching on to adenosine welcome sites—or receptors—in the brain. Once caffeine occupies these receptors, however, it does not stimulate them like adenosine, making you sleepy. Rather, caffeine blocks and effectively inactivates the receptors, acting as a masking agent. It's the equivalent of sticking your fingers in your ears to shut out a sound. By hijacking and occupying these receptors, caffeine blocks the sleepiness signal normally communicated to the brain by adenosine. The upshot: caffeine tricks you into feeling alert and awake, despite the high levels of adenosine that would otherwise seduce you into sleep.

Levels of circulating caffeine peak approximately thirty minutes after oral administration. What is problematic, though, is the persistence of caffeine in your system. In pharmacology, we use the term "half-life" when discussing a drug's efficacy. This simply refers to the length of time it takes for the body to remove 50 percent of a drug's concentration. Caffeine has an average half-life of five to seven hours. Let's say that you have a cup of coffee after your evening dinner, around 7:30 p.m. This means that by 1:30 a.m., 50 percent of that caffeine may still be active and circulating throughout your brain tissue. In other words, by 1:30 a.m., you're only halfway to completing the job of cleansing your brain of the caffeine you drank after dinner.

There's nothing benign about that 50 percent mark, either. Half a shot of caffeine is still plenty powerful, and much more decomposition work lies ahead throughout the night before caffeine disappears. Sleep will not come easily or be smooth throughout the night as your brain continues its battle against the opposing force of caffeine. Most people do not realize how long it takes to overcome a single dose of caffeine, and therefore fail to make the link between the bad night of sleep we wake from in the morning and the cup of coffee we had ten hours earlier with dinner.

Caffeine—which is not only prevalent in coffee, certain teas, and many energy drinks, but also foods such as dark chocolate and ice cream, as well as drugs such as weight-loss pills and pain relievers—is a common culprit that keeps people from falling asleep easily and sleep-

ing soundly thereafter, typically masquerading as insomnia, an actual medical condition. Also be aware that *de-caffeinated* does not mean *non-caffeinated*. Depending on the decaffeination method and the bean that is used, one cup of decaf can have between 3 to as high as 10 percent of the dose of a regular cup of coffee.

The "jolt" of caffeine does wear off. Caffeine is removed from your system by an enzyme within your liver,* which gradually degrades it over time. Based in large part on genetics,† some people have a more efficient version of the enzyme that degrades caffeine, allowing the liver to rapidly clear it from the bloodstream. Others, however, have a slower-acting version of the enzyme. It takes far longer for their system to eliminate the same amount of caffeine. As a result, they are very sensitive to caffeine's effects. One cup of tea or coffee in the morning will last much of the day, and should they have a second cup, even early in the afternoon, they will find it difficult to fall asleep in the evening. Aging also alters the speed of caffeine clearance: the older we are, the longer it takes our brain and body to remove caffeine, and thus the more sensitive we become in later life to caffeine's sleep-disrupting influence.

If you are trying to stay awake late into the night by drinking coffee, you should be prepared for a nasty consequence when your liver successfully evicts the caffeine from your system: a phenomenon commonly known as a "caffeine crash." Like the batteries running down on a toy robot, your energy levels plummet rapidly. You find it difficult to function and concentrate, with a strong sense of sleepiness once again.

We now understand why. For the entire time that caffeine is in your system, the sleepiness chemical it blocks (adenosine) nevertheless continues to build up. Your brain is not aware of this rising tide of sleep-encouraging adenosine, however, because the wall of caffeine you've created is holding it back from your perception. But once your liver dismantles that barricade of caffeine, you feel a vicious backlash: you are hit with the sleepiness

*There are other factors that contribute to caffeine sensitivity, such as age, other medications currently being taken, and the quantity and quality of prior sleep. A. Yang, A. A. Palmer, and H. de Wit, "Genetics of caffeine consumption and responses to caffeine," *Psychopharmacology* 311, no. 3 (2010): 245–57, http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4242593/.

†The principal liver enzyme that metabolizes caffeine is called cytochrome P450 1A2.