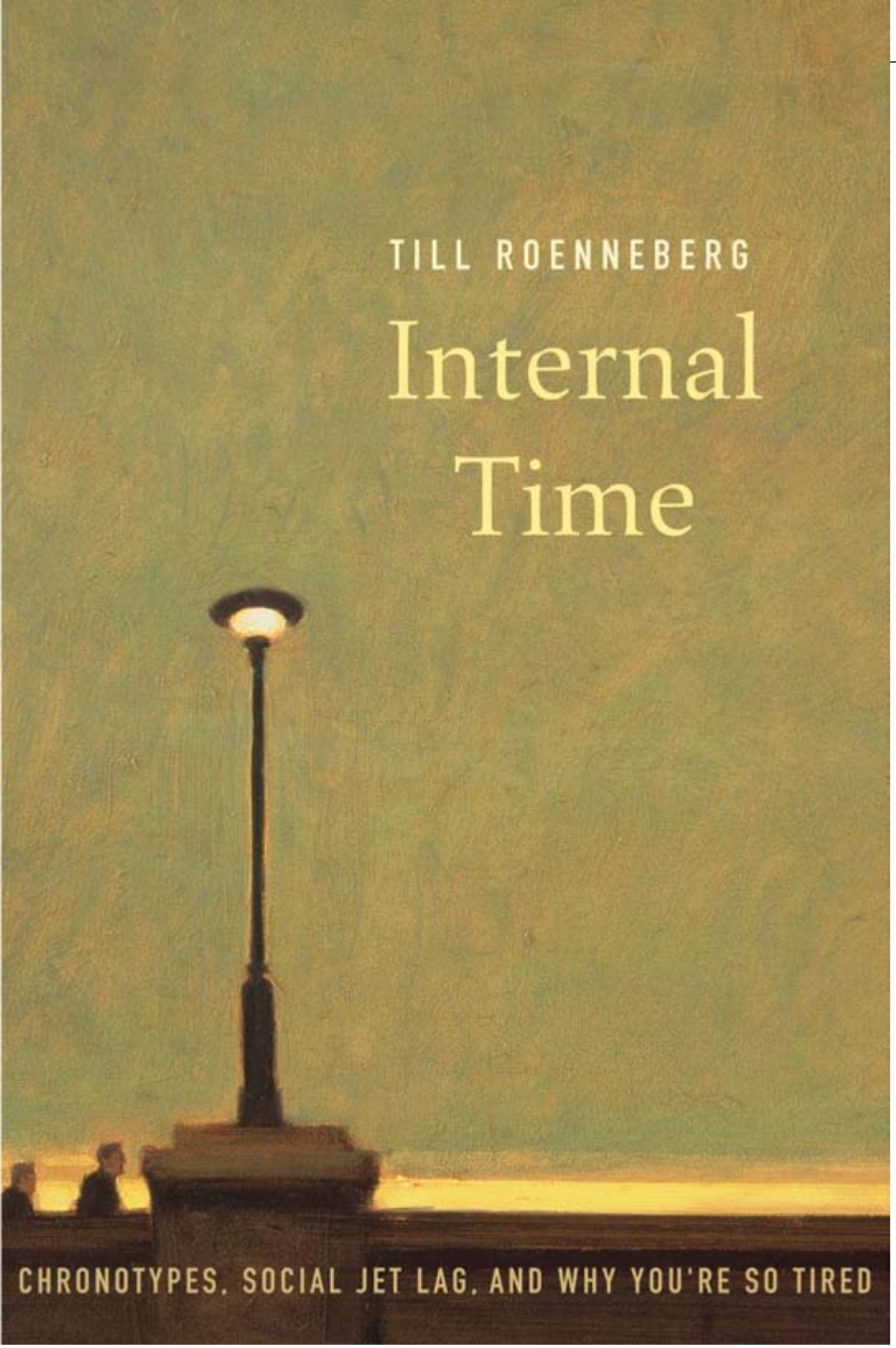
TILL ROENNEBERG
Internal Time
CHRONOTYPES, SOCIAL JET LAG, AND WHY YOU'RE SO TIRED

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Chronotypes, Social Jet Lag, and Why You're So Tired

Till Roenneberg

Harvard University Press • Cambridge, Massachusetts • London, England • 2012

First published in German translation as *Wie wir ticken: Die Bedeutung der inneren Uhr für unser Leben*, copyright © 2010 by DuMont Buchverlag, Cologne (Germany)

Library of Congress Cataloging-in-Publication Data

Roenneberg, Till.
[Wie wir ticken. English]
Internal time : chronotypes, social jet lag, and why you're so tired / Till Roenneberg.
p. cm.
Subtitle of original German text: Die Bedeutung der inneren Uhr für unser Leben.
Includes bibliographical references and index.
ISBN 978-0-674-06585-7 (alk. paper)
1. Chronology. 2. Biological rhythms. I. Title.
QP84.6.R64 2012
612′.022—dc23 2011050230

For Casper, Pauline, and Flora

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Internal Time

Introduction

This book is about clocks. Not about those you can buy, wear, or hang on a wall, but about the clock that ticks away in your body. The body clock is not a new invention in the long line of evolution. You share your ability to internally keep track of the time of day with practically every other creature on earth, from other mammals right down to those organisms that exist only as a single cell. This means that an internal biological clock must be extremely important for life on this planet. Living without or against the biological clock would mean premature death by predation or starvation for most animals in their natural environment. As I will elaborate in this book, living against our biological clock also jeopardizes our health and well-being. In modern society, we rarely live in synchrony with our body clock. Some of us travel fast across many time zones, and others (about 20 percent of the working population in industrialized societies) have to work in shifts. If you have ever suffered from jet lag, you know how strongly we are affected when our body clock is out of synch with social time. But even if you don't work in shifts and never travel across time zones by airplane, you can still suffer from a chronic type of jet lag, which we call *social jet lag.*

A book about clocks is evidently also about time, yet the time of the body clock is not necessarily the same as the social time that we use in everyday life to be on time for work, travel, appointments, or the evening news. Social time is the time people live by. In the nineteenth century, social time was local sun time: noon was when the sun had reached its highest point. This rather sensible long-standing

convention about time was eventually challenged by trains: they could transport humans over long distances within a few hours, rendering local sun time impractical because passengers had to reset their clocks at almost every station. States and countries, therefore, adopted a universal system in 1884, subdividing the world into twenty-four time zones that all refer to a zero line, the longitudinal meridian that crosses the observatory in Greenwich, near London. Theoretically, social time could adopt any time frame, as long as everyone used the same one. The entire territory of mainland China, for example, is covered by a single time zone based on Beijing time. This book will tell you how these different time systems interact: *sun time, social time,* and your very individual *internal time.*

Your internal time is produced by your own body clock. It varies from individual to individual just as body height, eye color, or personality varies, and it interacts with sun time and social time. In spite of internal time being probably the most important to our health and well-being—more important than sun time and certainly more important than social time—it has been thoroughly neglected. Every day, we are awake for approximately sixteen hours until we render the control of our movements, thoughts, and desires to a state resembling unconsciousness, which we call sleep. These daily changes are so utterly obvious that the underlying biological mechanism remained unexplored for centuries. In synchrony with the rise and fall of the sun, animals awaken and sleep, plants open and close their blossoms, and plankton travel up and down the water column. All these rhythms are controlled by a biological clock that represents the twenty-four-hour day of our planet. The alterations between sleep and wake are not simply two states of our existence that are being flipped like a coin once a day. They are reflections of a continuous change in all our bodily functions; a change that involves both turning genes on and off and continuously changing the cocktail of hormones and transmitters in all our tissues.

I have been studying the biological mechanism underlying our body clock for decades in very different creatures ranging from single

cells and simple fungi to humans. These studies were conducted either in the laboratory, where we try to control all environmental factors (such as light, temperature, and food), or in the real world—for example, in factories, where we measure different variables over the course of the day, or in the world at large, by simply asking normal people when they do what. My initial reason for studying the body clock was autobiographical and almost by chance. One of the pioneers of the field, Jürgen Aschoff, was the director of a research institute in the Bavarian countryside. Jürgen and his wife, Hilde, had six children, who attended the same school that I did. I became friends with all of them, despite age differences. The Aschoff family lived in a beautiful castle ("the Schloss") on the slope of a hill in Andechs, a village near the Ammersee, one of the larger Bavarian lakes. Andechs was a long way out in the countryside with almost no commuting possibilities. The Aschoff parents, therefore, allowed their children to invite friends to stay whenever they wanted, even overnight. To be part of a large crowd of youngsters who were all extremely interesting and interested was a lot of fun, and I stayed at the Schloss as often as I could. I also got on extremely well with the professor himself and became more and more interested in the science that he and his colleagues pursued.

When I was about seventeen, I began to work as a part-time assistant at Aschoff's institute during most of my school holidays. It allowed me to combine the fun of learning science, spending time with fascinating people, and earning some money—a dream situation. There were always many visitors: friends of the parents; friends of the children; but also lots of scientists, some of them internationally famous, who seemed to be engaged in endless scientific discussions. I had always loved science, but the atmosphere in Andechs gradually turned me into a junkie—this was exactly the life I wanted to lead.

Although I probably had assimilated more knowledge about body clocks by the time I entered university than most students do by the time they graduate, I started to study physics, in my view the

most fundamental science of all. But I soon realized that the true aim of my interests concerned humans and that physics just didn't get me any closer to understanding them. So I switched to medicine. But once again, I felt that this discipline would not be the right vehicle for my curiosity. Although I wanted to know everything about humans, the focus of my interests wasn't on helping or curing them. I began to appreciate that I could only start to learn something about humans if I understood more about evolution, genetics, biochemistry, comparative physiology, and ecology, but none of these subjects was taught in any depth in medical school.

I finally ended up studying biology. I enjoyed discussions with other students and scientists much more than attending lectures, and I read lots of papers and books that covered many more issues than those taught in a degree program. I felt that my learning only began when I started working in the lab, collecting experimental data and then trying to make sense of them. The attempts at making sense of data always were my utmost joy in science—and still are. I think that this joy, and the ways and methods I use to approach the mysterious world of data, go back to my intensive interactions with Jürgen Aschoff when I was at a very impressionable age.

After a detour into photobiology, neurophysiology, and brain research that lasted for many years, I finally returned to the field that investigates biological clocks (chronobiology) as a postdoctoral fellow. I spent my first postdoc time back in Andechs, working with Jürgen Aschoff—not as a student but as a (somewhat) fledged scientist. I remained a colleague and friend of "the old one," as his family and his close friends called him (although he never ceased to be my mentor), until he died in October 1998. After two years studying annual rhythms in humans with Aschoff, I was eager to learn more about how biological clocks work in cells, how they generate an internal day with the help of molecules. So I decided to work with another pioneer of chronobiology, Woody Hastings, a Harvard professor. I was part of his team in Cambridge, Massachusetts, for almost four years and kept going back during the summer for many more

years. Returning to Germany, I found a rocky academic landscape for someone who simultaneously studied humans and single-cell algae, someone who was more interested in the investigation of concepts, such as the biological clock, than in staying within the boundaries of the little boxes created by our disciplines and faculties. Where did I belong according to orderly German academic criteria—botany, zoology, ecology, anthropology, or medicine? I ended up in the medical faculty, specifically in the department of medical psychology. Ernst Pöppel, the chair of the department, provided this scientific home, where I still reside. He was one of the few also interested in concepts (especially those regarding time), and less focused on the specific model organisms that were used to study them.

Over the years of studying the biological clock, I began to realize that what clock researchers were discovering had an enormous significance for our everyday lives. I noticed that people were fascinated and eager to learn about the science behind circumstances of their daily existence, some of which they had never considered before. Once enlightened, they started to understand themselves (and others) much better, began to appreciate their own individual time, and were suddenly relieved of the weight of prejudice ridiculing their temporal habits: for example, being called lazy if you don't wake up fresh as a daisy by seven o'clock in the morning; or being called a boring person only because you don't enjoy going out with friends after ten at night.

In this book I tell a story about internal time, or rather many little stories covering different aspects of our body clock. Each of the twenty-four chapters—I'd be telling lies if I told you I chose to write twenty-four chapters by chance—has two sections, the case and the background. In the case, I lay out a story about internal time that the later background information explicates. In many of these cases I will manipulate the facts for the sake of a good story, but in all, the data concerning chronobiology are accurate. For example, no one knows exactly what passed through a certain eighteenth-century scientist's head when he came terribly close to discovering the phenom-

enon of internal time (which then lay idle for almost a quarter of a millennium), but, based on what he wrote, I use my imagination to get the facts across to you. Some cases describe relatively recent discoveries made by contemporary scientists. They are written to draw your attention to a question and to help you imagine how a discovery could have taken place. Although the scientific facts of the discovery itself are historically correct, other details, such as names and places, may be purely fictional.

With the case stories, I want to raise your curiosity and pique your urge to reason. If you are puzzled by a case, first try to identify what you don't understand, and then consider what parts of the story are reflected in your own life. The second section of each chapter describes the facts underlying the case story in detail. It should answer most of your questions and may help you relate what you read to your own temporal life.

The use of cases is part of the philosophy of problem-based learning. Its aim is to focus the mind on a problem without employing jargon or excessive scientific explanation. Problem-based learning is often applied in university education, particularly in medical, law, or business schools. Students, often working in groups, are asked to identify all the facts in the case and then work out the background behind the story with the help of textbooks, the internet, lectures, and specialists. The best part of problem-based learning is being forced to confront an everyday problem that is completely puzzling, at least at first. The drawback of traditional learning has always been the dissociation between the theory and its application. "Why do we have to learn this?" is probably one of the most frequent and justified questions teachers hear.

To understand the biology of the body clock does require some knowledge of biology. I have done my best to keep the biological explanations accessible for everyone. More detailed explanations can be found in the endnotes. Whether you are interested in just the case studies, the background information, or the more detailed scientific explanations in the endnotes, I hope you will gain a thorough under-

standing of internal time, *your* time. I want you to appreciate how important this concept is for living well. I hope you have as much fun reading this book as I had writing it—fun is the best way to understanding and allows us to remember new information without too much effort.

Worlds Apart

1

Ann woke to a hard and persistent knock on her bedroom door. After staying in bed as long as possible, she wrapped herself into a thick bathrobe, put on warm socks, and stumbled to the bathroom to brush her teeth. She didn't say "good morning" to her father and didn't expect any form of greeting from him, either. If she hadn't pushed him grumpily away from the basin to reach the faucet, one would have thought that neither was aware of the other. It was a school morning, shortly before the Christmas break. Ann was, as usual, far behind schedule and, like her father, Jim, began the new day in a state of semi-consciousness. Before Jim had school-aged children he used soap and a razor, which he thought produced a much cleaner shave, but now that he was forced into this early routine, he tolerated the noise of an electric razor, having cut himself too often. His wife, Helen, was already downstairs making breakfast together with their son, Toby.

In contrast to father and daughter, who went about their morning routines in silence, Toby and his mother were chatting with each other like a pair of canaries. Toby was telling her about his field trip to the dinosaur exhibit and got quite carried away when enumerating the different raptors he had seen. While his mother was preparing sandwiches for the children's school breaks, Toby set the table, but soon got distracted by the back of the cereal box, which he had just placed in front of his bowl. He read all about the new dinosaur collection that would be coming out next year—one in each package.

He decided to eat more cornflakes in the future, at least two bowls every morning.

Helen always put extra effort into the sandwiches for her firstborn. She wanted to make sure that her daughter would eat them because she usually left the house with nothing more than a cup of tea in her stomach. By the time Ann had crossed the threshold into puberty, she had stopped eating anything before leaving the house, and Helen had fought—and lost—endless battles about "proper breakfasts." It was actually Jim who had put an end to this struggle: "Make her a good sandwich with her favorite stuff on it and she will eat it in school as soon as she is hungry." Of course, no parent can ever be sure what really happens to lunches from home, but the fact that Ann uttered requests from time to time for variations in the narrow theme of her favorite foods encouraged Helen.

At around seven o'clock Jim joined the talkative pair, kissed Toby on his way through the kitchen and then Helen, who handed him a big mug of coffee. The three sat down at the breakfast table, and Helen, as usual, yelled, "Hurry up, Ann, the bus will be here in twenty minutes!" They were lucky because the bus stop was right in front of their house, and Ann made the best of this short distance by coming downstairs only a couple of minutes before it arrived. Helen's primordial cry was a remnant of her "proper breakfasts" fight.

At last, Ann did join the others, slowly sitting down at the table to sip her tea. Toby continued his lively dinosaurial narrative, mainly addressing his mother. He only approached his sister at breakfast if he was in a mischievous mood. She was an easy victim, unable to muster resistance, although later in the day she usually did get her revenge. Helen was half listening to Toby and half concentrating on planning the day, making her to-do list, and giving Jim or Ann short instructions. The chances that Helen could have a real conversation with her husband in the morning were greater in summer, when daylight flooded the kitchen and they occasionally had breakfast on the terrace. Now that the sun came up after the children were in school,

all of them were more subdued than usual—even Toby and his mother. Helen was thinking of the PTA meeting scheduled for that evening and decided to ask Jim to go—he was much more up to it at that time of day, and she could go to bed early.

Ann brooded about the school day ahead of her. Why math in the first period? Why not art or history? She was actually quite good at math, but she needed at least half a functioning brain to solve mathematical problems, and most of her brain certainly didn't wake up before ten o'clock or even later, no matter how early or late she got up. When Ann left the room to get her coat, Jim was able to produce the first smile of the day when he read the back of his daughter's tee shirt: "Early to rise and early to bed makes a bird healthy, wealthy, and dead."[1]

This first case represents—with minor variations—the morning routine of millions of households across the globe. In that sense, it is almost trivial. But apparent trivialities will play an important role in this book. How easily do we wake up in the morning, and why? Jim, Helen, Ann, and Toby seem to be worlds apart at this early hour: Helen and Toby feel fresh, and Jim and Ann feel woolly. The case is rich in information that you might have absorbed without even noticing, but it also triggers many questions: Is this a sex or gender issue?[2] Does age play a role? Does the ability to wake up depend on the time of day? Are different wake-up types also different fall-asleep types? What do eating habits have to do with these different wake-up types? Does performance in such different activities as math and art depend on the time of day? The wake-up type? Some of these questions can be answered by the story itself.

Jim, Helen, Ann, and Toby's morning touches upon many different aspects of temporal life and biological clocks. We are told when the story takes place (an early weekday morning shortly before Christmas), but we need to know where the family lives. Our conclu-

sions will differ radically if the family lives in South Africa, Peru, or Australia rather than Europe, Japan, or the United States. But the story gives several hints to indicate that the family lives somewhere in North America or northern Europe: if it is nearly Christmas and dark outside, the family must live in the northern hemisphere. The size of the house and family and what they eat may provide other hints.

It would also be helpful to know the approximate ages of the family members. Let's start with an educated guess: Toby appears to be younger than Ann, and Jim is probably older than Helen. Toby must be about six or seven because he is still young enough to be fascinated by dinosaurs but old enough to read the back of the cereal box. Ann, firstborn, has entered puberty but still lives at home, so let's put her at fourteen.[3] Helen and Jim, their parents, therefore might be in their early forties. Theoretically, Helen could be much younger and Jim much older, but that is somewhat beside the point.

Now let's turn to the central theme—the different wake-up types. Father and daughter are not exactly communicative. Is Ann mad at her father or does her grumpy behavior merely reflect her resentment of having to get up at that ungodly hour? We could ask the same questions about Jim. By contrast, Helen and Toby are in the best of moods, already fully awake and active. Is this just the normal contrast between teenagers and children, or could these behavioral differences be—at least partly—accounted for by different wake-up types? Being a certain wake-up type is obviously not a simple matter of age, sex, or gender since both Helen and Toby are more awake than either Jim or Ann.

Once again, the story answers our questions. Before Jim had children at school, he felt vigilant enough to give himself a clean shave. Ann is apparently quite good at math after ten o'clock. Different wake-up types are apparently also different fall-asleep types. Helen is fresh in the morning but feels sleepy quite early in the evening. Although Jim has to get up on weekdays at approximately the same time as Helen does, he is dead tired in the morning but still

quite alert in the evening—the PTA meeting will, therefore, be his task.

We know from experience—starting in our own families—that individuals possess different timing types, or *chronotypes.*[4] In many cultures and languages, chronotypes are often named after birds—early birds and late birds.[5] The common usage of *larks* and *owls* suggests that we are dealing with two categories. A Danish researcher has recently coined them, less poetically, A and B types, supporting the notion of two categories. However, the attempt to categorize any population of living beings into two categories is rarely correct. In general, human qualities, including chronotype, almost never fall strictly into two simple categories.

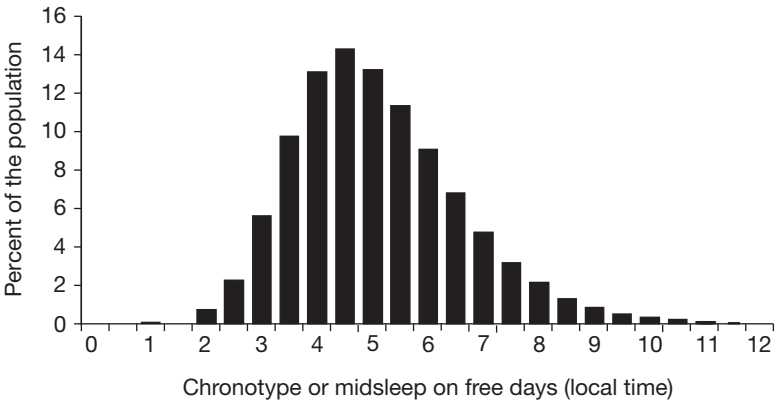
My colleagues and I have investigated human chronotypes for many years by asking thousands of people about their sleep habits with the help of a questionnaire.[6] We use the answers to these questions to define a person's chronotype. Defining the timing of an event is not necessarily straightforward. "When did you hear the shot?"; "When is high tide?"; or "When did the sun rise?" are easy questions because they concern clearly definable events. "When do you usually sleep?" is more complicated because we usually sleep for seven to eight hours. We therefore ask "When do you usually fall asleep?" or "When do you usually wake up?" But the answers to even these questions are difficult to translate into a person's chronotype. Let's suppose that Person A sleeps from 10 P.M. to 6 A.M., Person B from 10 P.M. to 8 A.M., and Person C from midnight to 6 A.M. If chronotype were defined by sleep onset, A and B would be the same type. If one defined it by sleep end, A and C would fall into the same category. The difficulty arises because sleep has (at least) two different and independent qualities: sleep *timing* and sleep *duration.*

It turns out that the midpoint of sleep is best for defining a person's chronotype and also solves the problems described above. The calculation of midsleep is easy: if a person usually falls asleep at midnight and usually wakes up at eight, then his usual midsleep is 4 A.M. All these sleep times should represent what is done daily, not what is

the exception, such as a party or a late night at work. Midsleep of Person A would be 2 A.M., that of Person B would be an hour later at 3 A.M., and Person C would have the same midsleep as B but would sleep four fewer hours, going to bed two hours later and waking up two hours earlier.

Our large database allows us to investigate the epidemiology of sleep behavior in different populations worldwide.[7] The figure shows the distribution of midsleep in Central Europe (containing the answers from approximately 100,000 participants, predominantly Germans).[8] The distribution is almost a perfect bell shape, although late types are slightly more numerous than early types.[9] Categories like larks and owls, A and B people, misrepresent the continuous distribution of chronotypes as much as dwarves and giants misrepresent the distribution of body height. These opposites simply label the extreme types at both ends of distributions, which are extremely rare.

We base the first assessment of an individual's chronotype on her sleep behavior on free days, when it is not dominated by work or school times but rather by individual preference, by a body clock that dictates her *internal time*. Slightly over 14 percent of the population (represented by our database) fall into a midsleep category of 4:30 to



The distribution of midsleep in Central Europe.