

Sensation & Perception

FIFTH EDITION



JEREMY M. WOLFE • KEITH R. KLUENDER • DENNIS M. LEVI

Linda M. Bartoshuk • Rachel S. Herz • Roberta L. Klatzky • Daniel M. Merfeld

Sensation & Perception

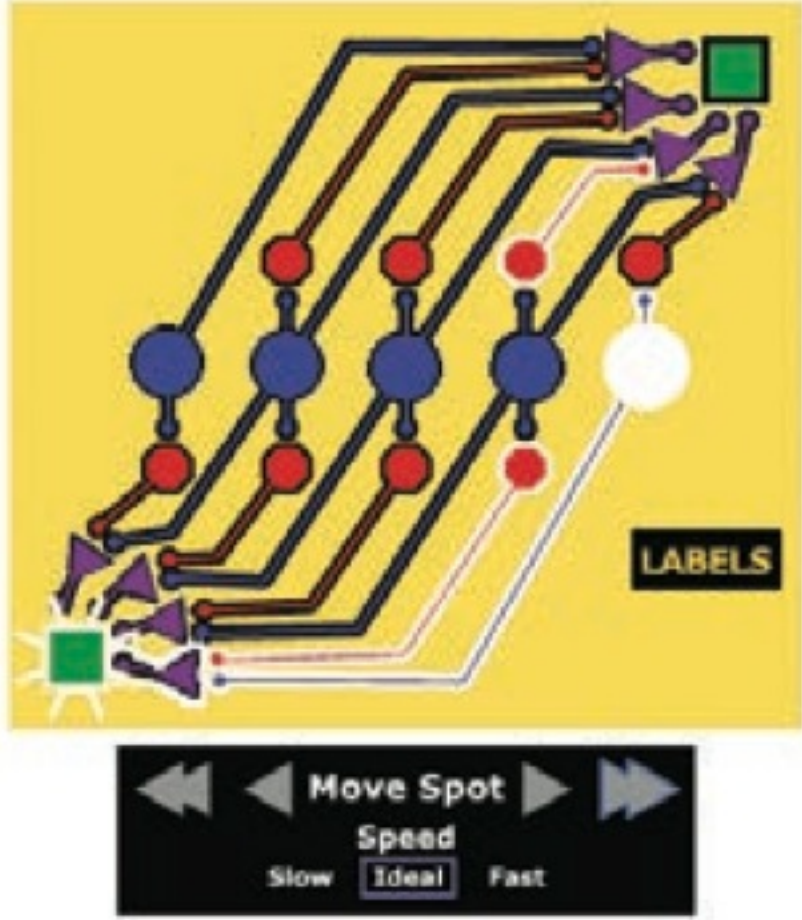
FIFTH EDITION

COMPANION WEBSITE

oup.com/us/wolfe5e

The **Sensation & Perception**, Fifth Edition Companion Website is a free companion to the textbook that offers you a variety of resources to review chapter content, explore systems and processes, and learn terminology. The site includes the following:

Activity 8.2 Motion Detection Circuit



Red Octagons: Delay Cells

The red octagons represent **delay cells**. As you can see, each delay cell receives input from a blue photoreceptor cell and sends output to a purple multiplication cell. Each delay cell fires whenever it is stimulated by the photoreceptor it synapses with. But, as indicated by their name, delay cells do not react immediately upon being stimulated. Rather, each delay cell begins to fire exactly one second after it is stimulated by a blue photoreceptor cell. The delay cell then stops firing exactly one second after it starts.

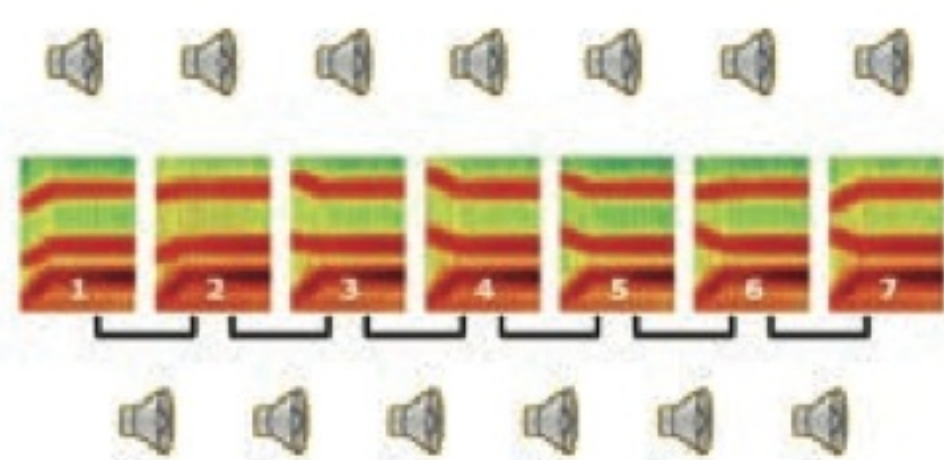
Set the Speed control to "Fast," move the spot of light to the far left position, and click the double-triangle on the right side of the control panel. Pay attention to the red delay cells as the spot moves quickly across the blue photoreceptors. You will see that the delay cells do indeed fire a second after their corresponding photoreceptor cells fire.

Also note that neither the purple nor the green cells fire when the spot of light moves at this "Fast" rate. To find out why, click on a purple cell to learn about what it does.

- Introduction
- Blue Circles: Photoreceptor Cells
- Red Octagons: Delay Cells
- Purple Triangles: Multiplication Cells
- Green Squares: Motion Detector Cells

ACTIVITY 8.2 Motion Detection Circuit

Activity 11.2 Categorical Perception



Introduction

As we've seen a number of times in the last few chapters, gradually increasing a tone's frequency also gradually increases the perceived pitch of the tone (e.g., the "gliding tones" in the Continuity and Restoration Effects activity). Similarly, gradually increasing a tone's amplitude raises the level of perceived loudness. More generally, this is how most psychophysical relationships work: if you change the stimulus a small amount, you get a small change in the perceptual response to the stimulus.

- Introduction
- Identification Trials
- Discrimination Trials
- Results, Part 1
- Results, Part 2

ACTIVITY 11.2 Categorical Perception

CHAPTER OVERVIEWS introduce you to the important concepts presented in each chapter and how the activities explore these concepts.

ACTIVITIES bring to life many of the concepts and examples from the textbook, and give you the opportunity to explore them at your own pace. Referenced throughout the textbook, the activities include perception experiments, illusions that illustrate key concepts, models of cognitive processes, and interactive diagrams of important structures.

ESSAYS expand on selected topics from the textbook and provide additional coverage and examples. Referenced throughout the textbook, the essays include fascinating descriptions of phenomena, explanations of concepts, and real-world case studies and applications.

FLASHCARDS help you learn and review the hundreds of new terms introduced in the textbook.

THE GLOSSARY gives you quick access to definitions for all of the textbook's important terms.

Companion Website Activities and Essays

Throughout the textbook, you will see references to Companion Website resources in **blue text**.

These refer to specific activities and essays that are relevant to the topic being discussed.

Below is the full list of activities and essays, by chapter.

CHAPTER	ACTIVITY	ACTIVITY	ESSAY
1	1.1 Psychophysics	1.3 Sensory Areas in the Brain	1.1 Senses of Reality Through the Ages
	1.2 Fourier Analysis	1.4 Neurons	
2	2.1 Visual System Overview	2.5 Retinal Structure	2.1 How Many Quanta Does It Take?
	2.2 From Sun to Eye	2.6 Phototransduction	2.2 Clinical Case: The Man Who Couldn't Read
	2.3 Eye Structure	2.7 Acuity versus Sensitivity	2.3 Seeing Illusory Stripes and Spots
	2.4 Simulated Scotoma	2.8 Ganglion Receptive Fields	
3	3.1 Visual Angle	3.4 Striate Receptive Fields	3.1 Hyperacuity
	3.2 Foveal Acuity	3.5 Hypercolumns	3.2 The Whole Brain Atlas
	3.3 Gabor Patches		3.3 Seeing Images on the Cortex
4	4.1 Object Substitution Masking	4.5 Pandemonium	4.1 The Role of Knowledge in Figure–Ground Assignment
	4.2 Gestalt Grouping Principles	4.6 Viewpoint Effects	4.2 Dynamic Occlusion
	4.3 Object Ambiguity	4.7 The Face Inversion Effect	4.3 Bayesian Analysis
	4.4 Infant Object Perception		4.4 Face Blindness
5	5.1 The Principle of Univariance	5.4 Afterimages	5.1 More About Opponent Processing in Color Vision
	5.2 Trichromacy	5.5 Color Constancy	5.2 The Philosophical Problem of “Inverted Qualia”
	5.3 Color Mixing	5.6 Illusions of Lighting	5.3 Experiencing Color Blindness
6	6.1 Monocular Depth Cues	6.3 Stereoscopes and Stereograms	5.4 Color Constancy in the Lab
	6.2 Binocular Disparity	6.4 Stereoscopic Correspondence	6.1 Making the Implicit Explicit
			6.2 Stereo Images on the Web
			6.3 Stereo Movies, TV, and Video Games
7	7.1 Attentional Cueing	7.4 The Attentional Blink and Repetition Blindness	6.4 The Moon Illusion
	7.2 Visual Search	7.5 Change Blindness	7.1 Balint Syndrome
	7.3 The RSVP Paradigm	7.6 The Attentional Bottleneck	7.2 Boundary Extension
			7.3 Attentional Capture
8	8.1 Motion Aftereffects	8.4 Motion Correspondence	8.1 Perceiving Motion in Static Images
	8.2 Motion Detection Circuit	8.5 Eye Movements	8.2 Beyond Second-Order Motion
	8.3 Types of Motion		
9	9.1 What We Hear	9.3 Equal-Loudness Curves	
	9.2 Structure of the Auditory System		
10	10.1 Auditory Localization Cues	10.4 Auditory Stream Segregation	10.1 Reverberations and the Precedence Effect
	10.2 The Missing-Fundamental Effect	10.5 Continuity and Restoration Effects	
	10.3 Timbre		
11	11.1 Notes, Chords, and Octaves	11.3 The McGurk Effect	11.1 Studying Brain Areas for Language Processing
	11.2 Categorical Perception	11.4 Word Breaks	
12	12.1 A Guided Tour of the Vestibular System	12.3 Observing Torsional Eye Movement	12.1 Gravity versus Linear Acceleration
	12.2 Sinusoidal Motion		12.2 Canal–Otolith Integration
13	13.1 The Need for Touch	13.4 The Rubber Hand Illusion	12.3 Space Motion Sickness
	13.2 Somatosensory Receptors	13.5 Two-Point Touch Thresholds	13.1 Living without Kinesthesia
	13.3 The Sensory Homunculus	13.6 Haptic Object Recognition	13.2 Body Image
			13.3 Phantom Limbs
14	14.1 Olfactory Anatomy	14.3 Sensory Memory Cues	13.4 Lego Blocks Front and Back
	14.2 Odor Adaptation and Habituation		14.1 Smell-O-Vision
			14.2 Olfactory Lateralization
15	15.1 Taste without Smell	15.2 Gustatory Anatomy	14.3 Verbal–Olfactory Interactions
			15.1 Water Tastes

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Jeremy M. Wolfe

Brigham & Women's Hospital
Harvard University Medical School

Keith R. Kluender

Purdue University

Dennis M. Levi

University of California, Berkeley

Linda M. Bartoshuk

University of Florida

Rachel S. Herz

Brown University

Roberta L. Klatzky

Carnegie Mellon University

Daniel M. Merfeld

The Ohio State University

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About the Authors



JEREMY M. WOLFE is Professor of Ophthalmology and Radiology at Harvard Medical School. Dr. Wolfe was trained as a vision researcher/experimental psychologist and remains one today. His early work includes papers on binocular vision, adaptation, and accommodation. The bulk of his recent work has dealt with visual search and visual attention in the lab and in real-world settings such as airport security and cancer screening. He taught Introductory Psychology for over twenty-five years at the Massachusetts Institute of Technology, where he won the Baker Memorial Prize for undergraduate teaching in 1989. He directs the Visual Attention Lab and the Center for Advanced Medical Imaging of Brigham and Women's Hospital.



DENNIS M. LEVI has taught at the University of California, Berkeley since 2001. He is Dean/Professor in the School of Optometry and Professor at the Helen Wills Neuroscience Institute. In the lab, Dr. Levi and colleagues use psychophysics, computational modeling, and brain imaging (fMRI) to study the neural mechanisms of normal pattern vision in humans, and to learn how they are degraded by abnormal visual experience (amblyopia).



KEITH R. KLUENDER is Department Head, Professor of Speech, Language, and Hearing Sciences, and Professor of Psychological Sciences at Purdue University. His research encompasses: how people hear complex sounds such as speech; how experience shapes the way we hear; how what we hear guides our actions and communication; clinical problems of hearing impairment or language delay; and practical concerns about computer speech recognition and hearing aid design. Dr. Kluender is deeply committed to teaching, and has taught a wide array of courses—philosophical, psychological, and physiological.



LINDA M. BARTOSHUK is Bushnell Professor, Department of Food Science and Human Nutrition at the University of Florida. Her research on taste has opened up broad new avenues for further study, establishing the impact of both genetic and pathological variation in taste on food preferences, diet, and health. She discovered that taste normally inhibits other oral sensations such that damage to taste leads to unexpected consequences like weight gain and intensified oral pain. Most recently, working with colleagues in Horticulture, her group found that a considerable amount of the sweetness in fruit is actually produced by interactions between taste and olfaction in the brain. This may lead to a new way to reduce sugar in foods and beverages.

RACHEL S. HERZ is an Adjunct Assistant Professor in the Department of Psychiatry and Human Behavior at Brown University's Warren Alpert Medical School and Part-time Faculty in the Psychology Department at Boston College. Her research focuses on a number of facets of olfactory cognition and perception and on emotion, memory, and motivated behavior. Using an experimental approach grounded in evolutionary theory and incorporating both cognitive-behavioral and neuropsychological techniques, Dr. Herz aims to understand how biological mechanisms and cognitive processes interact to influence perception, cognition, and behavior.



ROBERTA L. KLATZKY is the Charles J. Queenan, Jr. Professor of Psychology at Carnegie Mellon University, where she also holds faculty appointments in the Center for the Neural Basis of Cognition and the Human-Computer Interaction Institute. She has done extensive research on haptic and visual object recognition, space perception and spatial thinking, and motor performance. Her work has application to haptic interfaces, navigation aids for the blind, image-guided surgery, teleoperation, and virtual environments.



DANIEL M. MERFELD is a Professor at The Ohio State University and also serves as the Senior Vestibular Scientist at the Naval Medical Research Unit in Dayton (NAMRUD). Much of his research career has been spent studying how the brain combines information from multiple sources, with a specific focus on how the brain processes ambiguous sensory information from the vestibular system in the presence of noise. Translational work includes research developing new methods to help diagnose patients experiencing vestibular symptoms and research developing vestibular implants for patients who have severe problems with their vestibular organs.



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Preface

If you are lucky, you will have a career doing something that you really enjoy. We, the authors of this book, are lucky. We are fascinated by the human senses and we are fortunate enough to be employed to investigate how different aspects of different senses work. We want to know the answers to fundamental questions about the senses: How does our brain create a three-dimensional perception of the world from two-dimensional images, formed on the back of each eye? Why do some substances taste “sweet”? We also want to know the answers to perceptual questions that arise from important problems in the world, so we work on problems like oral pain or disorders of balance that have medical applications, or issues such as airport security that have broader societal implications.

We wrote this undergraduate textbook in the hope that we might spread some of our enthusiasm to you, our reader. In service of that goal, each of the 15 chapters of this book aims to tell a coherent and interesting story that will give the reader enough background and exposure to current research to understand why these topics are interesting and how they might be further investigated. For every topic in the book, we are acutely aware that there is vastly more information than we can squeeze into a chapter. Moreover, we are not naive or immodest enough to believe that you will devour a chapter on “The Perception of Color” or “Perceiving and Recognizing Objects” in the way that you might devour a good novel. However, we do hope that you will find each chapter to be more than a compilation of facts. We hope to be like Cleopatra in Shakespeare’s play “Anthony and Cleopatra”: while other texts may “cloy the appetites they feed,” we hope our work “makes hungry where most it satisfies” (Act 2, Scene 2). It is our hope that this book teaches enough to inspire the reader to want to know more.

In service of these goals, we have produced a textbook that is reasonably comprehensive while still being digestible. It is possible that you, the student, may not think so at 3:00 a.m. the day before the final exam, but that was the goal. We want to present a coherent introduction to

the important topics in our field. As noted, we can’t cover *everything*. If you, the instructor, or you, the interested student, think we missed something that should be in here, please feel encouraged to drop us an email. Each time we revise the book, we add some new topics and we take some material out.

Some of that extra material can be found on the text’s companion website, oup.com/us/wolfe5e. There you will find a number of brief essays on topics that we broken-heartedly removed from earlier versions of our chapters. Given the chance, each of us can talk your ear off on the topics in this book, but we have sincerely tried to avoid doing this. In addition to the essays, the website features a host of great demonstrations made possible by Evan Palmer of San Jose State University, the guardian of our website.

In trying to convey our enthusiasm for this material, we wanted to create a beautiful book. If we have succeeded, it is in no small part due to our publisher, Sinauer Associates. The people at Sinauer produce beautiful books and we have enjoyed working with their talented editors to produce a book that strives to be both aesthetically and intellectually appealing.

We were pleased by the reception of the earlier editions of our textbook and pleased that this reception warranted a Fifth Edition. Between editions, each of us keeps an eye out for new findings that seem worthy of note in the textbook. When it comes to writing, we always discover that we have more new material that we can squeeze in but, in each chapter, you will find some of what we have learned since the Fourth Edition. One new feature in the Fifth Edition is called *Scientists at Work*. In these highlighted sections, you will find a more extended discussion of one piece of research. The goal of this feature is to show you how to think like a scientist, and what the thought process is in designing experiments that yield scientific results. Another feature of the textbook are *Sensation & Perception in Everyday Life* boxes. Here we discuss the application of basic scientific knowledge to practical problems in the real world. For example, as you will see in Chapter 5, aspects of

the color picker in your graphics program can be directly traced to our understanding of how your eye and brain derive the experience of color from different mixtures of wavelengths of light. We trust that you will recognize or even invent other applications of the information presented here. That, as they say, is an exercise for the reader. Speaking of readers, it is always a question whether or not anyone actually reads the preface. If you did and you are reading this, please send a note to jwolfe@bwh.harvard.edu. It is fun to hear from folks in the field. If you are reading this for a course, tell us who is teaching. Odds are that one of us knows your instructor. Please also feel encouraged to send us notes and comments about the actual text. There are quite a few changes in the current edition that were driven by intelligent reader comments about the previous editions. Thanks.

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**Sensation &
Perception**
FIFTH EDITION

1

Introduction

■ Questions to Contemplate

Think about the following questions as you read this chapter. By the chapter's end, you should be able to answer and discuss them.

- How can scientists study something as personal as your internal sensations and perceptions?
- Are there laws that relate the physics of the world to your subjective experience?
- What is happening when you think that you might have heard something or felt something but you're not sure? If a stimulus is detectable, why isn't it detectable all the time?
- Are there rules that relate the activity of your brain to your subjective experience?
- How do sensation and perception change over the life span?

Welcome to Our World

You've taken the plunge to read at least part of a textbook on "sensation and perception." You may be majoring in psychology or studying an allied field, such as neuroscience or biology, or you may be simply curious. No matter what interests you most, your understanding will be informed by sensation and perception.

"Why?" you ask. Most everything you know or think that you know about the world around you depends on how you sense and how you perceive. These foundational experiences began even before you were born. Your senses help you to keep upright, stay warm or cool, avoid pain and poisonous things, and be safe from danger. Your experiences of the rich tapestry of life through movement, touch, smell, taste, hearing, and vision inform most everything that you believe to be true.



Aaron Jasinski, *Clarity II*, 2015

It is small wonder that the questions posed in this textbook have been front and center for big thinkers since the first written words, and probably sooner. Today, a small army of researchers continue to pursue answers. This first chapter provides an introduction to the sorts of questions that captivate the authors of this book and the sorts of methods that researchers have developed to answer those questions. These are only examples, as the list of possible others is endless. The rest of the book will introduce you to a panorama of questions that have occupied and continue to occupy the attention of anyone who really wants to know how we know what we think we know.

Sensation and Perception

What does your smartphone feel as you run your finger down its touch screen (**Figure 1.1**)? What does it hear as you whisper into its receiver? We assume that

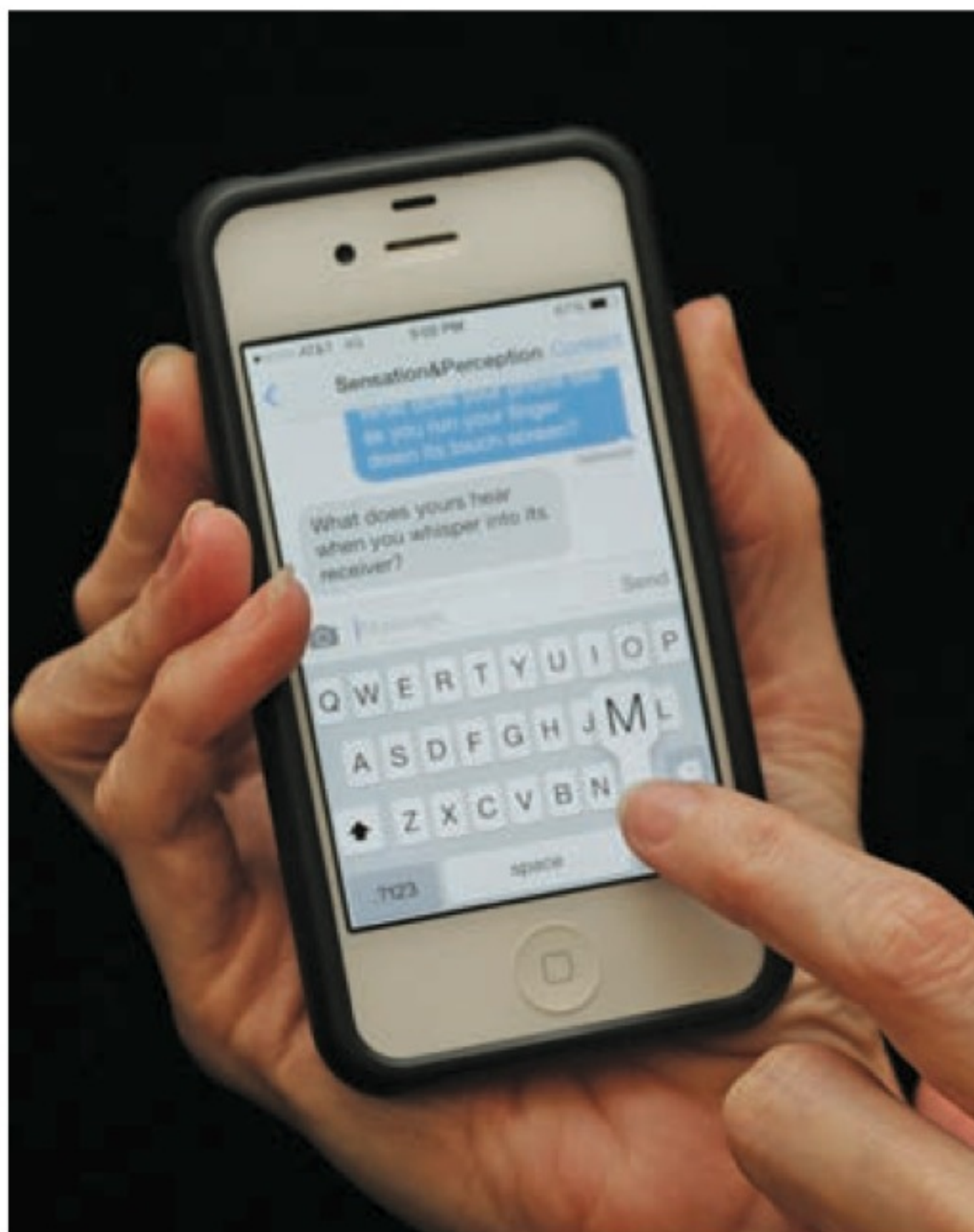


Figure 1.1 Would it make sense to ask what a cell phone feels when you stroke its screen?

sensation The ability to detect a stimulus and, perhaps, to turn that detection into a private experience.

perception The act of giving meaning to a detected sensation.

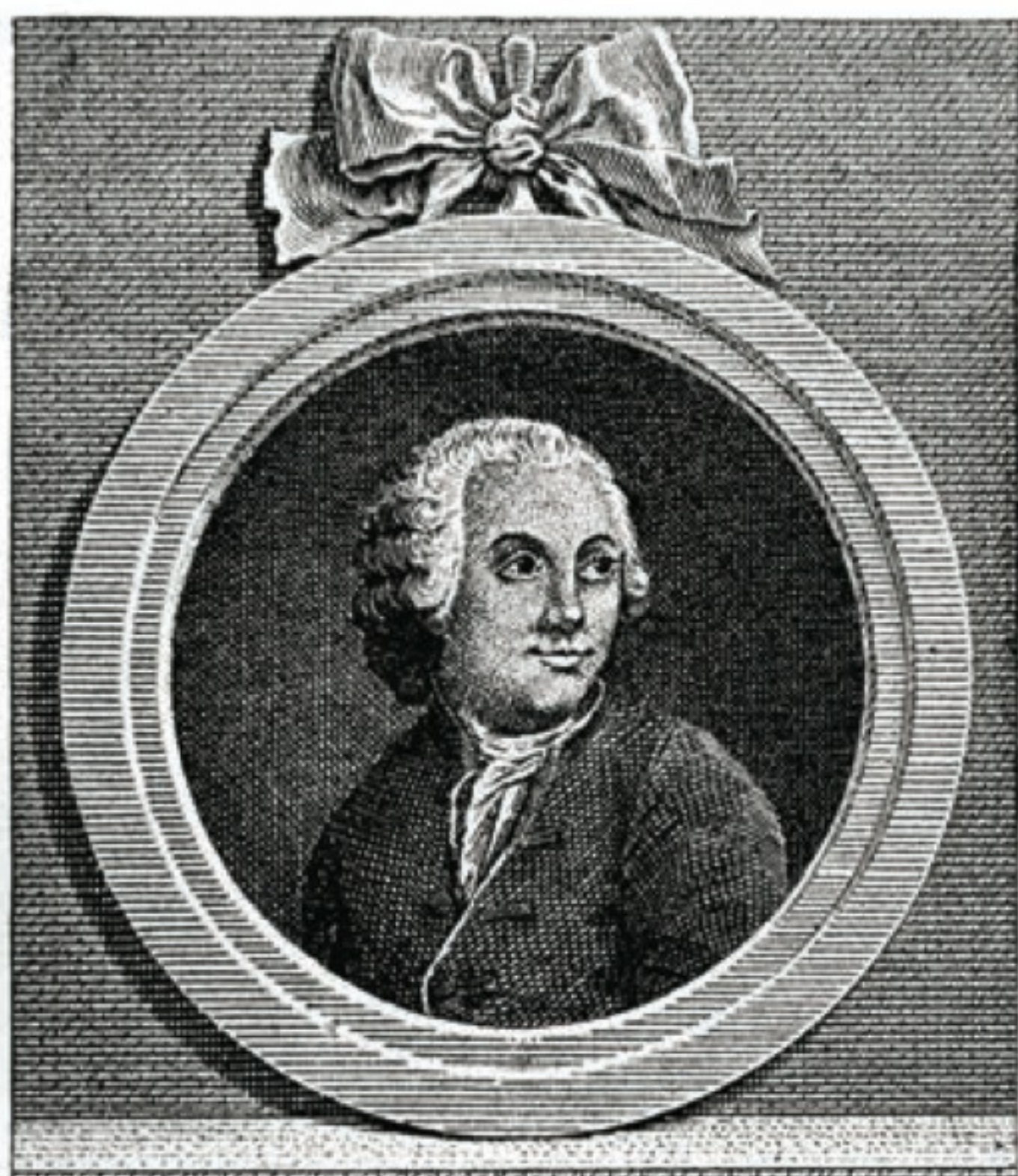


Figure 1.2 Étienne Bonnot de Condillac imagined how a statue could develop a mental life.

these are silly questions, though it would not be silly to ask about the lightest touch that the screen could sense or the faintest vibration in the air that the microphone could sense. What does your cat feel as you run your finger down its back? That seems a more reasonable question, though you have no access to the private experience of the cat. You don't even have access to the private sensations of a person whose back you might stroke. Your own sensory experience is directly accessible only to you.

This book is titled *Sensation & Perception*. The ability to detect the pressure of a finger and, perhaps, to turn that detection into a private experience is an example of **sensation**. **Perception** can be thought of as the act of giving meaning and/or purpose to those detected sensations. How do you *understand* the finger that runs down your back? Is it a gesture of affection? Is it an officer at an airport security checkpoint looking for contraband? This book will trace the path from stimuli in the world, through your sense organs, to the understanding of the world that you perceive.

Everything we feel, think, and do depends on sensations and perceptions. For this reason, philosophers have thought, talked, and written about the topic in profound and systematic ways for over two millennia. (See **Web Essay 1.1: Senses of Reality Through the Ages**.) The idea that mental life depends on sensation and perception has deep roots. The eighteenth-century French philosopher Étienne Bonnot de Condillac (1715–1780) (**Figure 1.2**) famously asked his readers to imagine the mental life of a statue with no senses, and he concluded that the statue would have no mental life. Then Condillac imagined opening the statue's nose and giving it a whiff of the scent of a rose. Then, he thought, the entire mental life of the statue would consist of that smell. If more senses and more experience were provided to the statue, Condillac imagined, a real mental life would develop. If our mental life depends on information from our senses, then it follows that the place for the study of the senses is within the science of human behavior and human mental life—that is, within psychology. Of course, psychologists do not have the topic entirely to themselves. Researchers studying topics in sensation and perception can be found in biology, computer science, medicine, neuroscience, and many other fields. Indeed, the authors of this book come from academic departments of ophthalmology, radiology, optometry, speech, language and hearing sciences, and community dentistry in addition to psychology. Critically, however, we approach the study of sensation and perception as a scientific pursuit. As such, it needs scientific methods. That's why the next sections of this chapter are devoted to an array of methods used in the study of the senses.

METHOD 1: THRESHOLDS What is the faintest sound you can hear? How would you know? What is the loudest sound you can hear? This last question is not as stupid as it may sound, though it could be rephrased like this: What is the loudest sound you can hear safely or without pain? If you listened to sounds above that limit, perhaps by blasting your music too enthusiastically, you would change the answer to the first question. You would damage your auditory system. Then, you would be unable to hear the faintest sound that you used to be able to hear. Your threshold would have changed (for the worse). How would you measure that? As we'll learn in this chapter, a variety of methods are available for measuring just how sensitive your senses are.

METHOD 2: SCALING—MEASURING PRIVATE EXPERIENCE When you say that you "hear" or "taste" something, are those experiences—what the philosophers

call **qualia** (singular *quale*)—the same as the experiences of the person you’re talking to? We can’t really answer the question of whether your qualitative experience of “red” is like my qualitative experience of “green” or, for that matter, “middle C.” We still have no direct way to experience someone else’s experiences. However, we can demonstrate that different people do, in some cases, inhabit different sensory worlds. Our discussion in this chapter will show how scaling methods can be used to perform this act of mind reading.

qualia In reference to philosophy, private conscious experiences of sensation or perception.

FURTHER DISCUSSION of qualia can be found in Chapter 5 on page 158.

METHOD 3: SIGNAL DETECTION THEORY—MEASURING DIFFICULT DECISIONS A radiologist looks at a mammogram, the X-ray test used to screen for breast cancer. There’s something on the X-ray that might be a sign of cancer, but it is not perfectly clear. What should the radiologist do? Suppose she decides to call it benign, not cancerous, and suppose she is wrong. Her patient might die. Suppose she decides to treat it as a sign of malignancy. Her patient will need more tests, perhaps involving surgery. The patient and her family will be terribly worried. If the radiologist is wrong and the spot on the mammogram is, in fact, benign, the consequences may be less dire than those of missing a cancer, but there will be consequences. This is a perceptual decision, made by an expert, that has real consequences. Our discussion of signal detection theory will show how decisions of this sort can be studied scientifically.

METHOD 4: SENSORY NEUROSCIENCE Grilled peppers appear on your table as an appetizer. They have an appealing, smoky smell. When you bite into one, it has a complex flavor that includes some of that smokiness. Fairly quickly you also experience a burning sensation. There is no actual change in the temperature in your mouth, and your tongue is no warmer than it was, but the “burn” is unmistakable. How does the pepper fool your nervous system into thinking that your tongue is on fire? This chapter’s exploration of sensory neuroscience will introduce the ways in which sensory receptors and nerves undergird your perceptual experience.

METHOD 5: NEUROIMAGING—AN IMAGE OF THE MIND Suppose you arrange to view completely different images with different eyes. We might present a picture of a house to one eye and of a face to the other (Tong et al., 1998). The result would be an interesting effect known as binocular rivalry (see Chapter 6). The two images would compete to dominate your perception: sometimes you would see a house, and sometimes you would see a face. You would not see the two together. One reason binocular rivalry is interesting is that it represents a dissociation of the stimuli, presented to the eyes, and your private perceptual experience. Even if we cannot share the experience, modern brain-imaging techniques enable us to see traces of that experience as it takes place in the brain. Methods of neuroimaging will be our final methodological topic in this chapter.

DEVELOPMENT Development, the study of the changes over the life span, is not really a “method,” but it is an approach to the study of sensation and perception that should be introduced in this opening chapter, so we will do so in the last section.

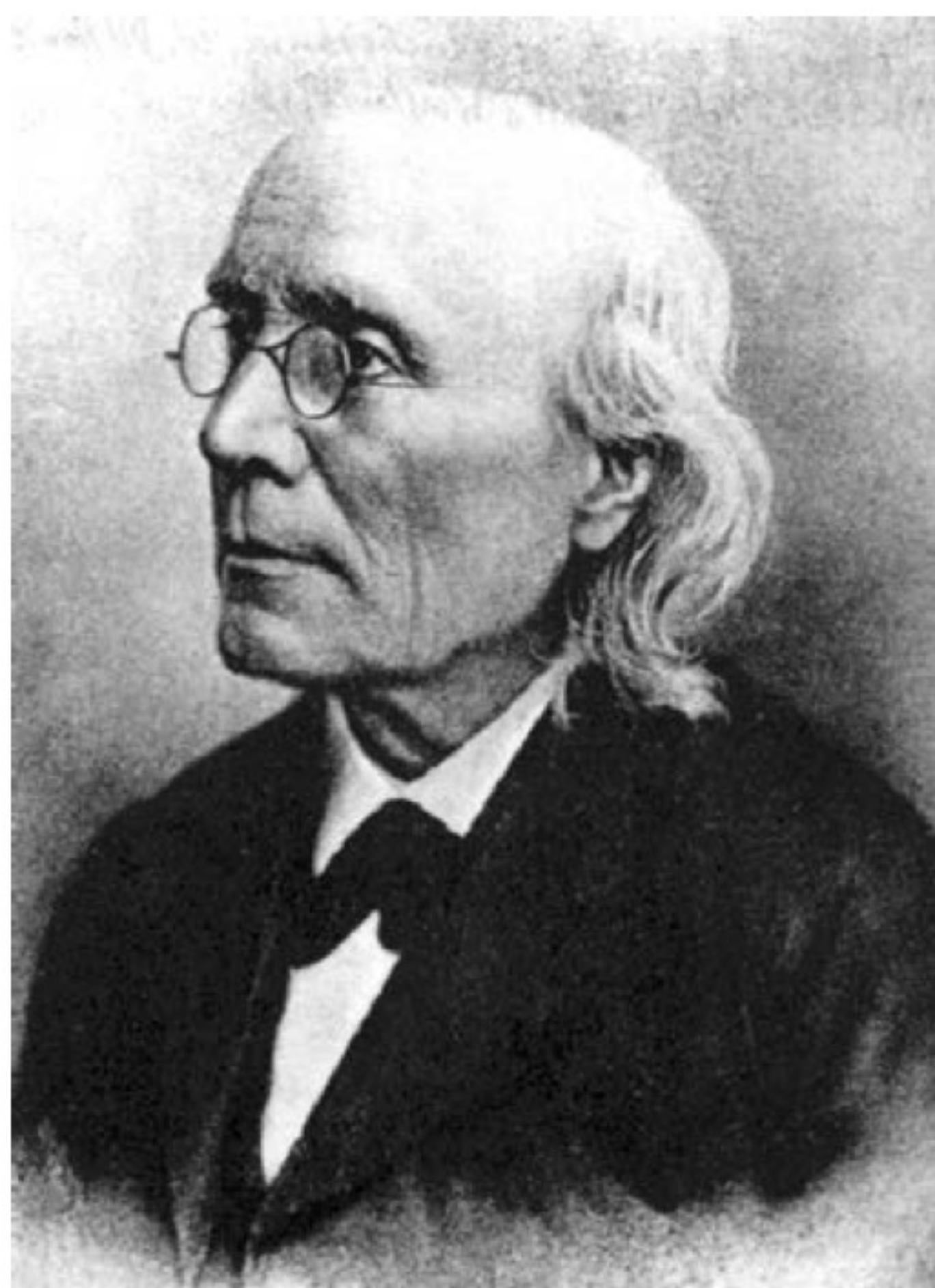


Figure 1.3 Gustav Fechner invented psychophysics and is thought by some to be the true founder of experimental psychology. Fechner is best known for his pioneering work relating changes in the physical world to changes in our psychological experiences.

dualism The idea that the mind has an existence separate from the material world of the body.

materialism The idea that the only thing that exists is matter, and that all things, including the mind and consciousness, are the results of interaction between bits of matter.

panpsychism The idea that the mind exists as a property of all matter—that is, that all matter has consciousness.

psychophysics The science of defining quantitative relationships between physical and psychological (subjective) events.

two-point touch threshold The minimum distance at which two stimuli (e.g., two simultaneous touches) are just perceptible as separate.

Thresholds and the Dawn of Psychophysics

Early on, study of the senses was a mix of experimental science and philosophy. Fascinating work can be found in ancient Greek philosophy, in medieval Islamic science, and in the writings of sages in China or India. We will start much later with the very interesting and versatile nineteenth-century German scientist-philosopher Gustav Fechner (1801–1887) (**Figure 1.3**). Fechner is sometimes considered to be the true founder of experimental psychology (Boring, 1950), even if that title is usually given to Wilhelm Wundt (1832–1920), who began his work sometime later.

Before making his first contributions to psychology, Fechner had an eventful personal history. Young Fechner earned his degree in medicine, but his interests turned from biological science to physics and mathematics. By 1833, he was a full professor of physics in Leipzig, Germany. Though this might seem an unlikely way to get to psychology, events proved otherwise. He became absorbed with the relationship between mind and matter. This pursuit placed him in the middle of a classic philosophical debate between adherents of **dualism** and **materialism**. Dualists hold that the mind has an existence separate from the material world of the body. Materialists hold that the mind is not separate. A modern materialist position, probably the majority view in scientific psychology, is that the mind is what the brain does. Fechner proposed to effectively split the difference by imagining that the mind, or consciousness, is present in all of nature. This **panpsychism**—the idea that the mind exists as a property of all matter—extended not only to animals, but to inanimate things as well. Fechner described his philosophy of panpsychism in a provocative book entitled *Nanna, or Concerning the Mental Life of Plants*. This title alone gives a pretty good idea of what Fechner had in mind.

Fechner was a very hardworking young scientist. He worked himself to exhaustion. In addition to being overworked, he suffered severe eye damage from gazing too much at the sun while performing vision experiments (a not uncommon problem for curious vision researchers in the days before reliable, bright, artificial light sources). The visually incapacitated Fechner had some form of mental breakdown that left him sometimes unable to speak or eat. Not only did he need to resign from his position at the university, he also withdrew from almost all his friends and colleagues. For 3 years he spent almost all of his time alone with his thoughts.

He apparently solved his eating problem with a diet of “fruit, strongly spiced ham and wine” (Fancher, 1990, p. 133). His vision was also recovering. Then on October 22, 1850 (a date still celebrated as “Fechner Day” by some), while lying in bed, Fechner had a specific insight into the relationship between mental life and the physical world. From his experience as a physicist, Fechner thought it should be possible to describe the relation between mind and body using mathematics. His goal was to formally describe the relationship between sensation (mind) and the energy (matter) that gave rise to that sensation. He called both his methods and his theory **psychophysics** (*psycho* for “mind,” and *physics* for “matter”).

In his effort, Fechner was inspired by the findings of one of his German colleagues, Ernst Weber (1795–1878) (**Figure 1.4**), an anatomist and physiologist who was interested in touch. Weber tested the accuracy of our sense of touch by using a device much like the compass one might use to draw circles. He used this device to measure the smallest distance between two points that was required for a person to feel touch on two points instead of one. Later, Fechner would call the distance between the points the **two-point touch threshold**. We will discuss two-point touch thresholds, and touch in general, in Chapter 13.

For Fechner, Weber’s most important findings involved judgments of lifted weights. Weber would ask people to lift one standard weight (a weight that stayed the same over a series of experimental trials) and one comparison weight that