I have perfect vision,” explains my colleague, Heather Sellers, an acclaimed writer and writing teacher. Her vision may be fine, but there is a problem with her perception. She cannot recognize faces.

In her memoir, *Face First*, Sellers (2010) tells of awkward moments resulting from her lifelong prosopagnosia—face blindness.

In college, on a date at the Spaghetti Station, I returned from the bathroom and plunked myself down in the wrong booth, facing the wrong man. I remained unaware he was not my date even as my date (a stranger to me) accosted Wrong Booth Guy, and then stormed out of the Station. I can’t distinguish actors in movies and on television. I do not recognize myself in photos or video. I can’t recognize my stepsons in the soccer pick-up line; I failed to determine which husband was mine at a party, in the mall, at the market.

Her inability to recognize acquaintances means that people sometimes perceive her as snobby or aloof. “Why did you walk past me?” someone might later ask. Similar to those of us with hearing loss who fake hearing during trite social conversation, Sellers sometimes fakes recognition. She often smiles at people she passes, in case she knows them. Or she pretends to know the person with whom she is talking. (To avoid the stress associated with such perception failures, people with serious hearing loss or with prosopagnosia often shy away from busy social situations.) But there is an upside: When encountering someone who previously irritated her, she typically won’t feel ill will, because she doesn’t recognize the person.

This curious mix of “perfect vision” and face blindness illustrates the distinction between sensation and perception. When Sellers looks at a friend, her sensation is normal: Her sensory receptors detect the same information yours would, and they transmit that information to her brain. And her perception—the organization and interpretation of sensory information that enables her to consciously recognize objects—is almost normal. Thus, she may recognize people from their hair, their gait, their voice, or their particular physique, just not their face. She can see the elements of their face—the nose, the eyes, and the chin—and yet, at a party, “[I introduce myself] to my colleague Gloria THREE TIMES.” Her experience is much like the struggle you or I would have trying to recognize a specific penguin in a group of waddling penguins.

Thanks to an area on the underside of your brain’s right hemisphere, you can recognize a human face (but not a penguin’s) in one-seventh of a second. As soon as you detect a face, you recognize it (Jacques & Rossion, 2006). How do you do it?

Twenty-four hours a day, all kinds of stimuli from the outside world bombard your body. Meanwhile, in a silent, cushioned, inner world, your brain floats in utter darkness. By itself, it sees nothing. It hears nothing. It feels nothing. *So, how does the world out there get in?*

To phrase the question scientifically: How do we construct our representations of the external world? How do a campfire’s flicker, crackle, and smoky scent activate neural
connections? And how, from this living neurochemistry, do we create our conscious experience of the fire’s motion and temperature, its aroma and beauty? In search of answers to such questions, let’s look more closely at what psychologists have learned about how we sense and perceive the world around us.

4.1 Sensing the World: Some Basic Principles

**1: What are sensation and perception? What do we mean by bottom-up processing and top-down processing?**

IN OUR EVERYDAY EXPERIENCES, **sensation** and **perception** blend into one continuous process. In this unit, we slow down that process to study its parts.

We start with the sensory receptors and work up to higher levels of processing. Psychologists refer to sensory analysis that starts at the entry level as **bottom-up processing**. But our minds also **interpret** what our senses **detect**. We construct perceptions drawing both on sensations coming bottom-up to the brain and on our experience and expectations, which psychologists call **top-down processing**. For example, as our brain deciphers the information in **Figure 4.1**, bottom-up processing enables our sensory systems to detect the lines, angles, and colors that form the horses, rider, and surroundings. Using top-down processing we consider the painting’s title, notice the apprehensive expressions, and then direct our attention to aspects of the painting that will give those observations meaning.

**Figure 4.1 What’s going on here?** Our sensory and perceptual processes work together to help us sort out the complex images, including the hidden faces in this Bev Doolittle painting, *The Forest Has Eyes*. Detail, *The Forest Has Eyes* by Bev Doolittle © The Greenwich Workshop, Inc., Trumbull, CT.
Nature’s sensory gifts suit each recipient’s needs. They enable each organism to obtain essential information. Consider:

- A frog, which feeds on flying insects, has eyes with receptor cells that fire only in response to small, dark, moving objects. A frog could starve to death knee-deep in motionless flies. But let one zoom by and the frog’s “bug detector” cells snap awake.
- A male silkworm moth has receptors so sensitive to the female sex-attractant odor that a single female need release only a billionth of an ounce per second to attract every male silkworm moth within a mile. That is why there continue to be silkworms.
- We are similarly equipped to detect the important features of our environment. Our ears are most sensitive to sound frequencies that include human voice consonants and a baby’s cry.

We begin the exploration of our sensory gifts with some basic questions that cut across all of our sensory systems: Where is the border between our conscious and unconscious awareness, and what stimuli cross that threshold?

### 4.1.1 Selective Attention

#### 2: How are we affected by selective attention?

Through selective attention, your conscious awareness focuses, like a flashlight beam, on only a very limited aspect of all that you experience. By one estimate, your five senses take in 11,000,000 bits of information per second, of which you consciously process about 40 (Wilson, 2002). Yet your mind’s unconscious track intuitively makes great use of the other 10,999,960 bits. Until reading this sentence, for example, you have been unaware that your shoes are pressing against your feet or that your nose is in your line of vision. Now, suddenly, your attentional spotlight shifts. Your feet feel encased, your nose stubbornly intrudes on the page before you. While attending to these words, you’ve also been blocking from awareness information coming from your peripheral vision. But you can change that. As you stare at the X below, notice what surrounds the book (the edges of the page, your desktop, and so forth).

Another example of selective attention, the *cocktail party effect*, is your ability to attend to only one voice among many. (Let another voice speak your name at a party and your cognitive radar, operating on the mind’s other track, will instantly bring that voice into consciousness. You may tune in just long enough to decide whether to join in or to ignore the conversation.)

Focused listening comes at a cost. Imagine hearing two conversations over a headset, one in each ear, and being asked to repeat the message in your left ear while it is spoken. When paying attention to what is being said in your left ear, you won’t perceive what is said in your right. Asked later what language your right ear heard, you may draw a blank (though you could report the speaker’s gender and loudness).
Selective Attention and Accidents

Talk on the phone while driving and your selective attention will shift back and forth from the road to the phone. But when a demanding situation requires your full attention, you'll probably stop talking. This process of switching attentional gears, especially when shifting to complex tasks, can entail a slight and sometimes fatal delay in coping (Rubenstein et al., 2001). The U.S. National Highway Traffic Safety Administration (2006) estimates that almost 80 percent of vehicle crashes involve driver distraction. In University of Utah driving-simulation experiments, students conversing on cell phones were slower to detect and respond to traffic signals, billboards, and other cars (Strayer & Johnston, 2001; Strayer et al., 2003).

Because attention is selective, attending to a phone call (or a GPS navigation system or a DVD player) causes inattention to other things. Thus, when Suzanne McEvoy and her University of Sydney colleagues (2005, 2007) analyzed phone records for the moments before a car crash, they found that cell-phone users (even with hands-free sets) were four times more at risk. Having a passenger increased risk only 1.6 times. Texting drains even more attention, putting long-haul truckers at a 23 times greater risk of a collision than when not texting (VTTI, 2009).

The effects of distraction on driving also appeared in an experiment that asked drivers to pull off at a freeway rest stop 8 miles ahead. Of drivers conversing with a passenger, 88 percent did so. Of those talking on a cell phone, 50 percent drove on by (Strayer & Drews, 2007). Even hands-free cell-phone talking is more distracting than a conversation with passengers, who can see the driving demands and pause the conversation.

Driven to distraction In driving-simulation experiments, people whose attention is diverted by cell phone conversation make more driving errors. SALLY FORTH

Walking while talking can also pose dangers, as one naturalistic observation of Ohio State University pedestrians found (Nasar et al., 2008). Half the people on cell phones and only a quarter without this distraction exhibited unsafe road crossing, such as by crossing when a car was approaching. It's like trying to listen to someone while checking an incoming text message: attention, at any precise moment, is in one place.

Selective Inattention

At the level of conscious awareness, we are “blind” to all but a tiny sliver of the immense array of visual stimuli constantly before us. Ulric Neisser (1979) and Robert Becklen and Daniel Cervone (1983) demonstrated this dramatically by showing people
a one-minute video in which images of three black-shirted men tossing a basketball were superimposed over the images of three white-shirted players. The viewers’ supposed task was to press a key every time a black-shirted player passed the ball. Most focused their attention so completely on the game that they failed to notice a young woman carrying an umbrella saunter across the screen midway through the video. When researchers replayed the video, viewers were astonished to see her. With their attention directed elsewhere, they exhibited inattentional blindness (Mack & Rock, 2000). In a recent repeat of the experiment, smart-aleck researchers Daniel Simons and Christopher Chabris (1999) sent a gorilla-suited assistant through the swirl of players (Figure 4.2). During its 5- to 9-second cameo appearance, the gorilla paused to thump its chest. Still, half the conscientious pass-counting participants failed to see it.

![Figure 4.2 Gorillas in our midst](image)

In other experiments, people have also exhibited a blindness to change. After a brief visual interruption, a big Coke bottle may disappear, a railing may rise, clothing color may change, but, more often than not, viewers won’t notice (Resnick et al., 1997; Simons, 1996; Simons & Ambinder, 2005). This form of inattentional blindness is called change blindness. It has occurred among people giving directions to a construction worker who, unnoticed by two-thirds of them, is replaced by another construction worker (Figure 4.3). Out of sight, out of mind. Change deafness can also occur. In one experiment, 40 percent of people focused on repeating a list of sometimes challenging words failed to notice a change in the person speaking (Vitevitch, 2003).
An equally astonishing form of inattention is the *choice blindness* discovered by a Swedish research team. Petter Johansson and his colleagues (2005) showed 120 volunteers two female faces for 2 to 5 or more seconds and asked them which face was more attractive. The researchers then put the photos face down and handed viewers the one they had chosen, inviting them to explain their choice. But on 3 of 15 occasions, the tricky researchers used sleight-of-hand to switch the photos—showing viewers the face they had not chosen. Not only did people seldom notice the deception (on only 13 percent of the switches), they readily explained why they preferred the face they had actually rejected. “I chose her because she smiled,” said one person (after picking the solemn-faced one). Asked later whether they would notice such a switch in a “hypothetical experiment,” 84 percent insisted they would. They exhibited a blindness the researchers call (can you see the twinkle in their eyes?) *choice-blindness blindness*.

Some stimuli, however, are so powerful, so strikingly distinct, that we experience *pop-out*, as with the only smiling face in Figure 4.4. We don’t choose to attend to these stimuli; they draw our eye and demand our attention.
Our selective attention extends even into our sleep, as we will see in Unit 5, when we are oblivious to most but not all of what is happening around us. We may feel “dead to the world,” but we are not.

**4.1.2 Thresholds**

### 3: What are the absolute and difference thresholds, and do stimuli below the absolute threshold have any influence?

We exist in a sea of energy. At this moment, you and I are being struck by X-rays and radio waves, ultraviolet and infrared light, and sound waves of very high and very low frequencies. To all of these we are blind and deaf. Other animals detect a world that lies beyond human experience (Hughes, 1999). Migrating birds stay on course aided by an internal magnetic compass. Bats and dolphins locate prey with sonar (bouncing echoing sound off objects). On a cloudy day, bees navigate by detecting polarized light from an invisible (to us) sun.

The shades on our own senses are open just a crack, allowing us only a restricted awareness of this vast sea of energy. Let’s see what psychophysics has discovered about the physical energy we can detect and its effect on our psychological experience.

**Absolute Thresholds**

To some kinds of stimuli we are exquisitely sensitive. Standing atop a mountain on an utterly dark, clear night, most of us could see a candle flame atop another mountain 30 miles away. We could feel the wing of a bee falling on our cheek. We could smell a single drop of perfume in a three-room apartment (Galanter, 1962).

German scientist and philosopher Gustav Fechner (1801–1887) studied our awareness of these faint stimuli and called them our absolute thresholds—the minimum stimulation necessary to detect a particular light, sound, pressure, taste, or odor 50 percent of the time (Figure 4.5). To test your absolute threshold for sounds, a hearing specialist would expose each of your ears to varying sound levels. For each tone, the test would define where half the time you correctly detect the sound and half the time you do not. For each of your senses, that 50-50 recognition point defines your absolute threshold.
Try out this old riddle on a couple of friends. “You’re driving a bus with 12 passengers. At your first stop, 6 passengers get off. At the second stop, 3 get off. At the third stop, 2 more get off but 3 new people get on. What color are the bus driver’s eyes?” Do your friends detect the signal—who is the bus driver?—amid the accompanying noise?

Absolute thresholds may vary with age. Sensitivity to high-pitched sounds declines with normal aging, leaving older ears in need of louder sound to hear a high-pitched cell-phone ring. That fact of life, as we will see in Unit 9, has been exploited by some students using a “mosquito” ringtone their teachers are unlikely to hear, and by some Welsh shopkeepers broadcasting annoying sounds that help disperse loitering teens without repelling older adults.

Signal Detection

Detecting a weak stimulus, or signal, depends not only on the signal’s strength (such as a hearing-test tone) but also on our psychological state—our experience, expectations, motivation, and alertness. Signal detection theory predicts when we will detect weak signals (measured as our ratio of “hits” to “false alarms”). Signal detection theorists seek to understand why people respond differently to the same stimuli (have you ever noticed that some teachers are much more likely than others to detect student cheating on a test?), and why the same person’s reactions vary as circumstances change. Exhausted parents will notice the faintest whimper from a newborn’s cradle while failing to notice louder, unimportant sounds.

In a horror-filled wartime situation, failure to detect an intruder could be fatal. Mindful of many comrades’ deaths, soldiers and police in Iraq probably became more likely to notice—and fire at—an almost imperceptible noise. With such heightened responsiveness come more false alarms, as when the U.S. military fired on an approaching car that was rushing an Italian journalist to freedom, killing the Italian intelligence officer who had rescued her. In peacetime, when survival is not threatened, the same soldiers would require a stronger signal before sensing danger.
Signal detection can also have life-or-death consequences when people are responsible for watching an airport scanner for weapons, monitoring patients from an intensive-care nursing station, or detecting radar blips. Studies have shown, for example, that people’s ability to catch a faint signal diminishes after about 30 minutes. But this diminishing response depends on the task, on the time of day, and even on whether the participants periodically exercise (Warm & Dember, 1986). To help motivate airport baggage screeners, the U.S. Transportation Security Administration periodically adds images of guns, knives, and other threatening objects into bag X-rays. When the signal is detected, the system congratulates the screener and the image disappears (Winerman, 2006). Experience matters, too. In one experiment, 10 hours of action video game playing—scanning for and instantly responding to any intrusion—increased novice players’ signal detection skills (Green & Bavelier, 2003). (See Unit 14 for research on less positive social effects of violent video games.)

Subliminal Stimulation

Hoping to penetrate our unconscious, entrepreneurs offer recordings that supposedly speak directly to our brains to help us lose weight, stop smoking, or improve our memories. Masked by soothing ocean sounds, unheard messages (“I am thin,” “Smoke tastes bad,” or “I do well on tests. I have total recall of information”) will, they say, influence our behavior. Such claims make two assumptions: (1) We can unconsciously sense subliminal (literally, “below threshold”) stimuli, and (2) without our awareness, these stimuli have extraordinary suggestive powers. Can we? Do they?

Can we sense stimuli below our absolute thresholds? In one sense, the answer is clearly yes. Remember that an “absolute” threshold is merely the point at which we detect a
stimulus half the time. At or slightly below this threshold, we will still detect the stimulus some of the time.

“The heart has its reasons which reason does not know.”

Pascal, Pensées, 1670

Can we be affected by stimuli so weak as to be unnoticed? Under certain conditions, the answer is yes. An invisible image or word can briefly prime your response to a later question. In a typical experiment, the image or word is quickly flashed, then replaced by a masking stimulus that interrupts the brain’s processing before conscious perception. For example, one experiment subliminally flashed either emotionally positive scenes (kittens, a romantic couple) or negative scenes (a werewolf, a dead body) an instant before participants viewed slides of people (Krosnick et al., 1992). The participants consciously perceived either scene as only a flash of light. Yet the people somehow looked nicer if their image immediately followed unperceived kittens rather than an unperceived werewolf. Another experiment exposed people to subliminal pleasant, neutral, or unpleasant odors (Li et al., 2007). Despite having no awareness of the odors, the participants rated a neutral-expression face as more likable after exposure to pleasant rather than unpleasant smells.

This experiment illustrates an intriguing phenomenon: Sometimes we feel what we do not know and cannot describe. An imperceptibly brief stimulus often triggers a weak response that can be detected by brain scanning (Blankenburg et al., 2003; Haynes & Rees, 2005, 2006). The conclusion (turn up the volume here): Much of our information processing occurs automatically, out of sight, off the radar screen of our conscious mind.

But does the fact of subliminal sensation verify entrepreneurial claims of subliminal persuasion? Can advertisers really manipulate us with “hidden persuasion”? The near-consensus among researchers is no. Their verdict is similar to that of astronomers who say of astrologers, yes, they are right that stars and planets are out there; but no, the celestial bodies don't directly affect us. The laboratory research reveals a subtle, fleeting effect. Priming thirsty people with the subliminal word thirst might therefore, for a brief interval, make a thirst-quenching beverage ad more persuasive (Strahan et al., 2002). Likewise, priming thirsty people with Lipton Ice Tea may increase their choosing the primed brand (Karremans et al., 2006). But the subliminal-message hucksters claim something different: a powerful, enduring effect on behavior.

To test whether commercial subliminal recordings have an effect beyond that of a placebo (the effect of one’s belief in them), Anthony Greenwald and his colleagues (1991, 1992) randomly assigned university students to listen daily for five weeks to commercial subliminal messages claiming to improve either self-esteem or memory. But the researchers played a very practical joke and switched half of the labels. Some students thought they were receiving affirmations of self-esteem when they actually were hearing the memory enhancement message. Others got the self-esteem message but thought their memory was being recharged.
Subliminal persuasion? Although subliminally presented stimuli can subtly influence people, experiments discount attempts at subliminal advertising and self-improvement. (The playful message here is not actually subliminal—because you can easily perceive it.) Babs Reingold

Were the recordings effective? Students’ scores on tests for both self-esteem and memory, taken before and after the five weeks, revealed no effects. And yet, those who thought they had heard a memory recording believed their memory had improved. A similar result occurred for those who thought they had heard a self-esteem recording. The recordings had no effects, yet the students perceived themselves receiving the benefits they expected. When reading this research, one hears echoes of the testimonies that ooze from the mail-order catalogs. Some customers, having bought what is not supposed to be heard (and having indeed not heard it!) offer testimonials like, “I really know that your tapes were invaluable in reprogramming my mind.” Over a decade, Greenwald conducted 16 double-blind experiments evaluating subliminal self-help tapes. His results were uniform: Not one had any therapeutic effect (Greenwald, 1992). His conclusion: “Subliminal procedures offer little or nothing of value to the marketing practitioner” (Pratkanis & Greenwald, 1988).

Difference Thresholds

To function effectively, we need absolute thresholds low enough to allow us to detect important sights, sounds, textures, tastes, and smells. We also need to detect small differences among stimuli. A musician must detect minute discrepancies in an instrument’s tuning. Students in the hallway must detect the sound of their friends’
voices amid all the other voices. Even after living two years in Scotland, sheep baa’s all sound alike to my ears. But not to those of ewes, which I have observed streaking, after shearing, directly to the baa of their lamb amid the chorus of other distressed lambs.

The LORD is my shepherd;  
I shall not want.  
He maketh me to lie down  
in green pastures:  
he leadeth me  
beside the still waters.  
He restoreth my soul:  
he leadeth me  
in the paths of righteousness  
for his name’s sake.  
Yea, though I walk through the valley  
of the shadow of death,  
I will fear no evil:  
for thou art with me;  
thy rod and thy staff  
they comfort me.  
Thou preparest a table before me  
in the presence of mine enemies:  
thou anointest my head with oil,  
my cup runneth over.  
Surely goodness and mercy  
shall follow me  
all the days of my life:  
and I will dwell  
in the house of the LORD  
for ever.

The difference threshold In this computer-generated copy of the Twenty-third Psalm, each line of the typeface changes imperceptibly. How many lines are required for you to experience a just noticeable difference?

The difference threshold, also called the just noticeable difference (jnd), is the minimum difference a person (or sheep) can detect between any two stimuli half the time. That detectable difference increases with the size of the stimulus. Thus, if you add 1 ounce to a 10-ounce weight, you will detect the difference; add 1 ounce to a 100-ounce weight and you probably will not. More than a century ago, Ernst Weber noted something so simple and so widely applicable that we still refer to it as Weber’s law: For their difference to be perceptible, two stimuli must differ by a constant proportion—not a constant amount. The exact proportion varies, depending on the stimulus. For the average person to perceive their differences, two lights must differ in intensity by 8 percent. Two objects must differ in weight by 2 percent. And two tones must differ in frequency by only 0.3 percent (Teghtsoonian, 1971). For example, to be perceptibly different, a 50-ounce weight must differ from another by about an ounce, a 100-ounce weight by about two ounces.

4.1.3 Sensory Adaptation

4: What is the function of sensory adaptation?
Entering your neighbors’ living room, you smell a musty odor. You wonder how they can stand it, but within minutes you no longer notice it. Sensory adaptation—our diminishing sensitivity to an unchanging stimulus—has come to your rescue. (To experience this phenomenon, move your watch up your wrist an inch: You will feel it—but only for a few moments.) After constant exposure to a stimulus, our nerve cells fire less frequently.

Why, then, if we stare at an object without flinching, does it not vanish from sight? Because, unnoticed by us, our eyes are always moving, flitting from one spot to another enough to guarantee that stimulation on the eyes’ receptors continually changes (Figure 4.6).

![Figure 4.6 The jumpy eye](image_url)

*Figure 4.6 The jumpy eye* University of Edinburgh psychologist John Henderson (2007) illustrates how a person’s gaze jumps from one spot to another every third of a second or so. Eye-tracking equipment shows how a typical person views a photograph of Edinburgh’s Princes Street Gardens. Circles represent fixations, and the numbers indicate the time of fixation in milliseconds (300 milliseconds = three-tenths of a second).

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“We need above all to know about changes; no one wants or needs to be reminded 16 hours a day that his shoes are on.”

Neuroscientist David Hubel (1979)

What if we actually could stop our eyes from moving? Would sights seem to vanish, as odors do? To find out, psychologists have devised ingenious instruments for maintaining a constant image on the eye’s inner surface. Imagine that we have fitted a volunteer, Mary, with one of these instruments—a miniature projector mounted on a contact lens (Figure 4.7a). When Mary’s eye moves, the image from the projector moves as well. So everywhere that Mary looks, the scene is sure to go.
For 9 in 10 people—but for only 1 in 3 of those with schizophrenia—this eye flutter turns off when the eye is following a moving target (Holzman & Matthyss, 1990).

If we project the profile of a face through such an instrument, what will Mary see? At first, she will see the complete profile. But within a few seconds, as her sensory system begins to fatigue, things will get weird. Bit by bit, the image will vanish, only later to reappear and then disappear—in recognizable fragments or as a whole (Figure 4.7b).

“My suspicion is that the universe is not only queerer than we suppose, but queerer than we can suppose.”

B. S. Haldane, Possible Worlds, 1927

Although sensory adaptation reduces our sensitivity, it offers an important benefit: freedom to focus on informative changes in our environment without being distracted by the constant chatter of uninformative background stimulation. Our sensory receptors are alert to novelty; bore them with repetition and they free our attention for more important things. Stinky or heavily perfumed classmates don’t notice their odor because, like you and me, they adapt to what’s constant and detect only change. This reinforces a fundamental lesson: We perceive the world not exactly as it is, but as it is useful for us to perceive it.

Our sensitivity to changing stimulation helps explain television’s attention-grabbing power. Cuts, edits, zooms, pans, sudden noises—all demand attention, even from TV researchers: During interesting conversations, notes Percy Tannenbaum (2002), “I cannot for the life of me stop from periodically glancing over to the screen.”

Sensory thresholds and adaptation are only two of the commonalities shared by the senses. All our senses receive sensory stimulation, transform it into neural information, and deliver that information to the brain. How do the senses work? How do we see? Hear? Smell? Taste? Feel pain? Keep our balance?

4.2 Vision
**5: What is the energy that we see as visible light?**

ONE OF NATURE’S GREAT WONDERS IS neither bizarre nor remote, but commonplace: How does our material body construct our conscious visual experience? How do we transform particles of light energy into colorful sights?

Part of this genius is our ability to convert one sort of energy to another. Our eyes, for example, receive light energy and **transduce** (transform) it into neural messages that our brain then processes into what we consciously see. How does such a taken-for-granted yet remarkable thing happen?

### 4.2.1 The Stimulus Input: Light Energy

Scientifically speaking, what strikes our eyes is not color but pulses of electromagnetic energy that our visual system perceives as color. What we see as visible light is but a thin slice of the whole spectrum of electromagnetic energy. As **Figure 4.8** illustrates, this *electromagnetic spectrum* ranges from imperceptibly short waves of gamma rays, to the narrow band we see as visible light, to the long waves of radio transmission. Other organisms are sensitive to differing portions of the spectrum. Bees, for instance, cannot see red but can see ultraviolet light.
Figure 4.8 The spectrum of electromagnetic energy  This spectrum ranges from gamma rays as short as the diameter of an atom to radio waves over a mile long. The narrow band of wavelengths visible to the human eye (shown enlarged) extends from the shorter waves of blue-violet light to the longer waves of red light.

Two physical characteristics of light help determine our sensory experience of them. Light’s wavelength—the distance from one wave peak to the next (Figure 4.9a)—determines its hue (the color we experience, such as blue or green). Intensity, the amount of energy in light waves (determined by a wave’s amplitude, or height), influences brightness (Figure 4.9b). To understand how we transform physical energy into color and meaning, we first need to understand vision’s window, the eye.
4.2.2 The Eye

How does the eye transform light energy into neural messages?

Light enters the eye through the cornea, which protects the eye and bends light to provide focus (Figure 4.10). The light then passes through the pupil, a small adjustable opening surrounded by the iris, a colored muscle that adjusts light intake. The iris dilates or constricts in response to light intensity and even to inner emotions. (When we’re feeling amorous, our telltale dilated pupils and dark eyes subtly signal our interest.) Each iris is so distinctive that an iris-scanning machine could confirm your identity.

Behind the pupil is a lens that focuses incoming light rays into an image on the retina, a multilayered tissue on the eyeball’s sensitive inner surface. The lens focuses the rays by changing its curvature in a process called accommodation.
For centuries, scientists knew that when an image of a candle passes through a small opening, it casts an inverted mirror image on a dark wall behind. If the retina receives this sort of upside-down image, as in Figure 4.10, how can we see the world right side up? The ever-curious Leonardo da Vinci had an idea: Perhaps the eye’s watery fluids bend the light rays, reinverting the image to the upright position as it reaches the retina. But then in 1604, the astronomer and optics expert Johannes Kepler showed that the retina does receive upside-down images of the world (Crombie, 1964). And how could we understand such a world? “I leave it,” said the befuddled Kepler, “to natural philosophers.”

Eventually, the answer became clear: The retina doesn’t “see” a whole image. Rather, its millions of receptor cells convert particles of light energy into neural impulses and forward those to the brain. There, the impulses are reassembled into a perceived, upright-seeming image.

The Retina

If you could follow a single light-energy particle into your eye, you would first make your way through the retina’s outer layer of cells to its buried receptor cells, the rods and cones (Figure 4.11). There, you would see the light energy trigger chemical changes that would spark neural signals, activating neighboring bipolar cells. The bipolar cells in turn would activate the neighboring ganglion cells. Following the particle’s path, you would see axons from this network of ganglion cells converging, like the strands of a rope, to form the optic nerve that carries information to your brain (where the thalamus will receive and distribute the information). The optic nerve can send nearly 1 million messages at once through its nearly 1 million ganglion fibers. (The auditory nerve, which enables hearing, carries much less information through its mere 30,000 fibers.) Where the optic nerve leaves the eye there are no receptor cells—creating a blind spot (Figure 4.12). Close one eye and you won’t see a black hole on your TV screen, however. Without seeking your approval, your brain fills in the hole.
There are no receptor cells where the optic nerve leaves the eye (see Figure 4.10). This creates a blind spot in your vision. To demonstrate, close your left eye, look at the spot, and move the page to a distance from your face (about a foot) at which the car disappears. The blind spot does not normally impair your vision, because your eyes are moving and because one eye catches what the other misses.

Rods and cones differ in their geography and in the tasks they handle (Table 4.1). Cones cluster in and around the fovea, the retina’s area of central focus (see Figure 4.10). Many cones have their own hotline to the brain—bipolar cells that help relay the cone’s individual message to the visual cortex, which devotes a large area to input from the fovea. These direct connections preserve the cones’ precise information, making them better able to detect fine detail. Rods have no such hotline; they share bipolar cells with other rods, sending combined messages. To experience this difference in sensitivity to details, pick a word in this sentence and stare directly at it, focusing its image on the cones in your fovea. Notice that words a few inches off to the side appear blurred? Their image strikes the more peripheral region of your retina, where rods predominate. The next time you are driving or biking, note, too, that you can detect a car in your peripheral vision well before perceiving its details.

**Table 4.1**
Cones also enable you to perceive color. In dim light they become ineffectual, so you see no colors. Rods, which enable black-and-white vision, remain sensitive in dim light, and several rods will funnel their faint energy output onto a single bipolar cell. Thus, cones and rods each provide a special sensitivity—cones to detail and color, and rods to faint light.

When you enter a darkened theater or turn off the light at night, your pupils dilate to allow more light to reach your retina. It typically takes 20 minutes or more before your eyes fully adapt. You can demonstrate dark adaptation by closing or covering one eye for up to 20 minutes. Then make the light in the room not quite bright enough to read this book with your open eye. Now open the dark-adapted eye and read (easily). This period of dark adaptation parallels the average natural twilight transition between the sun’s setting and darkness.

Some nocturnal animals, such as toads, mice, rats, and bats, have retinas made up almost entirely of rods, allowing them to function well in dim light. These creatures probably have very poor color vision. Knowing just this much about the eye, can you imagine why a cat sees so much better at night than you do?¹

¹There are at least two reasons: (1) A cat’s pupils can open much wider than yours, letting in more light; (2) a cat has a higher proportion of light-sensitive rods (Moser, 1987). But there is a trade-off: With fewer cones, a cat sees neither details nor color as well as you do.

### 4.2.3 Visual Information Processing

#### 7: How does the brain process visual information?

Visual information percolates through progressively more abstract levels. At the entry level, the retina processes information before routing it via the thalamus to the brain’s cortex. The retina’s neural layers—which are actually brain tissue that migrates to the eye during early fetal development—don’t just pass along electrical impulses; they also help to encode and analyze the sensory information. The third neural layer in a frog’s eye, for example, contains the “bug detector” cells that fire only in response to moving flylike stimuli.

After processing by your retina’s nearly 130 million receptor rods and cones, information travels to your bipolar cells, then to your million or so ganglion cells,
through their axons making up the optic nerve, to your brain. Any given retinal area relays its information to a corresponding location in the visual cortex, in the occipital lobe at the back of your brain (Figure 4.13).

![Figure 4.13 Pathway from the eyes to the visual cortex](image)

The same sensitivity that enables retinal cells to fire messages can lead them to misfire as well. Turn your eyes to the left, close them, and then gently rub the right side of your right eyelid with your fingertip. Note the patch of light to the left, moving as your finger moves. Why do you see light? Why at the left?

Your retinal cells are so responsive that even pressure triggers them. But your brain interprets their firing as light. Moreover, it interprets the light as coming from the left—the normal direction of light that activates the right side of the retina.

**Feature Detection**

Nobel Prize winners David Hubel and Torsten Wiesel (1979) demonstrated that neurons in the occipital lobe’s visual cortex receive information from individual ganglion cells in the retina. These **feature detector** cells derive their name from their ability to respond to a scene’s specific features—to particular edges, lines, angles, and movements.

Feature detectors in the visual cortex pass such information to other cortical areas where teams of cells (supercell clusters) respond to more complex patterns. One temporal lobe area just behind your right ear, for example, enables you to perceive faces. If this region were damaged, you might recognize other forms and objects, but, like Heather Sellers, not familiar faces. Functional MRI (fMRI) scans show other brain
areas lighting up when people view other object categories (Downing et al., 2001). Damage in these areas blocks other perceptions while sparing face recognition. Amazingly specific combinations of activity may appear (Figure 4.14). “We can tell if a person is looking at a shoe, a chair, or a face, based on the pattern of their brain activity,” notes researcher James Haxby (2001).

Psychologist David Perrett and his colleagues (1988, 1992, 1994) reported that for biologically important objects and events, monkey brains (and surely ours as well) have a “vast visual encyclopedia” distributed as cells that specialize in responding to one type of stimulus—such as a specific gaze, head angle, posture, or body movement. Other supercell clusters integrate this information and fire only when the cues collectively indicate the direction of someone’s attention and approach. This instant analysis, which aided our ancestors’ survival, also helps a soccer goalkeeper anticipate the direction of an impending kick, and a driver anticipate a pedestrian’s next movement.
Well-developed supercells In this 2007 World Cup match, Brazil’s Marta instantly processed visual information about the positions and movements of Australia’s defenders and goalkeeper (Melissa Barbieri) and somehow managed to get the ball around them all and into the net. Reuters/Claro Cortes IV (China)

Parallel Processing

Unlike most computers, which do step-by-step serial processing, our brain engages in parallel processing: doing many things at once. The brain divides a visual scene into subdimensions, such as color, movement, form, and depth (Figure 4.15), and works on each aspect simultaneously (Livingstone & Hubel, 1988). We then construct our perceptions by integrating the separate but parallel work of these different visual teams.

Figure 4.15 Parallel processing Studies of patients with brain damage suggest that the brain delegates the work of processing color, motion, form, and depth to different areas. After taking a scene apart, how does the brain integrate these subdimensions into the perceived image? The answer to this question is the Holy Grail of vision research.

To recognize a face, for example, the brain integrates information that the retina projects to several visual cortex areas, compares it to stored information, and enables you to recognize the image as, say, your grandmother. The whole process of facial recognition requires tremendous brain power—30 percent of the cortex (10 times the brain area devoted to hearing). If researchers temporarily disrupt the brain’s face-processing areas with magnetic pulses, people are unable to recognize faces. They will,
However, be able to recognize houses; the brain’s face-perception process differs from its object-perception process (McKone et al., 2007; Pitcher et al., 2007).

Destroying or disabling the neural workstation for other visual subtasks produces different peculiar results, as happened to “Mrs. M.” (Hoffman, 1998). Since a stroke damaged areas near the rear of both sides of her brain, she can no longer perceive movement. People in a room seem “suddenly here or there but I have not seen them moving.” Pouring tea into a cup is a challenge because the fluid appears frozen—she cannot perceive it rising in the cup.

Others with stroke or surgery damage to their brain’s visual cortex have experienced blindsight, a localized area of blindness in part of their field of vision (Weiskrantz, 1986). Shown a series of sticks in the blind field, they report seeing nothing. Yet when asked to guess whether the sticks are vertical or horizontal, their visual intuition typically offers the correct response. When told, “You got them all right,” they are astounded. There is, it seems, a second “mind”—a parallel processing system—operating unseen. (Recall Unit 3B’s discussion of how the separate visual systems for perception and action illustrate dual processing—the two-track mind.)

It’s not just brain-injured people who have two visual information systems, as Jennifer Boyer and her colleagues (2005) showed in studies of people without such injuries. Using magnetic pulses to shut down the brain’s primary visual cortex area, the researchers showed these temporarily disabled people a horizontal or vertical line, or a red or green dot. Although they reported seeing nothing, the participants were right 75 percent of the time in guessing the line orientation and 81 percent right in guessing the dot color.

A scientific understanding of visual information processing leaves many neuropsychologists awestruck. As Roger Sperry (1985) observed, the “insights of science give added, not lessened, reasons for awe, respect, and reverence.” Think about it: As you look at someone, visual information is transduced and sent to your brain as millions of neural impulses, then constructed into its component features, and finally, in some as-yet mysterious way, composed into a meaningful image, which you compare with previously stored images and recognize: “That’s Sara!” Likewise, as you read this page, the printed squiggles are transmitted by reflected light rays onto your retina, which triggers a process that sends formless nerve impulses to several areas of your brain, which integrates the information and decodes meaning, thus completing the transfer of information across time and space from my mind to your mind. The whole process (Figure 4.16) is more complex than taking apart a car, piece by piece, transporting it to a different location, then having specialized workers reconstruct it. That all of this happens instantly, effortlessly, and continuously is indeed awesome.
4.2.4 Color Vision

**8: What theories help us understand color vision?**

We talk as though objects possess color: “A tomato is red.” Perhaps you have pondered the old question, “If a tree falls in the forest and no one hears it, does it make a sound?” We can ask the same of color: If no one sees the tomato, is it red?

“I only mind has sight and hearing; all things else are deaf and blind.”

*Epicharmus, Fragments, 550 B.C.E.*

The answer is no. First, the tomato is everything but red, because it rejects (reflects) the long wavelengths of red. Second, the tomato’s color is our mental construction. As Isaac Newton (1704) noted, ”The [light] rays are not colored.” Color, like all aspects of vision, resides not in the object but in the theater of our brains, as evidenced by our dreaming in color.
In the study of vision, one of the most basic and intriguing mysteries is how we see the world in color. How, from the light energy striking the retina, does the brain manufacture our experience of color—and of such a multitude of colors? Our difference threshold for colors is so low that we can discriminate some 7 million different color variations (Geldard, 1972).

At least most of us can. For about 1 person in 50, vision is color deficient—and that person is usually male, because the defect is genetically sex-linked. To understand why some people’s vision is color deficient, it will help to first understand how normal color vision works.

Modern detective work on the mystery of color vision began in the nineteenth century when Hermann von Helmholtz built on the insights of an English physicist, Thomas Young. Knowing that any color can be created by combining the light waves of three primary colors—red, green, and blue—Young and von Helmholtz inferred that the eye must have three corresponding types of color receptors. Years later, researchers measured the response of various cones to different color stimuli and confirmed the Young-Helmholtz trichromatic (three-color) theory, which implies that the cones do their color magic in teams of three. Indeed, the retina has three types of color receptors, each especially sensitive to one of three colors. And those colors are, in fact, red, green, and blue. When we stimulate combinations of these cones, we see other colors. For example, there are no receptors especially sensitive to yellow. Yet when both red-sensitive and green-sensitive cones are stimulated, we see yellow.

Most people with color-deficient vision are not actually “colorblind.” They simply lack functioning red-or green-sensitive cones, or sometimes both. Their vision—perhaps unknown to them, because their lifelong vision seems normal—is monochromatic (one-color) or dichromatic (two-color) instead of trichromatic, making it impossible to distinguish the red and green in Figure 4.17 (Boynton, 1979). Dogs, too, lack receptors for the wavelengths of red, giving them only limited, dichromatic color vision (Neitz et al., 1989).
But trichromatic theory cannot solve all parts of the color vision mystery, as Ewald Hering soon noted. For example, we see yellow when mixing red and green light. But how is it that those blind to red and green can often still see yellow? And why does yellow appear to be a pure color and not a mixture of red and green, the way purple is of red and blue?

Hering, a physiologist, found a clue in the well-known occurrence of afterimages. When you stare at a green square for a while and then look at a white sheet of paper, you see red, green’s opponent color. Stare at a yellow square and you will later see its opponent color, blue, on the white paper (as in the flag demonstration in Figure 4.18). Hering surmised that there must be two additional color processes, one responsible for red-versus-green perception, and one for blue-versus-yellow.
yellow, you should see their opponent colors.) Stare at a white wall and note how the size of the flag grows with the projection distance!

A century later, researchers confirmed Hering’s opponent-process theory. As visual information leaves the receptor cells, we analyze it in terms of three sets of opponent colors: red-green, yellow-blue, and white-black. In the retina and in the thalamus (where impulses from the retina are relayed en route to the visual cortex), some neurons are turned “on” by red but turned “off” by green. Others are turned on by green but off by red (DeValois & DeValois, 1975).

Opponent processes explain afterimages, such as in the flag demonstration, in which we tire our green response by staring at green. When we then stare at white (which contains all colors, including red), only the red part of the green-red pairing will fire normally.

The present solution to the mystery of color vision is therefore roughly this: Color processing occurs in two stages. The retina’s red, green, and blue cones respond in varying degrees to different color stimuli, as the Young-Helmholtz trichromatic theory suggested. Their signals are then processed by the nervous system’s opponent-process cells, en route to the visual cortex.

4.3 Hearing

FOR HUMANS, VISION IS THE MAJOR SENSE. More of our brain cortex is devoted to vision than to any other sense. Yet without our senses of hearing, touch, body position and movement, taste, and smell, our capacities for experiencing the world would be vastly diminished.

Like our other senses, our audition, or hearing, is highly adaptive. We hear a wide range of sounds, but we hear best those sounds with frequencies in a range corresponding to that of the human voice. We also are acutely sensitive to faint sounds, an obvious boon for our ancestors’ survival when hunting or being hunted, or for detecting a child’s whimper. (If our ears were much more sensitive, we would hear a constant hiss from the movement of air molecules.)

We are also remarkably attuned to variations in sounds. We easily detect differences among thousands of human voices: Walking between classes, we immediately recognize the voice of a friend behind us. A fraction of a second after a spoken word stimulates receptors in the inner ear, millions of neurons have simultaneously coordinated in extracting the essential features, comparing them with past experience, and identifying the stimulus (Freeman, 1991). For hearing as for seeing, we will consider the fundamental question: How do we do it?

4.3.1 The Stimulus Input: Sound Waves

9: What are the characteristics of air pressure waves that we hear as sound?
Draw a bow across a violin, and the resulting stimulus energy is sound waves—jostling molecules of air, each bumping into the next, like a shove transmitted through a concert hall’s crowded exit tunnel. The resulting waves of compressed and expanded air are like the ripples on a pond circling out from where a stone has been tossed. As we swim in our ocean of moving air molecules, our ears detect these brief air pressure changes. Exposed to a loud, low bass sound—perhaps from a bass guitar or a cello—we can also feel the vibration, and we hear by both air and bone conduction.

The ears then transform the vibrating air into nerve impulses, which our brain decodes as sounds. The strength, or amplitude, of sound waves (recall Figure 4.9, which illustrated amplitude in relation to vision) determines their loudness. Waves also vary in length, and therefore in frequency. Their frequency determines the pitch we experience: Long waves have low frequency—and low pitch. Short waves have high frequency—and high pitch. A violin produces much shorter, faster sound waves than does a cello.

We measure sounds in decibels. The absolute threshold for hearing is arbitrarily defined as zero decibels. Every 10 decibels correspond to a tenfold increase in sound intensity. Thus, normal conversation (60 decibels) is 10,000 times more intense than a 20-decibel whisper. And a temporarily tolerable 100-decibel passing subway train is 10 billion times more intense than the faintest detectable sound.

The sounds of music A violin’s short, fast waves create a high pitch, a cello’s longer, slower waves a lower pitch. Differences in the waves’ height, or amplitude, also create differing degrees of loudness. Dennis MacDonald/PhotoEdit

4.3.2 The Ear

10: How does the ear transform sound energy into neural messages?
To hear, we must somehow convert sound waves into neural activity. The human ear accomplishes this feat through an intricate mechanical chain reaction (Figure 4.19). First, the visible outer ear channels the sound waves through the auditory canal to the eardrum, a tight membrane that vibrates with the waves. The middle ear then transmits the eardrum’s vibrations through a piston made of three tiny bones (the hammer, anvil, and stirrup) to the cochlea, a snail-shaped tube in the inner ear. The incoming vibrations cause the cochlea’s membrane (the oval window) to vibrate, jostling the fluid that fills the tube. This motion causes ripples in the basilar membrane, bending the hair cells lining its surface, not unlike the wind bending a wheat field. Hair cell movement triggers impulses in the adjacent nerve cells, whose axons converge to form the auditory nerve, which sends neural messages (via the thalamus) to the temporal lobe’s auditory cortex. From vibrating air to moving piston to fluid waves to electrical impulses to the brain: Voila! We hear.

My vote for the most intriguing part of the hearing process is the hair cells. A Howard Hughes Medical Institute (2008) report on these “quivering bundles that let us hear” marvels at their “extreme sensitivity and extreme speed.” A cochlea has 16,000 of them, which sounds like a lot until we compare that with an eye’s 130 million or so photoreceptors. But consider their responsiveness. Deflect the tiny bundles of cilia on the tip of a hair cell by the width of an atom—the equivalent of displacing the top of the Eiffel Tower by half an inch—and the alert hair cell, thanks to a special protein at its tip, triggers a neural response (Corey et al., 2004).
Be kind to your inner ear's hair cells. When vibrating in response to sound, the hair cells shown here lining the cochlea produce an electrical signal. Dr. Fred Hossler/Visuals Unlimited

Damage to hair cells accounts for most hearing loss. They have been likened to thick carpet fibers. Walk around on them and they will spring back with a quick vacuuming. But leave a heavy piece of furniture on them for a long time and they may never rebound. As a general rule, if we cannot talk over a noise, it is potentially harmful, especially if prolonged and repeated (Roesser, 1998). Such experiences are common when sound exceeds 100 decibels, as happens in venues from frenzied sports arenas to bagpipe bands to iPods playing near maximum volume (Figure 4.20). Ringing of the ears after exposure to loud machinery or music indicates that we have been bad to our unhappy hair cells. As pain alerts us to possible bodily harm, ringing of the ears alerts us to possible hearing damage. It is hearing's equivalent of bleeding.
The intensity of some common sounds At close range, the thunder that follows lightning has 120-decibel intensity. Richard Kaylin/Stone/Getty Images

Teen boys more than teen girls or adults blast themselves with loud volumes for long periods (Zogby, 2006). Males’ greater noise exposure may help explain why men’s hearing tends to be less acute than women’s. But male or female, those who spend many hours in a loud nightclub, behind a power mower, or above a jackhammer should wear earplugs. “Earplugs or walk away,” say hearing educators.

Perceiving Loudness

So, how do we detect loudness? It is not, as I would have guessed, from the intensity of a hair cell’s response. Rather, a soft, pure tone activates only the few hair cells attuned to its frequency. Given louder sounds, its neighbor hair cells also respond. Thus, the brain can interpret loudness from the number of activated hair cells.

If a hair cell loses sensitivity to soft sounds, it may still respond to loud sounds. This helps explain another surprise: Really loud sounds may seem loud both to people with hearing loss and to those with normal hearing. As a person with hearing loss, I used to wonder when exposed to really loud music what it must sound like to people with normal hearing. Now I realize it can sound much the same; where we differ is in our sensation of soft sounds. This is why we hard-of-hearing people do not want all sounds (loud and soft) amplified. We like sound compressed—which means harder-tohear sounds are amplified more than loud sounds (a feature of today’s digital hearing aids).

Perceiving Pitch

11: What theories help us understand pitch perception?
How do we know whether a sound is the high-frequency, high-pitched chirp of a bird or the low-frequency, low-pitched roar of a truck? Current thinking on how we discriminate pitch, like current thinking on how we discriminate color, combines two theories.

Hermann von Helmholtz’s place theory presumes that we hear different pitches because different sound waves trigger activity at different places along the cochlea’s basilar membrane. Thus, the brain determines a sound’s pitch by recognizing the specific place (on the membrane) that is generating the neural signal. When Nobel laureate-to-be Georg von Békésy (1957) cut holes in the cochleas of guinea pigs and human cadavers and looked inside with a microscope, he discovered that the cochlea vibrated, rather like a shaken bedsheets, in response to sound. High frequencies produced large vibrations near the beginning of the cochlea’s membrane, low frequencies near the end.

But there is a problem with place theory. It can explain how we hear high-pitched sounds, but not how we hear low-pitched sounds, because the neural signals generated by low-pitched sounds are not so neatly localized on the basilar membrane. Frequency theory suggests an alternative explanation: The brain reads pitch by monitoring the frequency of neural impulses traveling up the auditory nerve. The whole basilar membrane vibrates with the incoming sound wave, triggering neural impulses to the brain at the same rate as the sound wave. If the sound wave has a frequency of 100 waves per second, then 100 pulses per second travel up the auditory nerve.

Frequency theory can explain how we perceive low-pitched sounds. But it, too, is problematic: An individual neuron cannot fire faster than 1000 times per second. How, then, can we sense sounds with frequencies above 1000 waves per second (roughly the upper third of a piano keyboard)? Enter the volley principle: Like soldiers who alternate firing so that some can shoot while others reload, neural cells can alternate firing. By firing in rapid succession, they can achieve a combined frequency above 1000 waves per second.

Thus, place theory best explains how we sense high pitches, frequency theory best explains how we sense low pitches, and some combination of place and frequency seems to handle the pitches in the intermediate range.

Locating Sounds

12: How do we locate sounds?
Why don’t we have one big ear—perhaps above our one nose? The better to hear you, as the wolf said to Red Riding Hood. As the placement of our eyes allows us to sense visual depth, so the placement of our two ears allows us to enjoy stereophonic (“three-dimensional”) hearing.

Two ears are better than one for at least two reasons: If a car to the right honks, your right ear receives a more intense sound, and it receives sound slightly sooner than your left ear (Figure 4.21). Because sound travels 750 miles per hour and our ears are but 6 inches apart, the intensity difference and the time lag are extremely small. However, our supersensitive auditory system can detect such minute differences (Brown & Deffenbacher, 1979; Middlebrooks & Green, 1991). A just noticeable difference in the direction of two sound sources corresponds to a time difference of just 0.000027 second! To simulate what the ears experience with sound from varying locations, audio software can emit sound from two stereo speakers with varying time delays and intensity. The result: We may perceive a bee buzzing loudly in one ear, then flying around the room and returning to buzz near the other ear (Harvey, 2002).

So how well do you suppose we do at locating a sound that is equidistant from our two ears, such as those that come from directly ahead, behind, overhead, or beneath us? Not very well. Why? Because such sounds strike the two ears simultaneously. Sit with closed eyes while a friend snaps fingers around your head. You will easily point to the sound when it comes from either side, but you will likely make some mistakes when it comes from directly ahead, behind, above, or below. That is why, when trying to pinpoint a sound, you cock your head, so that your two ears will receive slightly different messages.

4.3.3 Hearing Loss and Deaf Culture

13: What are the common causes of hearing loss, and why does controversy surround cochlear implants?
The ear’s intricate and delicate structure makes it vulnerable to damage. Problems with the mechanical system that conducts sound waves to the cochlea cause **conduction hearing loss**. If the eardrum is punctured or if the tiny bones of the middle ear lose their ability to vibrate, the ear’s ability to conduct vibrations diminishes.

Damage to the cochlea’s hair cell receptors or their associated nerves can cause the more common **sensorineural hearing loss** (or **nerve deafness**). Occasionally, disease causes sensorineural hearing loss, but more often the culprits are biological changes linked with heredity, aging, and prolonged exposure to ear-splitting noise or music. (See Close-Up: Living in a Silent World.)

Experiments are also under way to restore vision—with a bionic retina (a 2-millimeter-diameter microchip with photoreceptors that stimulate damaged retinal cells), and with a video camera and computer that stimulate the visual cortex. In test trials, both devices have enabled blind people to gain partial sight (Boahen, 2005; Steenhuisen, 2002).

For now, the only way to restore hearing for people with nerve deafness is a sort of bionic ear—a **cochlear implant**. This electronic device translates sounds into electrical signals that, wired into the cochlea’s nerves, convey some information about sound to the brain. The implant helps children become proficient in oral communication (especially if they receive it as preschoolers or even before age 1) (Dettman et al., 2007; Schorr et al., 2005). The latest cochlear implants also can help restore hearing for most adults (though not for those whose adult brain never learned to process sound during childhood). By 2003, some 60,000 people worldwide had cochlear implants, and millions more were potential candidates (Gates & Miyamoto, 2003).

**Living in a Silent World**

The world’s 500 million people who live with hearing loss are a diverse group (Phonak, 2007). Some are profoundly deaf; others have limited hearing. Some were deaf prelingually (before developing language); others have known the hearing world. Some sign and identify with the language-based Deaf culture; more, especially those who lost their hearing postlingually, are “oral” and converse with the hearing world by reading lips or reading written notes. Still others move between the two cultures.

Despite its many variations, living without hearing poses challenges. When older people with hearing loss must expend effort to hear words, they have less remaining cognitive capacity available to remember and comprehend them (Wingfield et al., 2005). In several studies, people with hearing loss, especially if not wearing hearing aids, have also reported feeling sadder, being less socially engaged, and more often experiencing others’ irritation (Chisolm et al., 2007; Fellinger et al., 2007; National Council on Aging, 1999).

Deaf children who grow up around other Deaf people more often identify with Deaf culture and feel positive self-esteem. If raised in a signing household, whether by Deaf
or hearing parents, they also express higher self-esteem and feel more accepted (Bat-Chava, 1993, 1994).

Separated from a supportive community, Deaf people face many challenges (Braden, 1994). Unable to communicate in customary ways, speaking and signing playmates may struggle to coordinate their play. And because academic subjects are rooted in spoken languages, signing students’ school achievement may suffer. Adolescents may feel socially excluded, with a resulting low self-confidence.

Even adults whose hearing becomes impaired later in life may experience a sort of shyness. “It’s almost universal among the deaf to want to cause hearing people as little fuss as possible,” observed Henry Kisor (1990, p. 244), a Chicago newspaper editor and columnist who lost his hearing at age 3. “We can be self-effacing and diffident to the point of invisibility. Sometimes this tendency can be crippling. I must fight it all the time.” Helen Keller, both blind and deaf, noted, “Blindness cuts people off from things. Deafness cuts people off from people.”

I understand. My mother, with whom we communicated by writing notes on an erasable “magic pad,” spent her last dozen years in a silent world, largely withdrawn from the stress and strain of trying to interact with people outside a small circle of family and old friends. With my own hearing declining on a trajectory toward hers, I find myself sitting front and center at plays and meetings, seeking quiet corners in restaurants, and asking my wife to make necessary calls to friends whose accents differ from ours. I do benefit from cool technology that, at the press of a button, can transform my hearing aids into in-the-ear loudspeakers for the broadcast of phone, TV, and public address system sound (see www.hearingloop.org). Yet I still experience frustration when, with or without hearing aids, I can’t hear the joke everyone else is guffawing over; when, after repeated tries, I just can’t catch that exasperated person’s question and can’t fake my way around it; when family members give up and say, “Oh, never mind” after trying three times to tell me something unimportant.
As she aged, my mother came to feel that seeking social interaction was simply not worth the effort. However, I share newspaper columnist Kisor’s belief that communication is worth the effort (p. 246): “So, . . . I will grit my teeth and plunge ahead.” To reach out, to connect, to communicate with others, even across a chasm of silence, is to affirm our humanity as social creatures.

The use of cochlear implants is hotly debated. On the one side are the hearing parents of more than 90 percent of all deaf children. Most of these parents want their children to experience their world of sound and talk. If an implant is to be effective, they cannot delay the decision until their child reaches the age of consent. On the other side are Deaf culture advocates, who object to using the implants on children who were deaf prelingually. The National Association of the Deaf, for example, argues that deafness is not a disability because native signers are not linguistically disabled. In his 1960 book *Sign Language Structure*, Gallaudet University linguist William Stokoe showed what even native signers had not fully understood: Sign is a complete language with its own grammar, syntax, and meanings.


Deaf culture advocates prefer capitalizing “Deaf” when referring to people with deafness, and to the Deaf community in general. In referring to children without hearing, “deaf” is usually lowercased because young children have not yet had the opportunity to make an informed decision about whether they are a part of the Deaf community. I have followed this style throughout my text.

Deaf culture advocates sometimes further contend that deafness could as well be considered “vision enhancement” as “hearing impairment.” People who lose one channel of sensation do seem to compensate with a slight enhancement of their other sensory abilities (Backman & Dixon, 1992; Levy & Langer, 1992). Some examples:
- Blind musicians (think Stevie Wonder) are more likely than sighted ones to develop perfect pitch (Hamilton, 2000).
- With one ear plugged, blind people are also more accurate than sighted people at locating a sound source (Gougoux et al., 2005; Lessard et al., 1998).
- Close your eyes and with your hands indicate the width of a one-dozen egg carton. Blind individuals, report University of Otago researchers, can do this more accurately than sighted people (Smith et al., 2005).
- People who have been deaf from birth exhibit enhanced attention to their peripheral vision (Bavelier et al., 2006). Their auditory cortex, starved for sensory input, remains largely intact but becomes responsive to touch and to visual input (Emmorey et al., 2003; Finney et al., 2001; Penhune et al., 2003).

“By placing my hand on a person’s lips and throat, I gain an idea of many specific vibrations, and interpret them: a boy’s chuckle, a man’s ’Whew!’ of surprise, the ’Hem!’ of annoyance or perplexity, the moan of pain, a scream, a whisper, a rasp, a sob, a choke, and a gasp.”

Helen Keller, 1908

Close your eyes and immediately you, too, will notice your attention being drawn to your other senses. In one experiment, people who had spent 90 minutes sitting quietly blindfolded became more accurate in their location of sounds (Lewald, 2007). When kissing, lovers minimize distraction and increase their touch sensitivity by closing their eyes.

4.4 Other Senses

ALTHOUGH OUR BRAINS GIVE SEEING and hearing priority in the allocation of cortical tissue, extraordinary happenings occur within our four other senses—our senses of touch, body position and movement, taste, and smell. Sharks and dogs rely on their extraordinary sense of smell, aided by large brain areas devoted to this system. Without our own senses of touch, body position and movement, taste, and smell, we humans would also be seriously handicapped, and our capacities for enjoying the world would be devastatingly diminished.
The precious sense of touch As William James wrote in his Principles of Psychology (1890), “Touch is both the alpha and omega of affection.” Bruce Ayres/Stone/Getty Images

4.4.1 Touch

How do we sense touch and sense our body’s position and movement? How do we experience pain?

Although it may not be the first sense to come to mind, touch is vital. Right from the start, touch is essential to our development. Infant rats deprived of their mother’s grooming produce less growth hormone and have a lower metabolic rate—a good way to keep alive until the mother returns, but a reaction that stunts growth if prolonged. Infant monkeys allowed to see, hear, and smell—but not touch—their mother become desperately unhappy; those separated by a screen with holes that allow touching are much less miserable. As you will see in Unit 9, premature human babies gain weight faster and go home sooner if they are stimulated by hand massage. As lovers, we yearn to touch—to kiss, to stroke, to snuggle. And even strangers, touching only their forearms and separated by a curtain, can communicate anger, fear, disgust, love, gratitude, and sympathy at well above chance levels (Hertenstein et al., 2006).

Humorist Dave Barry may be right to jest that your skin “keeps people from seeing the inside of your body, which is repulsive, and it prevents your organs from falling onto the ground.” But skin does much more. Our “sense of touch” is actually a mix of distinct senses, with different types of specialized nerve endings within the skin. Touching various spots on the skin with a soft hair, a warm or cool wire, and the point of a pin reveals that some spots are especially sensitive to pressure, others to warmth, others to cold, still others to pain.
Figure 4.22 Warm + cold = hot When ice-cold water passes through one coil and comfortably warm water through another, we perceive the combined sensation as burning hot.

Surprisingly, there is no simple relationship between what we feel at a given spot and the type of specialized nerve ending found there. Only pressure has identifiable receptors. Other skin sensations are variations of the basic four (pressure, warmth, cold, and pain):

- Stroking adjacent pressure spots creates a tickle.
- Repeated gentle stroking of a pain spot creates an itching sensation.
- Touching adjacent cold and pressure spots triggers a sense of wetness, which you can experience by touching dry, cold metal.
- Stimulating nearby cold and warm spots produces the sensation of hot (Figure 4.22).

Touch sensations involve more than tactile stimulation, however. A self-produced tickle produces less somatosensory cortex activation than the same tickle would from something or someone else (Blakemore et al., 1998). (The brain is wise enough to be most sensitive to unexpected stimulation.) This top-down influence on touch sensation also appears in the rubber-hand illusion. Imagine yourself looking at a realistic rubber hand while your own hand is hidden (Figure 4.23). If an experimenter simultaneously touches your fake and real hands, you likely will perceive the rubber hand as your own and sense it being touched. Even just “stroking” the fake hand with a laser light produces, for most people, an illusory sensation of warmth or touch in their unseen real hand (Durgin et al., 2007). Touch is not only a bottom-up property of your senses but also a top-down product of your brain and your expectations.
**Figure 4.23 The rubber-hand illusion** When a researcher simultaneously touches a volunteer’s real and fake hands, the volunteer feels as though the seen fake hand is her own (MacLachlan et al., 2003).

**The intricate vestibular sense** These Cirque du Soleil performers can thank their inner ears for the information that enables their brains to monitor their bodies’ position so expertly. Michal Cizek/AFP/Getty Images
Important sensors in your joints, tendons, bones, and ears, as well as your skin sensors enable your **kinesthesia**—your sense of the position and movement of your body parts. By closing your eyes or plugging your ears you can momentarily imagine being without sight or sound. But what would it be like to live without touch or kinesthesia—without, therefore, being able to sense the positions of your limbs when you wake during the night? Ian Waterman of Hampshire, England, knows. In 1972, at age 19, Waterman contracted a rare viral infection that destroyed the nerves that enabled his sense of light touch and of body position and movement. People with this condition report feeling disembodied, as though their body is dead, not real, not theirs (Sacks, 1985). With prolonged practice, Waterman has learned to walk and eat—by visually focusing on his limbs and directing them accordingly. But if the lights go out, he crumples to the floor (Azar, 1998). Even for the rest of us, vision interacts with kinesthesia. Stand with your right heel in front of your left toes. Easy. Now close your eyes and you will probably wobble.

A companion **vestibular sense** monitors your head’s (and thus your body’s) position and movement. The biological gyroscopes for this sense of equilibrium are in your inner ear. The **semicircular canals**, which look like a three-dimensional pretzel (Figure 4.19a), and the **vestibular sacs**, which connect the canals with the cochlea, contain fluid that moves when your head rotates or tilts. This movement stimulates hairlike receptors, which send messages to the cerebellum at the back of the brain, thus enabling you to sense your body position and to maintain your balance.

If you twirl around and then come to an abrupt halt, neither the fluid in your semicircular canals nor your kinesthetic receptors will immediately return to their neutral state. The dizzy aftereffect fools your brain with the sensation that you’re still spinning. This illustrates a principle that underlies perceptual illusions: Mechanisms that normally give us an accurate experience of the world can, under special conditions, fool us. Understanding how we get fooled provides clues to how our perceptual system works.

### 4.4.2 Pain

Be thankful for occasional pain. Pain is your body’s way of telling you something has gone wrong. Drawing your attention to a burn, a break, or a sprain, pain orders you to change your behavior—“Stay off that turned ankle!” The rare people born without the ability to feel pain may experience severe injury or even die before early adulthood. Without the discomfort that makes us occasionally shift position, their joints fail from excess strain, and without the warnings of pain, the effects of unchecked infections and injuries accumulate (Neese, 1991).

More numerous are those who live with chronic pain, which is rather like an alarm that won’t shut off. The suffering of such people, and of those with persistent or recurring backaches, arthritis, headaches, and cancer-related pain, prompts two questions: What is pain? How might we control it?

**Understanding Pain**
Our pain experiences vary widely, depending on our physiology, our experiences and attention, and our surrounding culture (Gatchel et al., 2007). Thus, our feelings of pain combine both bottom-up sensations and top-down processes.

**Biological Influences** The pain system, unlike vision, is not located in a simple neural cord running from a sensing device to a definable area in the brain. Moreover, there is no one type of stimulus that triggers pain (as light triggers vision). Instead, there are different *nociceptors*—sensory receptors that detect hurtful temperatures, pressure, or chemicals (Figure 4.24).

![Figure 4.24 The pain circuit](image)

Sensory receptors (nociceptors) respond to potentially damaging stimuli by sending an impulse to the spinal cord, which passes the message to the brain, which interprets the signal as pain.

“*When belly with bad pains doth swell, It matters naught what else goes well.*”

---

Although no theory of pain explains all available findings, psychologist Ronald Melzack and biologist Patrick Wall’s (1965, 1983) classic *gate-control theory* provides a useful model. The spinal cord contains small nerve fibers that conduct most pain signals, and larger fibers that conduct most other sensory signals. Melzack and Wall theorized that
the spinal cord contains a neurological “gate.” When tissue is injured, the small fibers activate and open the gate, and you feel pain. Large-fiber activity closes the gate, blocking pain signals and preventing them from reaching the brain. Thus, one way to treat chronic pain is to stimulate (by massage, by electric stimulation, or by acupuncture) “gate-closing” activity in the large neural fibers (Wall, 2000). Rubbing the area around your stubbed toe will create competing stimulation that will block some pain messages.

“Pain is increased by attending to it.”

Charles Darwin, Expression of Emotions in Man and Animals, 1872

But pain is not merely a physical phenomenon of injured nerves sending impulses to the brain—like pulling on a rope to ring a bell. Melzack and Wall noted that brain-to-spinal-cord messages can also close the gate, helping to explain some striking influences on pain. When we are distracted from pain (a psychological influence) and soothed by the release of endorphins, our natural painkillers (a biological influence), our experience of pain may be greatly diminished. Sports injuries may go unnoticed until the after-game shower. People who carry a gene that boosts the availability of endorphins are less bothered by pain, and their brain is less responsive to pain (Zubieta et al., 2003). Others, who carry a mutated gene that disrupts pain circuit neurotransmission, may be unable to experience pain (Cox et al., 2006). Such discoveries may point the way toward new pain medications that mimic these genetic effects.

Playing with pain In a 2008 NBA championship series game, Boston Celtics star Paul Pierce screamed in pain after an opposing player stepped on his right foot, causing his knee to twist and pop. After being carried off the court, he came back and played through the pain, which reclaimed his attention after the game’s end. Tom Miha/keAFP/Getty Images
The brain can also create pain, as it does in people’s experiences of **phantom limb sensations**, when it misinterprets the spontaneous central nervous system activity that occurs in the absence of normal sensory input. As the dreamer may see with eyes closed, so some 7 in 10 amputees may feel pain or movement in nonexistent limbs, notes Melzack (1992, 2005). (An amputee may also try to step off a bed onto a phantom limb or to lift a cup with a phantom hand.) Even those born without a limb sometimes perceive sensations from the absent arm or leg. The brain, Melzack (1998) surmises, comes prepared to anticipate “that it will be getting information from a body that has limbs.”

A similar phenomenon occurs with other senses. People with hearing loss often experience the sound of silence: phantom sounds—a ringing-in-the-ears sensation known as **tinnitus**. Those who lose vision to glaucoma, cataracts, diabetes, or macular degeneration may experience phantom sights—nonthreatening hallucinations (Ramachandran & Blakeslee, 1998). Some with nerve damage have had taste phantoms, such as ice water seeming sickeningly sweet (Goode, 1999). Others have experienced phantom smells, such as nonexistent rotten food. The point to remember: **We feel, see, hear, taste, and smell with our brain**, which can sense even without functioning senses.

**Psychological Influences** The psychological effects of distraction are clear in the stories of athletes who, focused on winning, play through the pain. Carrie Armel and Vilayanur Ramachandran (2003) cleverly illustrated psychological influences on pain with another version of the rubber-hand illusion. They bent a finger slightly backward on the unseen hands of 16 volunteers, while simultaneously “hurting” (severely bending) a finger on a visible fake rubber hand. The volunteers felt as if their real finger were being bent, and they responded with increased skin perspiration.

We also seem to edit our **memories** of pain, which often differ from the pain we actually experienced. In experiments, and after medical procedures, people overlook a pain’s duration. Their memory snapshots instead record two factors: First, people tend to record pain’s **peak** moment, which can lead them to recall variable pain, with peaks, as worse (Stone et al., 2005). Second, they register how much pain they felt at the **end**, as Daniel Kahneman and his co-researchers (1993) discovered when they asked people to immerse one hand in painfully cold water for 60 seconds, and then the other hand in the same painfully cold water for 60 seconds followed by a slightly less painful 30 seconds more. Which of these experiences would you expect to recall as most painful?

Curiously, when asked which trial they would prefer to repeat, most preferred the longer trial, with more net pain—but less pain at the end. A physician used this principle with patients undergoing colon exams—lengthening the discomfort by a minute, but lessening its intensity (Kahneman, 1999). Although the extended milder discomfort added to their net pain experience, patients experiencing this taper-down treatment later recalled the exam as less painful than did those whose pain ended abruptly.

**Social-Cultural Influences** Our perception of pain also varies with our social situation and our cultural traditions. We tend to perceive more pain when others also seem to be experiencing pain (Symbaluk et al., 1997). This may help explain other apparent social aspects of pain, as when pockets of Australian keyboard operators during the mid-1980s suffered outbreaks of severe pain during typing or other repetitive work—without
any discernible physical abnormalities (Gawande, 1998). Sometimes the pain in sprain is mainly in the brain—literally. When feeling empathy for another’s pain, a person’s own brain activity may partly mirror that of the other’s brain in pain (Singer et al., 2004).

Thus, our perception of pain is a biopsychosocial phenomenon (Figure 4.25). Viewing pain this way can help us better understand how to cope with pain and treat it.

**Figure 4.25 Biopsychosocial approach to pain** Our experience of pain is much more than neural messages sent to the brain. Barros & Barros/Getty Images
Lawrence Migdale/Stock, Boston
Robert Nickelsberg/Getty Images

**Controlling Pain**

If pain is where body meets mind—if it is both a physical and a psychological phenomenon—then it should be treatable both physically and psychologically. Depending on the type of symptoms, pain control clinics select one or more therapies from a list that includes drugs, surgery, acupuncture, electrical stimulation, massage, exercise, hypnosis, relaxation training, and thought distraction.
Seeking relief This acupuncturist is attempting to help this woman gain relief from back pain by using needles on points of the patient’s hand. Gary Conner/PhototakeUSA.com

Even an inert placebo can help, by dampening the brain’s attention and responses to painful experiences—mimicking analgesic drugs (Wager, 2005). After being injected in the jaw with a stinging saltwater solution, men in one experiment were given a placebo that was said to relieve pain. They immediately felt better, a result associated with activity in a brain area that releases natural pain-killing opiates (Scott et al., 2007; Zubieta et al., 2005). Being given fake pain-killing chemicals caused the brain to dispense real ones. “Believing becomes reality,” noted one commentator (Thernstrom, 2006), as “the mind unites with the body.”

Another experiment pitted two placebos—fake pills and pretend acupuncture—against each other (Kaptchuk et al., 2006). People with persistent arm pain (270 of them) received either sham acupuncture (with trick needles that retracted without puncturing the skin) or blue cornstarch pills that looked like pills often prescribed for strain injury. A fourth of those receiving the nonexistent needle pricks and 31 percent of those receiving the pills complained of side effects, such as painful skin or dry mouth and fatigue. After two months, both groups were reporting less pain, with the fake acupuncture group reporting the greater pain drop.

Distracting people with pleasant images (“Think of a warm, comfortable environment”) or drawing their attention away from the painful stimulation (“Count backward by 3’s”) is an especially effective way to increase pain tolerance (Fernandez & Turk, 1989; McCaul & Malott, 1984). A well-trained nurse may distract needle-shy patients by chatting with them and asking them to look away when inserting the needle. For burn victims receiving excruciating wound care, an even more effective distraction comes from immersion in a computer-generated 3-D world, like the snow scene in Figure 4.26. Functional MRI (fMRI) scans reveal that playing in the virtual reality reduces the brain’s pain-related activity (Hoffman, 2004). Because pain is in the brain, diverting the brain’s attention may bring relief.
Figure 4.26 Virtual-reality pain control For burn victims undergoing painful skin repair, an escape into virtual reality can powerfully distract attention, thus reducing pain and the brain’s response to painful stimulation. The MRI scans (far right) illustrate a lowered pain response when the patient is distracted. Image by Todd Richards and Aric Bills, U.W., ©Hunter Hoffman, www.vrpain.com

4.4.3 Taste

15: How do we experience taste?

Like touch, our sense of taste involves several basic sensations. Taste’s sensations were once thought to be sweet, sour, salty, and bitter, with all others stemming from mixtures of these four (McBurney & Gent, 1979). Then, as investigators searched for specialized nerve fibers for the four taste sensations, they encountered a receptor for what we now know is a fifth—the savory meaty taste of umami, best experienced as the flavor enhancer monosodium glutamate.

Table 4.2

<table>
<thead>
<tr>
<th>Taste</th>
<th>Indicates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sweet</td>
<td>Energy source</td>
</tr>
<tr>
<td>Salty</td>
<td>Sodium essential to physiological processes</td>
</tr>
<tr>
<td>Sour</td>
<td>Potentially toxic acid</td>
</tr>
<tr>
<td>Bitter</td>
<td>Potential poisons</td>
</tr>
<tr>
<td>Umami</td>
<td>Proteins to grow and repair tissue</td>
</tr>
</tbody>
</table>

(Adapted from Cowart, 2005.)

Tastes exist for more than our pleasure (see Table 4.2). Pleasing tastes attracted our ancestors to energy-or protein-rich foods that enabled their survival. Aversive tastes deterred them from new foods that might be toxic. We see the inheritance of this biological wisdom in today’s 2-to 6-year-olds, who are typically fussy eaters, especially when offered new meats or bitter-tasting vegetables, such as spinach and Brussels
sprouts (Cooke et al., 2003). Meat and plant toxins were both potentially dangerous sources of food poisoning for our ancestors, especially for children. Given repeated small tastes of disliked new foods, children will, however, typically begin to accept them (Wardle et al., 2003).

Taste is a chemical sense. Inside each little bump on the top and sides of your tongue are 200 or more taste buds, each containing a pore that catches food chemicals. Into each taste bud pore, 50 to 100 taste receptor cells project antennalike hairs that sense food molecules. Some receptors respond mostly to sweet-tasting molecules, others to salty-, sour-, umami-, or bitter-tasting ones. It doesn’t take much to trigger a response that alerts your brain’s temporal lobe. If a stream of water is pumped across your tongue, the addition of a concentrated salty or sweet taste for but one-tenth of a second will get your attention (Kelling & Halpern, 1983). When a friend asks for “just a taste” of your soft drink, you can squeeze off the straw after a mere fraction of a second.

Taste receptors reproduce themselves every week or two, so when you burn your tongue with hot pizza it hardly matters. However, as you grow older, the number of taste buds decreases, as does taste sensitivity (Cowart, 1981). (No wonder adults enjoy strong-tasting foods that children resist.) Smoking and alcohol use accelerate these declines. Those who lose their sense of taste report that food tastes like “straw” and is hard to swallow (Cowart, 2005).

Essential as taste buds are, there’s more to taste than meets the tongue. As with other senses, your expectations influence your brain’s response. When people are forewarned that an unpleasant taste is coming, their brain responds more actively to negative tastes, which they rate as very unpleasant. When led to believe that the same taste will be merely mildly unpleasant, the brain region that responds to aversive tastes is less active, and the participants rate the taste as less unpleasant (Nitschke et al., 2006). Likewise, when adults are told that a wine costs $90 rather than its real $10 price, the inexpensive wine tastes better and triggers more activity in a brain area that responds to pleasant experiences (Plassmann et al., 2008). As happens with the pain placebo effect, the brain’s thinking frontal lobes offer information that other brain regions act upon.

Sensory Interaction

Taste also illustrates another curious phenomenon. Hold your nose, close your eyes, and have someone feed you various foods. A slice of apple may be indistinguishable from a chunk of raw potato; a piece of steak may taste like cardboard; without their smells, a cup of cold coffee may be hard to distinguish from a glass of Gatorade. To savor a taste, we normally breathe the aroma through our nose—which is why eating is not much fun when you have a bad cold. Smell can also change our perception of taste: A drink’s strawberry odor enhances our perception of its sweetness. This is sensory interaction at work—the principle that one sense may influence another. Smell plus texture plus taste equals flavor.
Sensory interaction similarly influences what we hear. If I (as a person with hearing loss) watch a video with simultaneous captioning, I have no trouble hearing the words I am seeing (and may therefore think I don’t need the captioning). If I then turn off the captioning, I suddenly realize I need it (Figure 4.27). But what do you suppose happens if we see a speaker saying one syllable while we hear another? Surprise: We may perceive a third syllable that blends both inputs. Seeing the mouth movements for *ga* while hearing *ba* we may perceive *da*—a phenomenon known as the *McGurk effect*, after its discoverers, psychologist Harry McGurk and his assistant John MacDonald (1976).

Much the same is true with vision and touch. A weak flicker of light that we have trouble perceiving becomes more visible when accompanied by a short burst of sound (Kayser, 2007). In detecting events, the brain can combine simultaneous visual and touch signals, thanks to neurons projecting from the somatosensory cortex back to the visual cortex (Macaluso et al., 2000).

So, the senses interact: Seeing, hearing, touching, tasting, and smelling are not totally separate channels. In interpreting the world, the brain blends their inputs. In a few select individuals, the senses become joined in a phenomenon called *synaesthesia*, where one sort of sensation (such as hearing sound) produces another (such as seeing color). Thus, hearing music or seeing a specific number may activate color-sensitive cortex regions and trigger a sensation of color (Brang et al., 2008; Hubbard et al., 2005). Seeing the number 3 may evoke a taste sensation (Ward, 2003). For many people, an odor, perhaps of mint or chocolate, may evoke a sensation of taste (Stevenson & Tomiczek, 2007).

### 4.4.4 Smell

**16: How do we experience smell?**

Impress your friends with your new word for the day: People unable to see are said to experience blindness. People unable to hear experience deafness. People unable to smell experience anosmia.
Inhale, exhale. Inhal, exhale. Breaths come in pairs—except at two moments: birth and death. Between those two moments, you will daily inhale and exhale nearly 20,000 breaths of life-sustaining air, bathing your nostrils in a stream of scent-laden molecules. The resulting experiences of smell (olfaction) are strikingly intimate: You inhale something of whatever or whoever it is you smell.

Like taste, smell is a chemical sense. We smell something when molecules of a substance carried in the air reach a tiny cluster of 5 million or more receptor cells at the top of each nasal cavity (Figure 4.28). These olfactory receptor cells, waving like sea anemones on a reef, respond selectively—to the aroma of a cake baking, to a wisp of smoke, to a friend’s fragrance. Instantly, they alert the brain through their axon fibers. Being an old, primitive sense, olfactory neurons bypass the brain’s sensory switchboard, the thalamus.

![Figure 4.28 The sense of smell](image)

"There could be a stack of truck tires burning in the living room, and I wouldn’t necessarily smell it. Whereas my wife can detect a lone spoiled grape two houses away."

Dave Barry, 2005

Even nursing infants and their mothers have a literal chemistry to their relationship. They quickly learn to recognize each other’s scents (McCarthy, 1986). Aided by smell, a mother fur seal returning to a beach crowded with pups will find her own. Our own sense of smell is less impressive than the acuteness of our seeing and hearing. Looking out across a garden, we see its forms and colors in exquisite detail and hear a variety of birds singing, yet we smell little of it without sticking our nose into the blossoms.

Humans have 10 to 20 million olfactory receptors. A bloodhound has some 200 million (Herz, 2001).
Odor molecules come in many shapes and sizes—so many, in fact, that it takes many different receptors to detect them. A large family of genes designs the 350 or so receptor proteins that recognize particular odor molecules (Miller, 2004). Richard Axel and Linda Buck (1991) discovered (in work for which they received a 2004 Nobel Prize) that these receptor proteins are embedded on the surface of nasal cavity neurons. As a key slips into a lock, so odor molecules slip into these receptors. Yet we don’t seem to have a distinct receptor for each detectable odor. This suggests that some odors trigger a combination of receptors, in patterns that are interpreted by the olfactory cortex. As the English alphabet’s 26 letters can combine to form many words, so odor molecules bind to different receptor arrays, producing the 10,000 odors we can detect (Malnic et al., 1999). It is the combinations of olfactory receptors, which activate different neuron patterns, that allow us to distinguish between the aromas of fresh-brewed and hours-old coffee (Zou et al., 2005).

The ability to identify scents peaks in early adulthood and gradually declines thereafter, with women’s smelling ability tending to surpass men’s (Figure 4.29). Despite our skill at discriminating scents, we aren’t very good at describing them. Words more readily portray the sound of coffee brewing than its aroma. Compared with how we experience and remember sights and sounds, smells are almost primitive and certainly harder to describe and recall (Richardson & Zucco, 1989; Zucco, 2003).

![Figure 4.29 Age, sex, and sense of smell](image)

Among the 1.2 million people who responded to a National Geographic scratch-and-sniff survey, women and younger adults most successfully identified six sample odors (from Wysocki & Gilbert, 1989). Smokers and people with Alzheimer’s, Parkinson’s, or alcohol dependence typically experience a diminished sense of smell (Doty, 2001).

“The smell and taste of things bears unfaltering, in the tiny and almost impalpable drop of their essence, the vast structure of recollection.”

French novelist Marcel Proust, in Remembrance of Things Past (1913), describing how the aroma and flavor of a bit of cake soaked in tea resurrected long-forgotten memories of the old family house.

As any dog or cat with a good nose could tell us, we each have our own identifiable chemical signature. (One noteworthy exception: A dog will follow the tracks of one identical twin as though they had been made by the other [Thomas, 1974].) Animals that have many times more olfactory receptors than we do also use their sense of smell
to communicate and to navigate. Long before the shark can see its prey, or the moth its mate, odors direct their way. Migrating salmon follow faint olfactory cues back to their home stream. If exposed in a hatchery to one of two odorant chemicals, they will, when returning two years later, seek whichever stream near their release site is spiked with the familiar smell (Barinaga, 1999).

For humans, too, the attractiveness of smells depends on learned associations (Herz, 2001). Babies are not born with a built-in preference for the smell of their mother’s breast; as they nurse, their preference builds. After a good experience becomes associated with a particular scent, people come to like that scent, which helps explain why people in the United States tend to like the smell of wintergreen (which they associate with candy and gum) more than do those in Great Britain (where it often is associated with medicine). In another example of odors evoking unpleasant emotions, Rachel Herz and her colleagues (2004) frustrated Brown University students with a rigged computer game in a scented room. Later, if exposed to the same odor while working on a verbal task, the students’ frustration was rekindled and they gave up sooner than others exposed to a different odor or no odor.

Though it’s difficult to recall odors by name, we have a remarkable capacity to recognize long-forgotten odors and their associated memories (Engen, 1987; Schab, 1991). The smell of the sea, the scent of a perfume, or an aroma of a favorite relative’s kitchen can bring to mind a happy time. It’s a phenomenon understood by the British travel agent chain Lunn Poly. To evoke memories of lounging on sunny, warm beaches, the company once piped the aroma of coconut suntan oil into its shops (Fracassini, 2000).

Our brain’s circuitry helps explain this power to evoke feelings and memories (Figure 4.30). A hotline runs between the brain area receiving information from the nose and the brain’s ancient limbic centers associated with memory and emotion. Smell is primitive. Eons before the elaborate analytical areas of our cerebral cortex had fully evolved, our mammalian ancestors sniffed for food—and for predators.
Figure 4.30 The olfactory brain Information from the taste buds (yellow arrow) travels to an area of the temporal lobe not far from where the brain receives olfactory information, which interacts with taste. The brain’s circuitry for smell (red arrow) also connects with areas involved in memory storage, which helps explain why a smell can trigger a memory explosion.

4.5 Perceptual Organization

17: How did the Gestalt psychologists understand perceptual organization?

Figure 4.31 A Necker cube What do you see: circles with white lines, or a cube? If you stare at the cube, you may notice that it reverses location, moving the tiny X in the center from the front edge to the back. At times, the cube may seem to float in front of the page, with circles behind it; other times the circles may become holes in the page through which the cube appears, as though it were floating behind the page. There is far more to perception than meets the eye. (From Bradley et al., 1976.)
WE HAVE EXAMINED THE PROCESSES by which we sense sights and sounds, touch and movement, tastes and smells. Now our central question is: how do we see not just shapes and colors, but a rose in bloom, a loved one’s face, a beautiful sunset? How do we hear not just a mix of pitches and rhythms, but a friend’s cry of pain, the hum of distant traffic, a symphony? In short, how do we organize and interpret our sensations so that they become meaningful perceptions?

Early in the twentieth century, a group of German psychologists noticed that when given a cluster of sensations, people tend to organize them into a gestalt, a German word meaning a “form” or a “whole.” For example, look at the Necker cube in Figure 4.31. Note that the individual elements of the figure are really nothing but eight blue circles, each containing three converging white lines. When we view them all together, however, we see a whole, a cube. The Gestalt psychologists, who had wide-ranging interests, were fond of saying that in perception the whole may exceed the sum of its parts. Combine sodium, a corrosive metal, with chlorine, a poisonous gas, and something very different emerges: salt. Likewise, a unique perceived form emerges from a stimulus’ components (Rock & Palmer, 1990).

Over the years, the Gestalt psychologists provided compelling demonstrations and described principles by which we organize our sensations into perceptions. As you read further about these principles, keep in mind the fundamental truth they illustrate: Our brain does more than register information about the world. Perception is not just opening a shutter and letting a picture print itself on the brain. We constantly filter sensory information and infer perceptions in ways that make sense to us. Mind matters.

4.5.1 Form Perception

Imagine designing a video/computer system that, like your eye/brain system, can recognize faces at a glance. What abilities would it need?

Figure and Ground

To start with, the system would need to recognize faces as distinct from their backgrounds. Likewise, our first perceptual task is to perceive any object (the figure) as distinct from its surroundings (the ground). Among the voices you hear at a party, the one you attend to becomes the figure; all others, part of the ground. As you read, the words are the figure; the white paper, the ground. In Figure 4.32, the figure-ground relationship continually reverses—but always we organize the stimulus into a figure seen against a ground. Such reversible figure-and-ground illustrations demonstrate again that the same stimulus can trigger more than one perception.
Grouping

Having discriminated figure from ground, we (and our video/computer system) now have to organize the figure into a meaningful form. Some basic features of a scene—such as color, movement, and light/dark contrast—we process instantly and automatically (Treisman, 1987). To bring order and form to these basic sensations, our minds follow certain rules for grouping stimuli together. These rules, identified by the Gestalt psychologists and applied even by infants, illustrate the idea that the perceived whole differs from the sum of its parts (Quinn et al., 2002; Rock & Palmer, 1990):

**Proximity** We group nearby figures together, as in Figure 4.33. We see three sets of two lines, not six separate lines.

**Similarity** We group similar figures together. We see the triangles and circles as vertical columns of similar shapes, not as horizontal rows of dissimilar shapes.

**Figure 4.32 Reversible figure and ground** Time Saving Suggestion, © 2003 Roger N. Shepard.

**Figure 4.33 Organizing stimuli into groups** We could perceive the stimuli shown here in many ways, yet people everywhere see them similarly. The Gestalt psychologists believed this shows that the brain follows rules to order sensory information into wholes.
**Continuity** We perceive smooth, continuous patterns rather than discontinuous ones. The pattern in the lower-left corner of Figure 4.33 could be a series of alternating semicircles, but we perceive it as two continuous lines—one wavy, one straight.

**Connectedness** Because they are uniform and linked, we perceive each set of two dots and the line between them as a single unit.

**Closure** We fill in gaps to create a complete, whole object. Thus we assume that the circles (below left) are complete but partially blocked by the (illusory) triangle. Add nothing more than little line segments that close off the circles (below right) and now your brain stops constructing a triangle.

Such principles usually help us construct reality. Sometimes, however, they lead us astray, as when we look at the doghouse in Figure 4.34.
Figure 4.34 Grouping principles What’s the secret to this impossible doghouse? You probably perceive this doghouse as a gestalt—a whole (though impossible) structure. Actually, your brain imposes this sense of wholeness on the picture. As Figure 4.39 shows, Gestalt grouping principles such as closure and continuity are at work here. Photo by Walter Wick. Reprinted from GAMES Magazine. © 1983 PCS Games Limited Partnership
4.5.2 Depth Perception

19: How do we see the world in three dimensions?

From the two-dimensional images falling on our retinas, we somehow organize three-dimensional perceptions. **Depth perception**, seeing objects in three dimensions, enables us to estimate their distance from us. At a glance, we estimate the distance of an oncoming car or the height of a house. This ability is partly innate. Eleanor Gibson and Richard Walk (1960) discovered this using a miniature cliff with a drop-off covered by sturdy glass. Gibson’s inspiration for these experiments occurred while she was picnicking on the rim of the Grand Canyon. She wondered: Would a toddler peering over the rim perceive the dangerous drop-off and draw back?
Eleanor Gibson and Richard Walk devised this miniature cliff with a glass-covered drop-off to determine whether crawling infants and newborn animals can perceive depth. Even when coaxed, infants are reluctant to venture onto the glass over the cliff. 

Back in their Cornell University laboratory, Gibson and Walk placed 6-to 14-month-old infants on the edge of a safe canyon—a visual cliff (Figure 4.35). When the infants’ mothers then coaxed them to crawl out onto the glass, most refused to do so, indicating that they could perceive depth. Crawling infants come to the lab after lots of learning. Yet newborn animals with virtually no visual experience—young kittens, a day-old goat, and newly hatched chicks—respond similarly. To Gibson and Walk, this suggested that mobile newborn animals come prepared to perceive depth.

Each species, by the time it is mobile, has the perceptual abilities it needs. But if biological maturation predisposes our wariness of heights, experience amplifies it. Infants’ wariness increases with their experiences of crawling, no matter when they begin to crawl (Campos et al., 1992). And judging from what they will reach for, 7-month-olds use the cast shadow of a toy to perceive its distance, while 5-month-olds don’t (Yonas & Granrud, 2006). This suggests that in human infants, depth perception grows with age.

How do we do it? How do we transform two differing two-dimensional retinal images into a single three-dimensional perception? The process begins with depth cues, some that depend on the use of two eyes, and others that are available to each eye separately.

**Binocular Cues**

Try this: With both eyes open, hold two pens or pencils in front of you and touch their tips together. Now do so with one eye closed. With one eye, the task becomes noticeably more difficult, demonstrating the importance of binocular cues in judging the distance of nearby objects. Two eyes are better than one.

Because our eyes are about 2½ inches apart, our retinas receive slightly different images of the world. When the brain compares these two images, the difference between them—their retinal disparity—provides one important binocular cue to the relative distance of different objects. When you hold your fingers directly in front of your nose, your retinas receive quite different views. (You can see this if you close one eye and then the other, or create a finger sausage as in Figure 4.36) At a greater distance—say, when you hold your fingers at arm’s length—the disparity is smaller.
The floating finger sausage

Hold your two index fingers about 5 inches in front of your eyes, with their tips a half-inch apart. Now look beyond them and note the weird result. Move your fingers out farther and the retinal disparity—and the finger sausage—will shrink.

The creators of 3-D (three-dimensional) movies simulate or exaggerate retinal disparity by photographing a scene with two cameras placed a few inches apart (a feature we might want to build into our seeing computer). When we view the movie through special glasses that allow the left eye to see the image from the left camera and the right eye the image from the right camera, the 3-D effect mimics or exaggerates normal retinal disparity. Similarly, twin cameras in airplanes can take photos of terrain for integration into 3-D maps.

Monocular Cues

How do we judge whether a person is 10 or 100 meters away? In both cases, retinal disparity while looking straight ahead is slight. At such distances, we depend on monocular cues (available to each eye separately). Monocular cues also influence our everyday perceptions. Is the St. Louis Gateway Arch (Figure 4.37)—the world’s largest human-made illusion—taller than it is wide? Or wider than it is tall? To most of us, it appears taller. Actually, its height and width are equal. Relative height is a possible contributor to this unexplained horizontal-vertical illusion—our perceiving vertical dimensions as longer than identical horizontal dimensions. No wonder people (even experienced bartenders) pour less juice when given a tall, thin glass rather than a short, wide glass (Wansink & van Ittersum, 2003, 2005).
Another monocular depth cue, the light-and-shadow effect, may have contributed to several accidents when the steps of our new campus field house were unfortunately painted black on the step’s edge (making it seem farther away) and bright silver on the flat surface of the step below (making it seem closer). The seeming result was the misperception of no step-down, and (for some) sprained ankles and backs. **Figure 4.38** illustrates relative height, light and shadow, and other monocular cues.
4.5.3 Motion Perception

Imagine that you could perceive the world as having color, form, and depth but that you could not see motion. Not only would you be unable to bike or drive, you would have trouble writing, eating, and walking.

Normally your brain computes motion based partly on its assumption that shrinking objects are retreating (not getting smaller) and enlarging objects are approaching. But you are imperfect at motion perception. Large objects, such as trains, appear to move more slowly than smaller objects, such as cars moving at the same speed. (Perhaps at an airport you’ve noticed that jumbo jets seem to land more slowly than little jets.)

To catch a fly ball, softball or cricket players (unlike drivers) want to achieve a collision—with the ball that’s flying their way. To accomplish that, they follow an unconscious rule—one they can’t explain but know intuitively: Run to keep the ball at a
constantly increasing angle of gaze (McBeath et al., 1995). A dog catching a Frisbee
does the same (Shaffer et al., 2004).

The brain will also perceive continuous movement in a rapid series of slightly varying
images (a phenomenon called stroboscopic movement). As film animation artists know
well, you can create this illusion by flashing 24 still pictures a second. The motion we
then see in popular action adventures is not in the film, which merely presents a
superfast slide show. The motion is constructed in our heads. Marquees and holiday
lights create another illusion of movement using the phi phenomenon. When two
adjacent stationary lights blink on and off in quick succession, we perceive a single light
moving back and forth between them. Lighted signs exploit the phi phenomenon with a
succession of lights that creates the impression of, say, a moving arrow.

All of these illusions reinforce a fundamental lesson: Perception is not merely a
projection of the world onto our brain. Rather, sensations are disassembled into
information bits that the brain, using both bottom-up and top-down processing, then
reassembles into its own functional model of the external world. Our brain constructs
our perceptions.

4.5.4 Perceptual Constancy

How do perceptual constancies help us organize our sensations into
meaningful perceptions?

So far, we have noted that our video/computer system must first perceive objects as
we do—as having a distinct form, location, and perhaps motion. Its next task is to
recognize objects without being deceived by changes in their shape, size, brightness, or
color—an ability we call perceptual constancy. Regardless of our viewing angle,
distance, and illumination, this top-down process lets us identify people and things in
less time than it takes to draw a breath. This human perceptual feat, which has
intrigued researchers for decades, provides a monumental challenge for our perceiving
computer.

Shape and Size Constancies

Sometimes an object whose actual shape cannot change seems to change shape with
the angle of our view (Figure 4.40). More often, thanks to shape constancy, we
perceive the form of familiar objects, such as the door in Figure 4.41, as constant
even while our retinal image of it changes.
Figure 4.40 Perceiving shape Do the tops of these tables have different dimensions? They appear to. But—believe it or not—they are identical. (Measure and see.) With both tables, we adjust our perceptions relative to our viewing angle. Shepard’s tables, © 2003 Roger Shepard.

Figure 4.41 Shape constancy A door casts an increasingly trapezoidal image on our retinas as it opens, yet we still perceive it as rectangular.

Thanks to size constancy, we perceive objects as having a constant size, even while our distance from them varies. We assume a car is large enough to carry people, even when we see its tiny image from two blocks away. This illustrates the close connection between perceived distance and perceived size. Perceiving an object’s distance gives us cues to its size. Likewise, knowing its general size—that the object is a car—provides us with cues to its distance.

It is a marvel how effortlessly size perception occurs. Given an object’s perceived distance and the size of its image on our retinas, we instantly and unconsciously infer the object’s size. Although the monsters in Figure 4.42a cast the same retinal images, the linear perspective tells our brain that the monster in pursuit is farther away. We therefore perceive it as larger.
This interplay between perceived size and perceived distance helps explain several well-known illusions. For example, can you imagine why the Moon looks up to 50 percent larger when near the horizon than when high in the sky? For at least 22 centuries, scholars have debated this question (Hershenson, 1989). One reason for the Moon illusion is that cues to objects’ distances make the horizon Moon—like the distant monster in Figure 4.42a and the distant bar in the Ponzo illusion in Figure 4.42b—appear farther away and therefore larger than the Moon high in the night sky (Kaufman & Kaufman, 2000). Take away these distance cues—by looking at the horizon Moon (or each monster or each bar) through a paper tube—and the object immediately shrinks.

Size-distance relationships also explain why in Figure 4.43 the two same-age girls seem so different in size. As the diagram reveals, the girls are actually about the same size, but the room is distorted. Viewed with one eye through a peephole, its trapezoidal walls produce the same images as those of a normal rectangular room viewed with both eyes. Presented with the camera’s one-eyed view, the brain makes the reasonable assumption that the room is normal and each girl is therefore the same distance from us. And given the different sizes of their images on the retina, our brain ends up calculating that the girls are very different in size.
Our occasional misperceptions reveal the workings of our normally effective perceptual processes. The perceived relationship between distance and size is usually valid. But under special circumstances it can lead us astray—as when helping to create the Moon illusion and the Ames illusion.

**Lightness Constancy**

White paper reflects 90 percent of the light falling on it; black paper, only 10 percent. In sunlight, a black paper may reflect 100 times more light than does a white paper viewed indoors, but it still looks black (McBurney & Collings, 1984). This illustrates *lightness constancy* (also called *brightness constancy*); we perceive an object as having a constant lightness even while its illumination varies.

Perceived lightness depends on *relative luminance*—the amount of light an object reflects relative to its surroundings (*Figure 4.44*). If you view sunlit black paper through a narrow tube so nothing else is visible, it may look gray, because in bright sunshine it reflects a fair amount of light. View it without the tube and it is again black, because it reflects much less light than the objects around it.
Color Constancy

“From there to here, from here to there, funny things are everywhere.”

Dr. Seuss, One Fish, Two Fish, Red Fish, Blue Fish, 1960

As light changes, a red apple in a fruit bowl retains its redness. This happens because our experience of color depends on something more than the wavelength information received by the cones in our retina. That something more is the surrounding context. If you view only part of a red apple, its color will seem to change as the light changes. But if you see the whole apple as one item in a bowl of fresh fruits, its color will remain roughly constant as the lighting and wavelengths shift—a phenomenon known as **color constancy**. Dorothea Jameson (1985) noted that a chip colored blue under indoor lighting matches the wavelengths reflected by a gold chip in sunlight. Yet bring a bluebird indoors and it won’t look like a goldfinch. Likewise, a green leaf hanging from a brown branch may, when the illumination changes, reflect the same light energy that formerly came from the brown branch. Yet to us the leaf stays greenish and the branch stays brownish. Put on yellow-tinted ski goggles and the snow, after a second, looks as white as before.

Though we take color constancy for granted, the phenomenon is truly remarkable. It demonstrates that our experience of color comes not just from the object—the color is not in the isolated leaf—but from everything around it as well. You and I see color thanks to our brains’ computations of the light reflected by any object relative to its **surrounding objects**. But only if we grew up with normal light, it seems. Monkeys raised under a restricted range of wavelengths later have great difficulty recognizing the same color when illumination varies (Sugita, 2004).

In a context that does not vary, we maintain color constancy. But what if we change the context? Because the brain computes the color of an object relative to its context,
the perceived color changes (as is dramatically apparent in Figure 4.45). This principle—that we perceive objects not in isolation but in their environmental context—matters to artists, interior decorators, and clothing designers. Our perception of the color of a wall or of a streak of paint on a canvas is determined not just by the paint in the can but by the surrounding colors. The take-home lesson: Comparisons govern perceptions.

![Figure 4.45 Color depends on context](image)

Believe it or not, these three blue disks are identical in color. R. Beau Lotto at University College, London

* * *

Form perception, depth perception, motion perception, and perceptual constancy illuminate how we organize our visual experiences. Perceptual organization applies to other senses, too. It explains why we perceive a clock’s steady tick not as a *tick-tick-tick-tick* but as grouped sounds, say, *TICK-tick, TICK-tick*. Listening to an unfamiliar language, we have trouble hearing where one word stops and the next one begins. Listening to our own language, we automatically hear distinct words. This, too, reflects perceptual organization. But it is more, for we even organize a string of letters—**THEDOGATEMEAT**—into words that make an intelligible phrase, more likely “The dog ate meat” than “The do gate me at” (McBurney & Collings, 1984). This process involves not only the organization we’ve been discussing, but also interpretation—discerning meaning in what we perceive—the topic we turn to next.
PHILOSOPHERS HAVE DEBATED WHETHER our perceptual abilities should be credited to our nature or our nurture. To what extent do we learn to perceive? German philosopher Immanuel Kant (1724–1804) maintained that knowledge comes from our inborn ways of organizing sensory experiences. Indeed, we come equipped to process sensory information. But British philosopher John Locke (1632–1704) argued that through our experiences we also learn to perceive the world. Indeed, we learn to link an object’s distance with its size. So, just how important is experience? How radically does it shape our perceptual interpretations?

4.6.1 Sensory Deprivation and Restored Vision

22: What does research on sensory restriction and restored vision reveal about the effects of experience?

Writing to John Locke, a friend asked a question that would test the idea that experience shapes perceptions. If “a man born blind, and now adult, [was] taught by his touch to distinguish between a cube and a sphere” could he, if made to see, visually distinguish the two? Locke’s answer was no, because the man would never have learned to see the difference.

Learning to see At age 3, Mike May lost his vision in an explosion. On March 7, 2000, after a new cornea restored vision to his right eye, he got his first look at his wife and children. Alas, although signals were reaching his long dormant visual cortex, it lacked the experience to interpret them. Faces, apart from features such as hair, were not recognizable. Expressions eluded him. Yet he can see an object in motion and is gradually learning to navigate his world and to marvel at such things as dust floating in sunlight (Abrams, 2002). Mike May, Allison Aliano Photography
This clever question has since been put to the test with a few dozen adults who, though blind from birth, have gained sight (Gregory, 1978; von Senden, 1932). Most were born with cataracts—clouded lenses that allowed them to see only light and shadows, rather as someone might see a foggy image through a Ping-Pong ball sliced in half. After surgery, the patients could tell the difference between figure and ground and could sense colors. This suggests that we are born with these aspects of perception. But much as Locke supposed, they often could not by sight recognize objects that were familiar by touch.

In experiments with infant kittens and monkeys, researchers have outfitted the young animals with goggles through which they could see only diffuse, unpatterned light (Wiesel, 1982). After infancy, when the goggles were removed, these animals’ reactions were much like those of humans born with cataracts. Their eyes were healthy. Their retinas still sent signals to their visual cortex. But the brain’s cortical cells had not developed normal connections. Thus, the animals remained functionally blind to shape. Experience guides and sustains the brain’s development as it forms pathways that affect our perceptions.

In both humans and animals, similar sensory restrictions later in life do no permanent damage. When researchers cover an adult animal’s eye for several months, its vision will be unaffected after the eye patch is removed. When surgeons remove cataracts that develop during late adulthood, most people are thrilled at the return to normal vision. The effect of sensory restriction on infant cats, monkeys, and humans suggests there is a critical period (Unit 9) for normal sensory and perceptual development. Nurture sculpts what nature has endowed.

### 4.6.2 Perceptual Adaptation

**23: How adaptable is our ability to perceive?**

Given a new pair of glasses, we may feel a little strange, even dizzy. Within a day or two, we adjust. Our perceptual adaptation to changed visual input makes the world seem normal again. But imagine a far more dramatic new pair of glasses—one that shifts the apparent location of objects 40 degrees to the left. When you first put them on and toss a ball to a friend, it sails off to the left. Walking forward to shake hands with the person, you veer to the left.
Perceptual adaptation “Oops, missed,” thinks researcher Hubert Dolezal as he views the world through inverting goggles. Yet, believe it or not, kittens, monkeys, and humans can adapt to an inverted world. Courtesy of Hubert Dolezal

Could you adapt to this distorted world? Chicks cannot. When fitted with such lenses, they continue to peck where food grains seem to be (Hess, 1956; Rossi, 1968). But we humans adapt to distorting lenses quickly. Within a few minutes, your throws would again be accurate, your stride on target. Remove the lenses and you would experience an aftereffect. At first your throws would err in the opposite direction, sailing off to the right. But again, within minutes you would adjust.

Indeed, given an even more radical pair of glasses—one that literally turns the world upside down—you could still adapt. Psychologist George Stratton (1896) experienced this when he invented, and for eight days wore, a device that flipped left to right and up to down, making him the first person to experience a right-side-up retinal image while standing upright. The ground was up, the sky was down.

At first, when Stratton wanted to walk, he found himself searching for his feet, which were now “up.” Eating was nearly impossible. He became nauseated and depressed. But Stratton persisted, and by the eighth day he could comfortably reach for an object in the right direction and walk without bumping into things. When Stratton finally removed the headgear, he readapted quickly.

In later experiments, people wearing the optical gear have even been able to ride a motorcycle, ski the Alps, and fly an airplane (Dolezal, 1982; Kohler, 1962). The world around them still seemed above their heads or on the wrong side. But by actively
moving about in these topsy-turvy worlds, they adapted to the context and learned to coordinate their movements.

### 4.6.3 Perceptual Set

**24: How do our expectations, contexts, and emotions influence our perceptions?**

As everyone knows, to see is to believe. As we less fully appreciate, to believe is to see. Our experiences, assumptions, and expectations may give us a perceptual set, or mental predisposition, that greatly influences (top-down) what we perceive. People perceive an adult-child pair as looking more alike when told they are parent and child (Bressan & Dal Martello, 2002). And consider: Is the image in the center picture of Figure 4.46 a man playing a saxophone or a woman’s face? What we see in such a drawing can be influenced by first looking at either of the two unambiguous versions (Boring, 1930).

![Figure 4.46 Perceptual set](image)

“Show a friend either the left or right image. Then show the center image and ask, "What do you see?" Whether your friend reports seeing a saxophonist or a woman’s face will likely depend on which of the other two drawings was viewed first. In each of those images, the meaning is clear, and it will establish perceptual expectations. Sara Nadar, © 1990 Roger N. Shepard

“The temptation to form premature theories upon insufficient data is the bane of our profession.”

Sherlock Holmes, in Arthur Conan Doyle’s *The Valley of Fear*, 1914

Once we have formed a wrong idea about reality, we have more difficulty seeing the truth. Everyday examples of perceptual set abound. In 1972, a British newspaper published genuine, unretouched photographs of a “monster” in Scotland’s Loch Ness—“the most amazing pictures ever taken,” stated the paper. If this information creates in you the same perceptual set it did in most of the paper’s readers, you, too, will see the monster in the photo reproduced in Figure 4.47a. But when Steuart Campbell (1986) approached the photos with a different perceptual set, he saw a curved tree trunk—as had others the day the photo was shot. With this different perceptual set, you may now notice that the object is floating motionless, without any rippling water or wake around it—hardly what we would expect of a lively monster.
Figure 4.47 Believing is seeing What do you perceive in these photos? (a) Is this Nessie, the Loch Ness monster, or a log? (b) Are these flying saucers or clouds? We often perceive what we expect to see. Frank Searle, photo Adams/Corbis-Sygma
Dick Ruhl

- When shown the phrase
  Mary had a
  a little lamb
  many people perceive what they expect, and miss the repeated word. Did you?

Perceptual set can similarly influence what we hear. Consider the kindly airline pilot who, on a takeoff run, looked over at his depressed co-pilot and said, “Cheer up.” The co-pilot heard the usual “Gear up” and promptly raised the wheels—before they left the ground (Reason & Mycielska, 1982). Perceptual set also influenced some bar patrons invited to sample free beer (Lee et al., 2006). When researchers added a few drops of vinegar to a brand-name beer, the tasters preferred it—unless they had been told they were drinking vinegar-laced beer and thus expected, and usually experienced, a worse taste. Perceptual set also influences preschool children’s taste preferences. By a 6 to 1 margin in one experiment, they judged french fries as tasting better when served in a McDonald’s bag rather than a plain white bag (Robinson et al., 2007). Clearly, much of what we perceive comes not just from the world “out there” but also from what’s behind our eyes and between our ears.

© The New Yorker Collection, 2002, Leo Cullum from cartoonbank.com. All rights reserved.
What determines our perceptual set? Through experience we form concepts, or schemas, that organize and interpret unfamiliar information (see Unit 9). Our preexisting schemas for male saxophonists and women’s faces, for monsters and tree trunks, for clouds and UFOs, all influence how we interpret ambiguous sensations with top-down processing.

Our schemas for faces prime us to see facial patterns even in random configurations, such as the Moon’s landscape, clouds, rocks, or cinnamon buns. Kieran Lee, Graham Byatt, and Gillian Rhodes (2000) demonstrated how we recognize people by facial features that cartoonists can caricature. For but a fraction of a second they showed University of Western Australia students three versions of familiar faces—the actual face, a computer-created caricature that accentuated the differences between this face and the average face, and an “anticaricature” that muted the distinctive features. As Figure 4.48 shows, the students more accurately recognized the caricatured faces than the actual ones. A caricatured Arnold Schwarzenegger is more recognizably Schwarzenegger than Schwarzenegger himself!

Figure 4.48 Recognizing faces When briefly flashed, a caricature of Arnold Schwarzenegger was more accurately recognized than Schwarzenegger himself. Ditto for other familiar male faces. Kieran Lee/FaceLab, Department of Psychology, University of Western Australia

Context Effects

A given stimulus may trigger radically different perceptions, partly because of our differing set, but also because of the immediate context. Some examples:

- Imagine hearing a noise interrupted by the words “eel is on the wagon.” Likely, you would actually perceive the first word as wheel. Given “eel is on the orange,” you would hear peel. This curious phenomenon, discovered by Richard Warren, suggests that the brain can work backward in time to allow a later stimulus to determine how we perceive an earlier one. The context creates an expectation that, top-down, influences our perception as we match our bottom-up signal against it (Grossberg, 1995).

Figure 4.49 Context effects: the magician’s cabinet Is the box in the far left frame lying on the floor or hanging from the ceiling? What about the one on the far right? In each case, the context defined by the inquisitive rabbits guides our perceptions. (From Shepard, 1990.)

- Did the pursuing monster in Figure 4.42a look aggressive? Did the identical pursued one seem frightened? If so, you experienced a context effect.
- Is the “magician’s cabinet” in Figure 4.49 sitting on the floor or hanging from the ceiling? How we perceive it depends on the context defined by the rabbits.
- How tall is the shorter player in Figure 4.50?
**Big and “little”** The “little guy” shown here is actually a 6’9” former Hope College basketball center who towers over me. But he seemed like a short player when matched in a semi-pro game against the world’s tallest basketball player, 7’9” Sun Ming Ming from China. Denis R. J. Geppert Holland Sentinel.

“We hear and apprehend only what we already half know.”

Henry David Thoreau, Journal, 1860

Even hearing sad rather than happy music can predispose people to perceive a sad meaning in spoken homophonic words—*mourning* rather than *morning*, *die* rather than *dye*, *pain* rather than *pane* (Halberstadt et al., 1995).

The effects of perceptual set and context show how experience helps us construct perception. In everyday life, for example, stereotypes about gender (another instance of perceptual set) can color perception. Without the obvious cues of pink or blue, people will struggle over whether to call the new baby “he” or “she.” But told an infant is “David,” people (especially children) may perceive “him” as bigger and stronger than if the same infant is called “Diana” (Stern & Karraker, 1989). Some differences, it seems, exist merely in the eyes of their beholders.

**Culture and context effects** What is above the woman’s head? In one study, nearly all the East Africans who were questioned said the woman was balancing a metal box or can on her head and that the family was sitting under a tree. Westerners, for whom corners and boxlike architecture are more common, were more likely to perceive the family as being indoors, with the woman sitting under a window. (Adapted from Gregory & Gombrich, 1973.)
Emotion and Motivation

Perceptions are influenced, top-down, not only by our expectations and by the context, but also by our emotions. Dennis Proffitt (2006a,b) and others have demonstrated this with clever experiments showing that

- walking destinations look farther away to those who have been fatigued by prior exercise.
- a hill looks steeper to those wearing a heavy backpack or just exposed to sad, heavy classical music rather than light, bouncy music.
- a target seems farther away to those throwing a heavy rather than a light object at it.

Even a softball appears bigger when you are hitting well, observed Jessica Witt and Proffitt (2005), after asking players to choose a circle the size of the ball they had just hit well or poorly.

Motives also matter. In Cornell University experiments, students viewed ambiguous figures, such as the horse/seal in Figure 4.51. If rewards were linked with seeing one category of stimulus (such as a farm animal rather than a sea animal), then, after just a one-second exposure to the drawing, viewers tended instantly to perceive an example of their hoped-for category (Balcetis & Dunning, 2006). (To confirm the participants’ honesty in reporting their perceptions, the researchers in one experiment redefined the to-be-rewarded perception after the viewing. Still, people reported perceiving a stimulus from their originally hoped-for category.)
Figure 4.51 Ambiguous horse/seal figure If motivated to perceive farm animals, about 7 in 10 people immediately perceived a horse. If motivated to perceive a sea animal, about 7 in 10 perceived a seal. “Ambiguity of form: Old and new” by G. H. Fisher, 1968, Perception and Psychophysics, 4, 189–192. Copyright 1968 by Psychonomic Society, Inc.

“When you’re hitting the ball, it comes at you looking like a grapefruit. When you’re not, it looks like a blackeyed pea.”

Former major league baseball player George Scott

Emotions color our social perceptions, too. Spouses who feel loved and appreciated perceive less threat in stressful marital events—“He’s just having a bad day” (Murray et al., 2003). Professional referees, if told a soccer team has a history of aggressive behavior, will assign more penalty cards after watching videotaped fouls (Jones et al., 2002). Lee Ross invites us to recall our own perceptions in different contexts: “Ever notice that when you’re driving you hate pedestrians, the way they saunter through the crosswalk, almost daring you to hit them, but when you’re walking you hate drivers?” (Jaffe, 2004).

To return to the question “Is perception innate or learned?” we can answer: It’s both. The river of perception is fed by sensation, cognition, and emotion. And that is why we need multiple levels of analysis (Figure 4.52). “Simple” perceptions are the brain’s creative products.
4.7 Is There Extrasensory Perception?

**25: What are the claims of ESP, and what have most research psychologists concluded after putting these claims to the test?**
There would also be some people, notes Michael Shermer (1999), who would have no need for caller ID, who would never lose at “rock, paper, scissors,” and for whom we could never have a surprise party.

CAN WE PERCEIVE ONLY WHAT WE sense? Or, as nearly half of Americans believe, are we capable of **extrasensory perception (ESP)** without sensory input (AP, 2007; Moore, 2005)?

Are there indeed people—any people—who can read minds, see through walls, or foretell the future? Five British universities have **parapsychology** units staffed by Ph.D. graduates of Edinburgh University’s parapsychology program (Turpin, 2005). Sweden’s Lund University, the Netherlands’ Utrecht University, and Australia’s University of Adelaide also have added faculty chairs or research units for parapsychology. Parapsychologists in such places do experiments that search for possible ESP and other paranormal phenomena. But other research psychologists and scientists—including 96 percent of the scientists in the U.S. National Academy of Sciences—are skeptical that such phenomena exist (McConnell, 1991). If ESP is real, we would need to overturn the scientific understanding that we are creatures whose minds are tied to our physical brains and whose perceptual experiences of the world are built of sensations. Sometimes new evidence does overturn our scientific preconceptions. Science, as we will see throughout this book, offers us various surprises—about the extent of the unconscious mind, about the effects of emotions on health, about what heals and what doesn’t, and much more. Before we evaluate claims of ESP, let’s review them.

### 4.7.1 Claims of ESP

Claims of paranormal phenomena (“psi”) include astrological predictions, psychic healing, communication with the dead, and out-of-body experiences. But the most testable and (for a perception discussion) most relevant claims are for three varieties of ESP:

- **Telepathy**, or mind-to-mind communication—one person sending thoughts to another or perceiving another’s thoughts.
- **Clairvoyance**, or perceiving remote events, such as sensing that a friend’s house is on fire.
- **Precognition**, or perceiving future events, such as a political leader’s death or a sporting event’s outcome.

Closely linked with these are claims of **psychokinesis (PK)**, or “mind over matter,” such as levitating a table or influencing the roll of a die (Figure 4.53). (The claim is illustrated by the wry request, “Will all those who believe in psychokinesis please raise my hand?”)
4.7.2 Premonitions or Pretensions?

“A person who talks a lot is sometimes right.”

Spanish proverb

Can psychics see into the future? Although one might wish for a psychic stock forecaster, the tallied forecasts of “leading psychics” reveal meager accuracy. No greedy—or charitable—psychic has been able to predict the outcome of a lottery jackpot, or to make billions on the stock market. During the 1990s, tabloid psychics were all wrong in predicting surprising events. (Madonna did not become a gospel singer, the Statue of Liberty did not lose both its arms in a terrorist blast, Queen Elizabeth did not abdicate her throne to enter a convent.) And the new-century psychics missed the big-news events, such as the horror of 9/11. (Where were the psychics on 9/10 when we needed them? Why, despite a $50 million reward offered, could none of them help locate Osama bin Laden after 9/11?) Gene Emery (2004), who has tracked annual psychic forecasts for 26 years, reports that almost never have unusual predictions come true, and virtually never have psychics anticipated any of the year’s headline events.

Analyses of psychic visions offered to police departments reveal that these, too, are no more accurate than guesses made by others (Reiser, 1982). Psychics working with the police do, however, generate hundreds of predictions. This increases the odds of an occasional correct guess, which psychics can then report to the media. Moreover, vague predictions can later be interpreted (“retrofitted”) to match events that provide a perceptual set for “understanding” them. Nostradamus, a sixteenth-century French
psychic, explained in an unguarded moment that his ambiguous prophecies “could not possibly be understood till they were interpreted after the event and by it.”

Police departments are wise to all this. When Jane Ayers Sweat and Mark Durm (1993) asked the police departments of America’s 50 largest cities whether they ever used psychics, 65 percent said they never had. Of those that had, not one had found it helpful.

Are the spontaneous “visions” of everyday people any more accurate? Consider our dreams. Do they foretell the future, as people often believe? Or do they only seem to do so because we are more likely to recall or reconstruct dreams that appear to have come true? Two Harvard psychologists (Murray & Wheeler, 1937) tested the prophetic power of dreams after aviator Charles Lindbergh’s baby son was kidnapped and murdered in 1932, but before the body was discovered. When the researchers invited the public to report their dreams about the child, 1300 visionaries submitted dream reports. How many accurately envisioned the child dead? Five percent. And how many also correctly anticipated the body’s location—buried among trees? Only 4 of the 1300. Although this number was surely no better than chance, to those 4 dreamers the accuracy of their apparent precognitions must have seemed uncanny.

Throughout the day, each of us imagines many events. Given the billions of events in the world each day, and given enough days, some stunning coincidences are sure to occur. By one careful estimate, chance alone would predict that more than a thousand times a day someone on Earth will think of someone and then within the ensuing five minutes will learn of the person’s death (Charpak & Broch, 2004). With enough time and people, the improbable becomes inevitable.

That was the experience of comics writer John Byrne (2003). Six months after his Spider-Man story about a New York blackout appeared, New York suffered a massive blackout. A subsequent Spider-Man story line involved a major earthquake in Japan. “And again,” he recalled, “the real thing happened in the month the issue hit the stands.” Later, when working on a Superman comic book, he “had the Man of Steel fly to the rescue when disaster beset the NASA space shuttle. The [1986] Challenger tragedy happened almost immediately thereafter” (with time for the issue to be redrawn). “Most recently, and chilling, came when I was writing and drawing Wonder Woman and did a story in which the title character was killed as a prelude to her becoming a goddess.” The issue’s cover “was done as a newspaper front page, with the headline ‘Princess Diana Dies.’ (Diana is Wonder Woman’s real name.) That issue went on sale on a Thursday. The following Saturday . . . I don’t have to tell you, do I?”

4.7.3 Putting ESP to Experimental Test

In the past, there have been all kinds of strange ideas—that bumps on the head reveal character traits, that bloodletting is a cure-all, that each sperm cell contains a miniature person. Faced with such claims—or with claims of mind-reading or out-of-body travel or communication with the dead—how can we separate bizarre ideas from those that sound bizarre but are true? At the heart of science is a simple answer: Test them to see
if they work. If they do, so much the better for the ideas. If they don’t, so much the better for our skepticism.

**Testing psychic powers in the British population** Hertfordshire University psychologist Richard Wiseman created a “mind machine” to see if people can influence or predict a coin toss. Using a touch-sensitive screen, visitors to festivals around the country were given four attempts to call heads or tails. Using a random-number generator, a computer then decided the outcome. When the experiment concluded in January 2000, nearly 28,000 people had predicted 110,972 tosses—with 49.8 percent correct. Courtesy of Claire Cole

“At the heart of science is an essential tension between two seemingly contradictory attitudes—an openness to new ideas, no matter how bizarre or counterintuitive they may be, and the most ruthless skeptical scrutiny of all ideas, old and new.”

Carl Sagan (1987)
This scientific attitude has led both believers and skeptics to agree that what parapsychology needs is a reproducible phenomenon and a theory to explain it. Parapsychologist Rhea White (1998) spoke for many in saying that “the image of parapsychology that comes to my mind, based on nearly 44 years in the field, is that of a small airplane [that] has been perpetually taxiing down the runway of the Empirical Science Airport since 1882 . . . its movement punctuated occasionally by lifting a few feet off the ground only to bump back down on the tarmac once again. It has never taken off for any sustained flight.”

Seeking a reproducible phenomenon, how might we test ESP claims in a controlled experiment? An experiment differs from a staged demonstration. In the laboratory, the experimenter controls what the “psychic” sees and hears. On stage, the psychic controls what the audience sees and hears. Time and again, skeptics note, so-called psychics have exploited unquestioning audiences with mind-blowing performances in which they appeared to communicate with the spirits of the dead, read minds, or levitate objects—only to have it revealed that their acts were nothing more than the illusions of stage magicians.

“A psychic is an actor playing the role of a psychic.”

Psychologist-magician Daryl Bem (1984)

The search for a valid and reliable test of ESP has resulted in thousands of experiments. Some 380 of them have assessed people’s efforts to influence computer-generated random sequences of ones and zeros. In some small experiments, the tally of the desired number has exceeded chance by 1 or 2 percent, an effect that disappears when larger experiments are added to the mix (Bösch et al. 2006a,b; Radin et al., 2006; Wilson & Shadish, 2006).

“People’s desire to believe in the paranormal is stronger than all the evidence that it does not exist.”
Another set of experiments has invited “senders” to telepathically transmit one of four visual images to “receivers” deprived of sensation in a nearby chamber (Bem & Honorton, 1994). The result? A reported 32 percent accurate response rate, surpassing the chance rate of 25 percent. But follow-up studies have (depending on who was summarizing the results) failed to replicate the phenomenon or produced mixed results (Bem et al., 2001; Milton & Wiseman, 2002; Storm, 2000, 2003).

If ESP nevertheless exists, might it subtly register in the brain? To find out, Harvard researchers Samuel Moulton and Stephen Kosslyn (2008) had a sender try to send one of two pictures telepathically to a receiver lying in an fMRI machine. In these pairs (mostly couples, friends, or twins), the receivers guessed the picture’s content correctly at the level of chance (50.0 percent). Moreover, their brains responded no differently when later viewing the actual pictures “sent” by ESP. “These findings,” concluded the researchers, “are the strongest evidence yet obtained against the existence of paranormal mental phenomena.”

From 1998 to 2010, one skeptic, magician James Randi, offered $1 million “to anyone who proves a genuine psychic power under proper observing conditions” (Randi, 1999, 2008). French, Australian, and Indian groups have parallel offers of up to 200,000 euros to anyone with demonstrable paranormal abilities (CFI, 2003). Large as these sums are, the scientific seal of approval would be worth far more to anyone whose claims could be authenticated. To refute those who say there is no ESP, one need only produce a single person who can demonstrate a single, reproducible ESP phenomenon. (To refute those who say pigs can’t talk would take but one talking pig.) So far, no such person has emerged. Randi’s offer has been publicized for years and dozens of people have been tested, sometimes under the scrutiny of an independent panel of judges. Still, nothing.
“So, how does the mind work? I don’t know. You don’t know. Pinker doesn’t know. And, I rather suspect, such is the current state of the art, that if God were to tell us, we wouldn’t understand.”

Jerry Fodor, “Reply to Steven Pinker,” 2005

To feel awe and to gain a deep reverence for life, we need look no further than our own perceptual system and its capacity for organizing formless nerve impulses into colorful sights, vivid sounds, and evocative smells. As Shakespeare’s Hamlet recognized, “There are more things in Heaven and Earth, Horatio, than are dreamt of in your philosophy.” Within our ordinary sensory and perceptual experiences lies much that is truly extraordinary—surely much more than has so far been dreamt of in our psychology.