Think About It

Do some people "taste" shapes or "hear" colors?

Can our eyes detect only a single particle of light?

Can certain blind people still "see" some of their surroundings?

Can we perceive invisible stimuli?

Can we "read" someone else's thoughts?

Listen in **MyPsychLab** to chapter audio

Before you read any further, try the exercise in **FIGURE 4.1**. Were you surprised that the white "X" disappeared from view? Were you even more surprised that you filled the missing space occupied by the "X" with a mental image exactly matching the fancy background pattern?

Sensation and perception are the underlying processes operating in this visual illusion; it's an **illusion** because the way you perceived the stimulus doesn't match its physical reality. Your brain—not your eyes—perceived a complete pattern even though some of it was missing. **Sensation** refers to the detection of physical energy by our sense organs, including our eyes, ears, skin, nose, and tongue, which then relay information to the brain (see Chapter 3). **Perception** is the brain's *interpretation* of these raw sensory inputs. Simplifying things just a bit, sensation first allows us to pick up the signals in our environments, and perception then allows us to assemble these signals into something meaningful.

We often assume that our sensory systems are infallible and that our perceptions are perfect representations of the world around us. We term these beliefs *naive realism* (see Chapter 1). We'll discover in this chapter that naive realism is wrong, because the world isn't precisely as we see it. Somewhere in our brains we reconstructed that fancy pattern in the figure and put it smack in the middle of the empty space, a perceptual process called *filling-in*, which occurs entirely without our awareness (Weil & Rees, 2011). Most of the time, filling-in is adaptive, as it helps us make sense of our often confusing and chaotic perceptual worlds. But sometimes it can fool us, as in the case of visual illusions.

FIGURE 4.1 Separating Sensation from Perception. Hold this page about 10 inches from your face. Close your right eye and keep focusing on the white circle. Can you see the white *X*? Now slowly move the page toward your face and then away from it; at some point the white *X* will disappear and then reappear. Surprisingly, your brain supplies an illusory background pattern that fills in the white space occupied by the *X*.

Perception researchers have studied filling-in by showing participants incomplete objects on computer screens and determining which *pixels,* or picture elements, participants rely on to make perceptual judgments about the object (Gold et al., 2000). The pixels that participants use to perceive images are often located next to regions where there's no sensory information, demonstrating that we use available sensory information to make sense of what's missing and thereby identify incomplete objects. In other words, we often blend the real with the imagined, going beyond the information given to us. By doing so, we simplify the world, and often make better sense of it in the process.

Two Sides of the Coin: Sensation and Perception

4.1 Identify the basic principles that apply to all senses.

4.2 Discuss the role of attention and the nature of the binding problem.

How do signals that make contact with our sense organs—like our eyes, ears, and tongue—become translated into information that our brains can interpret and act on? And how does the raw sensory information delivered to our brains become integrated with what we already know about the world, allowing us to recognize objects, avoid accidents, and find our way out the door each morning?

Here's how. Our brain picks and chooses among the types of sensory information it uses, often relying on expectations and prior experiences to fill in the gaps and simplify processing. The end result often differs from the sum of its parts—and sometimes it's a completely wrong number! Errors in perception, like the illusion in Figure 4.1 and others we'll examine in this chapter, are often informative, not to mention fun. They show us which parts of our sensory experiences are accurate and which parts our brains fill-in for us.

We'll first discover what our sensory systems can accomplish and how they manage to transform physical signals in the outside world into neural activity in the "inside world"—our brains. Then we'll explore how and when our brains flesh out the details, moving beyond the raw sensory information available to us.

illusion
perception in which the way we perceive a stimulus doesn't match its physical reality

sensation
detection of physical energy by sense organs, which then send information to the brain

perception
the brain's interpretation of raw sensory inputs

Watch in **MyPsychLab** the **Video:** The Basics: In Full Appreciation of the Cookie

Sensation: Our Senses as Detectives

Our senses enable us to see majestic scenery, hear glorious music, feel a loving touch, maintain balance as we walk across a stage, and taste wonderful food. Despite their differences, all of our senses rely on a mere handful of basic principles.

(© ScienceCartoonsPlus.com)

TRANSDUCTION: GOING FROM THE OUTSIDE WORLD TO WITHIN. The first step in sensation is converting external energies or substances into a "language" the nervous system understands. **Transduction** is the process by which the nervous system converts an external stimulus, like light or sound, into electrical signals within neurons. A specific type of **sense receptor**, or specialized cell, transduces a specific stimulus. As we'll learn, specialized cells at the back of the eye transduce light, cells in a spiral-shaped organ in the ear transduce sound, odd-looking endings attached to axons embedded in deep layers of the skin transduce pressure, receptor cells lining the inside of the nose transduce airborne odorants, and taste buds transduce chemicals containing flavor.

For all of our senses, activation is greatest when we first detect a stimulus. After that, our response declines in strength, a process called **sensory adaptation**. What happens when we sit on a chair? After a few seconds, we no longer notice it, unless it's an extremely hard seat, or worse, has a thumbtack on it. The adaptation takes place at the level of the sense receptor. This receptor reacts strongly at first and then tamps down its level of responding to conserve energy and attentional resources. If we didn't engage in sensory adaptation, we'd be attending to just about everything around us, all of the time.

PSYCHOPHYSICS: MEASURING THE BARELY DETECTABLE. Back in the 19th century, when psychology was gradually distinguishing itself as a science apart from philosophy, many researchers focused on sensation and perception. In 1860, German scientist Gustaf Fechner published a landmark work on perception. Out of his efforts grew **psychophysics**, the study of how we perceive sensory stimuli based on their physical characteristics.

Absolute Threshold. Imagine that a researcher fits us with a pair of headphones and places us in a quiet room. She asks repeatedly if we've heard one of many very faint tones. Detection isn't an all-or-none state of affairs because human error increases as stimuli become weaker in magnitude. Psychophysicists study phenomena like the **absolute threshold** of a stimulus—the lowest level of a stimulus we can detect on 50 percent of the trials when no other stimuli of that type are present. Absolute thresholds demonstrate how remarkably sensitive our sensory systems are. On a clear night, our visual systems can detect a single candle from 30 miles away. We can detect a smell from as few as 50 airborne odorant molecules; the salamander's exquisitely sensitive sniffer can pull off this feat with only one (Menini, Picco, & Firestein, 1995).

Just Noticeable Difference. Just how much of a difference in a stimulus makes a difference? The **just noticeable difference (JND)** is the smallest change in the intensity of a stimulus that we can detect. The JND is relevant to our ability to distinguish a stronger from a weaker stimulus, like a soft noise from a slightly louder noise. Imagine we're playing a song on an iPod but the volume is turned so low that we can't hear it. If we nudge the volume dial up to the point at which we can *just* begin to make out the song, that's a JND. **Weber's law** states that there's a constant proportional relationship between the JND and the original stimulus

transduction
the process of converting an external energy or substance into electrical activity within neurons

sense receptor
specialized cell responsible for converting external stimuli into neural activity for a specific sensory system

sensory adaptation
activation is greatest when a stimulus is first detected

psychophysics
the study of how we perceive sensory stimuli based on their physical characteristics

absolute threshold
lowest level of a stimulus needed for the nervous system to detect a change 50 percent of the time

just noticeable difference (JND)
the smallest change in the intensity of a stimulus that we can detect

Weber's Law
there is a constant proportional relationship between the JND and original stimulus intensity

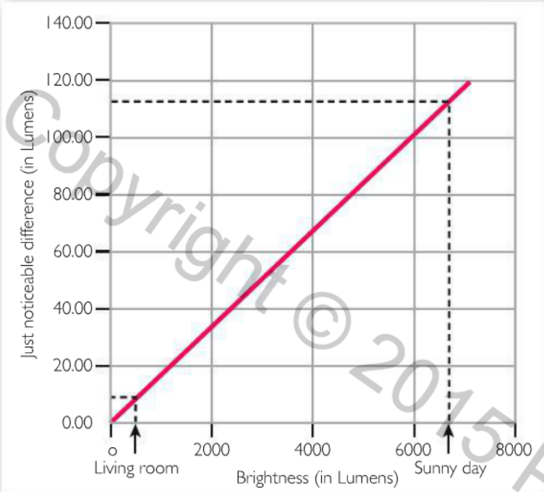


FIGURE 4.2 Just Noticeable Differences (JNDs) Adhere to Weber's Law. In this example, changes in light are shown measured in lumens, which are units equaling the amount of light generated by one candle standing one foot away. Weber's law states that the brighter the light, the more change in brightness is required for us to be able to notice a difference.

intensity (see **FIGURE 4.2**). In plain language, the stronger the stimulus, the bigger the change needed for a change in stimulus intensity to be noticeable. Imagine how much light we'd need to add to a brightly lit kitchen to notice an increase in illumination compared with the amount of light we'd need to add to a dark bedroom to notice a change in illumination. We'd need a lot of light in the first case and only a smidgeon in the second.

Signal Detection Theory. David Green and John Swets (1966) developed **signal detection theory** to describe how we detect stimuli under uncertain conditions, as when we're trying to figure out what a friend is saying on a cell phone when there's a lot of static in the connection—that is, when there's high background noise. We'll need to increase the signal by shouting over the static or else our friend won't understand us. If we have a good connection, however, our friend can easily understand us without our shouting. This example illustrates the *signal-to-noise ratio:* It becomes harder to detect a signal as background noise increases.

Green and Swets were also interested in *response biases,* or tendencies to make one type of guess over another when we're in doubt about whether a weak signal is present or absent under noisy conditions. They developed a clever way to take into account some people's tendency to say "yes" when they're uncertain and other people's tendency to say "no" when they're uncertain. Instead of always delivering a sound, they sometimes presented a sound, sometimes not. This procedure allowed them to detect and account for participants' response biases. As we can see in **TABLE 4.1**, participants can report that they heard a sound when it was present (a *true positive*, or hit), deny hearing a sound when it was present (a *false negative*, or miss), report hearing a sound that wasn't there (a *false positive*, or false alarm), or deny hearing a sound that wasn't there (a *true negative*, or correct rejection). The frequency of false negatives and false positives helps us measure how biased participants are to respond "yes" or "no" in general.

TABLE 4.1 Distinguishing Signals from Noise. In signal detection theory there are true positives, false negatives, false positives, and true negatives. Subject biases affect the probability of "yes" and "no" responses to the question "Was there a stimulus?"

	RESPOND "YES"	RESPOND "NO"
Stimulus present	True Positive	False Negative
Stimulus absent	False Positive	True Negative

Sensory Systems Stick to One Sense—Or Do They? Back in 1826, Johannes Müller proposed the doctrine of *specific nerve energies,* which states that even though there are many distinct stimulus energies—like light, sound, or touch—the sensation we experience is determined by the nature of the sense receptor, not the stimulus. To get a sense of this principle in action, the next time you rub your eyes shortly after waking up, try to notice phosphenes—vivid sensations of light caused by pressure on your eye's receptor cells. Many phosphenes look like sparks, and some even look like multicolored shapes in a kaleidoscope. Some people have speculated that phosphenes may explain certain reports of ghosts and UFOs (Neher, 1990).

Why do phosphenes occur? In the cerebral cortex, different areas are devoted to different senses (see Chapter 3). It doesn't matter to our brain whether light or touch activated the sense receptor: Our brains react the same way in either case. That is, once our visual sense receptors send their signals to the cortex, the brain interprets their input as visual, regardless of how our receptors were stimulated in the first place.

Most areas of the cortex are connected to cortical areas devoted to the same sense: Vision areas tend to be connected to other vision areas, hearing areas to other hearing areas, and so on. Yet scientists have found many examples of cross modal processing that produce different perceptual experiences than either modality provides by itself. One striking example is the *McGurk effect* (McGurk & MacDonald, 1976; Nahorna et al., 2012). This effect demonstrates that we integrate visual and auditory information when processing spoken language, and our brains automatically calculate the most probable sound given the information from the two sources. In the McGurk effect, hearing the audio track of one syllable (such as "ba") spoken repeatedly while seeing a video track of a different syllable being spoken (such as "ga") produces the perceptual experience of a different third sound

signal detection theory
theory regarding how stimuli are detected under different conditions

(such as "da"). This third sound is the brain's best "guess" at integrating the two conflicting sources of information (see Chapter 8).

Another fascinating example is an illusion that shows how our senses of touch and sight interact to create a false perceptual experience (Erhsson, Spence, & Passingham, 2004; Knox et al., 2006). This illusion involves placing a rubber hand on top of a table with the precise positioning that a participant's hand would have if she were resting it on the table. The participant's hand is placed under the table, out of her view. A researcher simultaneously strokes the participant's hidden hand and rubber hand gently with a paintbrush. When the strokes match each other, the participant experiences an eerie illusion: The rubber hand seems to be her own hand.

As we've seen, these cross-modal effects may reflect "cross-talk" among different brain regions. But there's an alternative explanation: In some cases, a single brain region may serve double duty, helping to process multiple senses. For example, neurons in the auditory cortex tuned to sound also respond weakly to touch (Fu et al., 2003). Visual stimuli enhance touch perception in the somatosensory cortex (Taylor-Clarke, Kennett, & Haggard, 2002). The reading of Braille by people blind from birth activates their visual cortex (Gizewski et al., 2003; see Chapter 3). And monkeys viewing videos with sound display increased activity in their primary auditory cortex compared with exposure to sound alone (Kayser et al., 2007).

Sir Francis Galton (1880) was the first to describe **synesthesia**, a rare condition in which people experience cross-modal sensations, like hearing sounds when they see colors—sometimes called "colored hearing"—or even tasting or smelling colors (Cytowic & Eagleman, 2009; Marks, in press). Synesthesia may be an extreme version of the cross-modal responses that most of us experience from time to time (Rader & Tellegen, 1987). No one knows for sure how widespread synesthesia is. An early estimate put it at no higher than about 1 in 2,000 people (Baron-Cohen et al., 1993); however, a more recent survey of 500 British university students estimated the prevalence to be about 4 percent, implying that it might not be as rare as once thought (Simner et al., 2006).

In the past, some scientists questioned the authenticity of synesthesia, yet research demonstrates that the condition is genuine (Ramachandran & Hubbard, 2001). **FIGURE 4.3** illustrates a clever test that detects grapheme-color synesthesia. Specific parts of the visual cortex become active during most synesthesia experiences, verifying that these experiences are associated with brain activity (Paulesu et al., 1995; Rouw et al., 2011).

synesthesia
a condition in which people experience cross-modal sensations

selective attention
process of selecting one sensory channel and ignoring or minimizing others

RULING OUT RIVAL HYPOTHESES
Have important alternative explanations for the findings been excluded?

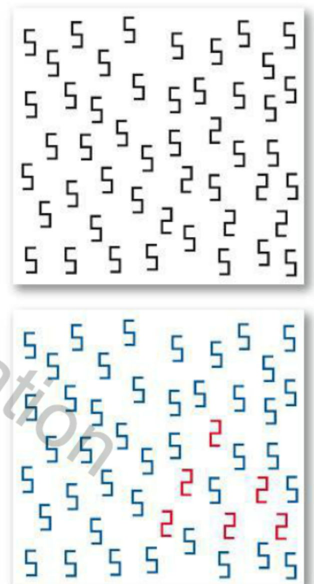


FIGURE 4.3 Are You Synesthetic? Although most of us see the top image as a bunch of jumbled numbers, some grapheme-color synesthetes, who "see" certain numbers as colors, perceive it as looking like the image on the bottom. Synesthesia makes it much easier to find the 2s embedded in a field of 5s.

The Role of Attention

In a world in which our brains are immersed in a sea of sensory input, flexible attention is critical to our survival and well-being. To zero in on a video game we play in the park, for example, we must ignore that speck of dust on our shirt, the shifting breeze, and the riot of colors and sounds in the neighborhood. Yet at any moment we must be prepared to use sensory information that signals a potential threat, such as an approaching thunderstorm. Fortunately, we're superbly well equipped to meet the challenges of our rich and ever-changing sensory environments.

SELECTIVE ATTENTION: HOW WE FOCUS ON SPECIFIC INPUTS. If we're constantly receiving inputs from all our sensory channels, like a TV set with all channels switched on at once, how do we keep from becoming hopelessly bewildered? **Selective attention** allows us to select one channel and turn off the others, or at least turn down their volume.

Simulate in **MyPsychLab** the **Experiment:** Selective Attention

Donald Broadbent's (1957) *filter theory of attention* views attention as a bottleneck through which information passes. This mental filter enables us to pay attention to important stimuli and ignore others. Broadbent tested his theory using a task called *dichotic listening*—in which participants hear two different messages, one delivered to the left ear and one to the right ear. When Broadbent asked participants to ignore messages delivered to one of the ears, they seemed to know little or nothing about these messages. Anne Treisman (1960) replicated these findings, elaborating on them by asking participants to repeat the messages they heard. Although participants could only repeat the messages to which they'd attended, they'd sometimes mix in some of the information they were

REPLICABILITY
Can the results be duplicated in other studies?

FIGURE 4.4 The Cocktail Party Effect. The cocktail party effect helps explain how we can become aware of stimuli outside of our immediate attention when it's relevant to us—like our names.

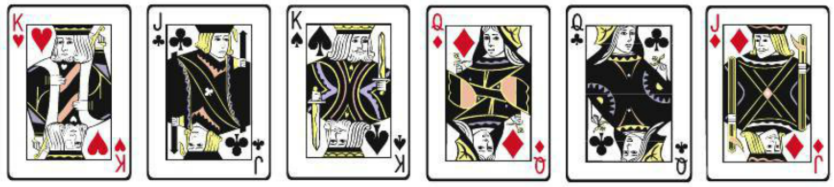


FIGURE 4.5 An ESP Trick? Try It and Find Out. Try this "ESP trick," adapted from a demonstration by Clifford Pickover. This remarkable trick will demonstrate that we—the authors of this book—can read your mind! Select one of the six cards and be sure to recall it. To help you remember it, repeat its name out loud several times. Once you're sure you have the card in mind, turn to page 138.

supposed to ignore, especially if it made sense to add it. If the attended ear heard, "I saw the girl … song was wishing," and the unattended ear heard, "me that bird … jumping in the street," a participant might hear "I saw the girl jumping in the street," because the combination forms a meaningful sentence. The information we've supposedly filtered out of our attention is still being processed at some level—even when we're not aware of it (Beaman, Bridges, & Scott, 2007).

An attention-related phenomenon called the *cocktail party effect* refers to our ability to pick out an important message, like our name, in a conversation that doesn't involve us. We don't typically notice what other people are saying in a noisy restaurant or at a party unless it's relevant to us—and then suddenly, we perk up. This finding tells us that the filter inside our brain, which selects what will and won't receive our attention, is more complex than just an "on" or "off" switch. Even when seemingly "off," it's ready to spring into action if it perceives something significant (see **FIGURE 4.4**).

INATTENTIONAL BLINDNESS. Before reading on, try the ESP trick in **FIGURE 4.5**. We're going to try to read your mind. Then come back and read the next paragraph.

We're surprisingly poor at detecting stimuli in plain sight when our attention is focused elsewhere (Henderson & Hollingworth, 1999; Levin & Simons, 1997; McConkie & Currie, 1996). In an astonishing demonstration of this phenomenon, called **inattentional blindness**, Daniel Simons and Christopher Chabris (1999, 2010) asked subjects to watch a video of people tossing a basketball back and forth quickly, and required them to keep track of the number of passes. Then, smack in the middle of the video, a woman dressed in a gorilla suit strolled across the scene for a full 9 seconds. Remarkably, about half the viewers failed to notice the hairy misfit even though she paused to face the camera and thumped her chest. This and other findings demonstrate that we often need to pay close attention to pick out even dramatic changes in our environments (Koivisto & Revonsuo, 2007; Rensink, O'Regan, & Clark, 1997).

A closely related phenomenon, called *change blindness*, is a failure to detect obvious changes in one's environment (if you've tried the ESP trick we mentioned, you'll know what we mean). Change blindness is a particular concern for airplane pilots, who may fail to notice another plane taxiing across the runway as they're preparing to land (Podczerwinski, Wickens, & Alexander, 2002). You may be relieved to hear that industrial/organizational psychologists are working actively with aviation agencies to reduce the incidence of this problem (see Chapter 1).

The Binding Problem: Putting the Pieces Together

The *binding problem* is one of the great mysteries of psychology. When we perceive an apple, different regions of our brains process different aspects of it. Yet somehow—we don't really know how—our brains manage to combine or "bind" these diverse pieces of information into a unified whole. An apple looks red and round, feels smooth, tastes sweet and tart, and smells, well, like an apple. Any one of its characteristics in isolation isn't an apple or even a part of an apple. One hypothesis is that rapid, coordinated activity across

inattentional blindness
failure to detect stimuli that are in plain sight when our attention is focused elsewhere

multiple cortical areas assists in binding (Engel & Singer, 2001). Binding may explain many aspects of perception and attention. When we see the world, we rely on shape, motion, color, and depth cues, each of which requires different amounts of time to detect individually (Bartels & Zeki, 2006). Yet our minds seamlessly combine these visual cues into a unified perception of a scene. To better understand how perception and attention work together, we'll next discuss the different senses we rely on to make our way in the world, starting with the visual system.

from inquiry to understanding

HOW DOES MAGIC WORK?

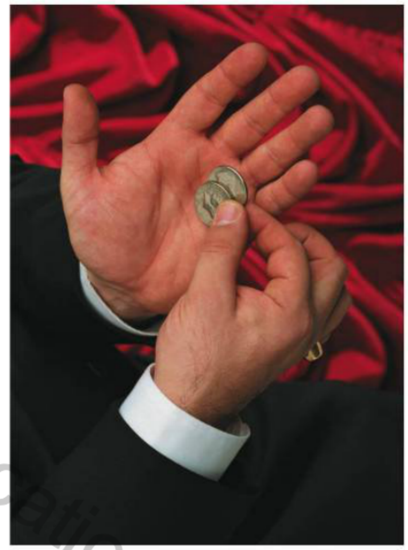
When you think of the astonishing tricks of stage magicians, does psychological science come to mind? Probably not. Yet in the past decade, psychologists and neuroscientists have partnered with famous magicians, including the Amazing Randi and Teller (of Penn & Teller fame) (Macknik et al., 2008), to establish a "science of magic." This science promises to unravel the psychological mechanisms of the reality-bending illusions that magicians create (Kuhn et al., 2008; Stone, 2012). Magic tricks that confound and astound us can yield their secrets (only a few spoilers here) to researchers, and contribute to our understanding of perception.

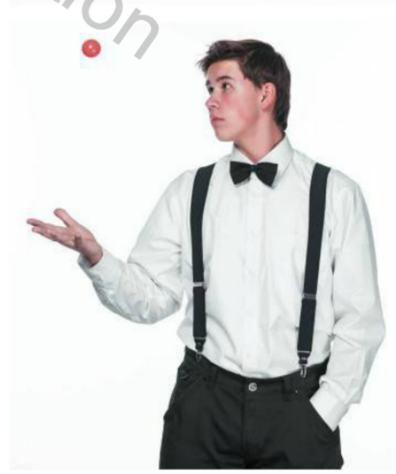
Many of us have heard the old saying, "The hand is quicker than the eye" with regard to the ability of stage magicians to create mind-boggling stunts involving sleight of hand. Yet this adage actually reflects a popular misconception, as most magic tricks are carried out at a normal speed (Kuhn et al., 2008). Researchers have discovered that a more accurate phrase to capture how magicians fool us is "The hand is quicker than the brain."

Consider the following example. A stage magician can get people to believe that a coin has disappeared after it is seemingly transferred from his right to left hand, because the audience can't tell that he secretly concealed (palmed) the coin in the right hand. The magician takes advantage of a little-known fact: viewers don't consciously register information for a small fraction of second after it arrives in the brain, making it appear that the coin is still in the left hand, when it actually has been removed and hidden in the right hand (Stone, 2012). Because the onlooker's visual neurons keep firing for one-hundredth of a second after the coin is transferred (Libet et al., 1983), it ensures that the coin will appear to be in the left hand just long enough to fool observers. So when the magician opens his left hand, to the amazement of the stunned audience, the coin appears to have vanished!

Researchers have studied the vanishing ball illusion to understand how mental predictions and expectancies, rather than reality, affect perception. Here's how this fascinating illusion works. The magician throws two balls into the air, one at a time, and catches each in his hand. On both throws, his head and eyes look up to track the flight of the ball. The third time, the magician pretends to throw the ball, but secretly palms it in his hand as he moves his head up to follow the imaginary ball. In one study of this illusion (Kuhn & Land, 2006), two-thirds of the observers who viewed this trick perceived the ball to leave the magician's hand and disappear in mid-flight. In a second condition, rather than move his head to follow the flight of the imaginary ball, the magician looked at the hand that concealed the ball. When this occurred, less than a third of the participants said the ball vanished. The success of the trick depended on the head direction of the magician, a social cue that created the expectation that the ball was in flight, which never actually happened.

Stage magicians also trick people by other means, such as by misdirecting attention and awareness. This technique fools us because we're consciously aware of and attend to only a tiny part of the information that enters our eyes (Kuhn et al., 2008; Rensink et al., 1997). By riveting the audience's attention to a grand theatrical movement, such as pulling the proverbial rabbit out of a hat, the performer distracts onlookers from noticing a less obvious movement related to a secret prop that's essential to the next trick. So the next time you witness the likes of "The Fabulous Fabrini" performing captivating feats of magic on stage or screen, don't be surprised if scientists are studying him to sleuth how attention, awareness, and perception can play tricks on our minds.





Stage magicians capitalize on tricks of perception. In the case of the vanishing coin trick, there's a delay between the time something is "seen" and when the information about the event arrives in the brain; in the case of the vanishing ball illusion, cues—the magician's head moving upwards—shape the perception of the ball moving in the air and disappearing when it's actually in his palm.

Study and Review in MyPsychLab

Assess Your Knowledge — FACT or FICTION?

1. Perception is an exact translation of our sensory experiences into neural activity. **True / False**
2. In signal detection theory, false positives and false negatives help us measure how much someone is paying attention. **True / False**
3. Cross-modal activation produces different perceptual experiences than either modality provides by itself. **True / False**
4. The rubber hand illusion shows how our senses of smell and touch interact to create a false perceptual experience. **True / False**
5. Selective attention allows us to pay attention to important stimuli and ignore others. **True / False**

Answers: 1. F (p. 126); 2. F (p. 128); 3. T (p. 129); 4. F (p. 129); 5. T (p. 129)

Seeing: The Visual System

4.3 Explain how the eye starts the visual process.
4.4 Identify the different kinds of visual perception.
4.5 Describe different visual problems.

The first thing we see after awakening is typically unbiased by any previous image. If we're on vacation and sleeping somewhere new, we may not recognize our surroundings for a moment or two. Building up an image involves many external elements, such as light, biological systems in the eye and brain that process images for us, and our past experiences.

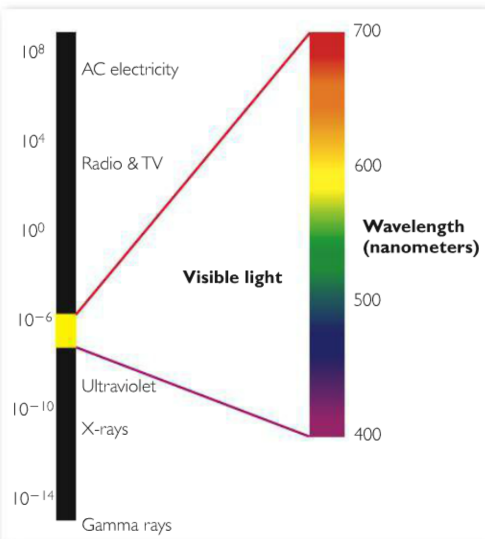


FIGURE 4.6 The Visible Spectrum Is a Subset of the Electromagnetic Spectrum. Visible light is electromagnetic energy between ultraviolet and infrared. Humans are sensitive to wavelengths ranging from slightly less than 400 nanometers (violet) to slightly more than 700 nanometers (red).

Light: The Energy of Life

One of the central players in our perception of the world is light, a form of electromagnetic energy—energy composed of fluctuating electric and magnetic waves. Visible light has a *wavelength* in the hundreds of nanometers (a nanometer is one billionth of a meter). As we can see in **FIGURE 4.6**, we respond only to a narrow range of wavelengths of light; this range is the human visible spectrum. Each animal species detects a specific visible range, which can extend slightly above or below the human visible spectrum. Butterflies are sensitive to all of the wavelengths we detect in addition to ultraviolet light, which has a shorter wavelength than violet light. We might assume that the human visible spectrum is fixed, but increasing the amount of vitamin A in our diets can increase our ability to see infrared light, which has a longer wavelength than red light (Rubin & Walls, 1969).

When light reaches an object, part of that light gets reflected by the object and part gets absorbed. Our perception of an object's *brightness* is influenced directly by the intensity of the reflected light that reaches our eyes. Completely white objects reflect all of the light shone on them and absorb none of it, whereas black objects do the opposite. So white and black aren't really "colors:" white is the presence of all colors, black the absence of them. The brightness of an object depends not only on the amount of reflected light, but also on the overall lighting surrounding the object.

Psychologists call the color of light **hue**. We're maximally attuned to three primary colors of light: red, green, and blue. The mixing of varying amounts of these three colors—called *additive color mixing*—can produce any color (see **FIGURE 4.7**). Mixing equal amounts of red, green, and blue light produces white light. This process differs from the mixing of colored pigments in paint or ink, called *subtractive color mixing*. As we can see in most printer color ink cartridges, the primary colors of pigment are yellow, cyan, and magenta. Mixing them produces a dark color because each pigment absorbs certain wavelengths. Combining them absorbs most or all wavelengths, leaving little or no color (see Figure 4.7).

hue
color of light

The Eye: How We Represent the Visual Realm

Without our eyes we couldn't sense or perceive much of anything about light, aside from the heat it generates. Keep an "eye" on **FIGURE 4.8** as we tour the structures of the eye.

HOW LIGHT ENTERS THE EYE. Different parts of our eye allow in varying amounts of light, permitting us to see either in bright sunshine or in a dark theater. Structures toward the front of the eyeball influence how much light enters our eye, and they focus the incoming light rays to form an image at the back of the eye.

The Sclera, Iris, and Pupil. Although poets have told us that the eyes are the windows to the soul, when we look people squarely in the eye all we can see is their sclera, iris, and pupil. The sclera is simply the white of the eye. The iris is the colored part of the eye, and is usually blue, brown, green, or hazel. Like the shutter of a camera, the iris controls how much light enters our eyes.

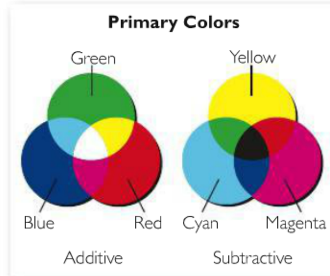


FIGURE 4.7 Additive and Subtractive Color Mixing. Additive color mixing of light differs from subtractive color mixing of paint.

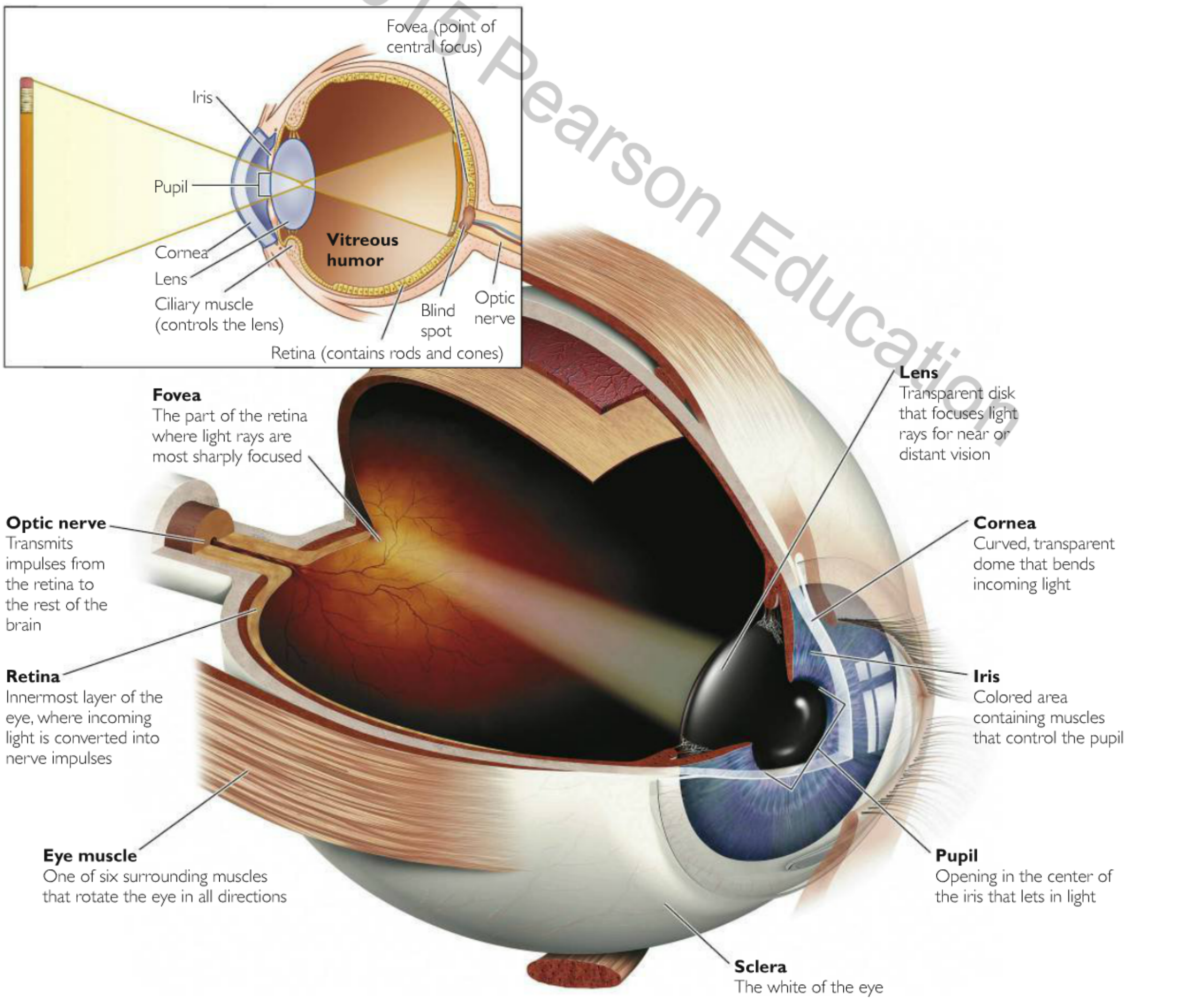
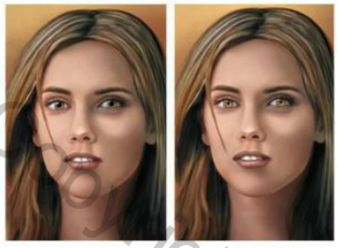


FIGURE 4.8 The Key Parts of the Eye.

The **pupil** is a circular hole through which light enters the eye. The closing of the pupil is a reflex response to light or objects coming toward us. If we walk out of a building into bright sunshine, our eyes respond with the pupillary reflex to decrease the amount of light allowed into them. This reflex occurs simultaneously in both eyes (unless there's neurological damage), so shining a flashlight into one eye triggers it in both.

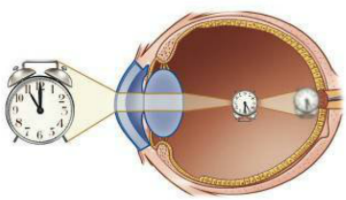
pupil
circular hole through which light enters the eye



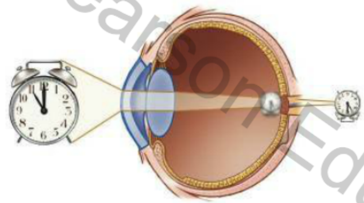
Research demonstrates that men tend to find the faces of women with larger pupils (in this case, the face on the left) more attractive than those with smaller pupils, even when they're unaware of the reason for their preference. (*Source:* Hess, 1965; Tombs & Silverman, 2004).

The dilation (expansion) of the pupil also has psychological significance. Our pupils dilate when we're trying to process complex information, like difficult math problems (Beatty, 1982; Karatekin, 2004). They also dilate when we view someone we find physically attractive, and reflect sexual interest of homosexual as well as heterosexual individuals (Rieger & Savin-Williams, 2012; Tombs & Silverman, 2004). These findings may help to explain why people find faces with large pupils more attractive than faces with small pupils, even when they're oblivious to this physical difference (Hess, 1965; Tomlinson, Hicks, & Pelligrini, 1978). Researchers found that when they're in the fertile phase of their menstrual cycles, women are especially prone to prefer men with large pupils (Caryl et al., 2009). For centuries European women applied a juice from a poisonous plant called belladonna (Italian for "beautiful woman"), sometimes also called deadly nightshade, to their eyes to dilate their pupils, and thereby make themselves more attractive to men. Today, magazine photographers often enlarge the pupils of models, reasoning it will increase their appeal.

The Cornea, Lens, and Eye Muscles. The **cornea** is a curved, transparent layer covering the iris and pupil. Its shape bends incoming light to focus the incoming visual image at the back of the eye. The **lens** also bends light, but unlike the cornea, the lens changes its curvature, allowing us to fine-tune the visual image. The lens consists of some of the most unusual cells in the body: They're completely transparent, allowing light to pass through them.



(a) Nearsighted eye



(b) Farsighted eye

FIGURE 4.9 Nearsighted and Farsighted Eyes. Nearsightedness or farsightedness results when light is focused in front of or behind the retina, respectively.

Explore in **MyPsychLab** the **Concept:** Normal Vision, Nearsightedness, and Farsightedness

In a process called **accommodation**, the lenses change shape to focus light on the back of the eyes; in this way, they adapt to different perceived distances of objects. So, nature has generously supplied us with a pair of "internal" corrective lenses, although they're often far from perfect. Accommodation can either make the lens "flat" (that is, long and skinny) enabling us to see distant objects, or "fat" (that is, short and wide) enabling us to focus on nearby objects. For nearby objects, a fat lens works better because it more effectively bends the scattered light and focuses it on a single point at the back of the eye.

The Shape of the Eye. How much our eyes need to bend the path of light to focus properly depends on the curve of our corneas and overall shape of our eyes. Nearsightedness, or *myopia,* results when images are focused in front of the rear of the eye due to our cornea being too steep or our eyes too long (see **FIGURE 4.9a**). Nearsightedness, as the name implies, is an ability to see close objects well coupled with an inability to see far objects well. Farsightedness, or *hyperopia,* results when our cornea is too flat or our eyes too short (see **FIGURE 4.9b**). Farsightedness, as the name implies, is an ability to see far objects well coupled with an inability to see near objects well. Our vision tends to worsen as we become older. That's because our lens can accommodate and overcome the effects of most mildly misshapen eyeballs until it loses its flexibility due to aging. This explains why only a few first-graders need eyeglasses, whereas most senior citizens do.

THE RETINA: CHANGING LIGHT INTO NEURAL ACTIVITY. The **retina**, which according to many scholars is technically part of the brain, is a thin membrane at the back of the eye. The **fovea** is the central part of the retina and is responsible for **acuity**, or sharpness of vision. We need a sharp image to read, drive, sew, or do just about anything requiring fine detail. We can think of the retina as a "movie screen" onto which light from the world is projected. It contains 100 million sense receptor cells for vision, along with cells that process visual information and send it to the brain.

Rods and Cones. Light passes through the retina to sense receptor cells located in its outermost layer. The retina contains two types of receptor cells. The far more plentiful **rods**, which are long and narrow, enable us to see basic shapes and forms. We rely on rods to see in low levels of light. When we enter a dimly lit room, like a movie theater, from a bright environment, **dark adaptation** occurs. Dark adaptation takes about 30 minutes, or about the time it takes rods to regain their maximum sensitivity to light (Lamb & Pugh, 2004). Some have even

cornea
part of the eye containing transparent cells that focus light on the retina

lens
part of the eye that changes curvature to keep images in focus

accommodation
changing the shape of the lens to focus on objects near or far

retina
membrane at the back of the eye responsible for converting light into neural activity

fovea
central portion of the retina

acuity
sharpness of vision

rods
receptor cells in the retina allowing us to see in low levels of light

dark adaptation
time in dark before rods regain maximum light sensitivity

speculated that pirates of old, who spent many long, dark nights at sea, might have worn eye patches to facilitate dark adaptation. There are no rods in the fovea, which explains why we should tilt our heads slightly to the side to see a dim star at night. Paradoxically, we can see the star better by *not* looking at it directly. By relying on our peripheral vision, we allow more light to fall on our rods.

The less numerous **cones**, which are shaped like—you guessed it—small cones, give us our color vision. We put our cones to work when reading because they're sensitive to detail; however, cones also require more light than do rods. That's why most of us have trouble reading in a dark room.

Different types of receptor cells contain *photopigments,* chemicals that change following exposure to light. The photopigment in rods is *rhodopsin*. Vitamin A, found in abundance in carrots, is needed to make rhodopsin. This fact led to the urban legend that eating carrots is good for our vision. Unfortunately, the only time vitamin A improves vision is when vision is impaired due to vitamin A deficiency.

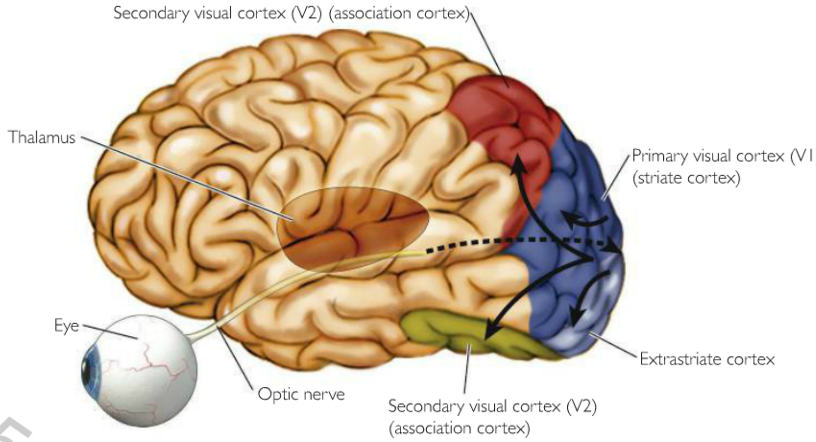


FIGURE 4.10 Perception and the Visual Cortex Visual information from the retina travels to the visual thalamus. Next, the visual thalamus sends inputs to the primary visual cortex (V1), then along two visual pathways to the secondary visual cortex (V2; see p. 136). One pathway leads to the parietal lobe, which processes visual form, position, and motion; and one to the temporal lobe, which processes visual form and color.

The Optic Nerve. The *ganglion cells,* cells in the retinal circuit that contain axons, bundle all their axons together and depart the eye to reach the brain. The **optic nerve**, which contains the axons of ganglion cells, travels from the retina to the rest of the brain. After the optic nerves leave both eyes, they come to a fork in the road called the optic chiasm. Half of the axons cross in the optic chiasm and the other half stay on the same side. Within a short distance, the optic nerves enter the brain, turning into the optic tracts. The optic tracts send most of their axons to the visual part of the thalamus and then to the primary visual cortex—called V1—the primary route for visual perception (see **FIGURE 4.10**). The remaining axons go to structures in the midbrain, particularly the *superior colliculus* (see Chapter 3). These axons play a key role in reflexes, like turning our heads to follow something interesting.

The place where optic nerve connects to the retina is a **blind spot**, a part of the visual field that we can't see. It's a region of the retina containing no rods or sense receptors (refer back to Figure 4.8). We have a blind spot because the axons of ganglion cells push everything else aside. The exercise we performed at the outset of this chapter made use of the blind spot to generate an illusion (refer back to Figure 4.1). Our blind spot is there all of the time, creating perhaps the most remarkable of all visual illusions—one we experience every moment of our seeing lives. Our brain fills in the gaps created by the blind spot, and because each of our eyes supplies us with a slightly different picture of the world, we don't ordinarily notice it.

Factoid

Our eyes do not emit tiny particles of light, which allow us to perceive our surroundings. Many children and about 50 percent of college students (including those who've taken introductory psychology classes) harbor this belief, often called "emission theory" (Winer et al., 2002). Nevertheless, there's no scientific evidence for this theory, and considerable evidence against it.

HOW WE PERCEIVE SHAPE AND CONTOUR. In the 1960s, David Hubel and Torsten Wiesel sought to unlock the secrets of how we perceive shape and form; their work eventually garnered them a Nobel Prize. They used cats as subjects because their visual systems are much like ours. Hubel and Wiesel recorded electrical activity in the visual cortexes of cats while presenting them with visual stimuli on a screen (see **FIGURE 4.11**). At first, they were unaware of

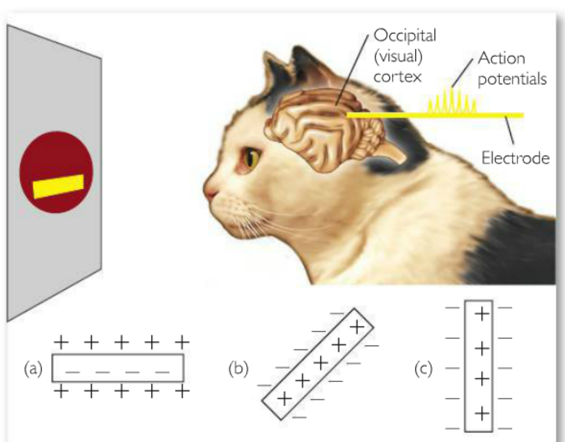


FIGURE 4.11 Cells Respond to Slits of Light of a Particular Orientation. *Top:* Hubel and Wiesel studied activity in the visual cortex of cats viewing slits of light on a screen. *Bottom:* Visual responses were specific to slits of dark on light (minuses on pluses—a) or light on dark (pluses on minuses—b) that were of particular orientations, such as horizontal, oblique, or vertical—(c). Cells in the visual cortex also detected edges.

cones
receptor cells in the retina allowing us to see in color

optic nerve
nerve that travels from the retina to the brain

blind spot
part of the visual field we can't see because of an absence of rods and cones