which stimuli would work best, so they tried many types, including bright and dark spots. At one point, they put up a different kind of stimulus on the screen, a long slit of light. As the story goes, one of their slides jammed in the slide projector slightly off-center, producing a slit of light (Horgan, 1999). Cells in the brain area V1 suddenly went haywire, firing action potentials at an amazingly high rate when the slit moved across the screen. Motivated by this surprising result, Hubel and Wiesel devoted years to figuring out which types of slits elicited such responses.

Here's what they found (Hubel & Wiesel, 1962; 1963). Many cells in V1 respond to slits of light of a specific orientation, for example, vertical, horizontal, or oblique lines or edges (refer again to Figure 4.11). Some cells in the visual cortex, *simple cells*, display "yes–no" responses to slits of a specific orientation, but these slits need to be in a specific location. Other cells, *complex cells,* are also orientation-specific, but their responses are less restricted to one location. This feature makes complex cells much more advanced than simple cells.

We're not alone when it comes to detecting edges and corners. In this example, a computer program detects edges (*blue*) and corners (*red*).

Feature Detection. Our ability to use certain minimal patterns to identify objects is called *feature detection*. Although simple and complex cells are **feature detector cells** in that they detect lines and edges, there are more complex feature detector cells at higher, that is, later levels of visual processing. They detect lines of specific lengths, complex shapes, and even moving objects. We use our ability to detect edges and corners to perceive many human-made objects, like furniture, laptops, and even the corners of the page you're reading at this moment.

As we saw in Figure 4.10, visual information travels from V1 to higher visual areas, called V2, along two major routes, one of which travels to the upper parts of the parietal lobe, and the other of which travels to the lower part of the temporal lobe (see Chapter 3). Numerous researchers have proposed a model of visual processing in which successively higher cortical regions process more and more complex shapes (Riesenhuber & Poggio, 1999). The many visual processing areas of the cortex enable us to progress from perceiving basic shapes to the enormously complex objects we see in our everyday worlds.

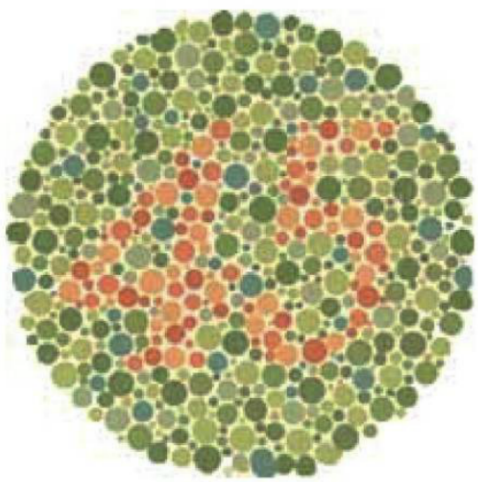


FIGURE 4.12 The Ishihara Test for Red–Green Color Blindness. If you can't see the two-digit number, you probably have red–green color blindness. This condition is common, especially among males.

HOW WE PERCEIVE COLOR. Color delights our senses and stirs our imagination, but how does the brain perceive it? Scientists have discovered that we use the lower visual pathway leading to the temporal lobe to process color (refer back to Figure 4.10), but it hardly starts there. Different theories of color perception explain different aspects of our ability to detect color, enabling us to see the world, watch TV, and enjoy movies, all in vibrant color.

Trichromatic Theory. Trichromatic theory proposes that we base our color vision on three primary colors—blue, green, and red. Trichromatic theory dovetails with our having three kinds of cones, each maximally sensitive to different wavelengths of light. Given that the three types of cones were discovered in the 1960s (Brown & Wald, 1964), it's perhaps surprising that Thomas Young and Hermann von Helmholtz described trichromatic theory over a century earlier. Young (1802) suggested that our vision is sensitive to three primary colors of light, and von Helmholtz (1850) replicated and extended his proposal by examining the colors that color-blind individuals could see. The Young-Helmholtz trichromatic theory of color vision was born.

REPLICABILITY ▶
Can the results be duplicated in other studies?

Persons with **color blindness** can't see all colors. Color blindness is most often due to the absence or reduced number of one or more types of cones stemming from genetic abnormalities. Still another cause is damage to a brain area related to color vision. Contrary to a popular misconception, *monochromats*—who have only one type of cone and thereby lose all color vision—are extremely rare, making up only about 0.0007 percent of the population. Most color-blind individuals can perceive a good deal of their world in color because they're *dichromats,* meaning they have two cones and are missing only one. Red–green dichromats see considerable color but can't distinguish reds as well as can people with normal color vision. We can find a test for red–green color blindness in **FIGURE 4.12**; many males have this condition but don't know it because it doesn't interfere much with their everyday functioning.

feature detector cell
cell that detects lines and edges

trichromatic theory
idea that color vision is based on our sensitivity to three primary colors

color blindness
inability to see some or all colors

Humans, apes, and some monkeys are *trichromats*, meaning we and our close primate relatives possess three kinds of cones. Most other mammals, including dogs and cats, see the world with only two cones, much like people with red–green color blindness (the most frequent form of color blindness). Trichromatic vision evolved about 35 million years ago, perhaps because it allowed animals to easily pick ripe fruit out of a green background. Recent fossil evidence suggests an alternative hypothesis, namely, that trichromatic vision may have enabled primates to find young, reddish, tender leaves that were nutritionally superior (Simon-Moffat, 2002). All scientists agree that seeing more colors gave our ancestors a leg up in foraging for food.

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

Opponent Process Theory. Trichromatic theory accounts nicely for how our three cone types work together to detect the full range of colors. But further research revealed a phenomenon that trichromatic theory can't explain—afterimages. Afterimages occur when we've stared at one color for a long time and then look away. We'll often see a different colored replica of the same image, as in **FIGURE 4.13**. Trichromatic theory doesn't easily explain why looking at one color consistently results in seeing another color in the afterimage, such as afterimages for red always appearing green. It turns out that afterimages arise from the visual cortex's processing of information from our rods and cones.

Factoid

There's preliminary evidence that a small proportion of women are *tetrachromats,* meaning their eyes contain four types of cones: the three cone types most of us possess plus an additional cone for a color between red and green (Jameson, Highnote, & Wasserman, 2001).

Some people occasionally report faint negative afterimages surrounding objects or other individuals. This phenomenon may have given rise to the paranormal idea that we're all encircled by mystical "auras" consisting of psychical energy (Neher, 1990). Nevertheless, because no one's been able to photograph auras under carefully controlled conditions, there's no support for this extraordinary claim (Nickel, 2000).

EXTRAORDINARY CLAIMS
Is the evidence as strong as the claim?

A competing model, which provides an explanation for afterimages, **opponent process theory**, holds that we perceive colors in terms of three pairs of opponent cells: red or green, blue or yellow, or black or white. Afterimages, which appear in complementary colors, illustrate opponent processing. Ganglion cells of the retina and cells in the visual area of the thalamus that respond to red spots are inhibited by green spots. Other cells show the opposite responses, and still others distinguish yellow from blue spots. Our nervous system uses both trichromatic and opponent processing principles during color vision, but different neurons rely on one principle more than the other. There's a useful lesson here that applies to many controversies in science: Two ideas that seem contradictory are sometimes both partly correct—they're merely describing differing aspects of the same phenomenon.

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

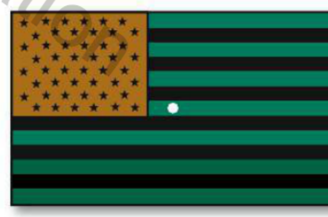


FIGURE 4.13 Opponent Processes in Action. Find a patch of blank white wall or place a blank sheet of white paper nearby before you begin. Then relax your eyes and fix your gaze on the white dot in the image above for at least 30 seconds without looking around or away. Afterward, stare at the white wall or paper for a few seconds. What do you see?

opponent process theory
theory that we perceive colors in terms of three pairs of opponent colors: either red or green, blue or yellow, or black or white

When We Can't See or Perceive Visually

We've learned how we see, and how we don't always see exactly what's there. Yet some 39 million people worldwide can't see at all (World Health Organization, 2012).

BLINDNESS. Blindness is the inability to see, or more specifically, the presence of vision less than or equal to 20/200 on the familiar Snellen eye chart, on which 20/20 is perfect vision. For people with 20/200 vision, objects at 20 feet appear as they would at 200 feet in a normally sighted person. The majority of cases of blindness—from cataracts, a clouding of the lens of the eye, and glaucoma, a disease that causes pressure on the eye and damages the optic nerve—are treatable, and are most likely to occur as people age.

The blind cope with their loss of vision in various ways—often relying more on other senses, including touch. This issue has been controversial over the years, with studies both replicating and contradicting a heightened sense of touch in the blind. Recent studies suggest that tactile (touch) sensitivity is indeed heightened in blind adults, giving them the same sensitivity as someone 23 years younger (Goldreich & Kanics, 2003). It's further known that the visual cortex of blind persons undergoes profound changes in function, rendering it sensitive to touch inputs (Sadato, 2005).

REPLICABILITY
Can the results be duplicated in other studies?

Ben Underwood has developed an amazing ability to use human echolocation to overcome many of the limitations of his blindness. Humans don't usually rely much on echolocation, although many whales do.

This means they can devote more cortex—somatosensory cortex and visual cortex—to a touch task, such as reading Braille. This phenomenon illustrates brain plasticity, in which some brain regions gradually take over the jobs previously assigned to others (see Chapter 3).

BLINDSIGHT: HOW ARE SOME BLIND PEOPLE ABLE TO NAVIGATE THEIR WORLDS? Recently, researchers (de Gelder et al., 2008) reported that a blind person, known by the initials TN, was able to walk around an obstacle course, with no assistance at all, side-stepping office equipment, boxes, and a variety of smaller objects. With normal eyes, TN is cortically blind—following several strokes, his brain fails to register sensory input. TN's rare ability may be the most impressive demonstration to date of a remarkable phenomenon called blindsight—the ability of blind people with damage to their cortex (Hamm et al., 2003) to make correct guesses about the appearance of things around them (Hamm et al., 2003; Weiskrantz, 1986). In TN's case, researchers used high-tech brain imaging to show that he was able to recognize facial expressions in angry, fearful, or joyous faces.

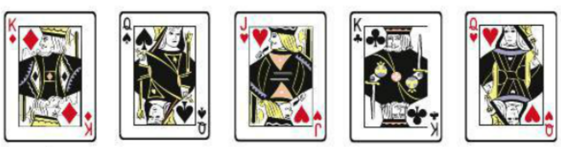
OCCAM'S RAZOR ▶
Does a simpler explanation fit the data just as well?

Because blindsight operates outside the bounds of conscious activity, some nonscientists have suggested that it may be a paranormal phenomenon. Yet there's a parsimonious natural explanation: People with blindsight have suffered damage to V1, the primary visual cortex, so that route of information flow to visual association areas is blocked. Coarser visual information still reaches the visual association cortex through an alternative pathway and bypasses V1. This visual information probably accounts for blindsight (Moore et al., 1995; Stoerig & Cowey, 1997; Weiskrantz, 1986).

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

Because TN was not deprived of auditory cues, the question arises of whether he might have been able to pull of his navigation feat with another equally amazing ability—echolocation. Certain animals, such as bats, dolphins, and many whales, emit sounds and listen to their echoes to determine their distance from a wall or barrier, a phenomenon called *echolocation*.

Remarkably, there's evidence that humans are capable of a crude form of echolocation. Echolocation might account for the fact that blind persons can sometimes detect objects a few feet away from them (Schörnich et al., 2012; Teng et al., 2011) and for TN's stumble free-walk. Ben Underwood, who was blinded at age 3 by retinal cancer, learned to make clicking noises that bounced off surfaces and clued him in to his surroundings. He rides his skateboard and plays basketball and video games. Recently, scientists have discovered that when blind people expert in echolocation use their ability to navigate in their environments, the same parts of the brain associated with visual images in sighted people become highly active (Thaler et al., 2011).



? See, we read your mind! Now look at the cards again; you'll notice that one is missing. We've removed the card you picked! **How did we do it?** (See answer upside down.)

Although the echolocation explanation can't be ruled out completely, the researchers who studied TN argue that echolocation is unlikely in that it is not a particularly effective way to detect the small objects TN successfully avoided. What's clear is that blindsight and echolocation are remarkable examples of how even subtle signals from neural pathways can impact our rich sensory experience of the world.

VISUAL AGNOSIA. *Visual agnosia* is a deficit in perceiving objects. A person with this condition can tell us the shape and color of an object, but can't recognize or name it. At a dinner party, such a person might say, "please pass that eight-inch silver thing with a round end" rather than, "please pass the serving spoon." Oliver Sacks's 1985 book, *The Man Who Mistook His Wife for a Hat,* includes a case study of a man with visual agnosia who did exactly as the title suggests; he misperceived his wife as a fashion accessory.

Answer: It's not an ESP trick after all. All five cards are different from those in the initial batch, but you probably didn't notice the change. The trick illustrates change blindness, a failure to notice obvious alterations in our environments.

Assess Your Knowledge FACT or FICTION?

1. The visible spectrum of light differs across species and can differ across individuals. True / False
2. The lens of the eye changes shape depending on the perceived distance of objects. True / False
3. Red-green color blindness results when rods are missing but cones are intact. True / False
4. Only nonhuman animals, like bats, engage in echolocation. True / False
5. People with visual agnosia have problems naming objects. True / False

Answers: 1. T (p. 132); 2. T (p. 134); 3. F (p. 136); 4. F (p. 138); 5. T (p. 138)

Study and Review in MyPsychLab

Hearing: The Auditory System

4.6 Explain how the ear starts the auditory process.

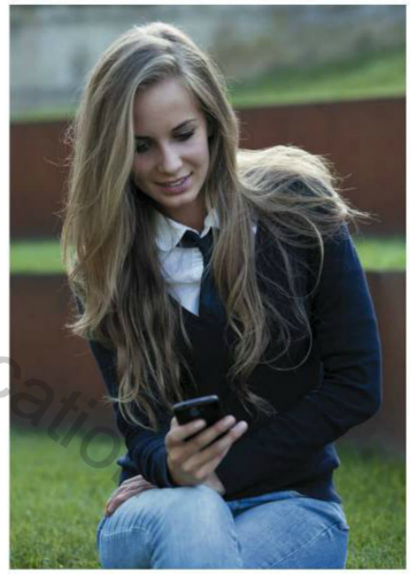
4.7 Identify the different kinds of auditory perception.

If a tree falls in the forest and no one is around to hear it, does it make a sound? Ponder that age-old question while we explore our sense of hearing: **audition**. Next to vision, hearing is probably the sensory modality we rely on most to acquire information about our world.

Sound: Mechanical Vibration

Sound is vibration, a kind of mechanical energy traveling through a medium, usually air. The disturbance created by vibration of molecules of air produces sound waves. Sound waves can travel through any gas, liquid, or solid, but we hear them best when they travel through air. In a perfectly empty space (a vacuum), there can't be sound because there aren't any airborne molecules to vibrate. That should help us answer our opening question: Because there are air molecules in the forest, a falling tree most definitely makes a loud thud even if nobody can hear it.

PITCH. Sounds have *pitch,* which corresponds to the frequency of the wave. Higher frequency corresponds to higher pitch, lower frequency to lower pitch. Scientists measure pitch in cycles per second, or hertz (Hz) (see **FIGURE 4.14**). The human ear can pick up frequencies ranging from about 20 to 20,000 Hz (see **FIGURE 4.15**). When it comes to sensitivity to pitch, age matters. Younger people are more sensitive to higher pitch tones than older adults. A ring tone for cell phones has ingeniously exploited this simple fact of nature, allowing teenagers to hear their cell phones ring while many of their parents or teachers can't (Vitello, 2006).



A high school student responds to the "teenagers only" ringtone.

Watch in MyPsychLab the Video: Ear Ringing

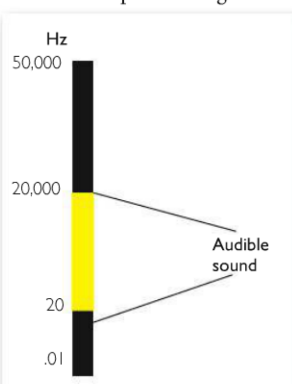


FIGURE 4.15 The Audible Spectrum (in Hz).

The human ear is sensitive to mechanical vibration from about 20 Hz to 20,000 Hz.

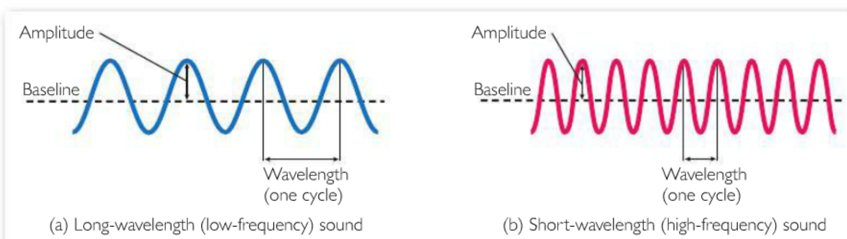


FIGURE 4.14 Sound Wave Frequency and Amplitude. Sound wave frequency (cycles per second) is the inverse of wavelength (cycle width). Sound wave amplitude is the height of the cycle. The frequency for middle C (a) is lower than that for middle A (b).

audition
our sense of hearing

LOUDNESS. The amplitude—or height—of the sound wave corresponds to *loudness,* measured in decibels (dB) (refer again to Figure 4.14). Loud noise results in increased wave amplitude because there's more mechanical disturbance, that is, more vibrating airborne molecules. **TABLE 4.2** lists various common sounds and their typical loudness.

TIMBRE. **Timbre** refers to the quality or complexity of the sound. Different musical instruments sound different because they differ in timbre, and the same holds for human voices.

The Structure and Function of the Ear

Just as sense receptors for vision transduce light into neural activity, sense receptors for hearing transduce sound into neural activity. The ear has three parts: outer, middle, and inner, each of which performs a different job (see **FIGURE 4.16**). The *outer ear*, consisting of the *pinna* (the part of the ear we see, namely, its skin and cartilage flap) and ear canal, has the simplest function; it funnels sound waves onto the *eardrum*.

On the other side of the eardrum lies the *middle ear*, containing the *ossicles*—the three tiniest bones in the body—named the hammer, anvil, and stirrup, after their shapes. These ossicles vibrate at the frequency of the sound wave, transmitting it from the eardrum to the inner ear.

Once sound waves enter the *inner ear*, the **cochlea** converts vibration into neural activity. The outer part of the spiral-shaped cochlea is bony, but its inner cavity is filled with a thick fluid. Vibrations from sound waves disturb this fluid and travel to the base of the cochlea, where pressure is released and transduction occurs.

Also located in the inner ear, the **organ of Corti** and **basilar membrane** are critical to hearing because *hair cells* are embedded within them (see Figure 4.16). Hair cells are where transduction of auditory information takes place: They convert acoustic information into action potentials. Here's how. Hair cells contain cilia (hairlike structures) that protrude into the fluid of the cochlea. When sound waves travel through the cochlea, the resulting pressure deflects these cilia, exciting the hair cells (Roberts, Howard, & Hudspeth, 1988). That information feeds into the *auditory nerve,* which travels to the brain, through the thalamus, which is a sensory relay station (see Chapter 3).

TABLE 4.2 Common Sounds. This decibel (dB) table compares some common sounds and shows how they rank in potential harm to hearing.

SOUND	NOISE LEVEL (DB)	EFFECT
Jet Engines (near) Rock Concerts (varies)	140 110–140	We begin to feel pain at about 125 dB
Thunderclap (near) Power Saw (chainsaw)	120 110	Regular exposure to sound over 100 dB for more than one minute risks permanent hearing loss
Garbage Truck/ Cement Mixer	100	No more than 15 minutes of unprotected exposure is recommended for sounds between 90 and 100 dB
Motorcycle (25 ft) Lawn Mower	88 85–90	Very annoying 85 dB is the level at which hearing damage (after 8 hours) begins
Average City Traffic Vacuum Cleaner Normal Conversation	80 70 50–65	Annoying; interferes with conversation; constant exposure may cause damage Intrusive; interferes with telephone conversation Comfortable hearing levels are under 60 dB
Whisper Rustling Leaves	30 20	Very quiet Just audible

(*Source:* NIDCD)

timbre
complexity or quality of sound that makes musical instruments, human voices, or other sources sound unique

cochlea
bony, spiral-shaped sense organ used for hearing

organ of Corti
tissue containing the hair cells necessary for hearing

basilar membrane
membrane supporting the organ of Corti and hair cells in the cochlea

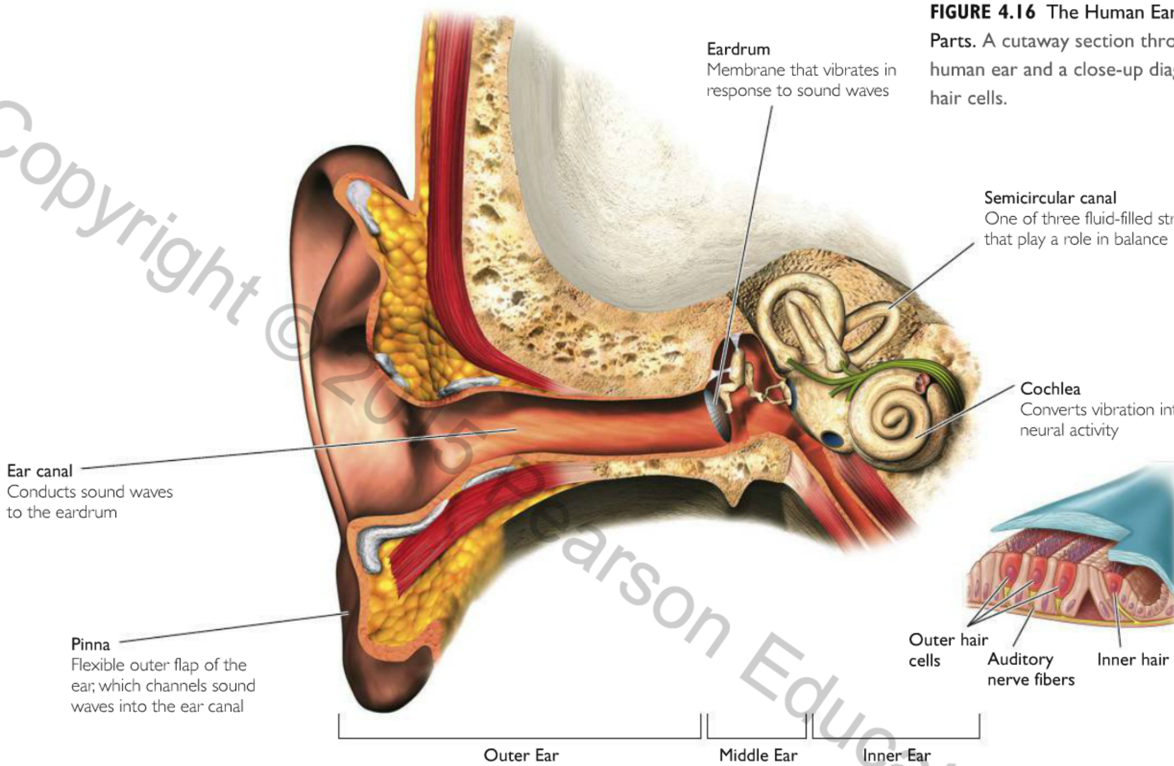


FIGURE 4.16 The Human Ear and Its Parts. A cutaway section through the human ear and a close-up diagram of the hair cells.

Once the auditory nerve enters the brain, it makes contacts with the brain stem, which sends auditory information higher—all the way up the auditory cortex. At each stage, perception becomes increasingly complex. In this respect, auditory perception is like visual perception.

The primary auditory cortex processes different tones in different places (see **FIGURE 4.17**). That's because each place receives information from a specific place in the basilar membrane. Hair cells located at the base of the basilar membrane are most excited by high-pitched tones, whereas hair cells at the top of the basilar membrane are most excited by low-pitched tones. Scientists call this model of pitch perception **place theory**, because a specific place along the basilar membrane—and in the auditory cortex, too—matches a tone with a specific pitch (Békésy, 1949). Place theory accounts only for our perception of high-pitched tones, namely those from 5,000 to 20,000 Hz.

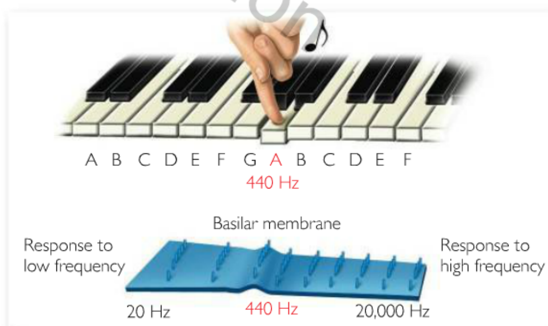


FIGURE 4.17 The Tone-Based Organization of the Basilar Membrane. Hair cells at the base of the basilar membrane respond to high-pitched tones, whereas hair cells at the top of the basilar membrane respond to low-pitched tones.

There are two routes to perceiving low-pitched tones. We'll discuss the simpler way first. In **frequency theory**, the rate at which neurons fire action potentials faithfully reproduces the pitch. This method works well up to 100 Hz, because many neurons have maximal firing rates near that limit. *Volley theory* is a variation of frequency theory that works for tones between 100 and 5,000 Hz. According to volley theory, sets of neurons fire at their highest rate, say 100 Hz, slightly out of sync with each other to reach overall rates up to 5,000 Hz.

When it comes to listening to music, we're sensitive not only to different tones, but to the arrangement of tones into melodies (Weinberger, 2006). We react differently to pleasant and unpleasant melodies. In one study, music that literally provoked feelings of "chills" or "shivers" boosted activity in the same brain regions corresponding to euphoric responses to sex, food, and drugs (Blood & Zatorre, 2001). So there may be a good reason why "sex," "drugs," and "rock and roll" often go together.

place theory
specific place along the basilar membrane matches a tone with a specific pitch

frequency theory
rate at which neurons fire the action potential reproduces the pitch

When We Can't Hear

About one in 1,000 people are deaf: They suffer from a profound loss of hearing. Many others have hearing deficits, called being "hard of hearing." There are several causes of deafness, some largely genetic, others deriving from disease, injury, or exposure to loud noise (Pascolini & Smith, 2009). *Conductive deafness* is due to a malfunctioning of the ear, especially a failure of the eardrum or the ossicles of the inner ear. In contrast, *nerve deafness* is due to damage to the auditory nerve.

If your grandmother warns you to "Turn down the sound on your iPod, or you'll go deaf by the time you're my age," there's more than a ring of truth in her warning. Loud sounds, especially those that last a long time or are repeated, can damage our hair cells and lead to *noise-induced hearing loss*. This type of hearing loss is often accompanied by tinnitus, a ringing, roaring, hissing, or buzzing sound in the ears that can be deeply disturbing (Nondahl et al., 2007). Hearing loss can also occur after exposure to one extremely loud sound, such as an explosion. But most of us lose some hearing ability as we age—especially for high-frequency sounds—as a by-product of the loss of sensory cells and degeneration of the auditory nerve, even if we've never attended a rock concert without earplugs (Ohlemiller & Frisina, 2008).

Study and **Review** in **MyPsychLab**

Assess Your Knowledge — FACT or FICTION?

1. The amplitude of the sound wave corresponds to loudness. **True / False**
2. Sound waves are converted to neural impulses by creating vibrations of fluid inside the cochlea. **True / False**
3. Place theory states that each hair cell in the inner ear has a particular pitch or frequency to which it's most responsive. **True / False**
4. Volley theory is a variation of frequency theory. **True / False**
5. As we age, we tend to lose hearing for low-pitched sounds more than high-pitched sounds. **True / False**

Answers: 1. T (p. 140); 2. T (p. 140); 3. T (p. 141); 4. T (p. 141); 5. F (p. 142)

Smell and Taste: The Sensual Senses

4.8 Identify how we sense and perceive odors and tastes.

Without smell and taste many of our everyday experiences would be bland. Cuisines of the world feature characteristic spices that enliven their dishes. Similarly, smell and taste stimulate our senses and elevate our spirits. The term "comfort food" refers to familiar dishes that we crave because of the warm memories they evoke.

Smell is also called **olfaction**, and taste **gustation**. These senses work hand in hand, enhancing our liking of some foods and our disliking of others. Smell and taste are the chemical senses because we derive these sensory experiences from chemicals in substances.

Animals use their sense of smell for many purposes—tracking prey, establishing territories, and recognizing the opposite sex, to name but a few. We humans aren't the most smell-oriented of creatures. The average dog is at least 100,000 times more sensitive to smell than we are, which explains why police use trained dogs rather than nosy people to sniff for bombs and banned substances.

The most critical function of our chemical senses is to sample our food before swallowing it. The smell and taste of sour milk are powerful stimuli that few of us can ignore even if we want to. An unfamiliar bitter taste may signal dangerous bacteria or poison in our food. We develop food preferences for "safe" foods and base them on a combination of smell and taste. One study of young French women found that only those who already liked red meat—its smell and its taste—responded favorably to pictures of it (Audebert, Deiss, & Rousset, 2006). We like what smells and tastes good to us.

olfaction
our sense of smell

gustation
our sense of taste

Culture also shapes what we perceive as delicious or disgusting. The prospect of eating sacred cow meat (as in a hamburger) would be as off-putting to Hindus as eating fried tarantulas, a delicacy in Cambodia, or Casu Marzu, a Sardinian cheese filled with insect larvae, would be to most Americans. Even within a society there are pronounced differences in food choices, as American meat lovers and vegans enjoy vastly different diets. We can acquire food preferences by means of learning, including modeling of eating behaviors; parental approval of food choices; and availability of foods (Rozin, 2006) (see Chapter 6).

What Are Odors and Flavors?

Odors are airborne chemicals that interact with receptors in the lining of our nasal passages. Our noses are veritable smell connoisseurs, capable of detecting between 2,000 and 4,000 different odors. Not everything, though, has an odor. Clean water, for example, has no odor or taste. Not all animals smell airborne molecules. The star-nosed mole, named for its peculiarly shaped snout, can detect odors underwater (Catania, 2006). The animal blows out air bubbles and "sniffs" them back in to find food underwater and underground.

In contrast, we can detect only a few tastes. We're sensitive to five basic tastes—sweet, salty, sour, bitter, and umami, the last of which is a recently uncovered "meaty" or "savory" taste. There's preliminary evidence for a sixth taste, one for fatty foods (Gilbertson et al., 1997).

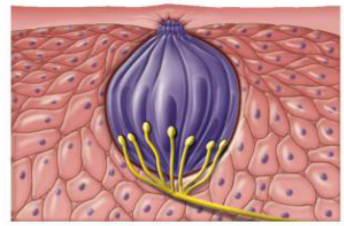


FIGURE 4.18 How We Detect Taste. The tongue contains many taste buds, which transmit information to the brain as shown in this close-up.

Sense Receptors for Smell and Taste

We humans have over 1,000 olfactory (smell) genes, 347 of which code for olfactory receptors (Buck & Axel, 1991). Each olfactory neuron contains a single type of olfactory receptor, which "recognizes" an odorant on the basis of its shape. This lock-and-key concept is similar to how neurotransmitters bind to receptor sites (see Chapter 3). When olfactory receptors come into contact with odor molecules, action potentials in olfactory neurons are triggered.

We detect taste with **taste buds** on our tongues. Bumps on the tongue called *papillae* contain numerous taste buds (**FIGURE 4.18**). There are separate taste buds for sweet, salty, sour, bitter, and umami (Chandrashekar et al., 2006).

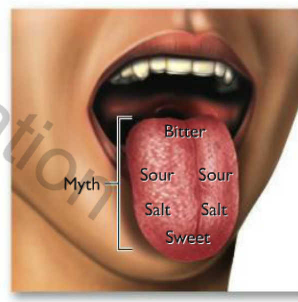


FIGURE 4.19 The "Tongue Taste Map" Myth. Although diagrams of the tongue, like this one, appear in many popular sources, they're more fiction than fact.

It's a myth, however, that a "tongue taste map" describes the tongue's sensitivity to different flavors, even though some books still contain this map (see **FIGURE 4.19**). In reality, there's only a weak tendency for individual taste receptors to concentrate at certain locations on the tongue, and any location on the tongue is at least slightly sensitive to all tastes. Try this exercise: Place a bit of salt on the tip of your tongue. Can you taste it? Now try placing a small amount of sugar on the back of your tongue. Chances are good you'll taste both the salt and the sugar, even though you placed them outside the mythical "tongue taste map." That's because receptors that detect sweet tastes are often located on the tip of the tongue and receptors that detect salt are often on the sides, but there's a good mix of receptors everywhere on the tongue.

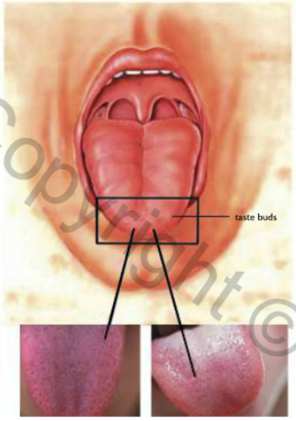
Umami taste receptors were controversial until physiological studies replicated earlier results and showed that these receptors were present on taste buds (Chandrashekar et al., 2006). That was nearly a century after Kikunae Ikeda isolated the molecules responsible for the savory flavor found in many Japanese foods, such as broth or dried seaweed (Yamaguchi & Ninomiya, 2000). These molecules producing a savory or meaty flavor all had one thing in common: They contained a lot of the neurotransmitter glutamate (see Chapter 3). Monosodium glutamate (MSG), a derivative of glutamate, is a well-known flavor enhancer (the commercial flavor enhancer *Accent* consists almost entirely of MSG). Today, most scientists consider umami the fifth taste.

◀ **REPLICABILITY**
Can the results be duplicated in other studies?

taste bud
sense receptor in the tongue that responds to sweet, salty, sour, bitter, umami, and perhaps fat

A similar controversy swirls around taste receptors for fat. It's clear that fat does something to our tongues. Richard Mattes (2005) and his associates found that merely putting fat on people's tongues alters their blood levels of fat. This means that as soon as fat enters our mouths it starts to affect our bodies' metabolism of fat. At first, researchers thought the responses were triggered by an olfactory receptor for fat. This hypothesis was ruled out when they showed that smelling fat didn't alter blood levels of fat; the fat had to make contact with the tongue.

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



? The two photographs above show the tongues of two people, one a supertaster and one a non-supertaster. **Which tongue belongs to a supertaster and why?** (See answer upside down on bottom of page.)

With only five or six taste receptors, why do we taste so many flavors? The secret lies in the fact that our taste perception is biased strongly by our sense of smell, which explains why we find food much less tasty when our noses are stuffed from a cold. Far more than we realize, we find certain foods "delicious" because of their smell. If you're not persuaded, try this exercise. Buy some multiflavored jelly beans, open the bag, and close your eyes so you can't see which color you're picking. Then pinch your nose with one hand and pop a jelly bean into your mouth. At first you won't be able to identify the flavor. Then gradually release your fingers from your nose and you'll be able to perceive the jelly bean's taste.

Our tongues differ in their number of taste receptors. Linda Bartoshuk (2004) calls those of us with a marked overabundance of taste buds—about 25 percent of people—"supertasters." If you find broccoli, coffee, and dark chocolate (we hope not) to be unbearably bitter, and sugary foods to be unbearably sweet, the odds are high you're a supertaster. At age 10, supertasters are most likely to be in the lowest 10 percent of height, probably a result of their sensitivity to bitter tastes and their fussy eating habits (Golding et al., 2009). Supertasters, who are overrepresented among women and people of African or Asian descent, are also especially sensitive to oral pain, and tend to avoid bitter tastes as a result. They also tend to avoid bitter tastes in alcohol and smoking tobacco, which may make them healthier than the rest of us (Bartoshuk, 2004).

Olfactory and Gustatory Perception

Our perceptions of smell and taste are often remarkably sensitive, and more informative than we consciously realize, although we're often not especially good at identifying odors by name. Babies can identify their mothers' odor and siblings can recognize each other on the basis of odor. Research suggests that women can even tell whether people just watched a happy or a sad movie from samples of their armpit odor (Wysocki & Preti, 2004). Should we perhaps call sad movies sweat-jerkers rather than tear-jerkers?

How do odors and tastes excite our receptors for smell and taste? After odors interact with sense receptors in the nasal passages, the resulting information enters the brain, reaching the olfactory cortex and parts of the limbic system (see **FIGURE 4.20**). Similarly, after taste information interacts with taste buds, it enters the brain, reaching a taste-related area called gustatory cortex, somatosensory cortex (because food also has texture), and parts of the limbic system. A region of the frontal cortex is a site of convergence for smell and taste (Rolls, 2004) (see Chapter 3).

Perfume manufacturers have long advertised fragrances as increasing attraction and romance. But at least in nonhuman animals, the chemicals that produce the most potent effects on sexual behaviors are actually odorless pheromones.

Watch in **MyPsychLab** the **Video:** Thinking Like a Psychologist: Can Smells Alter Mood and Behavior?

pheromone
odorless chemical that serves as a social signal to members of one's species

We analyze the intensity of smell and determine whether it's pleasing. Parts of the limbic system, such as the amygdala, help us to distinguish pleasant from disgusting smells (Anderson et al., 2003). Taste can also be pleasant or disgusting. Both tasting disgusting food and viewing facial expressions of disgust activate the gustatory cortex (Wicker et al., 2003) (see Chapter 11). Moreover, persons who suffer damage to the gustatory cortex don't experience disgust (Calder et al., 2000). These results underscore the powerful links among smell, taste, and emotion.

Emotional disorders, like anxiety and depression, can distort taste perception (Heath et al., 2006). Certain neurotransmitters, such as serotonin and norepinephrine—the same chemical messengers whose activity is enhanced by antidepressants—make us more sensitive to tastes (see Chapters 3 and 16). Tom Heath and his colleagues (2006) found that antidepressant drugs rendered participants more sensitive to various combinations of sweet, sour, and bitter tastes. Their research may shed light on appetite loss, which is a frequent symptom of depression.

Smell plays a particularly strong role in sexual behavior. Mice with a genetic defect in smell don't even bother to mate (Mandiyan, Coats, & Shah, 2005). Is smell central to human sexuality, too? Many perfume and cologne manufacturers sure seem to think so. Curiously, though, it may not be fragrant odors, but **pheromones**—odorless chemicals that serve as social signals to members of one's species—that alter our sexual behavior. There's evidence that rodents respond to pheromones during mating and social behavior (Biasi, Silvotti, & Tirindelli, 2001). So do most other mammals, including whales and horses (Fields, 2007). Most mammals use the *vomeronasal organ,* located in the bone between the

Answer: The tongue on the left, because supertasters have more taste buds on their tongues than do other people.

nose and the mouth, to detect pheromones. The vomeronasal organ doesn't develop in humans (Witt & Wozniak, 2006), causing some to suggest that humans are insensitive to pheromones. An alternative hypothesis is that humans detect pheromones via a different route. This idea is supported by the discovery of human pheromones (Pearson, 2006). A nerve that's only recently received attention, called "nerve zero," may step in to enable pheromones to trigger responses in the "hot-button sex regions of the brain" (Fields, 2007).

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

Still, we should be cautious about shelling out sizable chunks of our salaries on pheromone-based products that promise to stir up romance. Scientific evidence suggests they probably won't work. Pheromones are large molecules, so although it's easy to transfer a pheromone from one person to another during a passionate kiss, sending them across a restaurant table is definitely a stretch. Moreover, there's far more to human romance than physical chemistry; psychological chemistry matters, too (see Chapter 11).

Smells other than pheromones may contribute to human sexual behavior. Remarkably, human sperm cells may contain smell receptors that help them to find their way to female eggs (Spehr et al., 2003). Sometimes truth *is* stranger than fiction.

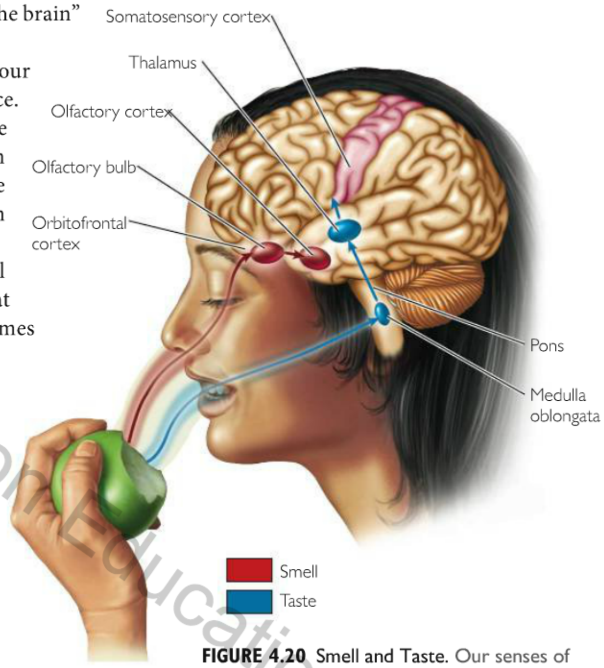


FIGURE 4.20 Smell and Taste. Our senses of smell and taste enter the brain by different routes but converge in the orbitofrontal cortex.

When We Can't Smell or Taste

About 2 million Americans suffer from disorders of taste, smell, or both. Gradual loss of taste and smell can be a part of normal aging, as the number of taste buds, routinely replaced when we're younger, declines. But these losses can also result from diseases, such as diabetes and high blood pressure.

There are many disorders of olfaction (Hirsch, 2003). Although not as serious as blindness or deafness, they can pose several dangers, such as an inability to detect gas leaks and smell spoiled food before we eat it. Damage to the olfactory nerve, along with brain damage caused by such disorders as Parkinson's and Alzheimer's disease can damage our sense of smell and ability to identify odors (Doty, Deems, & Stellar, 1988; Murphy, 1999; Wilson et al., 2007) (see Chapter 3).

Losing our sense of taste can also produce negative health consequences. Cancer patients who lose their sense of taste have a worse prognosis than other patients, because they eat less and die sooner (Schiffman & Graham, 2000). This effect isn't due merely to a lack of nutrition. Adding flavor enhancers to the diet appreciably improves patients' health status. So taste may add an essential "zest" to life; a psychological flavoring that can help to ward off disease by boosting appetite.

Advocates of aromatherapy claim that essential oils derived from plants have special healing powers. Many claim that such oils can cure depression, anxiety disorders, insomnia, and other ailments. Although the pleasant smells of such plants can no doubt lift our moods a bit, there's little evidence that they possess magical curative power (McCutcheon, 1996).

Assess Your Knowledge — FACT or FICTION?

1. The most critical function of our chemical senses is to sample our food before we swallow it. **True / False**
2. Humans can detect only a small number of odors but thousands of tastes. **True / False**
3. There's good evidence for a "tongue taste map," with specific taste receptors located on specific parts of the tongue. **True / False**
4. The limbic system plays a key role in smell and taste perception. **True / False**
5. The vomeronasal organ helps to detect pheromones in many mammals but doesn't develop in humans. **True / False**

Answers: 1. T (p. 142); 2. F (p. 143); 3. F (p. 143); 4. T (p. 144); 5. T (p. 145)

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