CHAPTER 4

Sensation

In this chapter, you will learn about:

- how we convert light into images
- how the ear responds to sound waves
- the senses of taste and smell
- the somatic sensory system

English physicist Sir Isaac Newton, in an experiment, observed that a ray of sunlight, or white light, was broken up into the brilliant colors of the spectrum when it passed through a glass prism. He then noticed that the ray recombined into white light when it was beamed back through another prism. It occurred to Newton that since light rays are not colored, color must not be an actual physical quality in the world. He concluded that color must exist only in the mind and not in nature.

If color does not actually exist in the world around us, then where do colors come from? To answer this question, we will need to understand how our visual sensory system translates different wavelengths of light into neural impulses so that our brain can interpret the information it receives as the sensation of color. The other types of sensation we experience—such as sound, smell, taste, touch, and pain—are also products of the brain's response to various kinds of sensory stimuli.

Sensory Systems

It is through our sensory systems—vision, hearing, taste, smell, and touch—that we experience and interact with the environment outside our bodies. Our sensory organs—eyes, ears, nose, tongue, skin—contain **receptors** that allow us to physically process the information we are constantly receiving from the world around us. Highly specialized sensory receptors pick up various specific forms of information. The following table lists the main receptors and the kinds of stimuli to which they respond.

Receptors and Stimuli

In the eye	Wavelengths of light
In the ear	Vibrations of air molecules
In the nose	Gaseous molecules in the air
On the tongue	Chemicals in food
In the skin	Pressure, temperature

Absolute Thresholds

For a sensation to occur, a minimum amount of stimulation is necessary. Scientists have explored the psychological aspects of physical stimuli and determined the **absolute thresholds**, or the minimum stimuli that can be detected by our main sensory systems. The following table illustrates the incredible sensitivity of the human sensory systems.

Absolute Threshold for Each Sensory System

Vision: A candle flame seen 30 miles away on a clear, dark night (equals 3 photons of light, a photon being the smallest unit of light)
Hearing: The tick of a watch under quiet conditions at 20 feet
Taste: 1 teaspoon of sugar in 2 gallons of water
Smell: 1 drop of perfume diffused into the entire volume of a three-room apartment
Touch: The wing of a bee falling on your cheek from a distance of 1 centimeter

How We Perceive

Sensory organs take in information from the environment by means of receptors and then convey the information to the brain in the form of neural, or nerve, impulses, a language the brain can understand. The brain then uses the information to create impressions. The brain interprets the neural impulses as particular sensations. In a process known as **perception**, the brain organizes the sensory information to make it meaningful. Although we do not yet know how all of this happens, scientists have proposed various theories to explain the process. So, although it may be difficult to grasp, all of our sensations and impressions about the world around us—everything we experience—is really constructed inside our brain. Sensations are based on stimuli from outside. "Seeing" does not take place in the eye but in the brain. And that, as we shall see, is why color exists only in the mind of the beholder.

Each sensory system in the body—the eyes, ears, nose, tongue, and skin—uses a complex form of **sensory coding** to send a message to the brain. Sensory codes are essential parts of a process that enables the brain to understand what it is we are experiencing.

When a sensory receptor receives a stimulus that continues at the same intensity over a period of time, the sensory receptor's response is stronger at first and then usually becomes weaker, as the receptor adapts to the stimulus. This process is called **sensory adaptation**. The manner and rate of adaptation vary, depending on the specific sensory organ and the particular stimulus. For example, adaptation to pain occurs very slowly, if at all, while adaptation to repetitive sounds may occur relatively quickly. While you may never stop noticing pain until the cause of the pain is removed, a sound that is repetitive, such as the ticking of a clock, tends to eventually become background noise.

Vision and Light

For sighted people, vision is the most important sense. About 70 percent of the information reaching their brains comes from vision. To begin to understand the workings of our visual sensory system, and the role of the brain in sight, we first must understand the nature of light.

What Is Light?

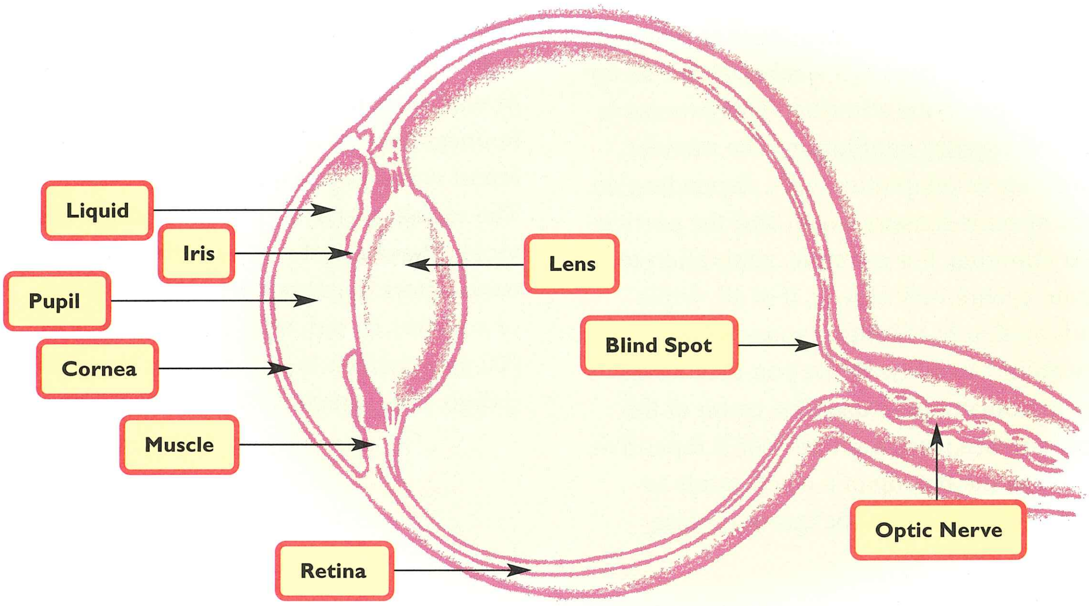
Electromagnetic radiation is all around us, in the form of light, gamma rays, ultraviolet rays, infrared rays, and radio waves. Light makes up just a narrow band of the electromagnetic spectrum, but light is the only form of electromagnetic radiation that we can see. Indeed, without light, we would see nothing. Ultraviolet rays move too slowly for us to see, and infrared rays are too fast for us to see. Visible light—white light from the sun or from a light bulb—is broken into different frequencies or wavelengths when it hits objects and bounces back at us. We interpret the different wavelengths as different colors. The visible spectrum of colors ranges from violet, the shortest wavelength at 400 nanometers (a nanometer is one-billionth of a meter), to red, with a wavelength of 700 nanometers. In between are the colors indigo, blue, green, yellow, and orange.

How the Eye Responds to Light

You have probably heard the eyes referred to as a "window into the soul." Indeed, the eyes are an amazingly vulnerable and sensitive sensory organ designed to catch light and convert it to neural impulses that the brain can interpret and understand. It is important to understand the purposes and functions of the main structures in the eye in order to appreciate the process by which we see.

- When light reaches the eye, it enters the cornea. This transparent, curved "window" bends light toward the eye's center.
- The cornea cannot change shape to adjust for distance, so additional focusing is done by the lens, which is behind the cornea.
- Light must pass through the pupil, the dark area in the center of the iris, to reach the lens. The pupil in the iris dilates (enlarges) in dim light to allow more light to enter, and contracts in bright light to limit the amount of light that can enter.
- The lens has often been compared to the lens of a camera. It focuses the incoming image on the **retina** in the interior of the eye by bending the light rays in a process known as *accommodation.* A series of muscles in the lens allows it to control the degree of bending.

The Human Eye



- After passing through the lens, the light reaches the retina, the light-sensitive element of the eye. The retina consists of neurons, and the neurons that are sensitive to light are called **photoreceptors.**
- In the photoreceptor layer, light is converted into electrical activity—the language of the brain. There are two types of photoreceptors—rods and cones.
- There are about 100 million rods in each eye. They function in dim light and at night and send gray, hazy images to the brain.
- Compared to rods, cones are a thousand times less sensitive to light. There are about 6.5 million cones in each eye. The cones function in bright light to produce color sensations and to pick up fine details.
- Each eye has an area where the optic nerve leaves the eye. There are no photoreceptors in this area, so when light hits there, the eye registers nothing. This area is called the blind spot.
- The photoreceptor cells send electrical, or neural, impulses to the optic nerve, which sends them on to the **visual cortex**, the part of the brain that interprets visual images.

How Do We See Color?

We do not have to learn how to see color. We are born with that capability, because that is the way the human visual sensory system and brain are designed. We see color because our eyes have different receptors for different wavelengths of light. The physical properties of a specific wavelength determine the nature and qualities of the color we will see:

- The *hue,* or name, of a color—such as red—corresponds to a particular wavelength. Black is not a color because no wavelength predominates.
- *Saturation* refers to the purity, richness, or intensity of a color. Colors produced by a very narrow band of wavelengths, such as red, are highly saturated, as compared to pink, which is a mixture of white and red.
- *Brightness* corresponds to the amplitude, or height, of a light wave and to the amount of light energy reaching the retina.

The process by which the human brain interprets various wavelengths of light as different colors is not completely understood. Yet, unless we are partially or totally color-blind, it seems obvious that the world around us is filled with color—an incredible variety of the most beautiful and subtle colors. Just think about the more spectacular sunsets or displays of fall foliage you've seen. What seems strange is the scientific fact that the world is not actually filled with color. An apple appears "red" to us because the apple reflects red light, not because the apple is red. A blue sky on a beautiful sunny day is really not blue. It just appears to be "blue" because the short blue wavelengths of light are scattered more effectively by the atmosphere than are the longer wavelengths of light.

How We See Color

Trichromatic Theory of Color Vision	Opponent-Process Theory of Color Vision
According to the trichromatic, or three-color, theory, there are three types of cones in the retina—red, green, and blue cones.	According to the opponent-process theory, there are three types of receptors, each capable of responding to either red-green, yellow-blue, or black-white, but not to all.
Different photosensitive pigments enable each cone to absorb light mainly in the red, green, or blue portion of the spectrum.	The colors of each pair oppose each other; they cannot be blended. But the four primary colors can be mixed with colors from the other pairs, thereby creating all the colors of the visible spectrum.
All other colors result from a combination of these three primary colors.	

Scientists have proposed several theories—including the trichromatic and the opponent-process—in an attempt to explain how we see color.

Color Blindness

The most common type of color blindness is a partial color blindness known as *color weakness*. This condition affects about 8 percent of the male population and less than 1 percent of the female population. It is usually inherited from the maternal grandfather. People who are partially color-blind are red-green blind. They cannot distinguish between red and green, both of which appear to them as yellowish brown. But they have normal color vision for yellow and blue. Total color blindness is much rarer. An individual with this condition sees the world in shades of gray.

Hearing and Sound

A gigantic, old redwood tree stood in the middle of a deep forest. Recently struck by lightning and partially burned, it was vulnerable to strong winds. One day a strong gust of wind roared through the forest, and a huge section of the redwood tree crashed to the forest floor. Had you been standing nearby, you would probably have covered your ears with your hands because of the loud noise. But what would it have sounded like if neither you nor anyone else was near enough to hear the tree crash? To answer this question, we need to understand the nature of sound.

What Is Sound?

Just as the sights we see are created in our brain in response to light waves activating receptors in our visual sensory system, so too are the sounds we hear created in our brain in response to external stimuli.

- An object generates sound waves when its vibrations cause vibrations in the surrounding air molecules.
- The patterns of vibrations in the air, known as *sound waves,* travel outward in all directions.
- Sound waves travel much more slowly than light waves. Sound waves can also travel through water, although at a slower rate than through air, and they can travel through solid matter, at a still slower speed.
- The sound waves are picked up by our auditory sensory system when the pattern of vibrating air molecules exerts pressure on our eardrum.
- This causes vibrations within the ear that are converted to neural impulses.
- When these impulses reach the brain, we interpret the pattern of impulses as sound.

Now let's go back to that tree in the forest. When the tree hit the ground, it caused sound waves. Patterns of vibrating air molecules traveled outward. But sound waves do not become "sound" until they are picked up by an auditory sensory system and interpreted as "sound" by the brain. So, strange as it may seem, there would not have been any sound at all if nobody had been around to hear it.

Characteristics of Sound

Sound has certain physical characteristics that are always present but that vary greatly. Think about sounds that you have enjoyed—favorite pieces of music, the surf at an ocean beach, or a kitten's purr. Now think of sounds that you may have heard and hope never to hear again—the loud crash of a car accident, or perhaps fingernails scratching the surface of a chalkboard. All of these sounds, pleasant or unpleasant, have the following **three** characteristics: pitch, timbre, and intensity.

1. **Pitch** refers to how high or low a sound is, and it is determined by the frequency of the sound waves.
2. **Timbre** refers to the quality or complexity of a sound.
3. **Intensity** refers to the loudness of a sound, and it is measured in decibels. A sound of zero decibels is the absolute threshold of sound, the softest possible sound humans are capable of hearing. Normal conversation is 60 decibels. Any sound above 130 decibels, the threshold of pain, can be harmful.

How Sound Waves Are Converted in the Ear

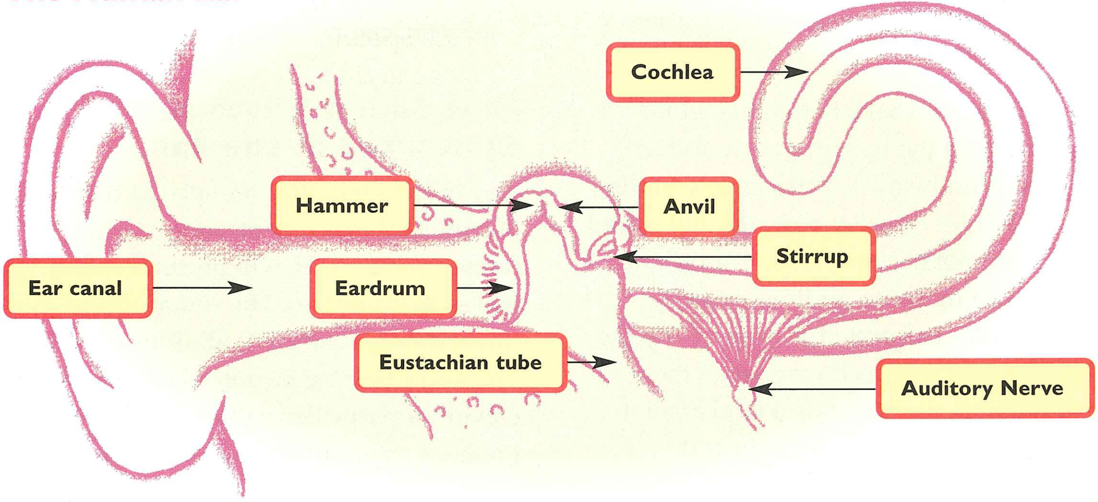
Any object set in motion, such as the string of a musical instrument, a tuning fork, or human vocal cords, will produce sound waves as it vibrates. The sound waves travel through the air in all directions. The process of hearing begins when the sound waves—a particular pattern of physical pressure waves of air molecules—are picked up by receptors in the ear and are transformed into neural impulses.

The human ear has **three** main parts:

1. **External Ear.** In the external ear, air conducts sound waves. The visible external part of the ear is shaped to help us capture sound waves. We turn our heads with our ear facing the direction of sound waves in order to pick up faint sounds.
2. **Middle Ear.** Here, bone conducts sound waves. The shape of the ear is designed to funnel sound waves into the ear, where they strike the eardrum in the middle ear. The thin membrane of the eardrum is stretched tightly like a drumhead in the ear canal, covering the entrance to the rest of the middle ear. When a sound wave hits the eardrum, it moves with each vibration of the sound wave, setting in motion three small bones called the *hammer*, the *anvil*, and the *stirrup*. Vibrations of these bones transmit sound to the inner ear.
3. **Inner Ear.** Fluid conducts sound waves in the inner ear. Sound is transmitted to the **cochlea,** a tubular snail-shaped structure filled with fluids and 20,000 tiny hair cells called *cilia*. The sound causes waves in the cochlea's fluid and sets the cilia in motion. As the cilia move, they trigger electrical impulses in the nerve cells to which they are attached. These, in turn, send neural impulses to the brain by way of the **auditory nerve.**

The auditory nerve conveys neural impulses to the hearing areas of the cerebral cortex, where they are interpreted as specific sounds. The brain can determine where a sound is coming from by contrasting the difference in the sound wave's arrival time, however slight, at each ear. The brain can also detect minute differences in the strength of the stimuli reaching the receptors in each ear.

The Human Ear



What Happens in Deafness?

Some people are born deaf. Others become partially or totally deaf through illness or injury. The following are the **three** main types of deafness:

1. **Conduction Deafness.** If the eardrums or middle ear bones are immobilized by disease or injury, sound waves are partially or completely prevented from entering the inner ear. This condition is called conduction deafness. Hearing aids, by amplifying sound waves so that they can reach the inner ear, can often alleviate the condition of conduction deafness.
2. **Nerve Deafness.** Nerve deafness is caused by damage to the auditory nerve. Auditory messages cannot reach the brain, no matter how loud the sound, so hearing aids are of no help.
3. **Stimulation Deafness.** Permanent hearing loss can occur when the cochlea is damaged by prolonged exposure to very loud noise. This condition is called stimulation deafness. Loud noise can also cause a persistent ringing in the ears.

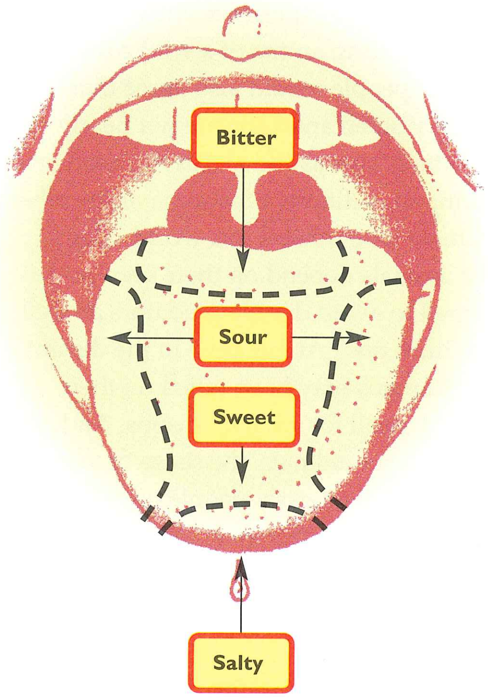
Smell and Taste

The senses of smell are known as the *chemical senses.* Receptors for smell in the nose respond to gaseous molecules in the air, and receptors for taste on the tongue and elsewhere in the mouth respond to the chemical composition of foods. Most people would agree that the quality of our lives is greatly enhanced by our senses of smell and taste. One of life's greatest pleasures—eating—would become a dreadfully boring activity if we could not taste anything. And imagine how much duller life would be if we could never experience such things as the intoxicating aroma of a wild rose. Even so, most people would also agree that the senses of smell and taste are not nearly as important to us as the senses of vision and hearing. It is different for some of the other creatures who inhabit this world. Many wild animals depend on their keen sense of smell to avoid deadly predators as well as to hunt prey. At one time in the distant past, humans may have relied on their sense of smell for similar reasons. And, just as with other animals, the sense of taste probably helped early people learn which foods could be safely eaten. Even today this ability can help us avoid harmful substances, which usually have a bitter taste.

How Do We Taste Food?

Most of our taste receptors, or taste buds, are located on the surface of the tongue, but they are also in other parts of the mouth, such as the palate (roof of the mouth). Specific taste buds are especially sensitive to chemicals associated with one of the four primary taste qualities—bitter, sour, salty, or sweet. The brain interprets the pattern of neural impulses from the taste buds as one of four primary tastes or any combination of the four.

People's sense of taste varies. You may remember that as a child you disliked certain foods. You probably refused to eat vegetables and many other items that you now enjoy. Young children like salty food, The Taste Buds



but turn away from spicy, sour, or bitter food. As people age, their taste buds become less sensitive, and many therefore develop a taste for spicy food.

The sense of smell is also involved in our experience of taste and allows us to experience complex tastes. You may have noticed that when you have a cold, food seems to lack its usual taste. When your nasal passages are blocked, you can't smell the food, and this restricts your ability to taste the food. Just for fun, next time you are enjoying one of your favorite foods, try pinching your nostrils together with your fingers and see if you note any change in the taste.

How Do We Smell Odors?

Receptors for smell are located in the nose. The process of olfaction, or smell, begins when we inhale. As odors enter the nose, receptors in the upper nasal passages detect them. This triggers a neural impulse to the olfactory bulbs, which are connected to the receptors. A sensory code in the olfactory bulbs sends information about the odors to the brain by way of the olfactory nerve. The brain then interprets the neural impulses as a particular odor.

Animals use their sense of smell in the process of attracting and selecting a mate. At the appropriate time, their bodies give off **pheromones**, or odor molecules, that other animals of their species interpret as a sexual message. Some people believe that humans may also make use of pheromones to communicate sexual interest. But others think that even if this were true, pheromones would be just one of many factors involved in the complex nature of human sexual attraction.

Touch, Pressure, Temperature, and Pain

Our body's nervous system includes receptors in the skin that respond to the following stimuli: touch, pressure, temperature (heat and cold), and pain. These are called **somatic receptors**. Scientists have determined that although somatic receptors are found all over the body, their density varies in different areas.

Pheromones

People wonder if humans use pheromones to attract the opposite sex. Some researchers think not. Neurobiologist Emily Liman, in experiments with rats, identified a gene for tiny pores called *ion channels.* Pheromones cause a rat's olfactory receptors to open the ion channels, sending nerve signals to the brain. But Liman found that the equivalent gene in humans is mutated and nonfunctional. If this evidence is confirmed by further research, it suggests that humans do not respond to pheromones, although they may have done so at an earlier stage of human evolution.

The tongue, lips, face, hands, and genitals have much greater numbers of receptors and are therefore more sensitive to stimuli. Pain receptors are also found inside the body, so we sometimes experience pain in internal organs.

As with the other kinds of sensory receptors, somatic receptors convert stimuli to neural impulses and send them to the brain. In the brain the neural impulses are interpreted as specific sensations in the somatic sensory cortex.

Why Do We Have to Feel Pain?

All of us have at one time or another experienced pain. Think about an episode of physical pain you had to endure. Depending on the intensity of the pain, or how long it lasted, the experience was either mildly unpleasant, absolutely awful, or something in-between. Most of us try to avoid pain and would prefer never to experience it. And yet, we are actually lucky to be able to feel pain. Pain serves as a warning signal, providing us with vital information about illness or possible tissue damage. For example, pain lets us know if we burn ourselves or if we are suffering from an attack of appendicitis. Pain thresholds vary with each individual. Some people have a very low tolerance for pain, while others can withstand a great deal of pain. And some people have a rare condition that prevents them from ever feeling physical pain—but they are not to be envied.

How Does the Body Alleviate Pain?

People have long resorted to the use of various types of narcotic drugs to reduce sensations of pain. But the body also produces its own substances, known as **endorphins**, which can help reduce or eliminate pain. Various types of endorphins are produced and released by neurons in the upper spinal cord and in several regions of the brain. The endorphins bind to receptors in the brain, just as narcotic drugs do, to reduce or eliminate the pain.

Since we do not experience pain until the brain interprets incoming neural impulses as pain, some scientists believe that pain can be lessened by preventing some of the pain "message" from reaching the brain. The **gate control theory** suggests that we have a built-in gating mechanism in the spinal cord that can block neural impulses outside the brain. There are two types of pain fibers entering the spinal cord: large (fast conducting) and small (slow conducting). A message sent in one pain fiber can close the "pain gate" to a message from the other fiber. If only one pain message gets through to the brain, the result is that we feel less pain. Scientists suspect that this theory may explain how the ancient Chinese practice of acupuncture works. It may be that acupuncture needles inserted in the appropriate places in the body affect the functioning of our pain gates. When the acupuncturist twirls the needles, this may cause small, sharp pains which, when carried by small fibers, close the gates to more intense or chronic pain.

Sidebar

Managing Pain

There is much evidence that pain can be controlled by psychological methods. People suffering from intense pain experienced some relief when distracted by something else—for example by being shown colored slides and asked to describe aloud what they saw. If you were in pain, on what would you focus your attention to alleviate the pain?

CRITICAL THINKING

What Does Sensory Deprivation Prove?

To gain a greater understanding of how our sensory systems work, some researchers have conducted experiments in sensory deprivation. Read about one experiment and analyze it.

THE ISSUES

John Lilly, M.D., was interested in sensation and how our brains create a vivid impression of the external world based on neural impulses responding to various kinds of stimuli. Lilly wanted to learn more about the functioning of human sensory systems and how our senses allow us to survive in the external world. He suspected that depriving a person for a period of time of all incoming stimuli might reveal useful insights into the way we use our senses to connect with reality.

Lilly devised an experiment in which volunteers would spend varying lengths of time in an "isolation tank." They would be cut off from all outside stimuli. Floating naked inside the tank in body-temperature water, the volunteers also wore darkened goggles. With no sensations of vision, hearing, taste, smell, or touch, they drifted in the silent darkness of the tank. At first their minds focused on their new environment and the condition of their bodies within it. Thoughts of the day would then occupy them. But soon, they began to lose track of time. And before long, many experienced vivid mental images that had nothing to do with outside stimuli. Lilly himself spent a lot of time in his isolation tank. He claimed to have left his body and visited other dimensions where he encountered "beings of higher intelligence."

While some volunteers found their experience boring and meaningless, others found it to be enlightening and profound, delightful, or scary. Some claim that this experiment demonstrates that when our senses are prevented from keeping us in touch with our ordinary sense of reality, our brains create an alternate reality.

THE PROCESS

① **Restate the argument.** In your own words, give the rationale for conducting this experiment.

② **Provide evidence.** List the evidence from the experiments that *supports* Lilly's belief that sensory stimuli help people connect with reality.

③ **Give opposing arguments.** What aspects of Lilly's experiment are *not conclusive?*

④ **Look for more information.** What else would you want to know about sensory deprivation? Make a list of your questions. Then research *Lilly* and *sensory deprivation* in an encyclopedia, on the Internet, or in the psychology section of a library.

⑤ **Evaluate the information.** Make a chart with two columns:

Lilly's Experiment

Worthwhile	Not Worthwhile

Record the evidence and give each item a number from 1 to 5 to show its importance. Number 1 is most important.

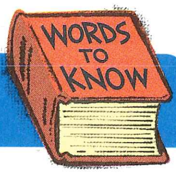
⑥ **Draw conclusions.** Write one paragraph explaining your view of Lilly's experiment.

Chapter 4 Wrap-up

SENSATION

Our knowledge of the world comes to us through our sensory systems, which respond to various types of stimuli. We can see because sensory receptors in the retina of the eye convert light waves into electrical neural impulses, the language of the brain. The neural messages travel along the optic nerve to the visual cortex of the brain, where they are interpreted as images of the external world. Sensory receptors in the ear convert sound waves into neural messages that the auditory cortex of the brain interprets as sound. A similar process occurs with our other senses—smell, taste, touch, pressure, temperature, and pain. In each case, sensory receptors are activated by stimuli and then convey information in the form of neural impulses to the brain, where the information is interpreted as particular sensations.

Psychology



absolute thresholds—minimum amounts of energy that can be detected by the sensory systems. *p. 52*

auditory nerve—bundle of nerves that carries sound to the brain. *p. 58*

cochlea—tubular snail-shaped structure in the inner ear containing cilia, the main receptors for sound waves. *p. 58*

endorphins—substances produced by the body that can reduce or eliminate pain. *p. 62*

gate control theory—theory of a built-in gating mechanism in the spinal cord that can block neural impulses outside the brain. *p. 62*

perception—process in which the brain organizes sensory information to make it meaningful. *p. 52*

pheromones—odor molecules given off by animals that communicate a sexual message. *p. 60*

photoreceptors—neurons, or nerve cells, in the retina that are sensitive to light and convert it into electrical neural impulses. *p. 55*

receptors—nerve cells within the sensory organs that convert stimuli, such as light or sound waves, into neural impulses. *p. 52*

retina—light-sensitive lining at the back of the eye that contains rods and cones. *p. 54*

sensory adaptation—reduction in sensory response to an unchanging form of stimulation. *p. 53*

sensory coding—particular pattern of a neural message that a sensory organ sends to the brain. *p. 53*

somatic receptors—receptors in the skin that respond to touch, pressure, temperature, and pain. *p. 60*

visual cortex—part of the brain in which neural impulses are interpreted as visual images. *p. 55*