Hardware for hearing: Cochlear implants work by translating sounds into electrical signals that are transmitted to the cochlea and, via the auditory nerve, on to the brain.

For now, the only way to restore hearing for people with nerve deafness is a sort of bionic ear—a cochlear implant, which, by 2009, had been given to 188,000 people worldwide (NIDCD, 2011). This electronic device translates sounds into electrical signals that, wired into the cochlea’s nerves, convey information about sound to the brain. Cochlear implants given to deaf kittens and human infants seem to trigger an “awakening” of the pertinent brain area (Klinke et al., 1999; Sireteanu, 1999). They can help children become proficient in oral communication (especially if they receive them as preschoolers or even before age 1) (Dettman et al., 2007; Schorr et al., 2005).

The latest cochlear implants also can help restore hearing for most adults. However, the implants will not enable normal hearing in adults if their brain never learned to process sound during childhood. Similarly, cochlear implants did not enable hearing in deaf-from-birth cats that received them when fully grown rather than as 8-week-old kittens (Ryugo et al., 2010).

**Perceiving Loudness**

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

If a hair cell loses sensitivity to soft sounds, it may still respond to loud sounds. This helps explain another surprise: Really loud sounds may seem loud to people with or without normal hearing. As a person with hearing loss, I used to wonder what really loud music must sound like to people with normal hearing. Now I realize it sounds much the same; where we differ is in our sensation of soft sounds. This is why we hard-of-hearing people do not want all sounds (loud and soft) amplified. We like sound compressed—which means harder-to-hear sounds are amplified more than loud sounds (a feature of today’s digital hearing aids).

**Perceiving Pitch**

**20-2 What theories help us understand pitch perception?**

How do we know whether a sound is the high-frequency, high-pitched chirp of a bird or the low-frequency, low-pitched roar of a truck? Current thinking on how we discriminate pitch, like current thinking on how we discriminate color, combines two theories.
Hermann von Helmholtz’s place theory presumes that we hear different pitches because different sound waves trigger activity at different places along the cochlea’s basilar membrane. Thus, the brain determines a sound’s pitch by recognizing the specific place (on the membrane) that is generating the neural signal. When Nobel laureate-to-be Georg von Békésy (1957) cut holes in the cochleas of guinea pigs and human cadavers and looked inside with a microscope, he discovered that the cochlea vibrated, rather like a shaken bedsheet, in response to sound. High frequencies produced large vibrations near the beginning of the cochlea’s membrane. Low frequencies vibrate more of the membrane, including near the end. But a problem remains: Place theory can explain how we hear high-pitched sounds but not low-pitched sounds. The neural signals generated by low-pitched sounds are not so neatly localized on the basilar membrane.

Frequency theory suggests an alternative: The brain reads pitch by monitoring the frequency of neural impulses traveling up the auditory nerve. The whole basilar membrane vibrates with the incoming sound wave, triggering neural impulses to the brain at the same rate as the sound wave. If the sound wave has a frequency of 100 waves per second, then 100 pulses per second travel up the auditory nerve. But again, a problem remains: An individual neuron cannot fire faster than 1000 times per second. How, then, can we sense sounds with frequencies above 1000 waves per second (roughly the upper third of a piano keyboard)?

Enter the volley principle: Like soldiers who alternate firing so that some can shoot while others reload, neural cells can alternate firing. By firing in rapid succession, they can achieve a combined frequency above 1000 waves per second. Thus, place theory best explains how we sense high pitches, frequency theory best explains how we sense low pitches, and some combination of place and frequency seems to handle the pitches in the intermediate range.

Locating Sounds

How do we locate sounds?

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

Two ears are better than one for at least two reasons. If a car to the right honks, your right ear receives a more intense sound, and it receives sound slightly sooner than your left ear (FIGURE 20.3). Because sound travels 750 miles per hour and our ears are but 6 inches apart, the intensity difference and the time lag are extremely small. A just noticeable difference in the direction of two sound sources corresponds to a time difference of just 0.000027 second! Lucky for us, our supersensitive auditory system can detect such minute differences (Brown & Deffenbacher, 1979; Middlebrooks & Green, 1991).

**Figure 20.3**

How we locate sounds. Sound waves strike one ear sooner and more intensely than the other. From this information, our nimble brain computes the sound’s location. As you might therefore expect, people who lose all hearing in one ear often have difficulty locating sounds.