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Hearing Rehabilitation for Individuals with Severe and Profound Hearing Impairment: Hearing Aids, Cochlear Implants, and Counseling

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Introduction

In the eight years since the first edition of this book was published, significant technologic advances have been made in digital processing of sound, electronic circuits, and microphone design for hearing aids and cochlear implants. In addition, new speech coding strategies have been developed for cochlear implants that provide significantly more information than was available in 1993. At that time, only linear hearing aids were available for those with severe or profound hearing impairment. Today fully digital hearing aids with multiband compression can be fit to provide a larger range of sound levels within an individual's small dynamic range of residual hearing. In addition, one recently introduced hearing aid provides additional high-frequency gain plus frequency compression for voiceless, high-frequency consonants so that those with little or no hearing in this frequency region can hear these speech sounds at lower frequencies (Davis, 2001). Although the range of speech recognition abilities is large among those who have severe or profound hearing impairment and who use hearing aids or cochlear implants, most enjoy significant improvement in their ability to recognize speech as a consequence of these technologic advances. This chapter reflects the impact that these technologic advances have had on fitting hearing aids and the effect that improvement in speech recognition with cochlear implants has had on the criteria for cochlear implantation.

Cochlear implants have undergone a major advance in their digital processing capabilities, with the latest generation now capable of making soft speech and other sounds audible. The digital processing in hearing aids also can make these soft sounds audible if the hearing loss is not profound. For some individuals who use hearing aids, this information makes a notable difference in their speech recognition as well as in their hearing in everyday life. That is, digital processing in appropriately fitted hearing aids brings greater clarity than earlier hearing aids, and no matter whether sounds are near or far away, dynamic changes in gain usually make these sounds comfortably loud. For other individuals, there is no noticeable difference in clarity between digital aids and analog compression or linear hearing aids. It appears that the ability of their inner ears to transduce the amplified sound energy to stimulate the surviving neurons is not as effective as for individuals who can hear sound with greater clarity. Or it may reflect the status of their auditory nerve or central auditory pathways. Just as with hearing aids, there is a wide range of speech recognition performance with cochlear implants that is related to the number of surviving neurons and a number of other factors. The implant, however, bypasses the normal transduction process and individual electrodes stimulate discrete populations of auditory neurons that provide different pitch percepts. With the implant, sound can be transmitted equally well at all frequencies up to 6000 and 8000 Hz. Earmold fit, feedback, and, for many, the lack of surviving hair cells at frequencies above 1000 Hz make this very difficult or impossible with hearing aids. Another approach to receiving information about high-frequency sound is through digital processing available in new frequency compression hearing aids. The challenge is to determine who will benefit more from a cochlear implant than from appropriately fitted hearing aids.

In our opinion, we are entering a new era when it is no longer appropriate to use the National Acoustic Laboratories (NAL) target of a 65- to 70-dB sound pressure level (SPL) speech spectrum (Byrne and Dillon, 1986; Byrne et al, 2001) as the major focus of a fitting procedure for either hearing aids or cochlear implants. Given digital processing in both devices, targets of 50- and 60-dB SPL are equally important. If a sound is not above threshold, it cannot be recognized. By the same token, an audible sound may not be recognized if there is insufficient transduction of complex acoustic signals in the cochlea. Nevertheless, adults and children need to hear sound at soft to loud levels to carry on fluent conversations. Recognition of soft speech sounds will help those with hearing aids or cochlear implants understand when a speaker lowers his or her voice during a conversation or is naturally soft-spoken, when the speaker does not get the listener's attention before speaking, or when someone speaks at some distance away. Hearing these soft sounds will reduce the effort needed to determine what has been said from incomplete cues and the misunderstandings that occur when what is said is not understood. This reduction in effort will mean that those with severe or profound hearing impairment will feel less tired at the end of the day, and those who communicate with them will expend less effort and be able to say more in an equal length of time. Access to these soft sounds is particularly important for children because their language development is significantly enhanced by hearing speech and other sounds in incidental listening situations.

The goal for fitting hearing aids and cochlear implants is to match incoming sound with each person's residual hearing so that (1) as large a range of speech and environmental sounds as possible is heard and recognized, (2) normal conversational speech (~60 dB SPL) is as clear as possible, (3) sound quality is acceptable, and (4) loud sounds are not too loud. With the complexity of prescribing gain, maximum output, and other parameters for wide dynamic range compression in hearing aids (Cornelisse et al, 1995; Byrne et al, 2001), it is no longer appropriate for audiologists to prescribe the amount of gain as was described for linear hearing aids in the first edition of this book. For this reason, procedures used to fit advanced technology hearing aids for two adults will be described as case studies. Two case studies of adults with cochlear implants will be included so that the results can be compared with those for hearing aids. In addition, results obtained from a few children who first used linear hearing aids and then used digital processing aids will be described, as well as information from one child who subsequently received a cochlear implant. Finally, one case study of an adult fitted with frequency compression hearing aids will be included. The present criteria for cochlear implantation will be considered in light of information from these adults and children.

For those with severe or profound hearing impairment, neither hearing aids nor cochlear implants will provide normal hearing. Even if these devices are adjusted to provide as much access to sound as possible, there will always be situations when an individual either does not hear or does not understand what is said. Speech reading serves as an incomplete supplement. Depending on an individual's residual hearing, speech reading abilities, cognitive and verbal skills, and willingness to ask for clarification of what has been said, as well as how clearly the other person speaks and the amount of background noise, the person with the hearing impairment may or may not be able to determine what has been said. Inevitably there will be communication breakdowns during which everyone, including family members, friends, and co-workers, feels awkward and unsure of how to communicate. Working through these breakdowns will depend on the individual's capacity to implement effective communication strategies and on the willingness of those with whom he or she is speaking to cooperate. Hearing rehabilitation counseling for adults is intended to enable patients to discover how to converse with their families, friends, and co-workers in as fluent, effective, and satisfying ways as possible. This counseling provides strategies for patients and their frequent communication partners to communicate effectively in situations encountered in everyday life and to practice employing these strategies with each other in face-to-face and telephone conversations. During this counseling, assistive devices can be considered to enhance the reception of speech and other sounds (such as hand-held microphones with direct audio input; high-gain telecoils; amplifiers, adapters, or teletypewriters (TTYs) for telephone use; FM, loop, and infrared systems for personal or wide area use; open and closed captioning; and alerting systems). Hearing rehabilitation counseling also may take the form of speech reading; auditory training; telephone training; evaluation, fitting, and guidance in how to use assistive devices, hearing aids and/or a cochlear implant effectively; listening to music; and environmental sound training. The ultimate goal is increased quality of life through developing greater self-acceptance as persons with a hearing impairment; this includes an acceptance of their right to ask others to work with them to communicate effectively.

This chapter focuses on concepts to consider when selecting hearing aids for adults and children, determination of cochlear implant candidacy in adults, and hearing rehabilitation counseling for adults needed to ensure maximal use and benefit from these devices. Determination of cochlear implant candidacy and provision of habilitation services for infants and young children with severe and profound hearing loss are more complex because the onset of these losses occurs before or during acquisition of spoken language. For this reason, information on these topics is not included in this chapter but can be found elsewhere (Allum, 1996; Tye-Murray, 1998; Moog and Geers, 1999; Robbins, 2000).

Severe and Profound Hearing Impairment

The degree of hearing impairment is often defined by the average hearing loss at 500, 1000, and 2000 Hz obtained with supra-aural earphones. For severe hearing impairment, this average is between a 70- and 89-dB hearing level (HL; ANSI, 1996); and for profound hearing impairment, it is 90-dB HL or greater (Katz and White, 1982). This chapter focuses on individuals with these degrees of binaural hearing impairment. For evaluation of this population, it is important to use an audiometer with an output extending to 130-dB SPL, with supra-aural earphones measured in a 6-cc coupler, to determine whether or not an individual can hear between 250 and 8000 Hz and at what threshold levels. Many individuals with profound hearing loss have no hearing at some audiometric frequencies (most commonly at 1000 Hz and above), and some have no hearing at any frequency.

Most people with severe or profound hearing impairment have *sensorineural* hearing loss. That is, there is significant loss or dysfunction of inner and outer hair cells of the cochlea and secondary degeneration of primary auditory neurons. Loudness recruitment may be present. It is defined as the abnormally rapid growth of loudness above threshold as the physical intensity of sound increases. For these individuals, the range from threshold to uncomfortable loudness level (UCL) is small (e.g., 5 to 30 dB) and can vary at each frequency. For this reason, it is important to evaluate an individual's growth of loudness in specific frequency regions. Threshold and growth of loudness to a loud level at individual frequencies provide a basis for fitting hearing aids. In addition to frequency-specific growth of loudness, there is summation of loudness across frequencies. The amount of loudness summation varies among individuals and must be evaluated with broadband sounds amplified by hearing aids to determine what gain will make speech comfortably loud and what maximum output will prevent loud sound from being uncomfortable. This same sequence of evaluating threshold, growth of loudness, and assessing loudness summation associated with stimulation across electrodes is used in fitting cochlear implants. Those with severe or profound sensorineural hearing impairment have decreased ability to detect changes in the intensity, frequency, and temporal aspects of sound as well as decreased ability to separate the frequency components of complex sounds that occur simultaneously (frequency selectivity). Although there is a large range of abilities of those using hearing aids or a cochlear implant, decrements in auditory processing capability often are associated with marked reduction in speech recognition, particularly in reverberant rooms and in the presence of noise.

Individuals with equivalent pure-tone thresholds can have very different auditory processing skills. Therefore, it is essential to recommend hearing aids or a cochlear implant based on an individual's ability to recognize speech. This ability cannot be adequately assessed with an audiometer because (1) the frequency response cannot be shaped so that amplified speech is matched to the individual's residual hearing, (2) speech often cannot be made loud enough to be comfortable, and (3) output limiting is not available for those with very small dynamic ranges. Consequently, speech recognition must be assessed with well-fitted hearing aids.

Some people have a *mixed* hearing impairment in which there are conductive and sensorineural components. The most common etiology for the conductive component is otosclerosis; other etiologies are outer ear and/or ossicular malformation, disease, or surgical intervention in the middle ear that cause abnormal transmission of sound energy through the middle ear. This conductive component results in a decrease in the SPL reaching the inner ear. For this reason, these individuals often need hearing aids with greater gain and maximum output than those with the same degree of *sensorineural* hearing impairment. These issues are described in Chapter 10.

A few patients have neural hearing impairment caused by loss or dysfunction of auditory neurons. This dysfunction can occur in cranial nerve VIII or central auditory pathways. A bilateral, severe, or profound hearing impairment is usually caused by space-occupying lesions of either the vestibular or auditory parts of cranial nerve VIII or lesions of the brainstem at the level of the cochlear nucleus or superior olivary complex. Although a hearing aid is often useful until sound is no longer loud enough to be heard comfortably, a cochlear implant is not appropriate in these cases because the auditory pathways medial to the implant are severely compromised. The auditory brainstem implant (see Chapter 11) that stimulates auditory neurons in the cochlear nucleus is appropriate for those with bilateral cranial nerve VIII neuromas (Otto et al, 2000).

Finally, there are some patients who have normal otoacoustic emissions (OAEs) and cochlear microphonic (CM) responses from one or both ears coupled with abnormal auditory brainstem responses (ABRs) and behavioral responses consistent with a bilateral severe or profound hearing loss. This pattern of auditory test results has been named auditory neuropathy (Starr et al, 1996). It is hypothesized that the normal OAEs reflect normal outer hair cell function but the abnormal ABRs reflect inner hair cell dysfunction and/or dysfunction of the auditory nerve and central auditory pathways. Although there are large individual differences in underlying causes, a number of individuals have received significant benefit from cochlear implantation (Shallop et al, 2001).

Speech Levels in Everyday Life

Speech is the most important sound we hear in everyday life. Consequently, an understanding of what speech levels occur is essential to fitting hearing aids and cochlear implants. Within a sentence spoken at one vocal effort, there is a constantly changing pattern of energy in the frequency and intensity domains as a function of time. The overall level from one phoneme to another within a sentence covers a range of ~30 dB (see Fig. 2.1 in Skinner, 1988). If the long-term spectrum of speech spoken at *one* vocal effort is measured over several minutes, the range of momentary energy in third-octave bands centered at each frequency across the range is approximately 30 dB (−12 dB above the long-term level and 18 dB below it) (see Fig. 2.2 in Skinner, 1988). The most comprehensive study of speech and environmental noise that occurs in everyday life was conducted by Pearsons et al (1977). Figure 12–1A shows the average spectra in one-third-octave bands centered at the audiometric frequencies across males, females, and children who spoke at five vocal efforts for that study plotted on a sound-field audiogram in dB HL. The long-term overall (OA) level of speech spoken in the sound field at each of these levels at 0-degree azimuth 1 m from the listener is as follows. Casual conversation was at 40-dB HL (i.e., 56-dB SPL), normal conversation was at 44-dB HL (i.e., 60-dB SPL, not 65- or 70-dB SPL as in linear prescriptive fitting procedures), raised voice was at 50-dB HL (66-dB SPL), loud voice was at 58-dB HL (74-dB SPL), and a shout was at 68-dB HL (84-dB SPL). In addition, soft speech can be considered to be at 50-dB SPL (34-dB HL). Note that as greater vocal effort is used, there is more high-frequency energy. Imagine a 30-dB range of energy around each of these contours with levels that are 18 dB less intense and 12 dB more intense across the frequency range. To illustrate this range, a dashed line has been placed 18 dB above the casual conversation contour (i.e., between 10- and 20-dB HL) and another has been placed 12 dB below the contour for shouted speech (i.e., between 50- and 80-dB HL). Figure 12–1B is the Mueller and Killion (1990) "count-the-dot" audiogram form for calculation of the articulation index (AI). Mueller and Killion have integrated concepts from the original theory of AI calculation from French and Steinberg (1947) with those of Pavlovic (1986) and his colleagues (1985) and others to provide audiologists with a simplified method to calculate the proportion of speech cues that are audible between 250 and 6000 Hz and contribute to the recognition of speech in everyday life. When an individual's unaided or aided audiogram is plotted on this form, the number of dots out of a total of 100 that lie above threshold represents the proportion of speech cues that are audible. Note that the dots lie between 13- and 49-dB HL. The dots for 250 and 6000 Hz nearest the upper solid line in Figure 12–1A are at 13- and 15-dB HL, respectively. The other dots that lie at the most sensitive level at each frequency are close to 20-dB HL and are at slightly higher levels than the upper solid line between 500 and 4000 Hz. For all speech cues to be audible according to the count-the-dot scheme,

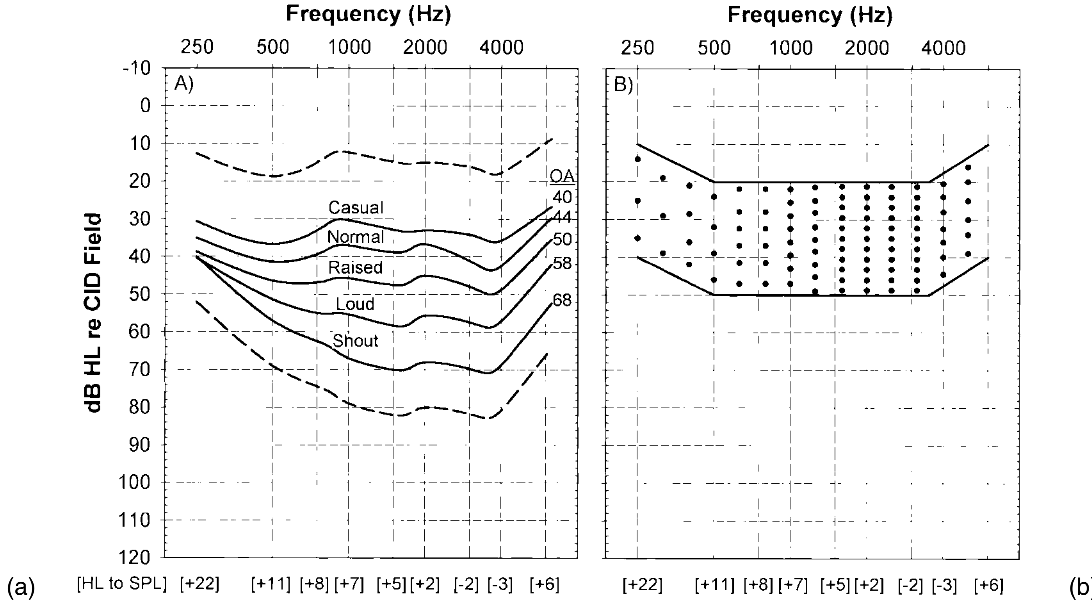

Figure 12–1(a and b). a: Average spectra across men, women, and children for speech spoken at five vocal efforts (casual, normal, raised, loud, and a shout; Pearsons et al, 1977) measured in one-third-octave band levels and plotted at the audiometric frequencies between 250 and 6000 Hz in dB HL [referred to the Central Institute for the Deaf (CID) sound field; Skinner, 1988]. The upper dashed line represents speech energy 18 dB less intense than that represented by the "casual" speech contour; the lower dashed line represents speech energy 12 dB more intense than that represented by the "shouted" speech contour. To convert from dB HL to dB SPL, the numbers at the bottom of the graph are added to the values at each audiometric frequency shown in the graph. The overall level (OA) of speech for each vocal effort is shown in dB HL at the right side of each spectrum; to convert from dB SPL to dB HL, 16 dB is subtracted from each dB SPL value. b: Count-the-dot audiogram form for calculation of the articulation index (AI). (From Mueller HG, Killion MC. An easy method for calculating the articulation index. *Hear J* 1990;49(9):1–4. Reprinted with permission from Lippincott Williams & Wilkins.)

aided thresholds would be at 20-dB HL at 300 through 4000 Hz, a goal that is in close agreement with Pascoe's (1975) target of aided thresholds at 20-dB HL across the frequency range for individuals with moderate, gently sloping hearing loss that were more severe in the higher frequencies. With appropriately fitted cochlear implants, audiologists can obtain thresholds near 20-dB HL between 250 and 6000 Hz in a substantial proportion of recipients. With appropriately fitted digital processing hearing aids, audiologists can approximate 20-dB HL thresholds for at least a few frequencies for individuals with severe hearing loss. In everyday life, the greater the proportion of speech sounds that is audible, the greater the potential is that soft sounds will be recognized and conversation will be more fluent.

Two Case Studies of Adults with Binaural Hearing Aids

These adults, who acquired their hearing loss after learning language, participated in two successive hearing aid studies 2 years ago. First, they were fitted with power, behind-the-ear (BTE) digital hearing aids that they used for 3 months. Then the patients were fitted with power, BTE analog programmable dual-microphone hearing aids that they used for 3 months. The research was not designed for direct comparison of the two types of hearing aids, but the subjects knew they could purchase the aids they preferred at the end of the two studies.

Different fitting procedures were used because the aids processed sound differently. In the power digital aid, the dynamic range compression was level dependent (i.e., gain varied as a function of the level of incoming sound), and the amount of overall compression was based on the dynamic range of the patient. That is, soft speech was intended to be above the patients' threshold levels and loud speech below their uncomfortable loudness levels. As part of the fitting process, the patients' audiometric thresholds using TDH-50 supra-aural earphones were obtained at 250 through 8000 Hz and entered into the fitting software. Loudness growth also was measured using the Independent Hearing Aid Fitting Forum (IHAFF) loudness rating scale (i.e., very soft, soft, comfortable but slightly soft, comfortable, comfortable but slightly loud, loud but OK, uncomfortably loud) for pure tones presented in 5-dB steps at half-octave intervals between 500 and 4000 Hz (Cox et al, 1997). Based on the threshold and "loud" levels entered into the programming software, the fitting software specified the crossover frequencies and amplification characteristics in the low-, mid-, and high-frequency bands. Over the next 4 to 6 weeks, the threshold and the "loud" levels were adjusted based on the patient's subjective comments. Sound-field measurements were performed because the real-ear system could not measure the dynamically changing gain of digital hearing aids at the time of the study.

The power analog programmable hearing aid could be adjusted with programming software for overall gain, gain in the low-, mid-, and high-frequency bands, and overall output. Patients had access to only one of the three memories during the study; the dual-microphone was activated at all times. Although this aid had several sound processing options, only linear processing up to its compression threshold of ~80 dB SPL was used. A 10:1 compression ratio with an adaptive release time was used above this high compression threshold. This hearing aid was programmed initially by calculating the NAL revised (NAL-R) (Byrne and Dillon, 1986) prescribed gain from the patient's thresholds and then adjusting the aid's real-ear insertion gain (REIG) so that its output for a speech-weighted composite noise presented at 65-dB SPL would approximate the prescribed gain. The output of the hearing aid was set so that a 90-dB SPL pure-tone sweep did not exceed the patient's overall loudness judgment of "loud." The programmed levels were then fine-tuned over a 4- to 6-week period based on the patient's subjective comments.

Both patients are still using the binaural hearing aids they purchased at the end of these studies. They had used these aids for approximately 2 years when their unaided and aided hearing was evaluated as described below.

Case Study for Patient 1

This patient is a 48-year-old state trooper who had an asymmetric sensorineural hearing loss with essentially normal hearing except for a moderate hearing loss at 3000 and 4000 Hz at the right ear and mild-to-moderate hearing loss with a moderately severe notch from 2000 to 4000 Hz in the left ear in 1991. Unaided word recognition was normal at the right ear and slightly reduced at the left ear. Medical and radiologic evaluation revealed no known reason for the asymmetric hearing loss other than the head-shadow effect during noise exposure. He began wearing in-the-canal, linear hearing aids binaurally in 1992. Over the next 2 years, he had three intense noise exposures: a submachine gun discharging 3 feet from him, concussion grenades detonating on the ground near him, and a shotgun discharging 2 to 3 feet from his head. Following these exposures, he had a mild to moderate flat sensorineural loss at the right ear, and a moderate to moderately severe loss at the left ear. He had slight difficulty with unaided word recognition binaurally; he was fit with binaural wide dynamic range compression

(WDRC) programmable analog BTE hearing aids. Over the next 3 to 4 years, his hearing continued to decline to a moderately severe to severe binaural sensorineural hearing loss with poor unaided word recognition. At that time he began participation in the hearing aid studies described above.

The adjustments made during the 6 weeks after initial fitting with the digital aids were as follows. All initial threshold values for both aids were increased by 5 to 20 levels in the programming software except for the low band in the left ear. This increase in threshold values was made so that the patient could hear soft sounds more clearly and hear people speaking from far away. For the left ear, the low-band level was reduced by 5 to eliminate a "barrel" sound quality. The "loud" levels were increased by 5 to 10 levels in all three bands. With these aids, binaural aided sound-field thresholds (dB HL) were in the teens and low twenties from 500 to 4000 Hz; these thresholds were 10 to 20 dB more sensitive compared to those with his previous programmable analog hearing aids. The fitting and adjustments with the dual-microphone power analog aids were as follows. The actual REIG was 5 to 10 dB below that prescribed by the NAL-R procedure at 3000 and 4000 kHz despite the high-frequency gain being set at maximum. In addition, overall output was programmed at the maximum. With this setting, a 90-dB SPL pure-tone sweep was reported as "loud." Although this patient reported a notable reduction in background noise from the dual-microphone, this was not as beneficial to him as the increase in soft sounds he experienced with the digital hearing aids. He also noticed that he could understand speech better in background noise, and the sound was crisper and much more distinct with the digital hearing aids that he decided to purchase. He uses full-shell, soft material earmolds with a pressure vent.

The data shown for patient 1 in Figure 12–2 were obtained during a recent evaluation. Figure 12–2a shows his thresholds and mean "loud" levels obtained with TDH-50, supra-aural earphones at the right and left ears. He has a flat, severe hearing loss bilaterally with a dynamic range between 19 and 32 dB across the frequency range. Figure 12–2b shows the real-ear aided response (REAR) for composite speech-shaped noise presented at 50-, 60-, 70-, 80-, and 90-dB SPL and measured with a probe tube microphone near the eardrum in the right and left ears. The output for the right hearing aid does not increase linearly. That is, there is a 3- to 5-dB increase in output for the 10-dB increase in input between 50- and 60-dB and 70- and 80-dB SPL with a slightly greater increase in output from 80- to 90-dB SPL. In contrast, the increase from 60- to 70-dB SPL is approximately 10 dB. The REARs for the left hearing aid show a different pattern. There is approximately a 5- to 9-dB increase in output for a 10-dB increase in input between 50- and 80-dB SPL, and only a 1- to 4-dB increase in output for a 10-dB increase in input between 80- and 90-dB SPL caused by the hearing aid approaching the patient's programmed maximum setting in the high band. His unaided mean "loud" levels (measured in dB SPL using a probe microphone near the eardrum) are shown in relation to the REAR values. At the right ear, they are at or above the output of the hearing aid for an input of 90-dB SPL except at 750, 1000, and 1500 Hz, where they are lower; a trial reduction in this frequency region resulted in less clarity so the original level was maintained. At the left ear, the mean "loud" levels are at higher levels than the output of the hearing aid for an input of 90-dB SPL at all frequencies.

In Figure 12–2c, the speech spectra measured in one-third-octave bands for the Hearing in Noise Test (HINT) sentences (Nilsson et al, 1994) and Consonant-Vowel Nucleus-Consonant (CNC) words (Peterson and Lehiste, 1962) for presentation levels of 50-, 60-, and 70-dB SPL (root mean square (RMS), slow, linear scale) are plotted in relation to patient 1's binaural sound-field thresholds shown by the circles. His thresholds are between 6- and 22-dB HL over the range of 250 and 3000 Hz; only at 4000 and 6000 Hz do they decrease to 32- and 30-dB HL, respectively. As shown in the left panel of Figure 12–2c, his scores for HINT sen-

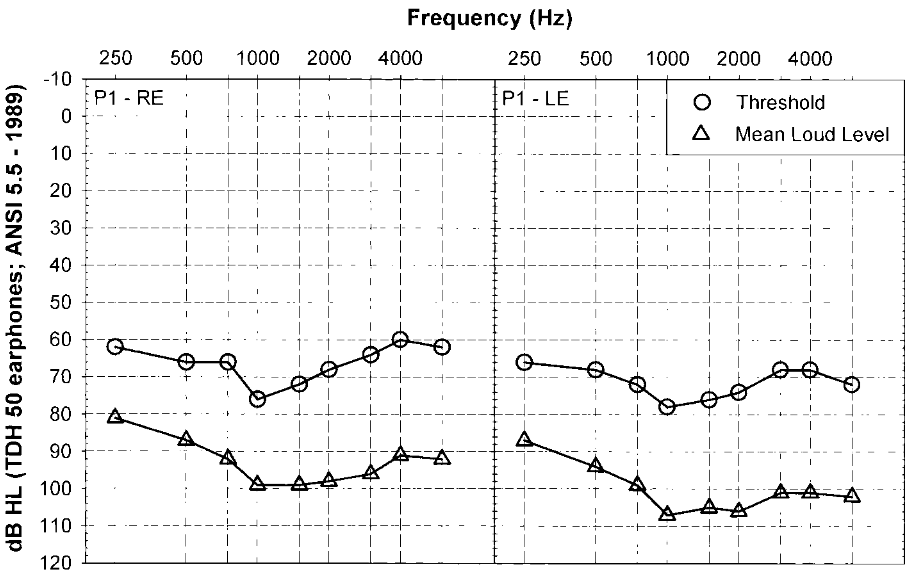

Figure 12–2a. Pure-tone thresholds and mean "loud" levels obtained with supra-aural earphones for patient 1's right ear (left panel) and left ear (right panel).

tences presented in quiet at soft (50-dB SPL), normal (60-dB SPL), and raised-to-loud (70-dB SPL) levels represent normal performance (98 to 100% correct). Scores at each level represent a mean across four lists. When HINT sentences were presented at 65-dB SPL in multitalker babble (recorded in Melbourne, Australia), the signal-to-noise ratio (SNR) was set at 5 dB to significantly reduce the score below that in quiet. At this

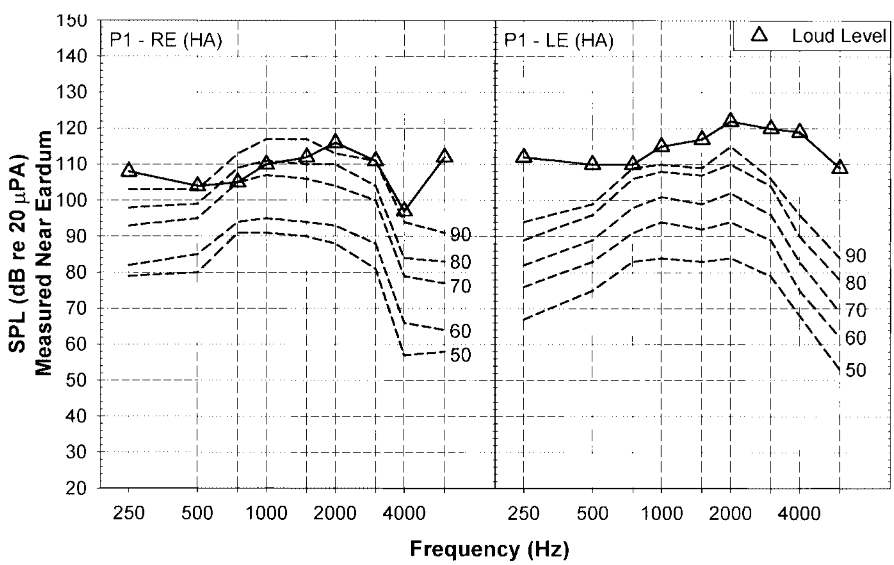

Figure 12–2b. Patient 1's mean "loud" levels (triangles) measured in dB SPL with a probe-tube near the eardrum at the right ear (left panel) and left ear (right panel) plotted in relation to the REAR measurements of hearing aid output for composite speech-shaped noise inputs of 50-, 60-, 70-, 80-, and 90-dB SPL at each ear.

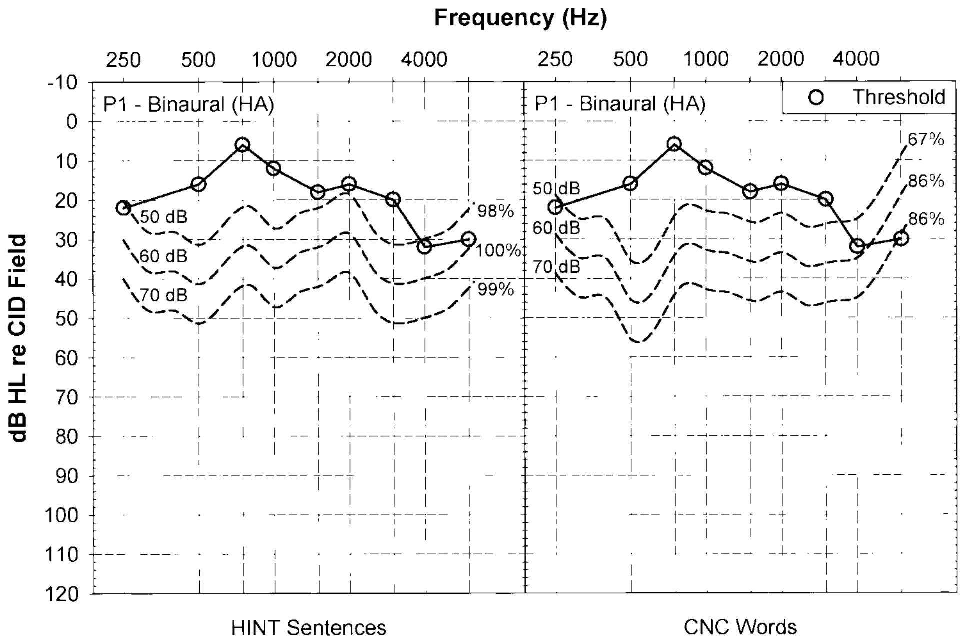

Figure 12–2c. Left panel: Speech spectra of Hearing in Noise Test (HINT) sentences measured in one-third-octave band levels and plotted at the audiometric frequencies between 250 and 6000 Hz in dB HL for the CID sound field (Skinner, 1988) in relation to patient 1's binaural sound-field thresholds with his hearing aids for warble tones at the audiometric frequencies. Sentences were presented at 50-, 60-, and 70-dB SPL as shown on the left side of the three contours; his scores are shown at the right side of the contours. Right panel: Speech spectra of CNC words measured in one-third-octave band levels and plotted at the audiometric frequencies between 250 and 6000 Hz in dB HL for the CID sound field (Skinner, 1988) in relation to patient 1's binaural sound-field thresholds with his hearing aids for warble tones at the audiometric frequencies. Words were presented at 50-, 60-, and 70-dB SPL as shown at the left side of the three contours; his scores are shown at the right side of the three contours.

SNR, his score was 69%. As shown in the right panel of Figure 12–2c, his scores for CNC words presented at the three levels in quiet are near normal (86%) at 70- and 60-dB SPL, and 19 percentage points lower (67%) at 50-dB SPL due to inaudibility of some acoustic cues. Scores at each level represent a mean across two lists. Based on his sound-field thresholds, the AI value calculated with the count-the-dot method was 0.90; that is, 90% of the dots were above threshold.

Patient 1 reported that there is a vast difference in hearing aid performance with the digital aids he uses now compared with his first pair of linear analog hearing aids in 1992. His hearing aids have enabled him to work effectively as a state trooper; otherwise, he would have lost his job. Today he wears his aids all waking hours, and he estimates a perceived problem of ~10% compared to not being able to hear at all without the hearing aids. He reports that he can hear what people say despite differences in the distance away, even if they turn their backs to him. However, if a distant sound is soft and a louder sound occurs close by, the hearing aid adjusts to process the louder sound. All sounds are heard as comfortably loud including those close by as well as those far away. He is able to hear in noise; for example, he can understand speech in the midst of the voices from multiple channels of police stations on the radio. To hear in traffic, he turns the hearing aid volume control all the way down (−6 dB), a setting that allows him to understand what people who are close say to him. At the end of the day, he is not tired from straining to hear what is said. In fact, he helps his son with his homework in the evening and has no problem hearing or interacting with him. For this patient, earmold fit is extremely important. Each time he gets new earmolds he files them to remove places that are causing irritation and pain in his ear canal until they are comfortable.

Case Study for Patient 2

Patient 2 is a 68-year-old retired minister. He had chronic ear infections as a child and bilateral stapedectomies in the 1960s for otosclerosis. He has worn hearing aids for over 25 years and is an avid user of a variety of assistive-listening devices, including a personal FM system. Prior to the research studies, he wore power linear BTE hearing aids. He had a severe to profound sensorineural hearing loss at that time with the left ear thresholds 5 to 10 dB poorer from 250 to 2000 Hz than the right ear thresholds. Unaided word recognition was 46% and 38% at the right and left ears, respectively. Two years later, his pure-tone thresholds showed no significant change, but his unaided word recognition was substantially worse (28% and 30% at the two ears, respectively).

During the first research study, the digital hearing aids were initially programmed with his threshold and "loud" rating levels. During the following weeks, threshold values in the programming software for both aids were decreased 3 to 5 levels in the low band. Threshold values in the middle and high bands were increased in both aids between 5 and 9 levels. The maximum levels were raised in all three bands from 5 to 12 levels, an increase that resulted in more linear amplification. Patient 2's aided soundfield thresholds (dB HL) were in the mid-20s and 30s. These represented a 5- to 15-dB improvement from 500 to 4000 Hz compared with those with his BTE nonprogrammable analog hearing aids. Despite the additional amplification, patient 2 reported that these aids did not have the volume to which he was accustomed. He also reported that speech did not seem as clear or distinct.

The dual-microphone hearing aids were initially programmed to approximate patient 2's NAL-R prescribed real-ear gain. The REIG did not meet this target above 2000 Hz in the right ear and 1500 Hz in the left ear, even with the high-frequency gain set to maximum. When the overall output was set at maximum, the 90-dB SPL pure-tone sweep was rated as "loud." After this initial fitting, an increase in the low- and mid-band gain settings was made to provide the additional volume and loudness he requested. The configuration of the REIG was very similar to the nonprogrammable hearing aids he had been wearing prior to the study. The dual microphone was very beneficial in the majority of his everyday environments. The telecoil, programmed to its maximum strength, was improved compared to his previous telecoil; this was a significant advantage in using the telephone and his FM system. He purchased these aids at the end of the study. He uses full-shell, soft material earmolds with a pressure vent.

The data shown in Figure 12–3 were obtained during a recent evaluation. Figure 12–3a shows his hearing thresholds and mean "loud" levels obtained with TDH-50 earphones. He has a severe to profound hearing loss in the right ear and a profound hearing loss in the left ear. The right ear has a dynamic range of approximately 30 dB from 500 to 2000 Hz; the left ear has a reduced dynamic range, primarily due to the poorer thresholds. At both ears, there are several frequencies at which his "loud" levels were beyond the limits of the audiometer. Figure 12–3b shows the REAR of his hearing aids for composite speech-shaped noise presented at 50-, 60-, 70-, 80-, and 90-dB SPL and measured with a probe tube microphone near the eardrum in the right and left ears. The shapes of the REAR are very similar for the two hearing aids, showing a very peaked response with maximum amplification at 1000 Hz. There is essentially linear amplifica-

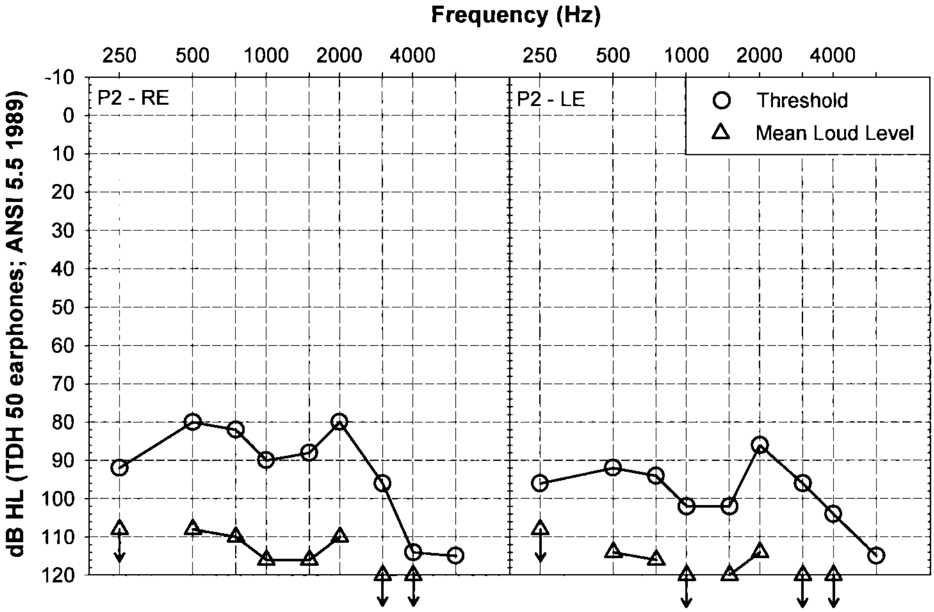

Figure 12–3a. Pure-tone thresholds and mean "loud" levels obtained with supra-aural earphones for patient 2's right ear (left panel) and left ear (right panel).

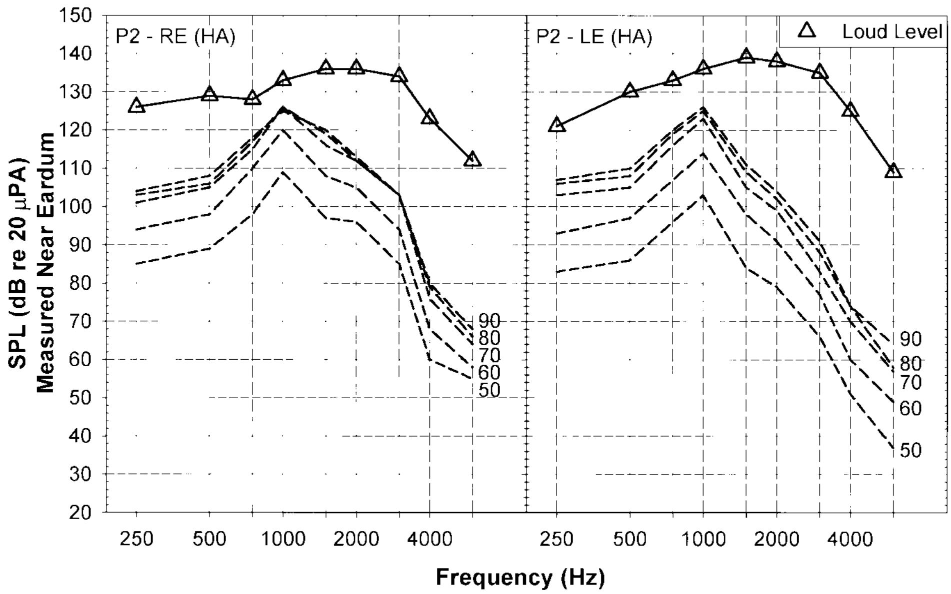

Figure 12–3b. Patient 2's mean "loud" levels (triangles) measured in dB SPL with a probe-tube near the eardrum at the right ear (left panel) and left ear (right panel) plotted in relation to the REAR measurements of hearing aid output for composite speech-shaped noise inputs of 50-, 60-, 70-, 80-, and 90-dB SPL at each ear.

tion for inputs between 50- and 70-dB SPL with nearly equivalent outputs for inputs at 70-, 80-, and 90-dB SPL. That is, these input levels caused saturation of the output. There was limited flexibility in programming the output of these hearing aids to patient 2's dynamic range because many of the settings were programmed at the maximum. Because of the severity of his loss at the left ear, soft to medium-level sounds are not audible. However, he believes the left ear provides useful amplification that benefits him in everyday situations. Because he has better aided thresholds at the right ear, his right hearing aid is more effective. Unlike patient 1, neither of patient 2's hearing aids' REARs follow the shape of his mean loud levels. Despite this apparent discrepancy between the shape of his "loud" judgments and the hearing aids' responses, he preferred this configuration with linear amplification that closely resembled that of his previous hearing aids. When flatter responses were tried, he said that the sound quality was diminished. It is hypothesized that he learned to recognize aided speech with the response characteristics of linear amplification over a period of 25 years; the change of the digital aids' response characteristics to a more appropriately shaped linear analog response did not provide him the cues on which he depended.

In Figure 12–3c, the speech spectra measured in one-third-octave bands for HINT sentences and CNC words for presentation

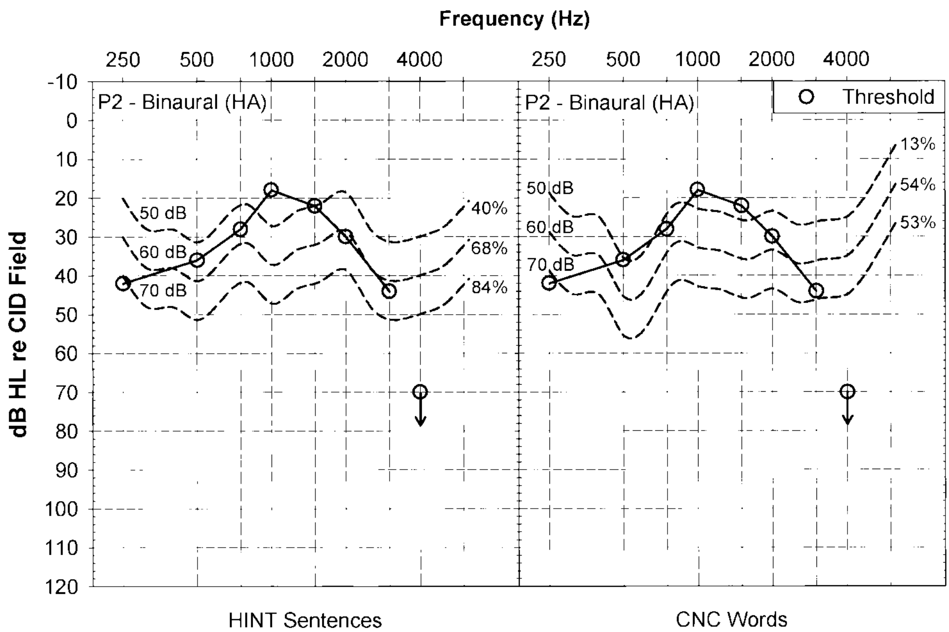

Figure 12–3c. Left panel: Speech spectra of HINT sentences measured in one-third-octave band levels and plotted at the audiometric frequencies between 250 and 6000 Hz in dB HL for the CID sound field (Skinner, 1988) in relation to patient 2's binaural sound-field thresholds with his hearing aids for warble tones at the audiometric frequencies. Sentences were presented at 50-, 60-, and 70-dB SPL as shown on the left side of the three contours; his scores are shown at the right side of the contours. Right panel: Speech spectra of CNC words measured in one-third-octave band levels and plotted at the audiometric frequencies between 250 and 6000 Hz in dB HL for the CID sound field (Skinner, 1988) in relation to patient 2's binaural sound field thresholds with his hearing aids for warble tones at the audiometric frequencies. Words were presented at 50-, 60-, and 70-dB SPL as shown at the left side of the three contours; his scores are shown at the right side of the three contours.

levels of 50-, 60-, and 70-dB SPL are plotted in relation to patient 2's binaural sound-field thresholds shown by the circles. His thresholds follow the same configuration as the REAR contours in Figure 12–3b. That is, the most sensitive threshold is at 18-dB HL at the point of greatest output, 1000 Hz. At 250 and 3000 Hz where there is substantially less output, the thresholds drop to 42- and 44-dB HL, respectively; a 4000-Hz warble tone was inaudible at 70-dB HL. As shown in the left panel of Figure 12–3c, his scores for HINT sentences presented in quiet at raised-to-loud (70-dB SPL), normal (60-dB SPL), and soft (50-dB SPL) levels decreased from 84 to 40% correct as the number of acoustic cues that were audible decreased (compare thresholds with spectral contours at the three levels). When HINT sentences were presented at 65-dB SPL in multitalker babble at a SNR of 15 dB, his score was 57%. As shown in the right panel of Figure 12–3c, his scores for CNC words presented at the three levels in quiet were moderately impaired (i.e., 53 to 54%) at 70- and 60-dB SPL, and 41 percentage points lower (i.e., 13%) at 50-dB SPL due to inaudibility of most acoustic cues. Based on his sound-field thresholds, the AI value calculated with the count-the-dot method was 0.50; that is, 50% of the dots were above threshold.

Patient 2 reported that he obtained a master's degree to teach in the seminary; by the time he finished, he believed that his hearing loss would prevent him from being an effective professor. Therefore, he chose to be a pastor in small churches. In this setting, he could communicate well in one-on-one relationships, and his wife helped him with Bible study classes. At the present time, he finds that his recognition of speech is primarily from his right ear. For him to determine what has been said, it is very important for people to speak slowly at a normal or slightly raised vocal effort. This process takes much energy and concentration. After concentrating very hard for an hour or two, tiredness takes over; usually he cannot understand anything when he is this tired. For example, he reported that his children have said, "Dad, aren't you listening? Aren't you interested in what we have to say?" He responded, "No matter how hard I try to listen right now, I can't understand." He summarized this poignant situation by saying, "Hearing is not a solitary problem; it is a family problem."

Two Case Studies of Adults with Cochlear Implants

Two patients were chosen for these case studies whose hearing loss was acquired after they had learned language. Both used the Nucleus 24 Cochlear Implant System with the straight electrode array for approximately 2 years. They have participated in a research study to determine whether the default or a high preamplifier gain would provide the best hearing in everyday life (James et al; unpublished manuscript). They were chosen based on their differing abilities to recognize speech in noise and in the amount of microphone preamplifier gain they choose for listening comfort in everyday life. Since the initial stimulation of the implant, the minimum [threshold (T)] and maximum [maximum comfort (C)] levels for monopolar stimulation (25 microseconds/phase pulse duration) have been adjusted many times to provide the best access to sound in everyday life in conjunction with the other parameters chosen for mapping incoming sound onto their electrical dynamic range of hearing. For this chapter, their sound-field thresholds for warble tones were obtained using the implant at the microphone sensitivity (i.e., microphone input gain), volume control (i.e., amount of reduction in maximum electrical output), and automatic noise reduction settings used in everyday life. Although patient 3 usually wears a hearing aid in his unimplanted right ear, it was turned off. These patients' speech recognition with the implant was evaluated with the same tests as were given to patients 1 and 2.

Case Study for Patient 3

Patient 3 is a 66-year-old retired computer programmer who was implanted at the left ear two and a half years ago. Prior to implantation, his hearing loss in the high frequencies was probably initially caused by exposure to artillery noise in the army and computer noise on his job. At the time he obtained his first hearing aid for the right ear in 1994, he had a mild sensorineural hearing loss at 250 and 500 Hz that sloped to 60-dB HL at 2000 and 4000 Hz. His thresholds at the left ear were 10 to 15 dB better at 250 and 500 Hz and 10 to 20 dB poorer at 2000 and 4000 Hz than at the right ear. By 1996, he was using hearing aids at both ears, and his thresholds at both ears were 10 to 20 dB worse than in 1994. From July to December 1996, he had a rapid deterioration in hearing at both ears. Audiologically, he was not a candidate for a cochlear implant in December 1996, but 1 year later he was when the thresholds at 500 Hz were 100-dB HL at both ears. During this progression in hearing loss from 1994 to 1998, he had no fluctuation in hearing, and he was not dizzy. His hearing did not improve with prednisone treatment, and the Harris Western Blot test was negative for autoimmune etiology (Harris and Aframen, 1994). Magnetic resonance imaging (MRI) and computed tomography (CT) radiologic studies were normal.

At surgery, four of the 10 supporting bands in the electrode array were reported outside the cochlea. He uses the SPrint body processor programmed with the advanced combination encoder (ACE) speech coding strategy and a stimulation rate of 1800 pulses per second (pps) on each electrode with eight of a total of 20 active electrodes stimulated each cycle (Skinner et al, in press). The frequency-to-electrode allocation for incoming sound spans the range from 187 to 7937 Hz. In everyday life, patient 3 finds sound is most comfortable at a relatively loud level; consequently, he uses a relatively high microphone preamplifier gain setting of 13 (out of a range of 1 to 20). To allow background noise to be more tolerable, he uses the noise-reduction setting to make loud sound less loud, and he uses the volume control set at 5 (i.e., out of a range of 1 to 9).

His sound-field thresholds plotted in relation to the spectral contours measured in one-third-octave band levels for HINT sentences presented at 70-, 60-, and 50-dB SPL in quiet are shown in the left panel of Figure 12–4a. At 70- and 60-dB SPL, his scores of 99% and 98% correct are consistent with the spectral cues between 250 and 6000 Hz being well above threshold. His slightly reduced score of 91% at 50-dB SPL is consistent with some acoustic cues being inaudible. The left panel of Figure 12–4b shows his sound-field thresholds in relation to the speech spectrum of HINT sentences presented at the raised level of 65-dB SPL. To reduce his score below that which he obtained in quiet, multitalker babble was presented at an SNR of 6 dB. His score was 56%. His sound-field thresholds plotted in relation to the spectral contours for CNC words presented at 70-, 60-, and 50-dB SPL in quiet are shown in the left panel of Figure 12–4c. Although most of the cues are audible at 70- and 60-dB SPL, his scores of 76% and 80% reflect the fact that he does not have normal hearing. That is, he is hearing processed sound delivered through stimulation of 20 electrodes in the inner ear. Nevertheless, his scores are among the highest of cochlear implant patients. His substantially lower score of 52% at 50-dB SPL reflects the fact that many of the acoustic cues in these words are close to or below threshold. However, this score is above the average score for large groups of cochlear implant recipients who listen to these words at 70-dB SPL (Osberger and Fisher, 1999; Skinner et al, in press). Based on his sound-field thresholds, the AI value calculated with the count-the-dot method was 0.95; that is, 95% of the dots were above threshold.

Patient 3 wears his implant at the left ear and a BTE hearing aid at the right ear in everyday life. With these devices, he reports that he has no trouble understanding in one-on-one conversation except with his 2-year-old granddaughter who speaks very softly. He can understand what someone says from across the room, if he is paying attention. If he is reading or watching TV, the person

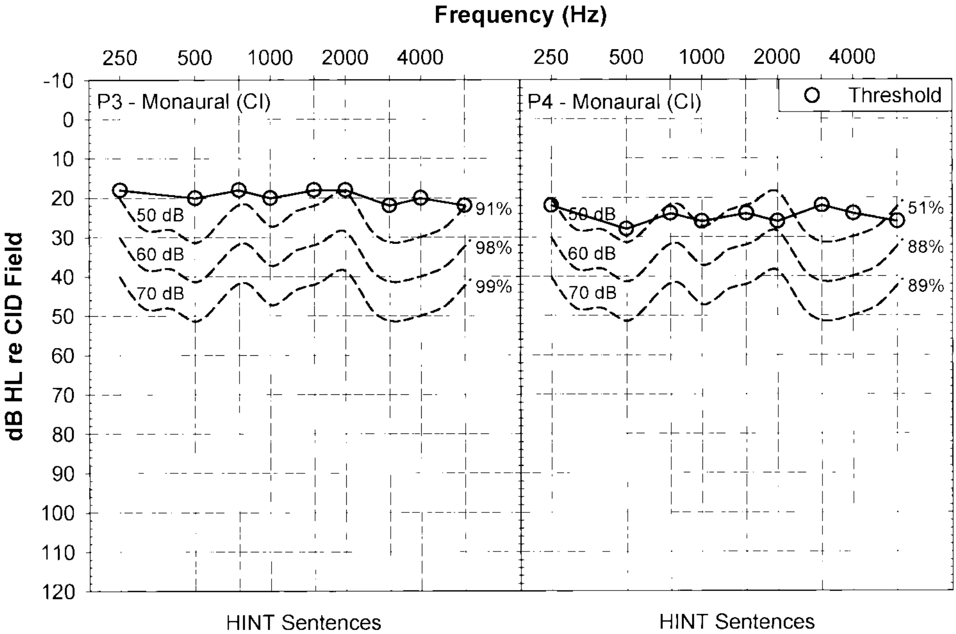

Figure 12–4a. Left panel: Speech spectra of HINT sentences measured in one-third-octave band levels presented at 50-, 60-, and 70-dB SPL and plotted in dB HL for the CID sound field in relation to patient 3's monaural sound-field thresholds with his cochlear implant for warble tones at the audiometric frequencies. His scores are shown at the right side of the three contours. Right panel: Same information for patient 4.

across the room needs to get his attention first. He can hear people speak to him from another room, but to understand what they are saying he needs to get closer. In the car, he can hear some things pretty well on the radio if the windows are closed, and he can understand someone talking with him, if he turns off the car radio. In church services, some voices are very clear, if the person speaks distinctly at a loud enough level directly into the microphone. In a restaurant, he cannot understand what is said if the noise is really loud. When he goes bowling, he can understand what is said to him reasonably well when he turns off his BTE hearing aid and uses the noise suppression setting on his implant. With a telephone adapter, he can talk easily with people on the phone except when they don't speak clearly. For example, he has trouble understanding one friend who slurs his words, but he also has difficulty when he is talking with him in person and has access to speech-reading cues. He does not feel tired at the end of the day from exerting great effort to understand what people have said.

Case Study for Patient 4

Patient 4 is a 62-year-old librarian with otosclerosis who was implanted at the right ear 2 years ago. At the age of 11, she failed a hearing test; at age 13, she obtained her first hearing aid (a body aid). When she was 19, she had a fenestration operation at the left ear that did not provide her with much improvement in hearing. Four years later, in 1961, the stapes was replaced in the left ear during another surgery with no improvement in hearing. Since then, she has had collection of debris in that cavity that has been cleaned regularly; she also has had ear infections. She has never used a hearing aid at the left ear. In 1961, her air conduction thresholds at the right ear were relatively flat at 60-dB HL; she had a mixed hearing loss. By

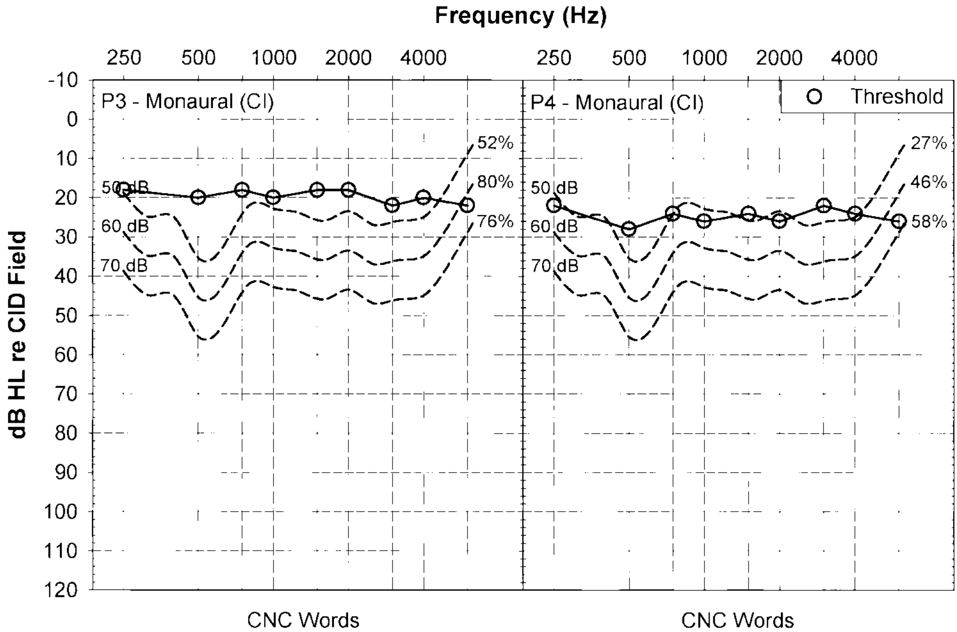

Figure 12–4b. Left panel: Speech spectrum of HINT sentences measured in one-third-octave band levels presented at 65-dB SPL and plotted in relation to patient 3's monaural sound-field thresholds with his cochlear implant for warble tones at the audiometric frequencies. Sentences were presented in eight-talker babble at a signal-to-noise ratio (SNR) of +6 dB. The score is shown at the right of the contour. Right panel: Same information for patient 4 except an SNR of +13 dB was used.

1971, her air conduction thresholds had decreased to 85- to 95-dB HL, and by 1976, these thresholds were 105-dB HL. With her powerful body air-conduction hearing aid, she was able to understand speech on the telephone until 1993. In 1994, she had no response at most frequencies during air conduction testing under earphones.

At surgery, 10 supporting rings and two electrodes were reported outside the cochlea. They could not be inserted further due to resistance, presumably from abnormal bone growth due to otosclerosis. She wears the SPrint body processor programmed with the ACE speech coding strategy using a stimulation rate of 1800 pps on each electrode with eight of a total of 16 active electrodes stimulated each cycle (Skinner et al, in press). The frequency-to-electrode allocation for incoming sound spans the range from 187 to 7937 Hz. In everyday life, patient 4 finds sound is most comfortable at a softer level than patient 3; consequently, she uses her microphone preamplifier gain at the default setting (i.e., 8 out of a range of 1 to 20). She does not use the noise-reduction setting except in noisy situations, such as traffic noise when driving her car. To reduce the loudness of loud sound, she uses the volume control turned down to 6 (i.e., out of a range of 1 to 9). Her sound-field thresholds plotted in relation to the spectral contours for HINT sentences presented at 70-, 60-, and 50-dB SPL in quiet are shown in the right panel of Figure 12–4a. These thresholds are on the average 5 dB poorer than those of patient 3 (see the left panel in Fig. 12–4A) because she uses a lower microphone sensitivity setting. At 70- and 60-dB SPL, her HINT sentences scores of 89% and 88% are consistent with many of the spectral cues between 250 and 6000 Hz being above threshold but not as high above threshold as for patient 3. In addition, she had a much longer duration of deafness than

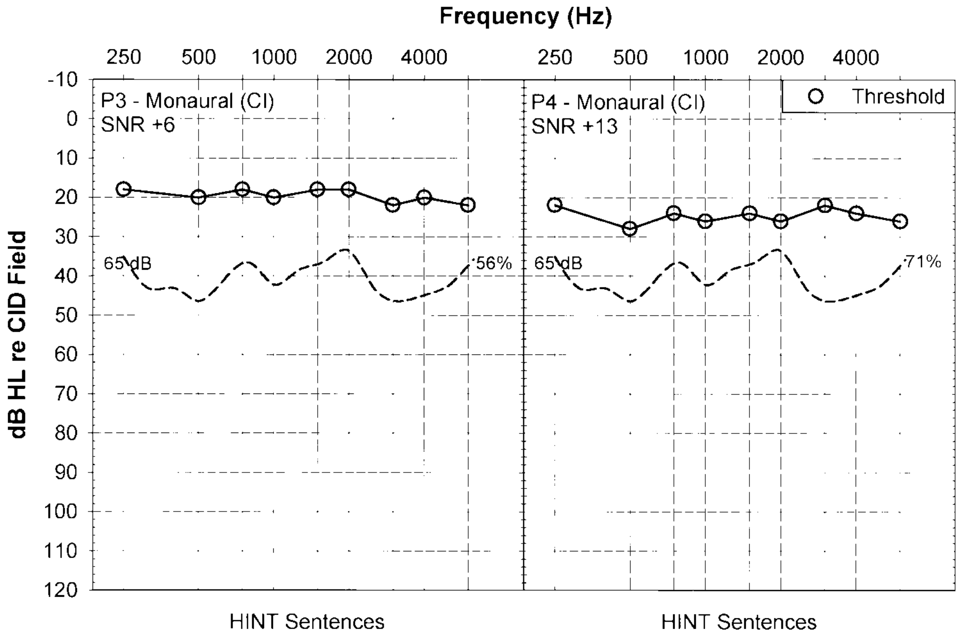

Figure 12–4c. Left panel: Speech spectra of CNC words presented at 50-, 60-, and 70-dB SPL plotted in dB HL for the CID field in relation to patient 3's monaural sound-field thresholds with his cochlear implant for warble tones at the audiometric frequencies. His scores are shown at the right side of the three contours. Right panel: Same information for patient 4.

patient 3 prior to being implanted. Her significantly reduced score of 51% at 50-dB SPL is consistent with approximately half of the acoustic cues being inaudible as shown by the intertwining of the threshold and speech spectrum contours (taking into account the 30-dB range, 12 dB above and 18 dB below the speech spectrum). The right panel of Figure 12–4b shows her sound-field thresholds in relation to the speech spectrum of HINT sentences presented at the raised level of 65-dB SPL. To reduce her score below that which she obtained in quiet, multitalker babble was presented at an SNR of 13 dB; that is, the noise level was 7 dB less intense than for patient 3. Her score was 71%. In comparison with patient 3, she could not recognize speech in noise as well, partly because the speech spectrum was 5 dB closer to threshold than for patient 3. Her sound-field thresholds plotted in relation to the spectral contours for CNC words presented at 70-, 60-, and 50-dB SPL in quiet are shown in the right panel of Figure 12–4c. Although most of the cues are audible at 70 SPL, her score of 58% reflects the fact she does not have normal hearing but is hearing processed sound delivered by stimulation of 16 active electrodes in the inner ear. Nevertheless, this score is above average for large groups of cochlear implant recipients who listen at this level (Osberger and Fisher, 1999; Skinner et al, in press). Her lower score of 46% at 60-dB SPL reflects the fact the acoustic cues in these words are 10 dB closer to threshold. Her substantially lower score of 27% at 50-dB SPL is because many of the cues are at or below threshold. Her score at this level is about half that of patient 3. Based on her sound-field thresholds, the AI value calculated with the count-the-dot method was 0.77; that is, 77% of the dots were above threshold.

Patient 4 reports that she has no difficulty understanding in one-on-one situations when talking in quiet at normal conversational levels and distances. If someone talks to her from across the room, she can hear the person but does not understand everything that is said. When she is at a meeting, she sets the microphone gain up to 15; this results in other people's voices being louder and more intelligible. Since she learned to listen with her implant, she has become very active in several church and community groups that require her attendance at meetings. If she is talking with someone in the entranceway at the end of a church service, she can understand what the person says fairly well if she turns away from the crowd, puts on the noise reduction setting A, and uses speech-reading cues. Although the trains blow their whistles as they come through town close to her house, the noise is OK when she is inside. However, road noise when she is driving bothers her. If use of the A setting makes it acceptable, then she leaves the implant on. She finds that she can talk with someone seated in the back of her car if she increases the microphone gain setting and uses the A setting. At the end of the day, she is often tired. She is not tired of listening; she just wants peace and quiet. Prior to implantation, she was withdrawn and depressed; in contrast, her friends have remarked on how radiant she is now.

Three Case Studies of Children with Hearing Aids

These three children have severe to profound sensorineural hearing loss. They attended a private oral school for the deaf. They were originally fitted with binaural linear hearing aids prior to arrival at the school. When digital, power BTE hearing aids became available, these children were fitted with this new technology. Adjustment of the linear hearing aids was based on pure-tone unaided thresholds obtained at each ear and real-ear to coupler difference measures (Moodie et al, 1994) made with the child's hearing aid earmolds. These measures were used to set the frequency-gain characteristics and output saturation pressure level 90 (OSPL90). Desired sensation level (DSL) hearing aid fitting targets for gain were approximated and maximum output targets were not exceeded (Seewald, 1995; Seewald et al, 1996). Further adjustments were made based on the child's response to amplification at each ear. For the digital hearing aids, pure-tone thresholds as well as real-ear to coupler measures were obtained at each ear. These values were then entered into the software of the Audioscan RM500 Speechmap/DSL fitting system. This system implements the DSL v.4.1 equations for average aided speech targets for WDRC instruments (Seewald et al, 1997). With this software and real-ear measurement system, the output of the aids was adjusted by changing the aids' fitting parameters so that the dynamic signal simulating speech was within the child's auditory area between the threshold and upper limit of comfortable loudness. No attempt was made to approximate the DSL targets. The gain for soft sound was maximized; however, a compromise was made between this goal and preventing feedback that causes an automatic reduction in gain. Further adjustments were made based on the child's response to the amplified sound at each ear. An FM system has been used effectively with the digital hearing aids in the school classroom. For both types of hearing aids, supersoft silicone earmolds with long canals and full shell molds were made for these children. The evaluation of all three children's binaural thresholds and speech recognition was performed with their linear aids just prior to digital hearing aid fitting and after 1 to 3 months' use of the digital hearing aids.

Case Study for Child 1

Child 1's hearing was normal until she had meningitis at 3 years 9 months of age, after which she had a profound sensorineural hearing loss at the right ear at all frequencies and a mild (i.e., 25-dB HL at 250 and 500 Hz) to profound (90-dB HL at 750 Hz and above) hearing loss at the right ear. She used linear hearing aids for 1 year prior to being fitted with digital hearing aids when she was 5 years old. As shown in Table 12–1, her binaural aided thresholds with the linear hearing aids were at slightly more sensitive lev-

Table 12–1. Binaural Aided Thresholds (dB HL) for Warble Tones Presented in the Sound Field with Linear and Then with Digital Hearing Aids for Three Children. Differences in Thresholds (dB) are Shown (i.e., Linear Minus Digital Hearing Aid Values); Positive Values Indicate Better Thresholds with Digital Hearing Aids

Case Study Child	*Child Hearing Aid*	*250 Hz*	*500 Hz*	*1000 Hz*	*2000 Hz*	*4000 Hz*
1	Linear	10	5	35	35	55
1	Digital	15	15	35	40	50
	Difference	*−5*	*−10*	*0*	*−5*	*5*
2	Linear	40	45	45	55	50
2	Digital	20	30	30	40	40
	Difference	*20*	*15*	*15*	*15*	*10*
3	Linear	45	20	40	40	50
3	Digital	20	25	20	35	45
	Difference	*25*	*−5*	*20*	*5*	*5*

els than the digital aids. With both sets of aids, she was evaluated with open-set, PBK-50 monosyllabic words (PBK: Phonetically Balanced Kindergarten; Haskins, 1949), presented at 70- and 50-dB SPL and with a closed-set test of spondees presented in noise at 65-dB SPL at 0-dB SNR. As shown in Table 12–2, her score was 44 percentage points higher for the spondees presented at the raised level of 70-dB SPL with the digital hearing aids compared to the linear aids, 16 percentage points higher for PBK-50 words presented at 70-dB SPL, and 24 percentage points higher when they were presented at the soft level of 50-dB SPL. This marked improvement in speech recognition at a soft level, coupled with the substantial improvement at the raised level, reflects the greater clarity with which she hears speech with the digital aids. Her results clearly show that the slight decrease in audibility with the digital hearing aids (i.e., slightly poorer thresholds) is offset by the substantial increase in clarity of speech, particularly at a soft level. Her linear hearing aids provided significant amplification in the low frequencies that may have caused an upward spread of masking for the right ear. The flexibility of the digital hearing aid allowed for reduction in low-frequency amplification at that ear. She has been mainstreamed in the public schools and is performing well. She regularly uses an FM system with ear-level receivers coupled to her hearing aids for classroom listening. The child has indicated that the digital hearing aids "work better" and "help me hear better" than her old hearing aids. Her parents have reported that she no longer is bothered by loud sounds and follows conversation in noise more easily. They noted that she has less nasal vocal quality, self-corrects her own speech errors more often, and imitates speech sounds more consistently. Extended family members also have noticed that her speech is easier to understand.

Case Study for Child 2

Child 2 had a progressive, sensorineural hearing loss of unknown etiology that became severe to profound. Hearing loss was identified at 12 months of age, and she used linear hearing aids for 8 years prior to being fitted with digital hearing aids when she was 9 years old. As shown in Table 12–1, her binaural aided thresholds with the digital hearing aids were at 10 to 20 dB more sensitive levels than with the linear aids; this improvement in thresholds was associated with a substantial improvement in audibility of soft speech. With both sets of aids, she was evaluated with open-set, PBK-50 monosyllabic words, presented at a raised level of 70-dB SPL binaurally and to each ear alone. Binaurally, her score was 12 percentage points higher with digital compared

Table 12–2. Scores (% correct) on Speech Tests Presented at Either 70- or 50-dB Sound Pressure Level (SPL) in the Sound Field for Three Children Who Used Binaural Linear and Then Binaural Digital Hearing Aids; The Spondees Were Presented in Noise at a 0-dB Signal-to-Noise Ratio (SNR); the PBK-50 Words Were Presented in Quiet

Child	*Binaural/ Specific Ear*	*Word Test*	*Level (dB SPL)*	*Linear Aids Score*	*Digital Aids Score*
1	Binaural	Spondees	65	32	76
1	Binaural	PBK-50	70	60	76
1	Binaural	PBK-50	50	28	52
2	Binaural	PBK-50	70	52	64
2	Right ear	PBK-50	70	16	40
2	Left ear	PBK-50	70	48	48
3	Binaural	PBK-50	70	36	72

with linear hearing aids (Table 12–2); at the right ear, it was 24 percentage points higher; at the left ear, there was no difference in score. These results suggest that the digital hearing aid provided greater clarity at the right ear but not at the left ear; the greater clarity at the right ear with the digital aid and the audibility of softer speech levels appear to be related to the binaural improvement in score. This child immediately liked the sound of the digital hearing aids. She reported that her old aids sounded like she was "hearing through a sponge" and that the digital hearing aids sounded clearer. She is an "A" student in a mainstream classroom at a private school. She has elected not to use a personal FM system in the classroom because her class size is relatively small and she reports she can hear well in most situations at school.

Case Study for Child 3

Child 3 had a profound sensorineural hearing loss for the right ear and moderate to profound sensorineural hearing loss for the left ear due to Mondini malformation of the inner ears. His hearing loss was identified at 2 years of age, and he used linear hearing aids for 6 years prior to being fitted with digital hearing aids. As shown in Table 12–1, his binaural aided thresholds with the digital aids were at 5 to 25 dB more sensitive than with the linear aids except at 500 Hz. It is possible that the linear aid had a peak in the amplification at 500 Hz that was eliminated with the digital aids. With both sets of aids, he was evaluated with open-set, PBK-50 monosyllabic words presented at 70-dB SPL binaurally. As shown in Table 12–2, his score was 36 percentage points higher with the digital hearing aids than the linear aids. These results suggest that the digital aids provide marked improvement in speech clarity that is related in part to the improvement in sound-field thresholds. This child has become more confident about initiating communication when using the digital hearing aids. He enjoys using a personal FM system with ear-level receivers. His teacher reported he is more "tuned in" while using the FM system in the classroom.

Case Study of a Child with Hearing Aids and Subsequently a Cochlear Implant

Child 4 had a progressive hearing loss with Mondini malformation of her inner ears. Prior to fitting digital hearing aids when she was 8 years old, she used binaural power analog hearing aids with WDRC processing. As shown in Table 12–3, her binaural aided thresholds with the digital aids were 5 to 10 dB less sensitive at 1000 and 2000 Hz than with the linear aids; however, she had no response (NR) to the 4000-Hz warble tone with the analog hearing aids, whereas she responded at 65-dB HL with the digital hear-

Table 12–3. For Child 4, Binaural Aided Thresholds (dB HL) for Warble Tones Presented in the Sound Field with Two Wide Dynamic Range Compression Hearing Aids (One with Analog Processing and the Other with Digital Processing). Monaural Thresholds also are Shown with the Nucleus 24 Cochlear Implant

Hearing Aid/Cochlear Implant	*250 Hz*	*500 Hz*	*1000 Hz*	*2000 Hz*	*4000 Hz*
Analog hearing aid	20	25	25	30	NR
Digital hearing aid	20	25	30	40	65
Cochlear implant	35	35	25	25	35

ing aid. Given this high-level threshold and the lower level at which speech sounds in this frequency region occur compared to the levels at lower frequencies, it is unknown whether this improved audibility at 4000 Hz was helpful to her in everyday life. With both sets of aids, she was evaluated with PBK-50 monosyllabic words, presented at 70- and 50-dB SPL and with open-set Bench-Kowal-Bamford (BKB) sentences (Bench and Bamford, 1979) presented at 70-dB SPL. With the digital aids, her score was 26 percentage points higher for the BKB sentences presented at the raised level of 70-dB SPL, 12 percentage points higher for PBK-50 words presented at 70-dB SPL, and 20 percentage points higher when they were presented at the soft level of 50-dB SPL than with the analog aids. This substantial improvement in speech recognition at loud and soft levels with little change in audibility (i.e., little difference in aided sound-field thresholds) seems to reflect the greater clarity with which she hears speech with the digital compared with the analog aids even though they both have WDRC processing. Her parents reported that she self-corrected her own speech and imitated sounds more consistently when using the digital hearing aids. They indicated that she did not seem to be as frustrated or irritable. Her extended family members remarked that she concentrated and paid attention better and that her speech was clearer.

It is important to note that despite her substantially higher scores on open-set tests with the digital hearing aids, her PBK-50 word scores with these aids were 20 to 32% lower than those of the three children described above. She still had particular difficulty with open-set word recognition for soft speech. After 1 year of digital hearing aid use, it was decided to implant her with the Nucleus 24 Contour electrode array. This potentially would provide better access to sound as she prepared to enter a mainstream classroom. At surgery, a full insertion of the electrode array was reported. She uses the SPrint body speech processor programmed with the ACE speech coding strategy (Skinner et al, in press) with a total stimulation rate of 7200 pps (i.e., eight channels stimulated each cycle at a rate of 900 pps/channel). She prefers using the microphone sensitivity set to 10 in most situations. Two electrodes have been deactivated due to short circuits, and a third has been deactivated due to aberrant sound quality. The frequency-to-electrode allocation of incoming sound spans the range from 187 to 7937 Hz. As shown in Table 12–3, her monaural aided thresholds with the cochlear implant are 5 to 30 dB more sensitive between 1000 and 4000 Hz than with the digital aids; they are 10 to 15 dB less sensitive at 250 and 500 Hz with the cochlear implant than the digital aids. After 8 months of cochlear implant use, her score with the cochlear implant alone for PBK-50 words presented at 70-dB SPL was 36 percentage points higher than with the digital aids (Table 12–4); for PBK-50 words presented at 50-dB SPL, it was 28 percentage points higher with the implant than the digital aids; and for BKB sentences presented at 70-dB SPL, it was 20 percentage points higher. It is clear that direct stimulation of small populations of auditory neurons by individual electrodes with the cochlear implant resulted in better speech recognition

Table 12–4. Scores (% correct) on Speech Tests Presented at Either 70- or 50-dB SPL in the Sound Field to Child 4 Who Listened with Binaural Linear Hearing Aids, Binaural Digital Hearing Aids, and Monaurally with a Cochlear Implant after 8 Months' Use

Child	*Test*	*Level (dB SPL)*	*Linear Aids Score*	*Digital Aids Score*	*Cochlear Implant Score*
4	PBK-50	70	32	44	80
4	PBK-50	50	8	28	56
4	BKB	70	46	72	92

BKB, Bench-Kowal-Bamford

than stimulation of neurons through transduction in the cochlea of the complex acoustic signal from digital hearing aids. Her parents and classroom teacher reported a significant improvement in this child's listening ability since receiving the cochlear implant. She enjoys an ease of listening that was not available through hearing aids alone. She attends when called the first time, can overhear the conversations of others, and can listen without watching the talkers. This child has an awareness of what is going on without effort. She monitors her own speech and includes high-frequency sounds in her speech. She underwent a trial of an FM system coupled to her cochlear implant processor that offered better speech understanding in background noise. It was noted that she needed to decrease the microphone sensitivity of her processor to at least 7 to obtain an advantage listening in noise with the FM system. This reduced microphone sensitivity level still allowed her to monitor her own voice and hear her peers sitting closely around her. She plans to use the FM system when she enters the mainstream classroom.

In summary, improvement in detection of warble tones in the sound field may be achieved with digital processing hearing aids, but this improvement may or may not be associated with improvement in speech recognition. And there may be no improvement in sound-field thresholds with digital aids, but there may be significant improvement in speech recognition because of the way these aids process sound. When a cochlear implant is used with a digital hearing aid in the unimplanted ear, there may or may not be an improvement in speech recognition in this binaural listening situation. If there is improvement, the conditions under which this occurs may vary. Finally, use of a hearing aid (i.e., linear or WDRC that uses either analog or digital processing) may facilitate or interfere with information from a cochlear implant when using the implant and aid at the same time. Fortunately for most implant recipients who have sufficient residual hearing in the unimplanted ear, use of the hearing aid facilitates recognition of speech and other sounds as well as provides cues about the direction from which the sound is coming. For those who use a hearing aid without advanced technology in the unimplanted ear, it is suggested they consider a trial of a fully digital aid to determine if it will provide better hearing. The few patients who find that use of a hearing aid in the unimplanted ear interferes with speech recognition with the implant may have central auditory processing difficulties.

Case Study of Adult with Wide Dynamic Range Versus Frequency Compression Hearing Aids

Individuals with hearing loss often have better hearing in the lower frequencies (e.g., 250 to 500 Hz) than the higher frequencies (i.e., >1000 Hz). The degree and configuration of their hearing loss make it difficult for conventional hearing aids to provide sufficient amplification to voiceless, high-frequency consonants to make these speech sounds audible without acoustic feedback. When they can be made audible, many of these individuals cannot identify these high-frequency consonants correctly in ongoing speech. A different strategy to compensate for the lack of audibility and/or lack of ability to recognize these consonants is to use proportional frequency compression. With frequency compression, the acoustic signal is moved to lower frequencies and more apical regions of the cochlea transmit information about the high-frequency consonants to the auditory system. This strategy is implemented with digital processing in commercially available in-the-ear (ITE) and BTE hearing aids and in an integrated BTE hearing aid/FM receiver (i.e., ImpaCt ITE, DSR13, DSR675, or Logicom 20; AVR Communications, Eden Prairie, Minnesota) that selectively applies proportional frequency compression only to the high-frequency voiceless consonants and does not modify the other speech sounds. With a process called dynamic speech recoding, sounds that need to be compressed are identified, and the relations of energy peaks within and between sounds are preserved. For example, the frequency range for /s/ and /sh/ is compressed into frequencies that can be adjusted to be 1.50 to 5.0 times lower than their original frequencies. That is, the full range of high-frequency sound that occurs in the real world impinges on the hearing aid microphone, but the original high-frequency consonant energy is delivered to and analyzed by the cochlea at substantially lower frequencies. For individuals who have better hearing capability at these lower frequencies, the high-frequency sounds are audible, and it is reported that they can learn to identify these sounds (Davis, 2001). To accommodate the frequency-compressed signal, adjustments are made in the fitting parameters based on an individual's, parent's, or related service professional's observations in the clinic as well as experiences in everyday life. It is important to change one parameter at a time so that its effect on hearing can be assessed. In addition, the individual needs to relearn new cues for recognizing sounds.

Case Study of Adult 5

Adult 5 has a moderately severe to profound bilaterally symmetrical hearing loss that she

Table 12–5. Adult 5's Unaided Earphone and Aided Sound-Field Thresholds, Scores (% correct) for NU-6 Monosyllabic Words Presented at 45-dB HL in the Sound Field, and Detection/Discrimination of the Ling Sounds /s/ and /t/ Presented at 45-dB HL Using Binaural Wide Dynamic Range Compression (WDRC) and ImpaCt Hearing Aids. Difference in Thresholds (dB) Are Shown (i.e., WDRC Minus ImpaCt Hearing Aid Values); Positive Values Indicate Better Thresholds with the ImpaCT Hearing Aids

	Warble tone Thresholds (dB HL)							*NU-6 Word Scores*	*Ling Sounds*	
	250	*500*	*1000*	*2000*	*3000*	*4000*	*6000*		*Not Detected*	*Not Discriminated*
Earphones										
RE (unaided)	55	70	80	85	—	90	105	DNT	DNT	DNT
LE (unaided)	50	70	80	85	—	90	100	DNT	DNT	DNT
Sound field										
Binaural (WDRC)	15	25	35	40	45	55	DNT	68	/s/	/t/, /s/
Binaural (ImpaCt)	15	20	20	25	25	25	25	92	—	——
Difference	0	5	15	15	20	30	—	24		

See Case 2 in article by WE Davis, 2001; Additional Information Provided by Claudia Hawley of West Metro Audiological Services, Minnetonka, MN (with permission from Davis and Hawley).

DNT, did not test. Total set of Ling sounds presented for detection and discrimination included /a/, /U/, /i/, /sh/, /s/, and /t/; results are shown for /s/ and /t/.

probably has had since birth. No fluctuations or progression have been reported. The etiology of her hearing loss is genetic. She teaches children with hearing loss in the public schools. She has used binaural hearing aids since early childhood; WDRC aids were used prior to fitting with ImpaCt DSR675 (DSR: dynamic speech recoding) BTE aids in fall of 2000. Her earphone air-conduction thresholds, age at testing, amount of recruitment (mild), and the fact that she had a prelinguistic hearing loss were entered into the AVR CFE (Clinicians fitting environment) Ver. 2.0 software. Based on this information, the initial values of the hearing aid characteristics were chosen based on a template fitting function available in CFE Ver. 2.0. A newer version of fitting software, CFE Lite, offers several hearing aid prescriptive procedures to derive initial values for setting the hearing aid. Because adult 5 had used power, linear, BTE hearing aids since early childhood, the ImpaCt aids were programmed with as much gain at all frequencies as available. Slight adjustments were made in the values specified in the template [e.g., frequency compression ratio, attack and release times, kneepoint of amplitude compression, automatic gain control (AGC) of maximum output, the amount of additional gain given to /s/ and /sh/ (DCB-1; dynamic consonant boost), and lower intensity voiceless, high-frequency consonants (e.g., /f/, /th/, /t/, /h/, etc.) (DCB-2)]. These changes were made during several sessions based on her description of how she heard sounds in everyday life with the aids.

Table 12–5 shows her unaided thresholds under earphones at the right and left ear (pure-tone average: 78.5-dB HL at both ears), her aided thresholds with WDRC and ImpaCt hearing aids, and her speech test results for stimuli presented at normal conversational level of 45-dB HL (61-dB SPL). Results with the WDRC aids were obtained shortly before being fitted with the ImpaCt aids; results with the ImpaCt aids were obtained a few weeks after initial fitting. Her thresholds between 1000 and 4000 Hz were 15 to 30 dB more sensitive with the ImpaCt aids. Warble tones delivered above 2000 Hz were frequency compressed to deliver information at lower frequencies where she had better hearing. Based on her sound-field thresholds, the AI value calculated with the count-the-dot method was 86% with the ImpaCt hearing aids and 35% with the WDRC hearing aids; that is, 86% and 35% of the dots were above threshold, respectively. Her scores for open-set, NU-6 monosyllabic words (Tillman and Carhart, 1966) were 24 percentage points higher with the ImpaCt aids. This improvement in word recognition is consistent with increased audibility of speech cues above 500 Hz as well as recognition of these cues despite their frequency compression.

Immediately after the ImpaCt aids were first fitted, she heard /s/ for the first time. Within the first few weeks, she heard many other high-frequency speech sounds as well as environmental sounds. During the next few months, she learned to recognize /s/ and other sounds in ongoing speech in therapy sessions. Earlier in her life, she had dreaded speech therapy because she could not hear the sounds. Recently she has obtained an FM boot and FM receiver for use with her aids. These devices enable her to hear and converse easily in the car and noisy restaurants. For the first time, she did not get carsick on a long trip because she could just listen and not have to speech read. She calls her ImpaCt aids "her new best friends."

In summary, it is important to try ImpaCt aids for children and adults when digital hearing aids do not provide audibility and clarity for high-frequency consonants. For cochlear implant recipients, this aid may provide more information to the unimplanted ear than digital aids that do not have frequency compression.

Implications of Case Study Findings to Criteria for Cochlear Implantation

The case study of adult 5 and the four case studies of children, all of whom have severe or profound sensorineural hearing loss, clearly show that there can be substantial differences in speech recognition in the same person with hearing aids that utilize different sound processing strategies. The results described above suggest that digital processing using WDRC with no frequency compression has the potential for amplifying speech more clearly to individuals with this degree of hearing loss than linear aids. Results with adult 5 suggest that digital processing with frequency compression may make voiceless, high-frequency consonants audible and recognizable. For this reason, hearing aids with digital processing should be considered for children and adults to determine how much benefit they will provide. However, individuals such as patient 2, who have learned to recognize speech cues through many years' use of linear amplification, may find that digital processing with WDRC results in a substantial decrement in speech recognition, and it is unknown whether their speech recognition will improve with training and experience. They may not want to consider digital processing. For individuals with profound hearing losses greater than 100 dB HL between 500 and 4000 Hz (none of whom were included in the case studies described above), it is unlikely that analog or digital hearing aids (with or without frequency compression) can provide enough gain for speech recognition and fluent communication at casual (56-dB SPL) and normal (60-dB SPL) conversational levels encountered in everyday life.

As shown for patients 3 and 4, a cochlear implant can be fitted to an individual's electrical range of hearing so that the microphone sensitivity control can be set high enough to obtain sound-field thresholds for warble tones that are between 20- and 25-dB HL between 250 and 6000 Hz. With these thresholds, soft speech sounds are audible and contribute significantly to the ease with which patients hear and understand conversational speech. It should be noted that some cochlear implant recipients have thresholds at 30- to 35-dB HL across the frequency range because their electrical dynamic ranges are very narrow or they have particular difficulty tolerating background noise. For patient 1 who uses hearing aids and patient 3 who uses a cochlear implant, aided sound-field thresholds are around 20-dB HL across most or all of the range from 250 to 6000 Hz, speech recognition at a soft level of 50-dB SPL remained remarkably high. In contrast, patient 2 (who uses hearing aids) had thresholds that sloped down to 40+-dB HL at 250 and 3000 Hz, had substantially lower scores at 50-dB SPL because many of the cues were inaudible. Because he cannot hear these sounds, he expends much effort trying to figure out what people say from incomplete cues; after an hour or two of intense concentration, he is too tired to listen any more. On the other hand, patients 1, 3, and 4 (a cochlear implant recipient) hear soft speech with relative ease and are not tired from listening for many hours. In our opinion, a measure of cognitive load, effort, and fatigue should be developed as one part of the evaluation for cochlear implant candidacy.

At the present time, the audiologic criterion for cochlear implantation in adults with postlinguistic onset of severe or profound bilateral sensorineural hearing loss is a speech recognition score of ≤50% for the recorded HINT sentences in quiet presented at 70-dB SPL (usually a mean score across two lists). Because 70-dB SPL is a raised-to-loud level that cannot be maintained during normal conversation, implant candidacy should be based on scores obtained at a normal level of 60-dB SPL. Unfortunately, there are no large-scale data available from cochlear implant recipients at this level. To meet this need, a study has been recently funded for which it is proposed to obtain data for CNC words and HINT sentences (in quiet) presented at 70-, 60-, and 50-dB SPL as well as HINT sentences in noise at 60-dB SPL (+8-dB SNR) from equal numbers of adult recipients of three implant systems (Firszt, personal communication, 2001). The audiologic criteria for cochlear implantation in infants and children are much more complex and depend heavily on the age of the child, language development, use of appropriately fitted hearing aids, oral/aural diagnostic teaching to determine the child's ability to respond to amplification, and mode(s) of communication. A consideration of these criteria is beyond the scope of this chapter. Nevertheless, criteria for infants and children should depend on the same general concepts as for adults; that is, there should be access to soft sound so that learning of language in incidental listening situations can occur and speech recognition should be evaluated at a normal conversational level of 60-dB SPL.

Evaluation for Cochlear Implant Candidacy in Adults

Results with the cochlear implant vary from person to person; however, most adult recipients who acquired a severe or profound hearing loss after learning language (i.e., postlinguistic onset of hearing loss) can understand significant amounts of speech without speech reading. Many can converse interactively on the telephone. Even individuals who had hearing loss as a child that progressed to profound loss as an adult are able to understand significant amounts of speech using the implant without speech reading. Unlike the postlinguistic population, adult prelinguistic recipients do not understand speech by sound alone with their implants. Because deafness occurred at birth or around the time of learning language, they have very limited auditory memory for speech. That is, they cannot effectively combine sound that the implant provides with sound they remember to recognize environmental sounds and understand speech. Prelinguistic adult recipients learn to identify sounds much like a baby learns to identify sounds by associating the sound with the object. Consequently, much work and commitment is required from the recipients for successful implant use. Nevertheless, they do enjoy some benefits. These include hearing sound from 250 to 6000 Hz at soft and even very soft levels, recognition of many environmental sounds, enjoyment of music, improvement in monitoring the loudness of their voice, and feeling less isolated and more involved in daily life. Whereas most adults with postlinguistic onset of severe or profound hearing loss who meet the audiologic criteria are considered potential cochlear implant candidates, those with prelinguistic onset should only be considered if they have a great desire to receive a cochlear implant to communicate more effectively by speaking and speech reading.

To determine whether a person is a cochlear implant candidate, the following tests need to be performed: an audiologic evaluation including evaluation of aided speech recognition skills with appropriately fitted hearing aids, medical examination, radiologic studies of the temporal bone, vestibular function, and a psychological evaluation. For patients who have no measurable hearing in an ear considered for implantation, preoperative electrical stimulation of the inner ear may provide important information.

The audiologic evaluation should include pure-tone air- and bone-conduction thresholds, speech reception or detection thresholds, and speech recognition scores obtained with an audiometer that has an output of 130-dB SPL between 500 and 4000 Hz. Acoustic immittance and otoacoustic emission testing also should be performed. The typical audiogram for a cochlear implant candidate will show a severe or profound hearing loss with very poor speech recognition scores bilaterally. For the reasons described above, it is essential that speech recognition skills be evaluated with appropriately fitted hearing aids.

A medical examination by an implant team otolaryngologist is required to rule out any outer or middle ear pathology. A complete history of past ear infections and surgeries will be obtained. Active ear infections need to be resolved before an implant can be considered (Clark et al, 1987). In addition, each candidate's general health must be sufficient to tolerate general anesthesia and the lengthy postoperative hearing rehabilitation program that includes fitting of the cochlear implant speech processor in weekly sessions over a period of about 6 weeks as well as counseling sessions that are scheduled once or twice weekly (e.g., 20 to 25 hours in our program).

Radiologic imaging with high-resolution CT is needed to rule out a space-occupying lesion of the internal auditory canal, evaluate patency of the cochleae, and provide information about possible cochlear abnormalities that will assist in surgical planning, selecting an ear for implantation, and patient counseling. Otosclerosis, temporal bone fracture, bacterial meningitis, and Mondini deformity all can affect insertion depth and/or placement of the electrode array that can affect performance with the cochlear implant. MRI may be useful for identifying the presence or absence of fluid within the cochlear turns and the size of the cochlear and vestibular nerves within the internal auditory canals (Tucci and Niparko, 2000).

If there is no response to amplified sound with a hearing aid, electrical stimulation of the inner ear can be performed to determine whether the individual can hear sound with the ear being considered for implantation. For this test, the ear canal and eardrum are anesthetized; the physician places the active needle electrode transtympanically so that the uninsulated tip is in the mucosa on the inferior edge of the promontory near the round window. The ground electrode is placed on the person's cheek. The electrical stimulus is a square-wave pulse train presented at 50, 100, and 200 Hz (500 msec on/off). The person's ability to hear sound by electrical stimulation is evaluated for the following tests: thresholds, growth of loudness, gap detection, perception of pitch differences for different rates of stimulation, and adaptation.

Although many individuals with severe or profound hearing impairment have decreased or absent response to caloric stimulation, it is important to evaluate the status of the vestibular system. Those with vestibular function may experience dizziness after surgery, and they need to be counseled appropriately prior to surgery. Occasionally the results of this evaluation will affect the ear chosen for implantation.

The psychological evaluation is an integral part of the evaluation process and should be conducted by a psychologist who has experience with individuals with severe or profound hearing impairment. This evaluation should provide information on patients' feelings about and ability to cope with hearing loss; the kind of relationships they have with family, friends, and coworkers; their expectations of benefit from the cochlear implant; their closure skills given incomplete information; their short-term and long-term memory function; and any other factors that may impact their learning during hearing rehabilitation. Because cochlear implantation often causes marked changes in a recipient's life and in patterns of relating to family and friends, implantation can be stressful, especially if expectations are not met. Depression or other preexisting psychological conditions that could complicate the postoperative process may need to be addressed prior to surgery. The psychological evaluation is valuable in guiding appropriate management of the psychosocial dynamics of the candidate and family during subsequent hearing rehabilitation counseling. Availability of the psychologist for psychotherapy after implantation is particularly helpful to some patients.

As part of our preoperative evaluation, the candidate and a family member or friend, called a frequent communication partner, meet for several 1-hour sessions with the rehabilitative audiologist. The following areas are evaluated: the candidate's communication skills; auditory-visual integration; contribution of each hearing aid and speech reading to overall understanding of speech; self-assessment of performance, use of communication strategies, and psychosocial adjustment to deafness [Communication Profile for the Hearing Impaired (CPHI); Demorest and Erdman, 1987); and expectations of benefit from the cochlear implant. As a basis for candidates to develop realistic expectations, the following information is discussed with the candidate and family member. First, information is provided about how the cochlear implant works, where the internal device is implanted, and risks of implantation as described in the informed consent document. Second, factors that affect how well adults recognize speech with the implant are described. That is, the shorter the duration of deafness, the younger the age at implantation, and the shorter the length of time between hearing aid use and implantation, the better the ability will be to recognize speech without speech reading (Gantz et al, 1993; Blamey et al, 1996). Although these factors are true in general, it is not possible to predict exactly how well implant candidates will recognize speech. However, it is expected that they will recognize speech substantially better than with hearing aids because they meet the audiologic criteria for candidacy. That is, sentence recognition scores with hearing aids are substantially below the mean score of large groups of cochlear implant recipients. Third, the more adequate implant recipients' speech, language, speech reading, and communicative assertiveness skills are, the more successful they will be with the implant. Fourth, the candidate needs to understand the following limitations: the implant does not provide normal hearing; understanding what is said in groups and in noisy situations will remain difficult; and speech reading and communication strategies will need to be used. Fifth, the postoperative program of speech processor fitting and counseling will require time, hard work, patience, and positive stress. The candidate needs to be willing to actively participate in this process. If the candidate has an open-minded approach to this process and to problem solving as well as a willingness to experience new situations and ways of managing them, implant use is likely to be more successful. Sixth, support from family, friends, and co-workers is very important to the success of implant candidates. The frequent communication partner who accompanies the candidate through the pre- and postoperative process provides moral support, is a liaison between the candidate and other family members regarding the implantation process and expectations, and is someone with whom the candidate can practice the listening and communication skills at home. In addition to discussion with the audiologist or speech pathologist, it is important for the candidate and partner to meet at least two implant recipients and their family members prior to receiving an implant to more fully understand implantation, the rehabilitation process, as well as benefits and limitations of the implant. If the candidate is employed, it is helpful for a member of the cochlear implant team to make a presentation to co-workers describing how the implant system works, emphasizing the need for patience as the recipient progresses through the postoperative program, and suggesting how to communicate most effectively with their co-worker. Finally, it is important to discuss which ear to implant. There may be medical reasons for not implanting an ear, such as presence of chronic middle-ear disease, or the CT scans may show that the one cochlea is more patent than the other. Finally, given the fact that many candidates have some aided, open-set speech recognition in one or both ears prior to implantation, factors such as duration of severe or profound hearing loss in each ear and duration of hearing aid use in each ear need to be considered.

All relevant aspects of a candidate's preoperative evaluation are discussed with the cochlear implant team before the candidate and implant surgeon meet to make a final decision on the ear to be implanted, to obtain the candidate's informed consent, and to schedule surgery.

Hearing Rehabilitation Counseling with Adults

Hearing rehabilitation includes the selection and fitting of hearing aids, cochlear implants and assistive devices as well as counseling that is intertwined with every aspect of the hearing rehabilitation process. The goal of hearing rehabilitation is to determine the hearing and communication problems of our patients and together seek solutions in a caring and accepting environment that is provided by us as audiologists or speech pathologists (Erdman, 1993; Clark and Martin, 1994). Ultimately, the goal of hearing rehabilitation counseling is to enable patients to find a "hearing loss lifestyle" that allows them to live as *individuals* (with hearing impairment) by transcending the stigma of being hearing-impaired (Conran and Binzer, 2000; Binzer, in press). That is, they recognize the impact of hearing loss on their lives, use either hearing aids and/or cochlear implant in conjunction with assistive devices to access sound to the best of their abilities, and have developed skills and self-acceptance needed to carry on mutually satisfying conversations with family, friends, and coworkers using whatever strategies are effective. Hearing rehabilitation counseling is a process during which the patient, his or her frequent communication partner, and the audiologist or speech pathologist make valuable contributions as they work together toward these goals. Hearing rehabilitation counseling also can occur with one or two clinicians (e.g., audiologists, speech pathologists, and/or certified psychotherapist) working with a group of patients and their partners; this setting enables patients and their partners to realize that others in the group share the same difficulties and to learn new coping strategies together. Prior research with those who use hearing aids has shown that groups such as this can decrease perceived hearing handicap (Abrams et al, 1992). A goal of this group counseling is for patients to develop the belief and confidence in their right to be assertive in implementing these strategies. Even though it may seem that there is a greater need for hearing rehabilitation counseling before and after cochlear implantation because the sound is different from what patients have heard before, individuals with hearing loss who use hearing aids may have just as great a need for it. Although allowance needs to be made for the different ways in which sound is processed with hearing aids or a cochlear implant, the counseling approach is the same.

Hearing rehabilitation counseling is an integral part of the hearing aid or cochlear implant fitting process as an audiologist closely observes a patient's nonverbal responses and description of what he or she hears. This information guides the adjustment of the next parameter in fine-tuning the device to meet the patient's needs. Given the large number of parameters available for fitting these devices, this fine-tuning process needs to take place over a sequence of sessions. Within a session, a sequence of parameters can be evaluated to determine what values provide the best hearing in the clinic. However, hearing the myriad of sounds in everyday life is a complex process; consequently, a patient must listen to sound processed with one set of parameters and compare this to sound processed with another set. This comparison is facilitated by the availability of multiple memories in digital hearing aids and cochlear implants. If patients are going to be able to hear soft sounds with their devices, they may need to be encouraged to listen to sounds that may seem loud at first, particularly if they have not heard loud sounds for a long time. In addition, they often need to learn to ignore background noise that was inaudible with earlier devices. The goal is to be able to carry on more fluent conversation that is facilitated by hearing soft speech with their devices.

Hearing rehabilitation counseling begins in the initial session during which important information is obtained for tailoring the rehabilitation program to the patient's needs. For example, at the same time the audiologists or speech pathologists obtain the client's case history, they observe the patient's visual attending skills, communication style, and use of strategies, attitude, motivation and capacity to cooperate, as well as the patient's understanding of the problem. Answers to open-ended questions, such as "Why are you seeking assistance now?" "When you experience hearing problems, how do you resolve them?" and "What gives you confidence in handling the challenges presented by your hearing loss?" can provide valuable insights (Wayner et al, 1999; Conran and Binzer, 2000). It is intended that the program build on an individual's strengths and at the same time provide new information and experiences to address needs.

For most people with severe and profound hearing loss, a major problem is the loss of conversational fluency. Involvement of a frequent communication partner with the patient in counseling is important so that they can practice new communication strategies in the sessions as well as at home. These strategies include basic rules for communication (such as maintaining eye contact, not dominating the conversation, and not pretending to understand), repair strategies when what has been said is not understood (such as asking the speaker to face you when speaking, to speak more slowly and clearly, rephrase what was said), and managing the listening environment (such as sitting away from noise sources, having light shine on the speaker's face). Examples of activities for practicing these strategies are available (Erber, 1996; Wayner and Abrahamson, 1996, 1998; Tye-Murray, 1998). These activities are practiced face to face as well as over the telephone. Through this experience, the partner has an opportunity to better understand and empathize with the patient. Because these activities focus on situations that involve the patient's failure to understand and a helper's inability to be understood, and individuals differ in their ability to change old habits and learn new ones, this process requires patience and an accepting attitude. When patients' underlying emotional response to hearing loss, to experiences of failure, or to other people's negative attitudes toward them (because of their inability to understand) makes it impossible for them to use these strategies in everyday life, then psychosocial therapy with a psychologist who is keenly aware of problems related to hearing impairment may be helpful. A psychosocial approach to group hearing rehabilitation with patients and their partners led by a certified psychotherapist and rehabilitative audiologists has been developed by Hogan (2001). The goal of this psychosocial group is to facilitate emotional growth in the context of hearing rehabilitation; that is, to build patients' self-acceptance as people with hearing loss, to build self-confidence, and to develop and practice communication strategies that are necessary for them to be successful communicators (Heydebrand et al, 2001; Hogan, 2001). Preliminary research with psychosocially oriented groups for those with cochlear implants have shown improvement in quality of life not seen in nonparticipants (Hogan et al, unpublished manuscript).

Conversational fluency may be enhanced through auditory training that is intended to improve speech comprehension without speech reading. Activities may focus on distinguishing between speech sounds in rhyming word pairs, following a written text that the audiologist or speech pathologist reads or is recorded on audiotaped books, and talking about preselected topics (e.g., Norton et al, 1985; Erber, 1996; Cochlear Corporation, 1998; Tye-Murray, 1998; Plant, 2000). Compensatory strategies can be developed for speech sounds that continue to be confused after auditory training. Auditory training is especially important for conversing on the telephone. Activities include evaluation of telephones and adaptors to find the combination that gives the greatest clarity, and learning to use appropriate strategies in a hierarchy of listening situations to accurately understand what has been said. This practice helps patients who have substantial open-set speech recognition feel competent and confident when using the telephone.

Conversational fluency also may be enhanced by training the integration of auditory and speech-reading information. For example, some patients have poor visual attention skills that can be changed by focusing on looking as well as listening to the person speaking to them. In addition, the patient may not be aware of what information is available on a speaker's face about the speech sounds that are being spoken (Berger, 1972). Learning what the cues are that convey this information, attending to these cues visually, and integrating them with the auditory information is particularly important for listening in noisy and/or reverberant listening situations. Speech tracking is useful in training this integration (DeFilippo and Scott, 1978). Conversational fluency can be enhanced by the use of assistive devices if speech amplified by their hearing aids or cochlear implant is not loud enough or at a favorable enough SNR in listening situations such as in classrooms, theaters, meetings, or in the car. In addition, patients need special devices to be alerted to sounds such as the telephone or doorbell ringing, a smoke alarm, or an alarm clock when they are not wearing hearing aids or cochlear implants (Ross, 1994).

For adults with prelinguistic onset of deafness, training in discrimination between various environmental sounds without the benefit of vision is critical for patient safety, well-being, and for hearing these sounds in noise (Eisenberg, 1985). Auditory training using pairs of words or sentences with substantial differences in length may enhance speech reading and is essential for using codes for telephone communication (Castle, 1984). Some of these adults may achieve finer discrimination of speech sounds and even some open-set speech recognition over a period of months or years.

A number of patients with severe or profound hearing impairment who use hearing aids and/or a cochlear implant have enjoyed music in the past and want to learn to enjoy it more with their present devices. Using quality musical equipment (e.g., tape recorders, CDs, keyboard instruments), enjoyment of music can be developed through a hierarchy of activities focusing first on rhythm, then on simple songs that are sung a capella, then on familiar songs with instrumental accompaniment, and then attending live musical performances. Gfeller and Lansing (1992) have developed a test of musical perception for cochlear implant recipients.

Hearing rehabilitation is a lifelong process. Many adults find that participating in organizations such as local chapters of Self-Help for Hard of Hearing People (7910 Woodmont Avenue, Suite 1200, Bethesda, MD 20814) and the Cochlear Implant Association (5335 Wisconsin Avenue, N.W., Washington, DC 20015–2034) provides opportunities for friendship with people who have many of the same difficulties they have. Through their participation in group activities and belonging to the national organizations that distribute valuable information to members in their bimonthly magazines, they continue the rehabilitation process and build self-esteem and greater independence.

In summary, hearing rehabilitation counseling is a key component in optimizing the benefit that hearing aids and/or a cochlear implant can provide those with severe or profound hearing impairment and enabling them and their families to live more meaningful, satisfying, and fruitful lives.

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