Programming Cochlear Implants

Third Edition

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Preface

Audiologists must effectively program a cochlear implant in order for the recipient to experience an optimal outcome. Effectively programming a recipient's cochlear implant sound processor can be a challenging task for a number of reasons. For example, recipients present with a variety of needs; significant differences exist in the hardware, signal processing, and programming strategies across the major cochlear implant manufacturers; and cochlear implant technology evolves rapidly. Fortunately, when audiologists adhere to evidence-based clinical practices to program a cochlear implant, recipients typically receive tremendous benefit from their cochlear implant and achieve excellent outcomes after implantation. This book provides a single source to which audiologists may turn to obtain comprehensive, evidence-based, and timely information pertaining to the programming of contemporary cochlear implants.

The primary goal of this book, *Programming Cochlear Implants* (3rd ed.), is to offer practical guidance for audiologists who program cochlear implants. It represents the only textbook in which a detailed step-by-step process of cochlear implant programming is provided with the goal of preparing the reader to successfully program the cochlear implants of recipients of all ages. This text is a thorough revision of its predecessor and includes new content pertaining to recent advances in cochlear implant technology and programming.

Not only are the basics of cochlear implant programming introduced, but the authors also expand into advanced programming techniques. Additionally, they provide in-depth manufacturer-specific descriptions of cochlear implant hardware and programming strategies. Specific topics include the basics of cochlear implant terminology, hardware, and programming; clinical protocols for cochlear implant management; programming considerations for Advanced Bionics, Cochlear, and MED-EL devices; troubleshooting during the programming process; programming considerations for bilateral cochlear implant recipients; basic use of objective measures as a guide to program cochlear implants; use of wireless hearing assistance technology with cochlear implants; programming and management considerations for recipients using electroacoustic stimulation; management of the difficult-to-program recipient; and case studies that illustrate the topics that are addressed throughout the book. This book is intended not only for practicing audiologists who are providing or who plan to provide services for cochlear implant users but also for graduate-level audiology students.

Introduction

Cochlear implants have transformed the lives of hundreds of thousands (and possibly millions by the time this text is read) of children and adults with severe to profound hearing loss. Children born deaf typically achieve age-appropriate spoken language skills when they receive cochlear implants during their first year of life. Additionally, they frequently achieve considerable levels of success alongside their hearing peers in academic, occupational, and social walks of life. With cochlear implants, adults with severe to profound hearing loss are typically able to converse over the telephone, communicate effectively in social and occupational settings, and overcome any barriers that hearing loss may impose to their enjoyment of music, their hobbies, their family life, etc.

In order for children and adults to reach their full potential with their hearing with their cochlear implants and maximize their communication abilities, hearing experiences, and quality of life, audiologists must effectively program the cochlear implant. The hearing needs of each cochlear implant recipient are unique, and audiologists must optimize the settings of a cochlear implant processor to optimize the hearing performance and experiences of each recipient. Effectively programming cochlear implant sound processors is a challenging task for a number of reasons. Recipients present with a variety of needs, and significant differences exist in the hardware, signal processing, and programming strategies across the major cochlear implant manufacturers, and cochlear implant technology evolves rapidly. Research has shown that recipient outcomes are only maximized when the audiologist optimally programs the cochlear implant processor to meet the particular needs of each recipient's auditory needs and preferences. Audiologists need a single source to which they can turn to obtain comprehensive and timely information pertaining to the programming of contemporary cochlear implants. This book is that source!

The primary objective of this book, *Programming Cochlear Implants, Third Edition*, is to offer practical guidance for clinicians who program cochlear implants. It provides a detailed, step-by-step process of cochlear implant programming with the goal of preparing the reader to successfully program cochlear implants to meet the unique needs of recipients of all ages. This book is a thorough revision of its predecessor and includes additional content pertaining to recent advances, such as advances in signal processing and the use of advanced objective measures to optimize cochlear implant settings for each recipient.

The basics of cochlear implant hardware, software, signal processing, and programming are introduced, but the authors also expand into advanced programming techniques. Additionally, the authors provide an in-depth manufacturer-specific description of cochlear implant hardware and programming strategies. Specific topics covered include the basics of cochlear implant terminology, hardware, and programming; clinical protocols for cochlear implant management; programming considerations for Advanced Bionics, Cochlear, and MED-EL devices; troubleshooting during the programming process; programming considerations for bilateral cochlear implant recipients; basic use of objective measures as a guide to program cochlear implants; use of wireless hearing assistance technology with cochlear implants; programming and management considerations for recipients using electroacoustic stimulation; management of the difficult-to-program recipient; case studies that illustrate the topics that are addressed throughout the book. This book is intended for practicing clinicians who are providing or who plan to provide services for cochlear implant users and also for graduate-level students.

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Basic Components and Terminology of a Cochlear Implant

Jace Wolfe and Erin C. Schafer

In most cases of sensorineural hearing loss, the primary site of lesion resides within the cochlea. Cochlear hearing loss results in insufficient transduction of acoustic-mechanical energy into neural impulses at the auditory nerve. The term *nerve deafness* is frequently used to describe sensorineural hearing loss, but this term is frequently a misnomer. The auditory nerve is often relatively intact and functional but does not receive adequate stimulation from the cochlea. Consequently, the cochlear implant is surgically inserted into the cochlea to bypass the deficient part of the auditory system and to provide direct stimulation to the auditory nerve. As a result, most people with sensorineural hearing loss respond favorably to a cochlear implant. In fact, multiple channel cochlear implants are the most successful sensory prosthetic device in the history of medicine. Children with severe to profound hearing loss who receive an implant at an early age often develop age-appropriate spoken language (Davidson et al., 2019; Geers, 2004; Geers et al., 2004, 2009). Adults with postlingual deafness who receive cochlear implants frequently achieve good open-set sentence recognition (Gifford et al., 2008; Helms et al., 2004; Holden et al., 2013; King et al., 2012) and can converse over the telephone (Anderson et al., 2006). Cochlear implants may also provide benefit to people with pathological conditions of the auditory nerve, such as auditory neuropathy spectrum disorder and fairly significant degeneration of spiral ganglion fibers (Humphriss et al., 2013; Rance & Barker, 2008; Sarankumar et al., 2018).

Success with a cochlear implant is strongly influenced by the quality of the user's program created by the audiologist. A cochlear implant program, also known as a MAP, is patient specific. The program determines how the cochlear implant will provide electrical stimulation to the auditory nerve to represent speech and environmental sounds detected by the sound processor microphone. At a fundamental level, cochlear implant programming involves the determination of stimulation levels required to restore audibility for soft sounds and achieve loudness normalization for a large range of inputs. In addition to stimulation levels, programming audiologists must also determine numerous other adjustable parameters to allow for optimal patient performance.

According to published research and in the authors' clinical experience, recipients using inappropriate cochlear implant programs will experience poor performance and outcomes (Geers et al., 2004; Wolfe & Kasulis, 2008). However, optimization of these inadequate programs often allows recipients to realize remarkably good performance. Optimum initial programming is particularly important for young children who frequently cannot provide verbal feedback about the quality of the signal they receive. Children must have consistent access to speech and environmental sounds during the first few years of life to prevent long-term delays in speech, language, and auditory development.

Although creating a cochlear implant program may seem complicated, and even intimidating, clinicians can rely on basic principles of hearing science, audiology, and aural rehabilitation/habilitation to create suitable programs for recipients. The provision of a quality program is one of the most rewarding facets of audiology, as it serves to restore the recipient's access to social, academic, and professional opportunities. The primary objective of this book is to provide direction to graduate students and professionals on creating the best possible programs/MAPs for cochlear implant recipients of all ages.

The chapters in this book address the basic components of cochlear implants, basic terminology of programming, basic principles of programming, manufacturer-specific programming considerations, practical clinical protocols for cochlear implant programming, troubleshooting of patient problems and complications, and use of hearing assistive technology with cochlear implants. Additionally, this book addresses electroacoustic stimulation (EAS), which is sometimes referred to as hybrid cochlear implantation. Furthermore, the final chapter in this book provides several case studies that serve to reinforce the content from the preceding chapters. The information in this book is applicable to almost all cochlear implant systems used in contemporary clinical settings. The manufacturer-specific chapters focus on the three manufacturers that provide cochlear implant systems in North America: Advanced Bionics LLC, Cochlear Ltd., and MED-EL Medical Electronics.

BASIC OPERATION OF COCHLEAR IMPLANTS

Although differences exist in hardware across manufacturers, there are several common components among all cochlear implant devices. As shown in Figure 1–1, these components include an external sound processor with a transmitting cable and electromagnetic radio-frequency (RF) transmitting coil, an internal receiving coil, an internal stimulator with an electrode array, and an interface device to connect the recipient sound processor to the clinician's programming computer.

The basic operation of a cochlear implant is also similar regardless of manufacturer. The microphone of the external sound processor captures acoustic signals in the user's environment and transduces the input into an electrical signal. This electrical signal typically is sent to a preamplifier to improve the signal-to-noise ratio (SNR) during transmission to the processor. The preamplifier occasionally provides a greater boost for high-frequency components of the input signal because high-frequency phonemes, such as /s/, are less intense and more susceptible to masking. Next, the signal is analyzed by a sophisticated digital signal processor (DSP) in the external sound processor to classify the input according to intensity, frequency, and time domains and to convert the signal into an electrical code that will represent these features at the auditory nerve. The coded signal is then converted from a digital signal back into an electrical signal and sent to the RF coil via a transmitting cable. At the RF coil, the electrical signal is converted to an electromagnetic signal (i.e., magnetic lines of flux are created as the electrical signal travels through the transmitting coil) and transmitted via electromagnetic induction to an internal receiving coil (antenna) that is directly wired to the internal stimulator. Magnets are located in the center of both the external RF coil and internal receiving coil, which provides adhesion of the external RF coil to the head and alignment directly over the internal receiving coil. The RF signal, which is device specific, also serves as the power supply for the internal stimulator. When the magnetic lines of flux (RF) pass over

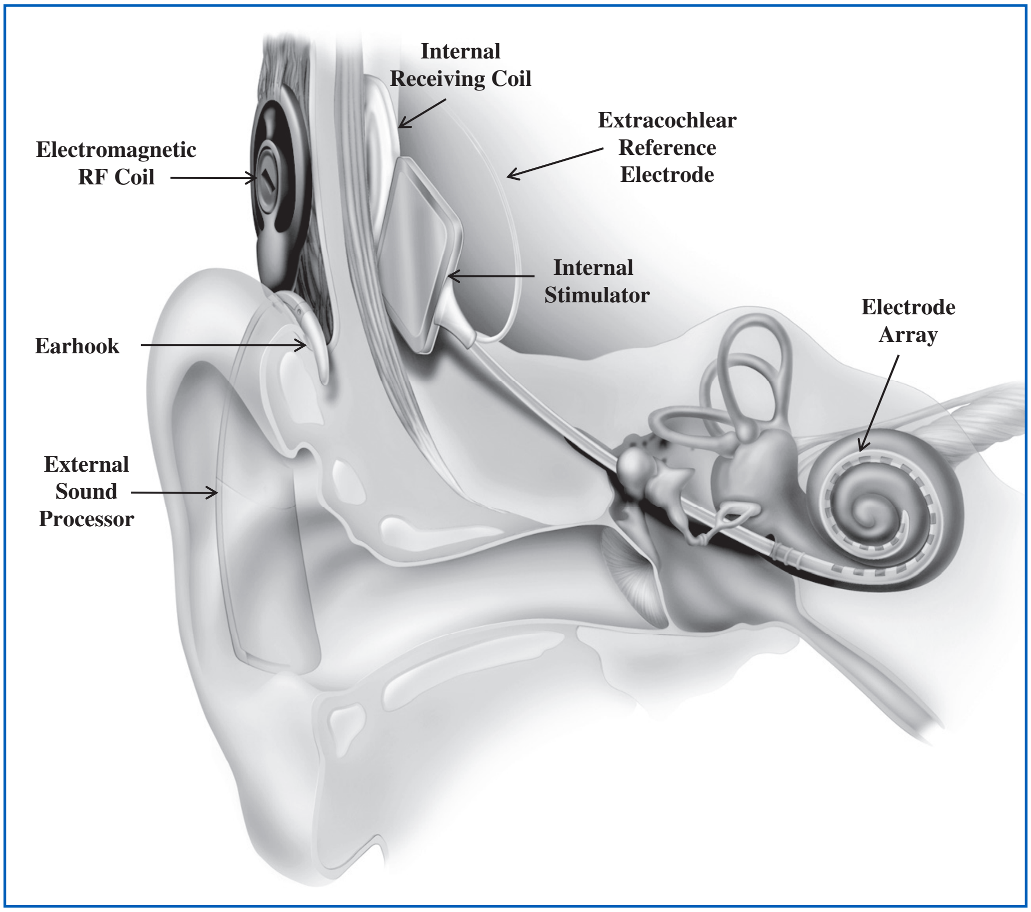

FIGURE 1–1. Basic operation of a cochlear implant. *Note.* Provided courtesy of Cochlear Ltd., © 2009 Cochlear Ltd.

the internal receiving coil, an electrical signal is induced in the internal coil and passed onto the internal stimulator. The internal stimulator, which also contains a DSP, converts the electrical signal into a digital code. The processor determines the stimulation needs for the user, and it converts the digital code to electrical pulses based on the characteristics of the input signal and a set of rules defined by the coding strategy. The electrical pulses are then sent along the electrode lead to the stimulating intracochlear electrode contacts (see Figure 1–1), where the pulses stimulate auditory nerve fibers innervating the cochlea. The electrical stimulation delivered to the intracochlear electrode contacts returns to an extracochlear electrode, which serves as the return or ground electrode (also known as the reference electrode). Extracochlear return electrodes can be located on the internal device (i.e., on the case as shown in Figure 1–2) or at a location remote from the primary electrode lead (see Figure 1–1).

As mentioned previously, the electrical signal from the external transmitting coil provides power to the internal device. The strength of this electrical signal is adjusted on an individualized basis to minimize the necessary transmission strength and power consumption (i.e., optimize battery life). At the same time, this signal will need to provide enough power to the internal device to stimulate and effectively represent without interruption high-level inputs, which require stronger RF strength and higher levels of stimulation.

In the most current cochlear implant systems, the external sound processor uses digital

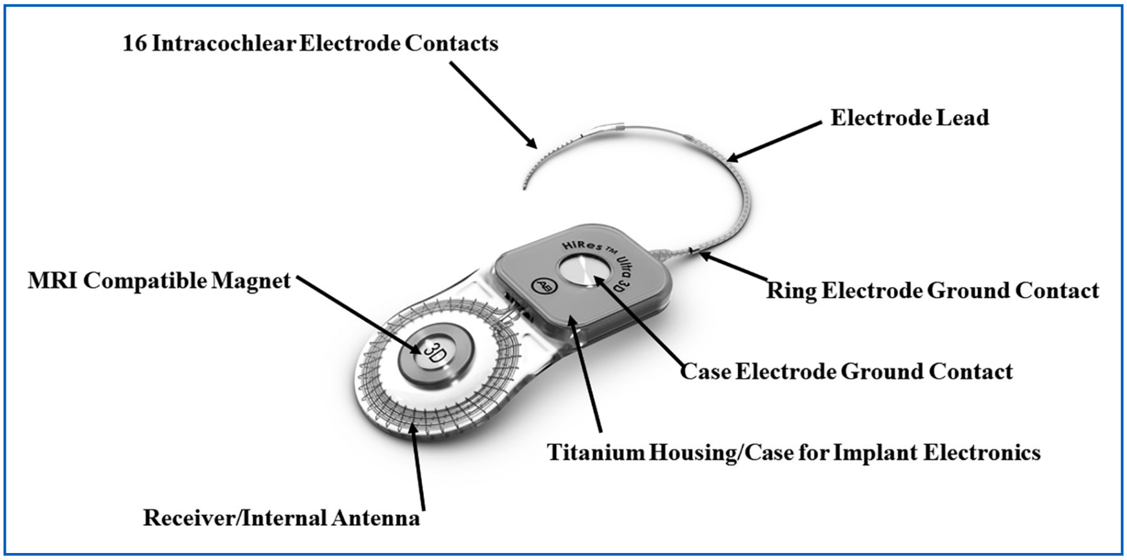

FIGURE 1–2. Advanced Bionics HiRes Ultra 3D internal stimulator and HiFocus SlimJ electrode. *Note.* Image provided courtesy of Advanced Bionics. http://www.AdvancedBionics.com

bandpass filtering, fast Fourier transformation, or Hilbert transformation to divide the complex input signal into individual frequency segments referred to as channels (Figure 1–3). The output from these bandpass filters is then sent to a rectifier that captures and produces the spectral envelope (i.e., boundary across frequencies) of the input. Next, the output of the rectifier is used to modulate a train of biphasic electrical pulses (see Figure 1–3), which are delivered to the electrode contact that corresponds to a given channel. Multiple channel cochlear implants take advantage of the natural tonotopic organization of the cochlea by delivering high-frequency signals to electrodes located toward the basal end of the cochlea and low-frequency signals to more apical locations.

The power used to operate the external sound processor is delivered from a battery that is directly coupled to the sound processor. The most recent external sound processors may be operated with manufacturer- and device-specific lithium-ion rechargeable batteries. This type of battery has several advantages over other types of rechargeable batteries, including a long shelf and service life, a flat voltage-discharge curve, a relatively robust voltage capacity, and no memory effect. As a result, the battery does not have to be completely discharged prior to recharging it.

BASIC COMPONENTS OF CURRENT COCHLEAR IMPLANT SYSTEMS

There are significant differences in the appearance and features of most current commercial sound processors for each manufacturer; however, many of the components are similar across the three manufacturers. For instance, behind-the-ear sound processors contain an earhook to facilitate retention of the sound processor on the external ear, a microphone to capture acoustic signals in the user's environment, a DSP to analyze input signals and determine how these signals should be relayed to the user, a single power source for the sound processor and the internal device, and a transmitting cable and RF coil to transmit the signal to the internal device.

BASIC TERMINOLOGY OF COCHLEAR IMPLANT PROGRAMMING

Although several parallels exist between cochlear implants and hearing aids, numerous differences

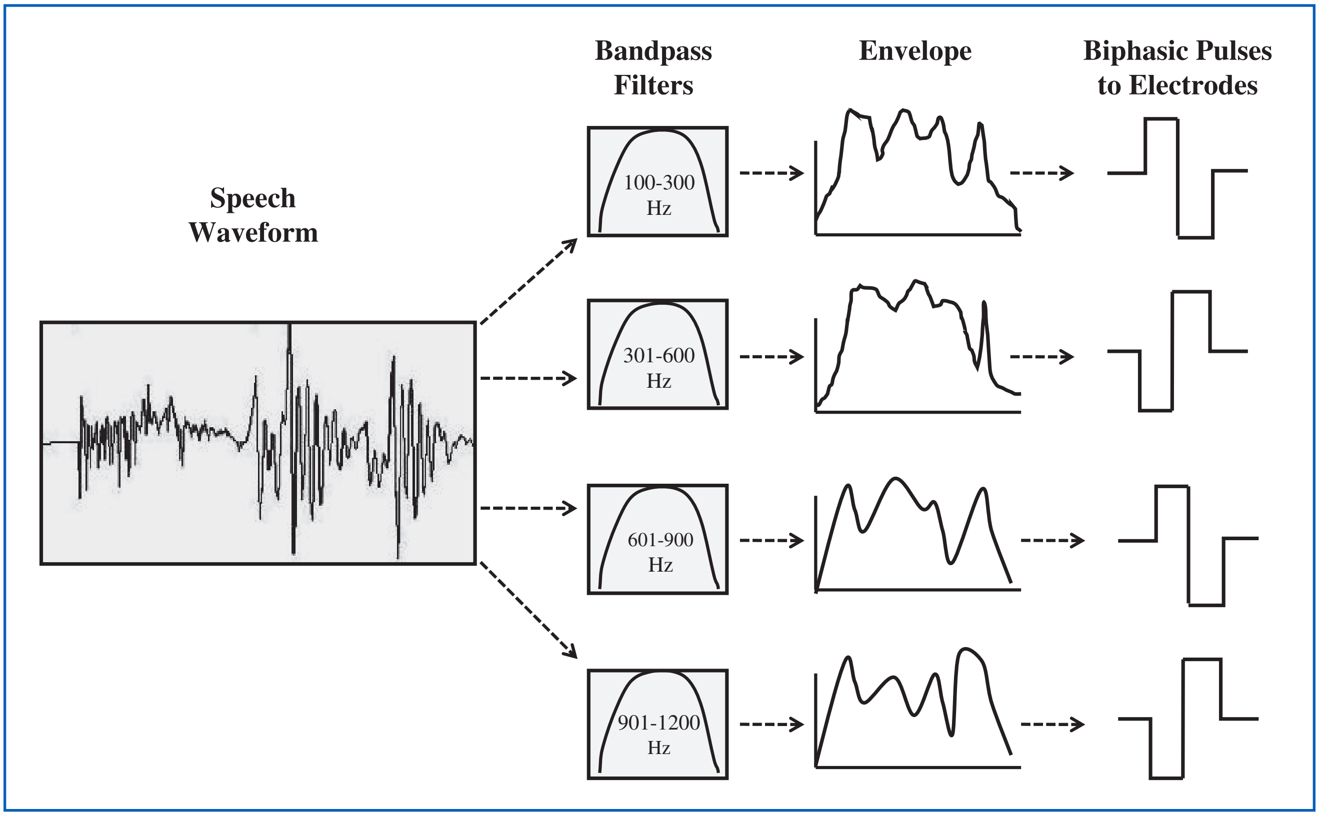

FIGURE 1–3. Diagram of how a complex signal is sent through a bandpass filter and a rectifier to determine the temporal envelope of each channel before biphasic pulses are sent to the electrode contacts.

occur in the terminology used in the programming of each device. The following sections outline how various implant programming parameters influence how the acoustic signal is coded into an electrical signal, basic terminology associated with programming, and signal coding strategies.

Parameters Affecting Signal Coding in the Intensity Domain

A summary of the parameters that influence coding in the intensity domain is provided in Table 1–1.

Stimulation Levels

In most cases, the most important parameter a clinician determines when programming a recipient's cochlear implant is the magnitude of stimulation provided from the implant to the auditory nerve. The fundamental goal of programming is to restore audibility for a range of speech sounds extending from soft speech to loud speech. Ideally, stimulation levels also are set to optimize identification of speech sounds. Finally, it is desirable to set stimulation levels so that normal loudness percepts are restored for speech in addition to environmental sounds. Sounds that are perceived as soft to a person with normal-hearing sensitivity also should sound soft to a cochlear implant user, while sounds that are perceived as loud for a person with normal-hearing sensitivity also should be loud but not uncomfortable to the user.

Achieving the aforementioned goals is challenging because speech and everyday acoustic sounds have a wide range of intensities of approximately 100 dB. For most cochlear implant users, this wide range of intensities must be coded into a relatively small electrical dynamic range (EDR; often around 20 dB when converted from clinical units to decibels; Nelson et al., 1996; Zeng &

Table 1–1. Summary of Factors Affecting Signal Coding in the Intensity Domain

Term	*Brief Description*
Threshold (T level, THR)	Softest electrical input level detectable by user for each electrode contact
Upper stimulation level (C level, M level, MCL)	Electrical input level that is perceived as loud but comfortable to user
Amplitude	Current amplitude per phase of a biphasic electrical pulse
Pulse width	Duration or length of one single phase (typically in microseconds)
Electrical dynamic range	Difference in electrical units between threshold and upper stimulation level
Input dynamic range	Range of acoustic inputs mapped into electrical dynamic range
Sensitivity	Determines gain of processor microphone, which subsequently determines the quietest sound picked up by the microphone
Channel gain	Controls per-channel location of stimulation within the electrical dynamic range
Volume	Determines the upper stimulation level setting used by the recipient, which subsequently determines the loudness level of the incoming acoustic signal
Compression	Codes the acoustic inputs into the measured electrical dynamic range

Galvin, 1999). The EDR is defined as the difference between the cochlear implant user's perceptual threshold and most comfortable level (i.e., loud but not uncomfortable) for electrical stimulation. Cochlear implant manufacturers use various types of compression to code the acoustic inputs of interest into the recipient's measured EDR. This section introduces programming parameters related to the EDR, whereas the following section discusses how these parameters dictate the EDR.

Threshold of Stimulation

The threshold of electrical stimulation refers to the least amount of stimulation a recipient can detect when electrical signals (typically biphasic electrical pulses) are delivered to individual electrode contacts. In practice, the exact definition and name of the electrical threshold of stimulation vary across programming software manufacturers. For Advanced Bionics cochlear implants, the electrical threshold is comparable to the audiometric threshold and is best defined as the lowest amount of electrical stimulation a user can detect with 50% accuracy. For Cochlear Nucleus implants, the electrical threshold is defined as the minimum amount of electrical stimulation the recipient can detect 100% of the time. In contrast, MED-EL defines electrical threshold as the highest level at which a response is not obtained (i.e., the amount of electrical stimulation just below that which elicits an audible percept). Abbreviated terms, such as "T level" for Advanced Bionics and Nucleus and "THR" or "threshold" level in MED-EL devices, often are used to describe the electrical threshold.