Assessing Hearing Aid Fittings: An Outcome Measures Battery Approach

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Introduction

Outcome measures quantify the results of intervention. With respect to audiology and hearing aid fittings, outcome measures determine the success of the interaction between a medical professional and a patient. The process of using outcome measures has many subtleties that impact the accuracy, usefulness, and ease with which outcome measures are used. For example, to determine how something turns out, the audiologist must also have a measurement of how things began. Therefore, outcome measures should be accompanied by an evaluation of how patients begin, as well as end, their interaction with the audiologist. This chapter discusses the who, what, where, when, and how of outcome measures to clarify the use and importance of these measures in audiologic rehabilitation (Bray, 1997).

The audiologic rehabilitation process concerns three domains that hearing loss can impact: impairment, disability, and handicap (column 2 in Table 5–1). Identification and measurement of all three must be accomplished before intervention can begin. Table 5–1 assigns each of the health condition domains (how an individual is affected) to the part of the auditory processing system that is impacted by a hearing impairment (what is affected).

Table 5–1 is used as the nucleus in this chapter for discussions about outcome measures so audiologists can learn when certain measures should be made and where the measures are best obtained. The questions of who is to provide the measures and who benefits from these measures will lead to a discussion of why outcome measures are important.

This chapter has two objectives. The first is to help audiologists establish an outcome measures protocol for their clinical practice using a battery approach. The battery approach provides assessment of treatment effects in all three auditory processing systems (i.e., physiologic, communication, and psychological) and health condition domains. The second objective is to help hearing care providers and their patients set realistic, achievable, individual expectations and goals for intervention that use the outcome measures protocol as both a roadmap (where the intervention is headed) and a yardstick (what the intervention has accomplished).

Remember these points while reading this chapter:

1. As audiologists, the vast majority of your clinical intervention will require the fitting of hearing aids as an audiologic rehabilitation tool. For this reason, this chapter emphasizes outcome measures as they pertain to the fitting and
benefit of amplification systems. The audiologist must use an outcome measures battery (OMB) approach to do the following:

a. Identify impairment in the physiologic system and assess amplification with respect to targets.
b. Identify disability in the communication system and assess changes in speech recognition.
c. Identify the handicap in the psychological system and assess benefit and/or satisfaction.

2. As the involved auditory processing system moves from the physiologic level to the psychological level, several realities should be observed:

a. The systems become increasingly complex.
b. The effects of intervention become increasingly latent.
c. Communication assessments, then psychological assessments, are performed later in the audiologic rehabilitation process.

**The “What” of Outcome Measures**

Outcome measures are tools used by the audiologist to assess performance, or a change in performance, that results during the course of audiologic rehabilitation. Change in and of itself, be it measured or perceived, should be, but is not always, beneficial to the patient.

As audiologic rehabilitation is a treatment course that involves complex systems, no single measure is sufficient to adequately evaluate progress. For this reason, an OMB is recommended to sequentially assess (1) the physiologic system, (2) the communication system, and (3) the psychological system (Table 5–1).

The physiological system is composed of the auditory pathways that convert acoustic waveforms into meaningful neurologic events. This is the realm of diagnostic audiology, where frequency-specific and amplitude-controlled stimuli are used to measure the sensitivity of the auditory system. Significant loss of auditory sensitivity will negatively impact the communication system because one cannot understand what one cannot hear.

Performance of the communication system is one of the principal sources of complaints by patients when seeking medical attention because of the heavy reliance by most people on auditory input to convey information. With normal hearing, conversational speech is easily understood. With hearing loss, particularly sensorineural impairment, speech recognition is degraded, especially in the presence of background noise. Significant loss of speech recognition ability can negatively impact social interactions. The ability to communicate and interact is a major component of one’s quality of life, and a degradation in the ability to communicate very often leads to isolation and/or depression (for additional information on quality of life...

The psychological system is the set of behaviors associated with interpersonal communication. In the case of acquired hearing loss, otherwise normal behavior may change to what has been described by Myklebust (1960) as the psychology of the hearing impaired. This may result in a loss in quality of life, including miscommunications, frustration, social withdrawal, and depression. Patients often do not associate these behavioral changes with the hearing impairment and do not realize how their quality of life is being impacted.

A battery approach is a grouping of test instruments where each test assesses a portion of the whole system. A typical diagnostic test battery of the physiologic system includes observation of the external ear through otoscopy, evaluation of the middle ear through immittance audiometry, measurement of the function of the inner ear through air and bone conduction audiometry, and integrity of the auditory pathways using measurements of evoked potential. For audiolingual rehabilitation, it is recommended that audiologists use an OMB approach that evaluates performance in the physiologic, communication, and psychological systems.

The “How” of Outcome Measures

Using the World Health Organization (WHO) (1980) guidelines, hearing impairment may be described as the abnormal function of the auditory system. Disability refers to the effects on everyday hearing ability and communication performance. Handicap refers to the disadvantages (imposed by the impairment or the disability) that limit the individual’s psychosocial functioning (Table 5–1). Although the WHO (1980) terminology has been revised (WHO, 1997) to change disability to activity limitations and handicap to participation restrictions, we will use the 1980 terminology in this chapter. For additional discussion on the WHO guidelines (1980, 1997) with regard to audiology, see Erdman, 1993; McCarthy, 1997; Weinstein, 1997; Abrams and Hnath-Chisolm, 2000; Hosford-Dunn and Huch, 2000.

Assessment of hearing impairment in the physiologic system involves quantification of the impairment through identification of the location and degree of pathology. The result is a map of auditory sensitivity called the audiogram. From this map, amplification targets may be constructed to appropriately restore audibility. Hearing aid performance measurements used to evaluate compliance to targets include electroacoustic tests, probe microphone measures, and sound-field measures.

The primary disability resulting from a significant hearing impairment is decreased communication ability. In fact, the primary symptom resulting in an assessment of hearing loss is a complaint of loss of speech recognition. Based on the audiogram, reliable predictions may be made on the degree of speech recognition loss; based on the amplification target, predictions may also be made as to the restoration of speech recognition. Outcome measurement instruments that quantify whether or not speech recognition has been adequately achieved include speech-based tests in quiet and in noise with measurements obtained at the phoneme, syllable, word, and sentence levels.

The handicaps that may result from a hearing impairment are the behavioral changes resulting from decreased communication abilities. Although the audiologist is typically focused on identifying impairment in the physical system and disability in the communication system, the ultimate goal of any audiolingual intervention is to reduce the handicap, as measured by favorable changes in behavior. Self-assessment questionnaires are commonly used to quantify behavior in the psychological system. These include scales of handicap, of benefit (or reduction in handicap), and of satisfaction (of which benefit is a major component).

The “When” of Outcome Measures

Identification measurements of impairment, disability, and handicap should be made
prior to treatment, and may all be made at the initial diagnostic session. The assessment of compliance with amplification targets, improvement in speech recognition, and benefit or satisfaction must be time-sequenced as the provision of amplification produces changes in recognition that, over time, can result in changes in behavior. The greater the complexity of the system being sampled (physiologic, communication, then psychological), the more intervention time must be allowed to pass before assessment begins. This is to provide ample time for adaptation to occur and multiple listening situations to be encountered (Table 5–1).

Assessment of the match between hearing aid performance and prescriptive amplification targets should occur at the beginning of the rehabilitation process. Reasons for measurement at the onset are that assurance of the proper implementation of the prescription sets the foundation for improvements in communication and benefit, and no adaptation time is needed for electroacoustic performance in the coupler or in the real ear, or for sound-field measures of threshold or comfort.

Assessment of improvement in the communication system should not occur until there is documentation that the physiologic system is receiving proper amplification. This requires time for the patient to utilize the amplification system in a variety of listening environments and to report back to the audiologist about the situations that are unsatisfactory. Once electroacoustic modifications are complete and the patient has had time to adapt to the amplified signals presented to the impaired auditory system, speech understanding measures may be made to assess whether or not there has been an increase in recognition and a concomitant decrease in disability.

Self-assessment questionnaires of handicap typically query patients about their day-to-day performance in a variety of environmental situations, with an emphasis on any possible impact of hearing loss. Self-assessment measures of benefit look for a reduction in disability and handicap, and typically ask the patient about the amplified sound quality, impact of amplification on speech understanding ability, and effect of amplification on personal behavior in a variety of environmental situations. Self-assessment of satisfaction not only evaluates benefit, but also looks at the patient’s perception of the services provided, including satisfaction with the audiologist, the clinic, and the cost-effectiveness of the amplification solution provided. Because these questionnaires are global assessments of treatment efficacy, they should be administered toward the end of the intervention process.

Most outcome measures involve comparative data obtained before and after the administration of the services. First, a baseline is established, and then performance is compared after the treatment to determine how the measure has changed. Some measures require that the baseline be measured before treatment, whereas other measurements allow the baseline to be obtained at the same session that the treatment data are obtained because the treatment can be removed (e.g., comparison of unaided and aided performance). Other measures are made after the treatment, with patients comparing conditions while expressing their opinions.

Baseline measures may be assessments of the physiologic system. They may also be assessments of the communication system to evaluate what physical performance decrements are apparent to the patient and to verify complaints with a performance measure. These measures may also be assessments of the psychological system to gain understanding of the impact of the hearing loss on the individual, to understand the significant areas that can be improved by treatment, and to set realistic expectations of the potential improvement once treatment begins.

Interim measures can demonstrate that amplification provides a good fit to the physiologic impairment and that clinical goals are being met regarding change in auditory sensitivity with respect to frequency. Following this, there may be assessment of the communication system to evaluate speech recognition in quiet and in noise. For both physiologic and communication as-
assessments, change in performance from the baseline yields the indication of benefit. Some adaptation to the amplification system, however, may be needed before the optimal aided performance is obtained for speech recognition measures.

Post-rehabilitation measures provide assessment of the whole person and substantiate that the physiologic and communication benefit measured in the clinic have translated into psychological benefit in the real world. As these are subjective measures using self-assessment questionnaires, the patient must have adaptation time to evaluate real-world performance across many listening environments.

The question of when post-rehabilitation assessments should occur has been widely investigated. Gatehouse (1992, 1993) reported that the benefit from amplification changed over time, whereas Surr et al (1998) reported no significant change in benefit with long-term hearing aid use. Although assessment of small-scale, long-term changes in group benefit is of great importance in research studies, the majority of hearing aid benefit in clinical applications has been obtained within the first 6 to 10 weeks of intervention (Cox and Alexander, 1992; Cox et al, 1996; Turner et al, 1996; Horwitz and Turner, 1997).

The “Where” of Outcome Measures

Hearing aid systems must successfully operate in a variety of environments that are of importance to the patient, and which often cannot be tested by the audiologist. In contrast, audiologists perform hearing aid evaluations in the clinic, an environment that is of limited direct value to the patient. A balanced OMB must sample performance in both environments (Table 5–1).

The audiologist works in a highly controlled world. Performance measurements are typically made in an audiometric test room, or other sound-controlled environment, where measurements of compliance with amplification targets and improvements in speech recognition can be made without interference from extraneous auditory stimuli. In the clinic, procedures are based on objective measures that are not biased by social or psychological factors. This level of control is necessary to maximize the sensitivity and reliability of the test. Comparisons to norms or other baselines are only possible if the measures are made in the same environment. Such control is not possible in the infinite variations encountered in the real world.

The patient, however, must successfully utilize hearing aids in the real world. Although environmental simulations can be constructed in the clinic, these are only an approximation for a few of the actual situations the patient will encounter, such as in the car, at home, in the office, and in public. In the uncontrolled real world, clinical measures cannot be reliably made, but questionnaires can be used to assess performance. These self-assessment questionnaires are considered subjective measures as they are records of the patient’s psychological reaction to the treatment and may be influenced by day-to-day variations in feelings, moods, and opinions.

The “Who” of Outcome Measures

In the course of audiologic rehabilitation, there are many perspectives involved, beginning with the patient’s and the audiologist’s perspectives (Table 5–1), and including the possible interest of many other individuals (e.g., family members), or agencies, termed “third parties.” Outcome measures should verify and validate our processes using standardized procedures and specifically include assessment from the patients’ point of view (including their complaints and expectations). Depending on one’s perspective of the process, specific tasks may be viewed as either verification or validation, where verification establishes self-knowledge and validation confirms another’s information.

From the audiologist’s perspective, the diagnosis of hearing loss involves the verification of the pathology (in the physiologic system) and disability (in the communication
system) to determine if amplification should be recommended as treatment. These quantities are compared to norms or previous measures to verify a diagnosis or progression of hearing loss. If rehabilitation is recommended, the audiologist may apply treatment and measure the outcomes to verify appropriate amplification (physiologic system) and improvement in speech recognition (communication system). The impact on social interactions, however, and overall behavior must be validated using questionnaires to understand the treatment effects as perceived by the patient.

From the patient’s perspective, the impact on communication ability, social interactions, and psychological changes are understood and need to be quantified by an “expert” (the audiologist). For patients, self-assessment scales of handicap or benefit are a verification process of their perceived handicap that establishes a value for comparison purposes. The patient comes to the medical professional for validation of the disability and handicap, with the hope that there is a physical cause that can be mitigated by treatment.

There are many third parties who have interests in the rehabilitation outcome as well. These may include individuals, such as family and friends; organizations, such as the clinic, an insurer, and an employer; or government agencies such as the Veterans Administration (VA) or the Food and Drug Administration (FDA) (1994). Each entity has a different motivation for being interested in the patient’s treatment. The interpretation of an outcome measure is influenced by the entity’s motivation; many third-party payers are fiscally motivated, whereas family and friends are more personally motivated. The audience for the OMB also determines the level of detail and the organization of the battery.

From the audiologist’s perspective, verification confirms or substantiates, using reliable materials with repeatable methods, that the amplification chosen has met the electroacoustic performance goals that the audiologist intended. Verification involves performance measures that do not include the patient’s opinion. The abilities to detect, repeat, tolerate, interpret, or respond are all objective measures. This is not to say that objective measures cannot be biased (from attentiveness, effort, scoring, etc.), but these measures do not involve opinions.

If the goal of a hearing aid fitting is to improve speech intelligibility, a measure of speech recognition before and after the fitting would verify if a change has occurred. The amount of change may be statistically or quantitatively significant in that it can be reliably measured (the amount of change is within the sensitivity of the test in use), but it may not be clinically significant if it does not meet patients’ expectations about how much their performance should change. This is where the subjective measures come in.

From the audiologist’s perspective, validation is support for expectations or beliefs that the rehabilitation process accomplished the correct goal. Validation asks if the patient is aware of a change (specifically with hearing aids in auditory-related experiences). It is possible to verify a performance change and not validate that the patient believes there is a change. Conversely, subjective validation does not require a significant change in performance on a verification measure. Instead, validation measures require patients to express the opinion that they are performing differently.

There are many factors that determine patients’ belief. These do not express or verify performance improvements, but measure patients’ willingness to say that their lifestyle or personal interactions are different from before. Measures can be strongly biased by factors such as age (older patients’ expectations are different), education, income, etc. Subjective measures validate patients’ belief that they have received value, that services and products have met their expectations, or that their quality of life has improved.

The “Why” of Outcome Measures
Outcome measures are needed to ensure that quality work processes are in place and to document that satisfactory results have
been achieved. In the case of audiologic rehabilitation, this is accomplished by simultaneous verification and validation from both the audiologist’s and the patient’s perspective (Table 5–1).

Outcome measures help the audiologist establish and then meet clinical goals and expectations, and they require communication between the two parties. Outcome measures help patients express their opinions, and guide their evaluation across a range of parameters that must be evaluated in terms of real-world performance. They help define appropriate expectations, as well as limits (with respect to performance and abilities). They also help conclude the process and define what has been accomplished.

Many third-party payers are beginning to require proof of the value of services rendered, and therefore require outcome measures. Institutions under managed care, such as health maintenance organizations (HMOs) and the VA, negotiate large contracts for products and services for their patients and use outcome measures to optimize value. The proper use of outcome measures ensures that patients are experiencing a positive effect from the audiologic rehabilitation for the money spent. Unless outcome measures are administered correctly and appropriately, audiologists may not be recognized for valuable services, or patients may be charged unnecessarily for unsatisfying or unbeneficial services.

**An Outcome Measures Battery (OMB) Approach**

Successful audiologic rehabilitation requires a comprehensive OMB approach. Identification and measurement of impairment in the physiologic system produces amplification targets for assessment during treatment. Measurement of disability in the communication system establishes guidelines for improvement in speech understanding. Quantification of the handicap establishes a baseline for treatment benefit and satisfaction (Table 5–1).

An OMB uses objective data collection from the audiologist’s controlled world combined with subjective data from the patient’s real world. The audiologist’s task is to develop an OMB specific to each clinical setting that meets the needs of the audiologist, the patients, and the organization that supports the clinic. The battery of tests should combine clinical measures (objective) of the physiologic and communication systems with self-assessments (subjective) of the patient’s behavior in different environments.

In planning an OMB, the audiologist must be aware that each test instrument evaluates at a certain level within a system (physiologic, communication, or psychological) and has an individual degree of resolution within that level. There is also a system-level trade-off that becomes important in choosing among different test instruments. As the audiologist evaluates at a higher level within the system, measurement resolution may be lost, but the evaluation may have greater relevance or applicability to the real world. For example, when evaluating speech understanding, a confusion matrix of consonant misunderstandings, using a consonant-vowel (CV) or vowel-consonant (VC) test, has high resolution, whereas a percent-understanding score of key words in sentences has high communicative value.

Another key concept in planning an OMB is the comparative value of the various test instruments. To assess value, audiologists must know if a test instrument has performance guidelines, or targets for acceptable performance. Depending on the outcome measure of interest, the reference should be different. Therefore, the more benchmarks available, such as normal-hearing population, the hearing-impaired population, or the hearing-impaired individual, the more outcomes that can be evaluated. This benchmarking may take the form of absolute ability (i.e., normal hearing) or improvement (unaided or with a hearing device).

In assessing the comparative value of outcome measures, each instrument has a specific utility resulting from its applicability to the real world, including the purpose of the
instrument and generality of measure, the similarity of materials to the situation of interest, and the trade-off between sensitivity or statistical power and reality. In terms of statistical significance, each instrument has different levels of sensitivity when used to objectively verify clinical protocols. “Clinical significance” (a change in performance large enough to be recognized by the patient and positively affect satisfaction), as opposed to statistical significance, tends to require some measure of the psychological system and comes from positive changes in patient benefit. Clinical significance is achieved through generating improved consumer satisfaction and can be documented with subjective measures.

Rule of thumb: Utilize an OMB that demonstrates benefit measured clinically and in the real world, with the goal of significantly improving the quality of life for the patient.

Outcome Measures for Evaluation of the Physiologic System

A successful OMB approach begins with objective verification of the hearing loss and its etiology, followed by verification that the hearing aids are delivering proper amplification for the hearing loss under treatment. The three major methods for measuring hearing aid performance are (1) coupler measures, which measure the electroacoustic response of the aids in a controlled environment of general characteristics; (2) probe microphone measures, which measure the electroacoustic response of the aids in an uncontrolled environment specific to the characteristics of an individual’s real ear; and (3) sound-field measures with nonspeech stimuli, which document minimal performance capabilities.

Regardless of the three approaches used, performance targets are available using a prescriptive approach (see Chapter 1). These three methods are ways to implement and verify the frequency-specific and amplitude-dependent characteristics of the hearing aid fitting in accordance with a specified hearing loss. Table 5–2 summarizes the key concepts that are discussed in this section (see Chapters 1 and 2 for additional information on physical assessment of hearing aid performance with prescription formulas to determine the appropriate gain and output).

Table 5-2. Comparison between Three Test Methods to Assess Implementation of Amplification Targets within the Physiological System

<table>
<thead>
<tr>
<th></th>
<th>Coupler</th>
<th>Probe Microphone</th>
<th>Sound Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum output assessment</td>
<td>90-dB SPL output curve</td>
<td>Real-ear saturation response: Real-ear aided response at 90 dB SPL</td>
<td>Aided maximum: (aided maximum – unaided threshold = dynamic range)</td>
</tr>
<tr>
<td>Components of physical system assessed</td>
<td>Hearing aid; in absentia; no real-ear complications</td>
<td>Hearing aid in situ: real-ear effects on microphone, vent, and receiver</td>
<td>Hearing aid in situ; real-ear effects, low-level auditory performance</td>
</tr>
<tr>
<td>Comparative strengths</td>
<td>High measurement resolution</td>
<td>High measurement resolution</td>
<td>Good real-world prediction</td>
</tr>
<tr>
<td>Comparative weaknesses</td>
<td>Poor real-world prediction</td>
<td>Accurate results technique-dependent</td>
<td>Low measurement resolution</td>
</tr>
</tbody>
</table>

SPL, sound pressure level
**Electroacoustic measures** of hearing aid performance in a coupler provide a highly consistent and reliable method to evaluate performance (American National Standards Institute [ANSI], 1992, 1996), but have a low relevance to real-world performance. The value in these measurements comes from the stability of the hearing aid and coupler system, and allows the audiologist to easily perform comparisons between devices, styles, and manufacturers’ products. A major component of the performance stability is that the measurements are made with the patient *in absentia.* This is also why the measurements have limited real-world value, as the patient’s physical ear structures are not well represented by the 2-cc coupler (see Chapter 1 in Hearing Aids: Standards, Options, and Limitations, 2nd edition, Thieme Medical Publishers, for additional information on electroacoustic measures of hearing aid performance).

Based on the audiogram, 2-cc coupler amplification targets for gain and output are established. The gain target is most often specified for measurement with a 50-dB sound pressure level (SPL) pure-tone signal; the output target is specified using a 90-dB SPL pure-tone signal. The gain target is an optimal frequency response configuration for low-intensity signals that is designed to restore audibility of conversational speech. The output target is a separate frequency response that limits the maximum SPL from the hearing aid such that the amplification does not create pain or discomfort when used in the presence of high sound levels (see Chapter 2 for more information on the selection and verification of output). Figure 5–1 shows gain and output targets, with actual hearing aid settings, for a moderate sensorineural hearing loss. Note the excellent agreement between the target and measured response for both input levels.

**Rule of thumb:** 2-cc coupler responses, set to match standardized targets based on audiometric thresholds, rarely incorporate individual variation in auditory system physiology. As such, the match to prescribed coupler targets is the *starting point* of the hearing aid fitting process, not the *end point.*

**Probe microphone measures** of hearing aid performance in the real ear provide a reliable method to evaluate performance (ANSI 1997b), with relevance to real-world performance. The value in these measurements comes from direct in situ measurement of the SPL of the hearing aid near the eardrum. The measurement procedure utilizes the same high-resolution signals as coupler measurements, yet also incorporates external ear effects on the microphone input, vent effects on the frequency response, and residual ear canal volume effects on receiver efficiency. The major limitations to the measure are that accurate results are dependent on good technique, and although the measure is in situ, it

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**Figure 5–1.** Display of 2-cc coupler response to assess right and left device performance with respect to target. Coupler response targets are for a 50-dB sound pressure level (SPL) signal (large open diamonds) and a 90-dB SPL signal (large closed diamonds).
does not incorporate any documentation of actual auditory processing by the patient (see Chapter 3 for additional information on physical assessment of hearing aid performance with probe microphones).

As with coupler measures, probe microphone amplification targets for gain and output are based on the audiogram. Targets may be specified for pure-tone or broadband signals, and in the case of single-channel hearing aids, either works satisfactorily. With the new digital, multichannel compression aids, however, pure-tone targets may overprescribe gain and output, unless the prescriptions have been adjusted for the specific multichannel architecture of the hearing aid. For this reason, broadband targets, which are generally insensitive to multichannel architecture, are recommended when measuring advanced technology devices.

Prescriptive targets for probe microphone measures may be specified in dB gain or dB SPL. Compliance with gain targets is typically evaluated with the real-ear insertion response (REIR in dB), which is the difference between the real-ear aided response (REAR in dB SPL) and the real-ear unaided response (REUR in dB SPL). Loudness discomfort to the output target is typically obtained with the REAR using a 90-dB input, which is also known as the real-ear saturation response (RESR in dB SPL). Figure 5-2 shows SPL targets and Figure 5-3 shows gain targets, with actual hearing aid settings, for a moderate sensorineural hearing loss. Note the excellent agreement between the target and measured response for the 50- and 90-dB input levels.

Rule of thumb: Real-ear aided responses are best evaluated as a family of curves. The curves obtained with higher input levels should have higher output levels. The curves should have an overall smooth pattern and should not have sharp peaks and/or valleys. Curves should converge where compression circuitry is utilized, either across all input levels for wide dynamic range compression (WDRC), or in the higher input levels for compression limiting.

Rule of thumb: Real-ear insertion responses should be evaluated as a family of curves. Lower input levels should produce higher gain curves when using level-dependent gain systems, such as WDRC circuitry. Note the change in REIR for the 50-, 70-, and 90-dB input levels in Figure 5-3.

Sound-field measures of hearing aid performance with nonspeech stimuli have a high relevance to real-world performance but are obtained with a lower-resolution measurement scale than coupler or probe microphone measures. When assessing the hearing aids at the physical system level, this is the only measure of the three techniques that involves the auditory pathways and requires patient responses. The major consequence is that measurement resolution is no
longer in 1-dB increments at 100-Hz intervals (as with coupler and probe microphones), but instead is in 5-dB increments at half-octave intervals.

Nonspeech amplification targets for gain and output in a sound field are also audiogram based. The functional gain (FG) target is specified as the difference between the aided threshold (AT) and the unaided threshold (UT) using frequency-modulated tones presented in a sound field. The aided dynamic range (ADR in dB) is the difference between the aided maximum (AM) with frequency-modulated tones presented at high intensities and the AT. The unaided dynamic range (UDR in dB) is the difference between the unaided maximum (UM) and the UT (Table 5–2, Fig. 5–4).

In evaluating the effectiveness of amplification performance using sound-field measures, 20 years of clinical experience and 10 years of algorithm development dictate that the aided thresholds should approach 20-dB hearing level (HL) values, or should reduce the amount of threshold loss by at least 50%. To achieve this, greater amounts of functional gain must be achieved for greater amounts of hearing loss. Regardless of the...
amount of functional gain achieved, the aided maximum should be no lower than the unaided maximum. That is to say that the patient should not lose maximum tolerance for high input sounds in the aided condition. Functional gain at any frequency should never be negative, and the ADR should always be greater than the UDR.

It is important to note that the presence of sensorineural hearing loss results in a narrowing of the unaided dynamic range. Successful hearing aid fittings will produce an expanded dynamic range in the aided conditions through a combination of improved audibility for low-intensity inputs without changing the tolerance levels for high-intensity inputs. Figure 5–4 shows the relationship of various sound-field measures obtained with nonspeech stimuli.

Rule of thumb: Acceptable frequency-specific aided threshold targets are 20-dB HL for losses ≤40-dB HL, or one-half the threshold loss for losses ≥45-dB HL. The aided dynamic range should always exceed the unaided dynamic range.

Prescriptive amplification targets can be evaluated with couplers, probe microphones, or sound-field measures. All prescriptive methods produce a frequency-specific target that can be verified with any of these approaches. More sophisticated prescriptions, which incorporate nonlinear algorithms for WDRC hearing aids, specify frequency-specific targets that are also level dependent. As knowledge of the interactions between speech acoustics, hearing loss, and auditory processing for speech continues to grow, prescriptive approaches of the future will be specifically designed to improve speech intelligibility in noise (Pavlovic, 1984; Rankovic, 1991, 1995; Hou and Thornton, 1994; Magnusson et al, 2001).

With coupler measurement techniques, the best way to evaluate multilevel response curves on nonlinear hearing aids is using the ANSI S3.42 guidelines (ANSI, 1992) for measurement with a family of broadband signals. For probe microphone measurement protocols, the best technique is to measure the REAR with a range of input levels, such as 50-, 65-, and 80-dB SPL. For sound-field measures of nonlinear targets, loudness scaling must be utilized, incorporating aided judgments of soft, comfortable, and loud levels.

**Outcome Measures for Evaluation of the Communication System**

Once proper prescriptive amplification is in place, the OMB continues with objective verification that the hearing aids are providing improvement in speech recognition. Table 5–3 provides an overview of several word and sentence tests that can be used to assess changes in the communication system. These measures are made in the sound field with communicatively relevant materials, with the evaluation occurring at the phoneme, syllable, word, or sentence level. Unaided measures are obtained to establish the disability baseline; aided measures then determine change in ability, be it positive or negative. It is important to note that although almost all hearing aid fittings successfully provide some degree of amplification, this does not necessarily translate into a guarantee of improved speech recognition, especially in noise.

**Phoneme and syllable identification tasks**, such as with a CV or VC pairing, measure the basic ability to detect the components of speech. The physical characteristics of these stimuli are well characterized in the physical domain, and correct perception of the stimuli can be directly related back to audibility as the measured frequency-by-intensity in the coupler, probe microphone, or sound-field nonspeech measures. CV and VC recognition can also be analyzed in the domain of speech features, such as voicing, manner, and place of articulation, yielding patterns of correct and incorrect perception. An example of this test is the Nonsense Syllable Test (NST) (Levitt and Resnick, 1978).

**Word identification tasks** evaluate the ability to integrate speech components into semantic units carrying information. These tasks can be influenced by knowledge and experience with the semantic units typically
Table 5–3. Comparison of Test Instruments to Assess Speech Recognition in the Communication System (see also Thibodeau, 2000)

<table>
<thead>
<tr>
<th>Signal</th>
<th>Masker</th>
<th>Procedure</th>
<th>Items</th>
<th>Test</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonsense syllable test (NST)</td>
<td>Male, CV or VC with carrier phrase noise</td>
<td>Edited cafeteria noise</td>
<td>Fixed level; closed set</td>
<td>91 items organized into 11 subsets of 7–9 syllables;</td>
<td>One set unaided and aided (182 syllables)</td>
</tr>
<tr>
<td>NU-6 and W-22</td>
<td>CVCs with carrier phrase</td>
<td>Optional, not standardized</td>
<td>Fixed level; open set</td>
<td>50 item, phonemically balanced word lists</td>
<td>One list unaided and one list aided (100 words)</td>
</tr>
<tr>
<td>Speech perception in noise (SPIN)</td>
<td>Male, last word in sentence</td>
<td>12-talker babble</td>
<td>Fixed level; can vary SNR</td>
<td>50 sentences per list; both low and high probability lists</td>
<td>One list unaided and aided (100 key words)</td>
</tr>
<tr>
<td>Synthetic Sentence Identification (SSI)</td>
<td>Male, synthetic sentences</td>
<td>Male, single talker</td>
<td>Fixed level varying SNR; closed set</td>
<td>10 sentences per list</td>
<td>Three lists unaided and four lists aided (70 sentences)</td>
</tr>
<tr>
<td>Speech in noise (SIN)</td>
<td>Female, Institute of Electrical and Electronics Engineers (IEEE) sentences</td>
<td>Four-talker babble</td>
<td>Two signal levels (70 and 40 dB HL) and four SNR (0, +5, +10, +15) at each level</td>
<td>Five sentences with five key words per test condition</td>
<td>One list unaided and aided (200 key words)</td>
</tr>
<tr>
<td>Hearing in noise test (HINT)</td>
<td>Male, revised Bamford-Kowel-Bench sentences</td>
<td>Noise matched to long-term average spectrum of signal</td>
<td>Adaptive for reception threshold for sentences w/ masker fixed at 65 dBA</td>
<td>10 phonemically balanced sentences per list; SNR</td>
<td>Two lists unaided and aided (40 sentences)</td>
</tr>
<tr>
<td>Connected Speech Test (CST)</td>
<td>Female, continuous speech</td>
<td>Six-talker babble</td>
<td>Fixed-level presentation</td>
<td>25 key words in 10 sentences per passage</td>
<td>Two passages unaided and aided (100 key words)</td>
</tr>
</tbody>
</table>

CV, consonant-vowel; VC, vowel-consonant; SNR, signal-to-noise ratio
used in language. Examples of word identification tasks are the Central Institute for the Deaf (CID) W-22 words lists (Hirsh et al, 1952), the Northwestern University (NU)-6 word lists (Tillman and Carhart, 1966), and the speech perception in noise (SPIN) test (Kalikow et al, 1977; Bilger et al, 1984).

Sentence identification tasks determine the ability of the patient to combine units into meaningful structures. These tasks can be scored focusing on key words in a sentence, or on the complete sentence. Sentence identification is influenced by word context, entropy, and familiarity with the speaker’s voice and language. Examples of sentence identification tasks are: the synthetic sentence identification (SSI) (Speaks and Jerger, 1965), the speech in noise (SIN) test (Killion, 1997a), the hearing in noise test (HINT) (Nilsson et al, 1994), and the connected speech test (CST) (Cox et al, 1987, 1988).

Prescriptive speech recognition targets provide guidance to assess the acceptability of the aided communication. Like prescriptive targets of frequency-by-intensity for the physiologic system, speech recognition targets provide guidance for the audiologist in determining acceptable aided performance for the patient. The targets can be established using (1) performance level for the normal-hearing population, (2) the performance level of the hearing-impaired population, or (3) the performance level of the hearing-impaired patient.

Comparison of an individual’s performance to the normal-hearing population tells us how well the individual is able to take advantage of all of the innate abilities of the auditory system. These targets are best-case values; unaided or aided hearing cannot be expected to be better than this. The ultimate goal of amplification is to work toward normal hearing, and this comparison will determine how closely performance attains this goal.

Comparison of an individual’s performance with the hearing-impaired population determines whether the amount of difficulty the patient is experiencing is predicted by the amount of hearing loss measured. In other words, this comparison is used to help diagnose whether speech intelligibility impairments are solely peripheral or whether there may be other factors that the audiogram does not take into account (language experience, attention deficits, retrocochlear pathology, central auditory processing disorder).

Comparison of patients’ performance to themselves (such as comparing aided to unaided, or hearing aid A to hearing aid B) determines whether performance, as measured by multiple tests with the same person, is changing over time or with intervention. The ability of amplification to help with a hearing loss is initially calculated by comparing performance before and after the hearing aid fitting. The comparison can also determine if there are differences between various signal-processing algorithms, or even between various amplification targets. The analysis typically involves changes in performance, but not a gauge of absolute performance (which would involve the previous comparisons to normal-hearing or other hearing-impaired listeners).

Speech recognition in noise is the key performance measure of interest. Pure-tone thresholds have a strong predictive relationship to speech recognition measures in quiet; therefore, additional measures are of limited value. Measures in noise, however, are suprathreshold and therefore are not well predicted by threshold measures. Complex formulas have been developed that require an accurate representation of an individual’s hearing loss, the speech signal in question, as well as any noise. The articulation index (ANSI, 1969) and more recent speech intelligibility index (ANSI, 1997a) define functions that use the frequency-importance of speech, the dynamic range of speech, and the spectrum of both the speech and any competing noise to predict how much useful information is available to the patient. The method is quite robust, but requires much more information than is typically available to the audiologist. Instead,
measurement of speech recognition performance in noise is often easier.

Clinical Implementation

Audiologists involved in fitting and dispensing hearing aids should establish expected performance levels for speech recognition test results. These performance targets should be based on measurements of both the normal-hearing population and the hearing-impaired population. Once these levels are established, hearing-impaired patients can be counseled regarding their unaided and aided ability, with respect to normal-hearing and hearing-impaired persons (Ross and Levitt, 1997).

The first step in creating performance levels specific to a clinic is to select and repeatedly administer a set of test materials. Next, the test presentation must be standardized with respect to the intensity levels of the speech and noise, the loudspeaker configuration (single or multiple speakers), and the testing environment. Finally, the test must be administered to persons with a range of hearing abilities to establish expected performance levels. The example used will be with the HINT (Nilsson et al, 1994), using 20 sentence lists, administered with the masker fixed at 65 dBA and a single loudspeaker positioned 1 m from the listener at 0-degree azimuth and incidence.

Rule of thumb: For speech, sensorineural hearing loss results in both a loss of sensitivity (elevated thresholds in quiet) and a loss of clarity (elevated thresholds in noise). In general, greater loss in sensitivity is accompanied by greater loss in clarity, but there is significant individual variation in the interaction of these two components.

Figure 5–5 plots performance data for the speech threshold in quiet (abscissa) and the speech threshold in noise (ordinate) for 50 subjects in the unaided condition. The solid line through the scatterplot is a linear regression line for best fit to the data. In the lower left corner of the plot is a cluster of data points with thresholds in quiet less than 20 dBA and thresholds in noise from $-2$ to $-6$ dB signal-to-noise ratio (SNR). This defines the expected performance level for the normal-hearing population.

The hearing-impaired population is characterized by the other data points. It is important to realize that as hearing loss for speech in quiet increases from 30 to 70 dBA, the average SNR for reception threshold for sentences in noise increases from $-2$ to $+4$ dB SNR. This establishes that, using this particular test configuration, the expected increase in SNR loss as hearing loss increases is about 1.5 dB per decade of hearing loss for mild to severe losses (see also Plomp, 1978; Killion, 1997a–c).

Figure 5–5. Performance measurements using the hearing in noise test (HINT) with normal-hearing and hearing-impaired patients obtained in a clinical environment. The reception threshold for sentences (RTS) in quiet (dBA) is plotted on the abscissa and the RTS in noise [dB signal-to-noise ratio (SNR)] is plotted on the ordinate. Performance for normal-hearing persons is between 10 and 20 dBA in quiet and between $-2$ and $-6$ dB SNR in noise. The dotted lines are ±2 dB from the solid regression line for best fit to the data.
Once the normative data for a clinic have been established, individual data plotted on the graph can be used as a counseling tool, as shown in Figures 5–5 and 5–6. For example, points 1U, 2U, and 3U represent similar unaided thresholds in quiet, at about 50 dBA, but markedly different unaided thresholds in noise. In the unaided condition, patient 1 would have an SNR loss of −1 dB SNR, which is about 2 dB better than expected for this degree of hearing loss in quiet, but still 2 dB worse than the normal-hearing group. Patient 2 has an SNR loss that is in the expected range for the degree of hearing loss, but is 4 dB worse than the normal group. In contrast, patient 3 has an SNR loss of +6 dB SNR, which is 5 dB worse than expected for a moderate loss, and 9 dB worse than the normal-hearing group.

In recommending hearing aid technology, it is possible that patient 1 could satisfactorily use a simple amplification system that overcomes the hearing loss for quiet, whereas patient 3 requires not only amplification in quiet, but extra assistance to improve hearing in noise. As hearing aids incorporating multichannel compression, directional microphones, and/or digital noise reduction provide more advantageous benefit for those with greater SNR loss (Bray, 2001), patient 3 clearly requires an advanced technology system.

Following the hearing aid fitting and the necessary fine-tuning to ensure that the amplification prescription has been met (the physiologic system target), testing of speech recognition with the hearing aids is conducted. The aided score can be plotted on the graph alongside the unaided score. In Figure 5–6, comparison of the unaided and aided scores shows 20 dB movement to the left, representing a 20-dB gain in hearing threshold in quiet. For hearing in noise, patient 1 has no change in performance, patient 2’s performance is degraded by 2 dB SNR, and patient 3’s performance is improved by 4 dB SNR. Hearing aid fittings that make hearing in noise worse are unacceptable (patient 2), fittings that do not make hearing worse in noise are acceptable (patient 1), and fittings

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**Figure 5–6.** Individual patient HINT measures plotted with respect to normative performance levels for the clinic, as shown in Figure 5–5. Unaided (U) and aided (A) scores are plotted for patients 1, 2, and 3. In the unaided condition, all subjects have equal hearing loss in quiet (50 dBA) and different amounts of hearing loss in noise (−2 to +6 dB SNR). In the aided condition in quiet, all three patients move to 30-dBA thresholds, receiving an improvement of 20 dB. Also in the aided condition, patient 1 has unchanged performance in noise (acceptable results); patient 2 has degraded performance in noise (unacceptable results); and patient 3 has improved performance in noise (desired results).
that dramatically improve hearing in noise are desirable (patient 3).

In summary, the movement on the graph from right to left (change in speech threshold in quiet) results from application of gain to increase thresholds in quiet. Movement on the graph from top to bottom (change in speech threshold in noise) most often results from applications of advanced technology, such as excellent frequency shaping, multichannel compression, directional microphones, and/or digital noise reduction. In comparing the unaidered (U) to aided (A) results for any patient, the aided value should always plot to the left of the unaidered value (i.e., hearing in quiet is better), and should not be above the unaidered value (i.e., hearing in noise is no worse). Hearing aid fittings that do not meet these criteria are to be considered unsatisfactory with regard to expected performance targets for speech recognition.

Rule of thumb: With respect to the unaidered performance, aided speech recognition performance should show benefit in both quiet and noise conditions. Hearing aid fittings that degrade performance in either dimension are unacceptable.

**Outcome Measures for Evaluation of the Psychological System**

The impact of hearing loss on the patient’s behavior is multidimensional. Behaviors change not only in the response to physical stimuli (patients can’t react to what they don’t hear), but some behaviors and situations can be avoided altogether to alleviate the embarrassment or concern of others (social withdrawal). Therefore, most assessments of the psychological system attempt to evaluate the impact of the hearing loss on behavior with respect to multiple levels, such as expectations from hearing aids, unaidered and aided performance in the real world, the impact of intervention on social interactions and personal image, and the patient’s overall satisfaction with the rehabilitation process. It is also necessary to obtain subjective measures, as they appear to be largely independent of speech intelligibility in noise as assessed in the clinic (Cox and Alexander, 1992; Beamer et al, 2000; Cord et al, 2000).

The self-assessment questionnaires are useful because they guide the patient in contemplating the global effect of the loss. Typically, a patient comes in for evaluation based on a single dimension whose handicap has become a dominant factor (e.g., “I can’t understand what my spouse says.”). A simple question assessing the patient’s potential improvement in this one area will not produce evaluations of other behaviors that the patient has grown accustomed to as a result of the impairment (e.g. “I don’t play bridge anymore. I can’t follow the conversation.”). The standardized questionnaires that are currently available (Table 5–4 lists many of these standardized questionnaires) sample a wide range of behaviors to more accurately assess the full impact of the impairment on handicaps across multiple dimensions.

Handicap is the psychosocial disadvantage to the individual resulting from the physiologic impairment and the communicative disability. In the identification stage of the evaluation of the psychological system, measures of handicap serve as the unaidered baseline for needed changes in the ensuing assessment of benefit. Self-assessment of handicap quantifies the disadvantage from the patient’s perspective, and may or may not be consistent with the audiologist’s expectations based on the hearing loss and communication deficit.

Measures of handicap include the Communication Profile for the Hearing Impaired (CPHI) (Demorest and Erdman, 1987, 1989a,b; Garstecki and Erler, 1996), the Hearing Handicap Inventory for Adults (HHIA) (Newman et al, 1990, 1991), the Hearing Handicap Inventory for the Elderly (HHIE) (Ventry and Weinstein, 1983; Newman and Weinstein, 1988, 1989; Malinoff and Weinstein, 1989), the Hearing Handicap Scale (HHS) (Tannahill, 1979), the Hearing Measurement Scale (HMS) (Noble and Atherley, 1970); the Hearing Performance Inventory (HPI) (Giolas et al, 1979; Owens and Fujikawa, 1980), and the Performance...
### Table 5–4. Comparison of Self-Assessment Questionnaires to Assess Components in the Psychological System*

<table>
<thead>
<tr>
<th><strong>Test</strong></th>
<th><strong>Items</strong></th>
<th><strong>Ratings</strong></th>
<th><strong>Sections</strong></th>
<th><strong>H</strong></th>
<th><strong>P</strong></th>
<th><strong>B</strong></th>
<th><strong>E</strong></th>
<th><strong>S</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>APHAB</td>
<td>24 statements</td>
<td>Seven-point scale: always–never</td>
<td>Four subscales</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>COSI</td>
<td>Patient picks up to five listening situations</td>
<td>Five-point scale: degree of change</td>
<td>16 categories</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CPHI</td>
<td>145 items</td>
<td>Five-point scale: agree–disagree</td>
<td>Four subscales</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECHO</td>
<td>15 items</td>
<td>Seven-point scale: not at all–tremendously</td>
<td>Four subscales</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GHABP</td>
<td>24 questions (minimum)</td>
<td>Five-point scale</td>
<td>Six subscales</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>HAPI</td>
<td>64 statements</td>
<td>Five-point scale: helps–hinders</td>
<td>Four subscales</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HANA</td>
<td>11 questions</td>
<td>Three-point scale</td>
<td>Four subscales</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>HASS</td>
<td>34 items</td>
<td>Five-point scale</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HAUQ</td>
<td>11 questions with subquestions</td>
<td>Four-point scale</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HHIA</td>
<td>25 items</td>
<td>Three-point scale: yes–no</td>
<td>Two subscales</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HHIA-S</td>
<td>10 items</td>
<td>Three-point scale: yes–no</td>
<td>Two subscales</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HHIE</td>
<td>25 items</td>
<td>Three-point scale: yes–no</td>
<td>Two subscales</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HHIE-S</td>
<td>10 items</td>
<td>Three-point scale: yes–no</td>
<td>Two subscales</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HPI</td>
<td>158 situations</td>
<td>Five-point scale: always–never</td>
<td>Six subscales</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HPI-R</td>
<td>90 situations</td>
<td>Five-point scale: always–never</td>
<td>Six subscales</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IOI-HA</td>
<td>7 items</td>
<td>Five-point scale</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PHAB</td>
<td>66 statements</td>
<td>Seven-point scale: always–never</td>
<td>Seven subscales</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>PHAP</td>
<td>66 statements</td>
<td>Seven-point scale</td>
<td>Seven subscales</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PIPSL</td>
<td>74 questions</td>
<td>Seven-point scale: always–never</td>
<td>Six subscales</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SADL</td>
<td>15 items</td>
<td>Seven-point scale: not at all–tremendously</td>
<td>Four subscales</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>SHAPI</td>
<td>38 items</td>
<td>Five-point scale: helps–hinders</td>
<td>Four subscales</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Check marks indicate if the self-assessment scale evaluates handicap (H), aided performance (P), aided benefit (B), expectation (E), and satisfaction (S). (see also Huch and Hosford-Dunn, 2000.)
performance Inventory for Profound and Severe Loss (PIPSL) (Owens and Raggio, 1988).

Shortened measures of handicap include the Hearing Handicap Inventory for Adults-Screener (HHIA-S) (Newman et al, 1991), Hearing Handicap Inventory for the Elderly-Screener (HHIE-S) (Newman et al, 1991), and the Hearing Performance Inventory Revised (HPI-R) (Lamb et al, 1983).

Handicap scales vary in their clinical feasibility and relevance. Shortened versions have been created to address concerns about test completion time, but the sensitivity and ability to interpret results varies. A good choice for measuring handicap should include no more than 25 items and provide normative data from a population similar to the patient as well as guidelines as to significance.

Aided performance or aided benefit can be assessed following hearing aid intervention. Aided performance measures evaluate the aided handicap level without reference to the unaided condition (i.e., no unaided baseline), whereas the aided benefit measures determine a change in performance, or benefit, by establishing the difference in handicap between the unaided and aided conditions.

Measures of aided performance include the Hearing Aid Performance Inventory (HAPI) (Walden et al, 1984), and the Profile of Hearing Aid Performance (PHAP) (Cox and Gilmore, 1990).

Shortened measures of aided performance include the Abbreviated Profile of Hearing Aid Performance (APHAP) (Purdy and Jer-ram, 1998), the Shortened Hearing Aid Performance Inventory (SHAPI) (Schum, 1992, 1993; Jerram and Purdy, 1997), and the Shortened Hearing Aid Performance for the Elderly (SHAPIE) (Dillon, 1994).

Measures of aided benefit include the Client-Oriented Scale of Improvement (COSI) (Dillon et al, 1997, 1999), the Glasgow Hearing Aid Benefit Profile (GHBAP) (Gatehouse, 1994, 1999), and the Profile of Hearing Aid Benefit (PHAB) (Cox et al, 1991; Cox and Rivera, 1992).

Shortened measures of benefit include the Abbreviated Profile of Hearing Aid Benefit (APHAB) (Cox and Alexander, 1995) and the International Outcome Inventory for Hearing Aids (IOI-HA) (Cox et al, 2000).

Similar to handicap measures, aided performance or benefit measures also vary in their clinical feasibility and relevance. The same guidelines should be used when selecting a measure.

Satisfaction measures go beyond assessing aided performance or benefit to include factors such as the patient’s perspective of the rehabilitation process and the impact of the audiologist, facilities, and fees. Because satisfaction measures are quite global, they may be influenced by the patient’s psychological mindset prior to beginning the rehabilitation process. This preexisting mindset or baseline for satisfaction can be assessed with expectations measures.

Measures of satisfaction include the Hearing Aid User’s Questionnaire (HAUQ) (Dil- lon et al, 1999), the MarkeTrak Hearing Aid Satisfaction Survey (HASS) (Kochkin, 1992, 1994a,b, 1997a,b, 1998, 2000a,b), and the Satisfaction with Amplification in Daily Life (SADL) (Cox and Alexander, 1999, 2001; Hosford-Dunn and Halpern, 2000, 2001).

Assessments of expectations include the Expected Consequences of Hearing Aid Ownership (ECHO) (Cox and Alexander, 2000) and the Hearing Aid Needs Assessment (HANA) (Schum, 1999). The ECHO is designed as a companion scale to the SADL; the HANA is a companion scale to the HAPI and the SHAPI.

Clinical Implementation

How does the audiologist choose from among the various instruments evaluating handicap, aided performance, aided benefit, expectations, and satisfaction? Following the guidelines established in this chapter, outcome measures for a patient are a two-step process; within a system, assessment of intervention follows only after identification of the impairment, disability, or handicap. Scales that incorporate both the baseline unaided handicap and the aided benefit will be most useful. An example of such a scale is the APHAB.
In administering the APHAB, the benefit derived is the difference in ratings between the unaided and aided conditions. Ratings are categorized into four subscales: ease of communication in favorable conditions (EC), ease of communication in reverberant rooms such as classrooms (RV), ease of communication in settings with high background noise (BN), and the aversiveness of environmental sounds with amplification (AV). The unaided conditions have been normalized to see how much handicap is perceived by the individual and whether or not there are any predictors for level of benefit with amplification.

An individual who expresses problems in the three communication subscales while unaided (EC, RV, and BC) is describing difficulty in almost all communication situations. If the AV score is low, the individual has few problems tolerating environmental sounds and should have little difficulty adapting to amplification. If the AV score is high, some form of dynamic range compression or compression limiting will be necessary to control the harshness of typical environmental sounds (such as toilets flushing). An individual who expresses problems in only a single condition (such as BN) may or may not become a successful amplification user, as the limitations of amplification may outweigh the benefits. This user is more likely to require advanced-technology hearing aids to provide benefit in difficult listening conditions, without sacrificing performance in other listening conditions.

In measuring benefit, the change in perceived handicap between unaided and aided conditions is of great importance. The benefit is an indication not of the absolute number of problems encountered but of whether amplification has significantly reduced the number of problems experienced. Cox (1997) describes in detail several methods of interpreting APHAB scores with respect to a normal-hearing reference (which would quantify absolute impairment), a hearing-impaired reference (which describes the individual’s success relative to other, similar users of amplification), as well as comparisons between unaided and aided conditions or between two hearing aids on an individual (required differences between scores for significance are described).

In Figures 5–7 and 5–8, the same patients are profiled with the APHAB as with the HINT speech recognition test results in Figure 5–6, and similar interpretations are possible. Using the Cox (1997) guidelines, patient 1 obtains significant overall benefit from the >22% improvement in the EC subscale, patient 2 does not obtain significant overall benefit, and patient 3 obtains signifi-
cant overall benefit from both the >22% improvement in the EC condition and the >5% benefit on the EC, RV, and BN subscales.

It is important to remember that perceived benefit as indicated by a subjective measure is not guaranteed by improvements in measured physiologic or communicative performance. For this reason, as part of a complete OMB, self-assessment questionnaires provide the needed additional level of detail characterizing patient performance, thereby verifying benefit and/or satisfaction from the patient’s perspective.

Rule of thumb: Relative to the unaided condition, the aided condition should reduce the percent of reported problems in the EC, RV, and BN subscales, while not increasing the percentage of problems in the AV subscale.

Rule of thumb: Clinically significant benefit ($p = 0.1$) is obtained when $\geq 5$ benefit points are obtained on the EC, RV, and BN subscales, or $\geq 22$ benefit points are obtained on the EC, RV, or BN subscale (Cox, 1997).

**Examples of the Outcome Measures Battery (OMB) Approach**

The OMB approach specifies pre- and post-measures across multiple auditory processing systems to identify and assess impairment, disability, and handicap. Only with combined identification and assessment measures can benefit be calculated, which is an important evaluation of outcome. OMB approaches have been described in several proposals for standardized protocols (Valente et al, 1997; Walden, 1997; Arlinger, 1998; Humes, 1999), all of which measure across processing systems, as well as before and after treatment.

Valente et al (1997) describe a clinical OMB with the objective of improving patient satisfaction. The protocol includes evaluation of the impairment and disability during a prefitting session (using pure-tone and speech audiometry, immittance audiometry, as well as real-ear measures, and the unaided APHAB), followed by coupler measures of devices and real-ear comparison to fitting targets during the fitting. The second half of the APHAB is administered during a follow-up visit. This protocol depends more heavily on the benefit shown in the psychological system than evaluation of benefit in the communication system.

Walden (1997) recommends a research OMB with evaluation of the communication system in multiple environments (speech in quiet, speech in reduced cues, and speech in background noise) using the CST materials, followed by subjective measures of benefit using the PHAB. In this protocol, the subscales of the PHAB have been grouped ac-
cording to their correspondence to four prototype listening situations (the three listed above as well as listening to environmental sounds) and can be used to determine the relationship between self-perceived benefit and the laboratory measures.

Arlinger (1998) describes a minimum OMB for clinical assessment of modern hearing aids, and states, “Assessment should contain at least the three dimensions: perceived hearing aid benefit (preferably including perceived sound quality and preference between test and reference aids), speech recognition in noise, and electroacoustic verification by means of real-ear measurements” (p. 50). Evaluation of the physiologic system is performed using real-ear measures, evaluation of the communication system is performed with speech in noise (with no specific speech test recommended), and evaluation of the psychological system is performed again with the APHAB.

Another example of a proposal for an OMB comes from Humes (1999) who states, “The most complete description of hearing aid outcome will be obtained when including at least one measure of aided speech recognition performance, one or more measures of objective benefit in speech recognition, one or two subjective measures of sound quality or listening effort, and one measure of either subjective benefit, satisfaction, or use” (p. 26). Identification and assessment of the communication and psychological systems are suggested, with emphasis on benefit and satisfaction measures, and no stated evaluation of the physiologic system. This OMB is not trying to focus on where the problem exists (as is done with a physical/diagnostic test battery), but is quantifying if treatment has been effective across multiple levels/systems.

**Conclusion**

As part of his ongoing MarkeTrak analysis of consumer satisfaction with hearing aids, Kochkin (2000c) intensively investigated the in-the-drawer (ITD) phenomenon exhibited by the 16.2% of hearing aid patients in the United States who no longer use their hearing aids. The top two reasons reported for not wearing hearing aids was “poor benefit” from the hearing aids (29.6% of respondents) and “background noise” (25.3% of respondents).

The biggest area of dissatisfaction that hearing aid consumers identified to Kochkin was poor benefit. Benefit, from the patient’s perspective, can be easily measured with a standardized questionnaire such as the 24-item APHAB or an individualized form such as the 5-item COSI. When using an OMB approach, if the objective measures verify that the prescriptive target is appropriate and speech recognition in noise is improved, but the patient does not report satisfactory benefit, further investigation is indicated. Guidance as to where to look for the lack of perceived benefit can come from evaluation of the subscales in a questionnaire (such as EC, BN, RV, and AV of the APHAB) or in more global measures such as expectations and satisfaction from amplification.

The second largest dissatisfaction area reported is performance in noisy situations. This encompasses multiple aspects of aided performance, including poor speech understanding in noise and uncomfortably loud amplification of sounds. Both of these situations should be evaluated as part of the OMB. Acceptable tolerance to amplified sounds is the RESR (REAR-90) portion of the probe-microphone battery or the aided tolerance measurement in the sound-field evaluation of the physiologic system. Improved, and certainly nondegraded, speech recognition in background noise is the key performance measure in assessment of the communication system.

Audiologists who follow a three-step OMB, as recommended in this chapter, will not wind up with patients who have ITD hearing aids. The rationale for this argument is that satisfactory performance on outcome measures assures the audiologist that these two causes creating >50% of patient dissatisfaction, and other “top-ten” reported problems such as “fit and comfort,” “negative side effects,” and “sound quality” have been overcome. It is hard to imagine that a patient
cannot successfully use hearing aids that (1) have gain, output, and frequency response appropriately set to improve audibility without increasing discomfort; (2) improve speech understanding in both quiet and in noise; and (3) produce significant benefit on a self-assessment scale comparing unaided to aided performance.

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