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A Structured Approach to Hearing Aid Selection

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ABSTRACT

Many different procedures have been suggested for use in hearing aid selection: the practicing audiologist must choose among them. A structured approach to the hearing aid selection process is most likely to result in an optimal choice for each patient. This paper describes one such approach to the process of hearing aid selection which attempts to customize the selection procedure to make maximum use of each individual patient's response capabilities. The approach is presented in generic form and one implementation is described in detail.

There are two predominant approaches to the selection of hearing aids. The "comparative" approach[9] uses comparisons of hearing aids with each other as the basis for selection. Many procedures using this basic approach have been described.[24, 29, 32, 41, 42] The other approach focuses on the determination of appropriate electroacoustic characteristics for the hearing aid, particularly frequency/gain function and SSPL90, and does not use interaid comparisons. As a result, it has become known as the "prescriptive" approach. Many different prescriptive selection procedures have been described over the years.[2, 8, 12, 17, 35, 37, 40]

The practicing audiologist must make a decision about which approach to use in the selection of hearing aids and which procedure to use in the implementation of a particular approach. Should the approach incorporate comparisons between hearing aids or should it be strictly prescriptive (i.e., assume that any instrument satisfying the prescription will be equally beneficial)? Once an approach has been chosen, should the same procedure be used for everyone or should the procedure be varied to suit the patient? If the procedure is varied for different patients, how should the optimal procedure be chosen for a particular patient? The available options are numerous enough to be somewhat bewildering. The purpose of this article is to describe one means of coping with this quandary which attempts to customize the hearing aid selection process according to the capabilities of each individual patient.

The approach is based on the principle that hearing aid selection should utilize all of the data that can reasonably be obtained for a given patient. This means that the same procedure is not applied to every individual since some are capable of more complex responses than others. When patients are capable of making relatively high-level judgments about test signals—such as loudness, speech intelligibility, or quality judgments—these data should be utilized in the selection process. The assumption is that the more that is known about the patient's auditory capabilities and preferences, the more precisely the hearing aid can be tailored to suit his/her needs. On the other hand, if the only data a patient can provide are threshold data, the first estimate of what is needed must be derived from this information alone.

OVERVIEW

Figure 1 shows, in general outline, one algorithm that can be applied to the hearing aid selection problem. The flowchart symbols have the usual meanings: a parallelogram depicts an input operation (data are collected from the patient); a rectangle signifies a processing operation (typically, the interpretation of data); a diamond indicates that a decision is called for; entry and exit points are shown in oval symbols. To facilitate discussion, each symbol has been given a number. In the discussion below, any symbol is referred to as a "block." It should be emphasized that Figure 1 depicts a generic procedure; this procedure can be implemented in many different ways.

The hearing aid selection process shown in Figure 1 consists of two stages. In the first stage, (blocks 2 to 5) the prescription for frequency/gain and frequency/SSPL is derived (expressed in HA-1 or HA-2 coupler sound pressure levels) and the aided gain or aided thresholds which should be obtained with a fitting that satisfies the prescription are noted.

A review of the literature reveals that there are two basic types of hearing aid prescriptions. One type derives the prescription for gain and SSPL on the basis of threshold measurements. The other type derives the prescription on the basis of measurements of the patient's loudness perceptions. The threshold-based procedures have the advan-

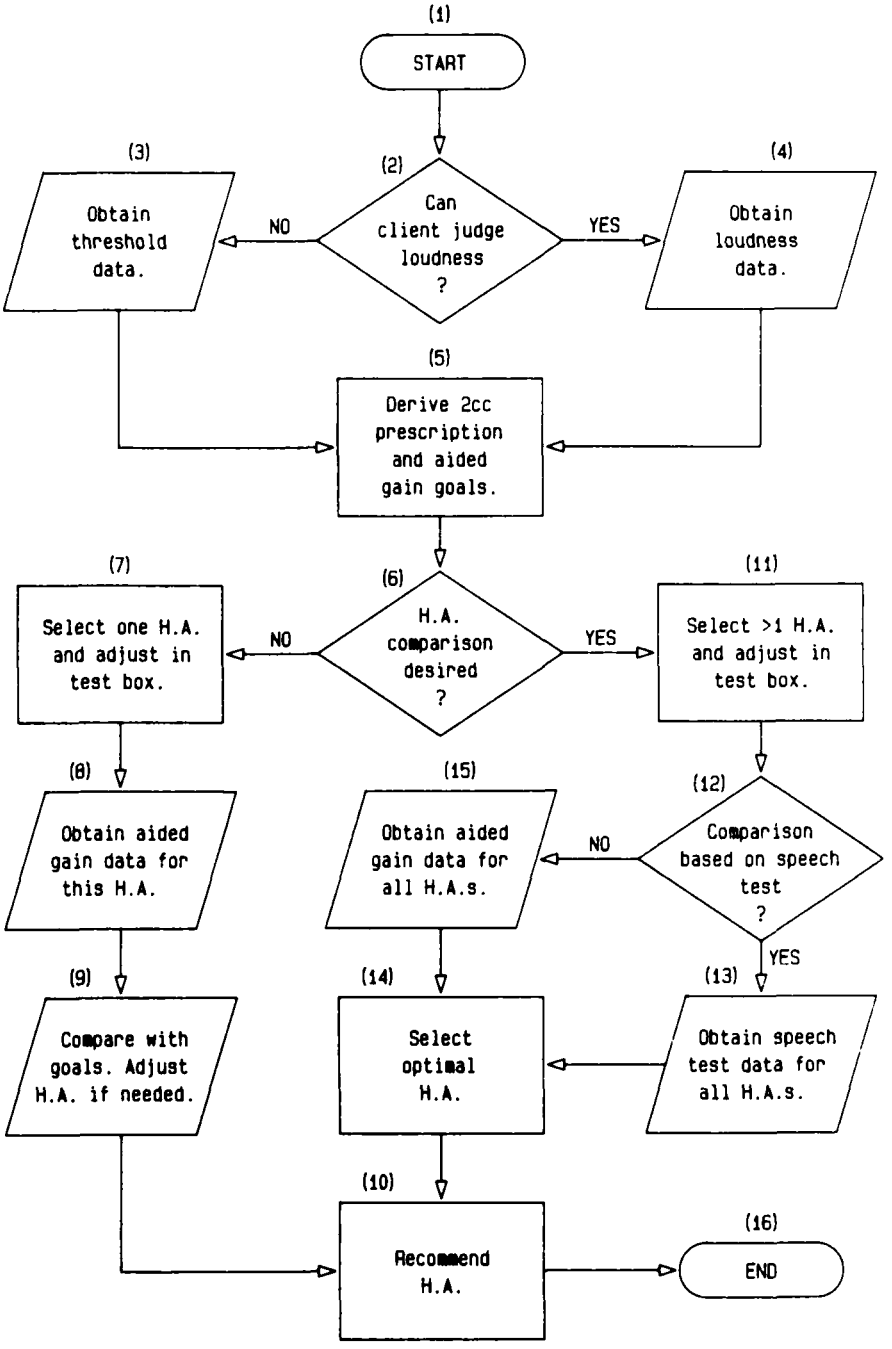

Figure 1. Flowchart showing a generic approach to hearing aid selection. This approach may be implemented using a variety of specific procedures. H.A., hearing aid.

tage that they are applicable to almost all patients since they require only the ability to register a response to the presence of sound. However, since hearing-impaired persons listen to amplified sound at suprathreshold levels, and since the loudness growth function varies considerably across hearing-impaired individuals,[27] the potential for an inaccurate prescription seems relatively large with the threshold-based procedures. The loudness-based procedures have the apparent advantage of providing more germane information about a patient's auditory functioning and evidence is accumulating that loudness-based frequency/gain prescriptions give more satisfactory results than threshold-based frequency/gain prescriptions.[6, 28, 30] However, not all patients are capable of making loudness judgments. In the approach depicted in Figure 1, if the patient is capable of making loudness judgments, the prescription is derived on the basis of his/her responses to tests of loudness perception. Otherwise, the prescription is based on threshold data.

The second stage of the selection process is encompassed in blocks 6 through 15. In blocks 11 to 15, several hearing aids which all satisfy the prescription are compared on some basis: speech test results (intelligibility and/or pleasantness), or aided gain/threshold results (behavioral or real ear probe microphone measurement). The hearing aid that comes closest to meeting the goals of the procedure

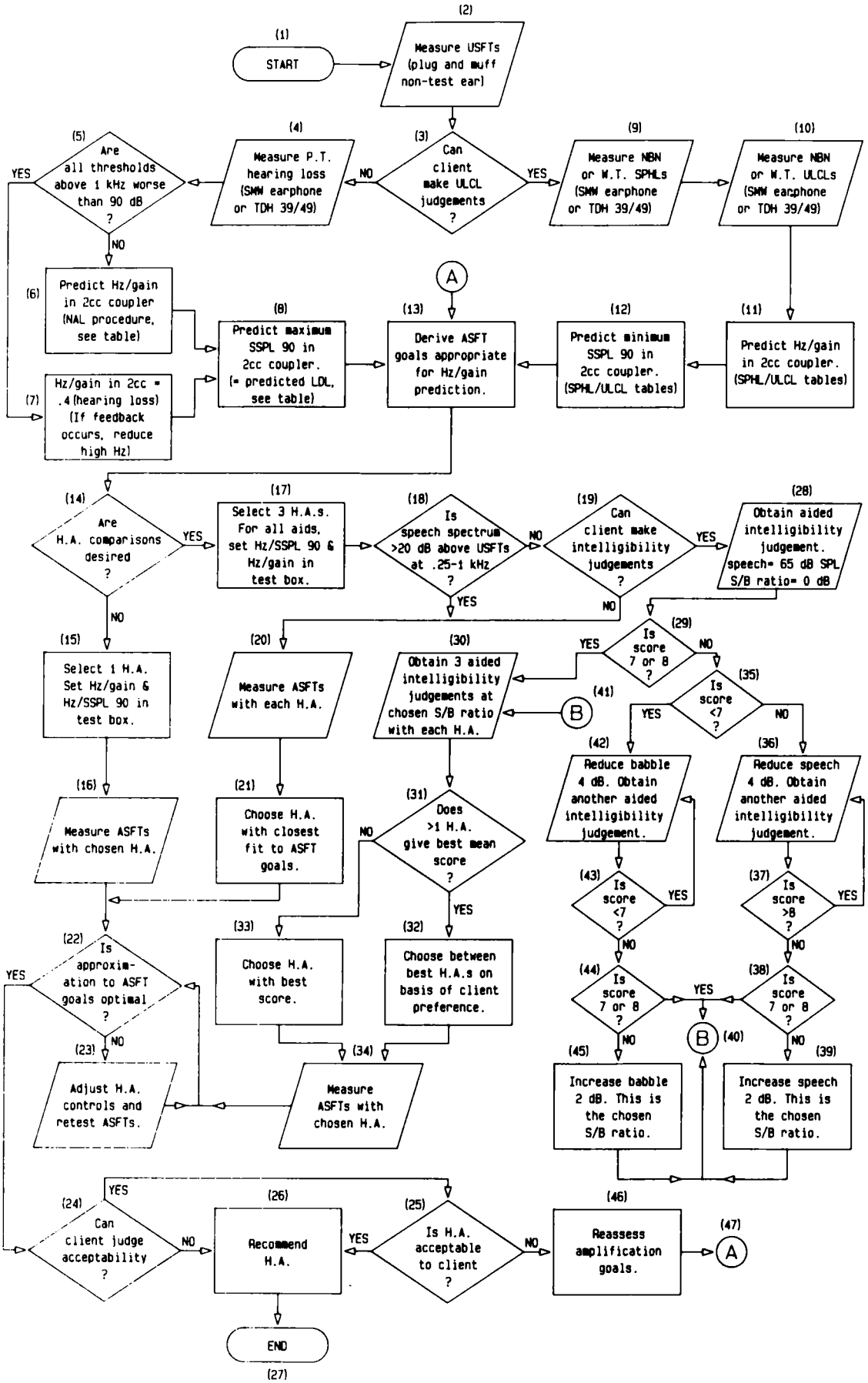

Figure 2. Flowchart showing one implementation of the generic approach depicted in Figure 1. H.A., hearing aid; USFT, unaided sound field threshold; ASFT, aided sound field threshold; SPHL, sound pressure hearing level; ULCL, upper limit comfortable loudness; W.T., warbled tone; P.T., pure tone; NBN, narrow band noise.

is then chosen for recommendation. Alternatively, the second (comparative) stage may be bypassed if it is not relevant or possible to compare several instruments. In this event, only one hearing aid is tried and its controls are adjusted to produce the closest possible coincidence between the aided results and the aided gain/threshold goals. This is shown in blocks 7 to 9.

IMPLEMENTING THE APPROACH

The generic approach depicted in Figure 1 can be implemented with any of several different combinations of procedures for deriving threshold-based prescriptions,[2] loudness-based prescriptions,[21] comparative speech tests,[3,33] and comparisons of aided behavioral thresholds[34] or insertion gain.[22] Figure 2 shows the specific details of one implementation which has been used by the author. This implementation is suitable for both over-the-ear (OTE) and in-the-ear (ITE) monaural hearing aid fittings for individuals with sensorineural hearing impairment. There are many different routes through this procedure. The route taken with any particular patient will depend upon that patient's abilities and amplification needs. The minimum requirement for hearing aid selection is an ability to measure auditory thresholds on the patient. At the opposite extreme, hearing aid selection for a capable patient may be based on a consideration of that individual's loudness perceptions, aided speech intelligibility and/or quality scores, and aided and unaided sound field thresholds.

The Figure 2 flowchart uses all of the symbols seen in Figure 1. In addition, a connector (exit to, or entry from, another part of the procedure) is indicated by a small circle containing a letter.

PRESCRIPTIVE STAGE

As Figure 2 shows (block 2), the first step in this hearing aid selection procedure is the measurement of unaided sound field thresholds (USFTs) for the ear to be amplified. The USFTs are used in the evaluation in block 18. In addition, these data when plotted on an SPL audiogram, such as the one used in Figure 3, provide a graphic illustration of the extent of the patient's sensitivity loss and the audibility of the unaided speech signal.

Preselection Test Configurations Following the USFT measurements, the prescription is derived and expressed in HA-1 or HA-2 coupler levels. One of several different signal delivery systems is used for the "preselection" tests. These tests yield the data which are used to derive the prescription.

ITE Hearing Aid If the fitting is to be an ITE hearing aid, the preselection tests are performed using TDH39 or TDH49 supra-aural earphones to deliver the test stimuli. The prescription is expressed in HA-1 coupler levels (the 6 cm^3 coupler to HA-1 coupler transformation is discussed in Cox[14]). Later, the ITE aid is attached to an HA-1 coupler and adjusted to match the prescription.

OTE Hearing Aid If the fitting is to be an OTE hearing aid, one of two signal delivery systems is chosen for the preselection tests:

1. The preselection tests are performed using TDH49 or TDH39 supra-aural earphones to deliver the test stimuli (for details, see Cox[14]). The prescription is expressed in HA-1 coupler levels. Later, the OTE aid is attached to the HA-1 coupler using the patient's custom earmold and adjusted to match the prescription.
2. The preselection tests are performed using a button-type hearing aid receiver to deliver the test stimuli (Danavox SMW 100-ohm) attached to the patient's custom earmold (for details, see Cox[12]). The prescription is expressed in HA-2 coupler levels. Later, the OTE aid is attached to an HA-2 coupler in the standard manner (i.e., with entrance through 25 mm of 2 mm i.d. tubing) and adjusted to match the prescription.

With either of the above OTE preselection test configurations, it is necessary to obtain an appropriate earmold prior to the hearing aid selection procedure.

There are several advantages associated with the use of insert receivers in OTE hearing aid selection: the effects of individual differences in real ear acoustic impedance are accounted for in a simple, transparent manner; results are easily expressed in equivalent HA-2 coupler levels which facilitates adjustment of hearing aids to match a prescription; finally, the effects of earmold vents and unintentional leaks are accounted for in the generation of the prescription rather than requiring post hoc adjustments.[11,19,23,36] Calibration of the SMW-100 ohm receiver is achieved in an HA-2 coupler with entrance through 25 mm of tubing (i.d., 2 mm). Levels may be calibrated directly in SPL, or HTL corrections may be obtained using the following reference equivalent sound pressure levels: 250 Hz, 22 dB; 500 Hz, 14.5 dB; 750 Hz, 9 dB; 1.0 kHz, 8.5 dB; 1.5 kHz, 4 dB; 2.0 kHz, 12 dB; 2.5 kHz, 7.5 dB; 4.0 kHz, 2 dB. For calibration and testing, a plastic adaptor (Hal Hen cat. No. 309L) is attached to the nubbin of the SMW receiver to facilitate easy coupling to earmold tubing.

Loudness-based Prescription Initially (block 3), the audiologist must decide whether the patient can make loudness judgments. This decision is made on the basis of the patient's functioning as demonstrated in the intake interview. Most adults can make loudness judgments at some level. However, some loudness tests are more easily comprehended than others. The loudness measure used in this procedure is a test of the upper limit of the comfortable loudness range (ULCL). It is described in Appendix A. The instructions are relatively uncomplicated. As a result, the loudness-based prescriptive procedure can be entered (block 9) with many adult patients.

In the ULCL-based prescriptive procedure, measurements are made of the patient's thresholds [sound pressure hearing levels (SPHLs), block 9] and ULCLs (block 10) in seven frequency regions. The stimuli for these tests are calibrated in SPL. Warble tones are typically used; however, one-third octave noise bands may also be satisfactory for flat or gently sloping loss configurations. These data are utilized (block 11) to derive a frequency/gain function which amplifies speech at 70 dB SPL to a point in the middle of the range between the SPHL and ULCL con-

tours. Also, minimum SSPL90 levels are specified at a constant 12 dB above the ULCL in each frequency region (block 12). The rationale and empirical bases for this prescriptive procedure are presented in detail in Cox.[12-14]

If preselection tests have used a TDH39 or TDH49 earphone for signal delivery, the prescription values are obtained by consulting Tables B-1 through B-7 (Appendix B). A separate table is consulted for each test frequency. For any SPHL/ULCL combination, the table for that frequency shows the needed gain in the HA-1 coupler, the minimum SSPL90, and the aided threshold goal (discussed below). If the preselection tests used the insert receiver for signal delivery, the gain, SSPL90, and aided threshold goal values obtained from the tables in Appendix B must be corrected using the values in Table C-1 (Appendix C) to derive the final prescription values (prescription tables specifically for use with insert receiver preselection data are also available in Cox[12]).

Threshold-based Prescription If the patient is unable to make the necessary loudness judgments, the threshold-based prescriptive procedure is entered. In block 4, hearing loss for pure tones is measured. Block 5 requires an evaluation of these threshold data. If the thresholds at frequencies above 1000 Hz are all poorer than 90 dB HTL, it is assumed that this patient probably will not benefit greatly from speech cues available in this high-frequency region.[4, 18] Consequently, the frequency/gain prescription puts more weight on maximizing audibility of sounds in the 250 to 1000 Hz region than on shaping the frequency response to maximize audibility of the entire speech spectrum. This results in the frequency/gain prescription rule given in block 7—a simple "four-tenths" rule which specifies that the gain desired at any frequency is equal to 0.4 times the hearing loss at that frequency. Several investigators have reported the relationship between hearing loss and used gain in hearing aids[5, 7, 20, 31] and between hearing loss and preferred listening level.[15] These data indicate that preferred listening level typically increases at the rate of 3 to 5 dB for each 10 dB of hearing loss. The rule given in block 7 was selected on the basis of the data reported in these studies. Since earmold effects are accounted for, the differences between 2 cm^3 coupler gain and functional gain (FG) for a 0° azimuth signal should be minor at frequencies = <1000 Hz.[26] For this reason, no distinction is made between 2 cm^3 coupler gain and FG for the low-frequency gain prescription called for in block 7.

On the other hand, if the patient has high-frequency thresholds of 90 dB HTL or better, it is assumed that optimal amplification will be achieved if the entire speech spectrum can be amplified to the patient's preferred listening level.[30, 39] Consequently, a modification of the National Acoustic Laboratories (NAL) procedure[8] is used to derive the frequency/gain prescription (block 6). Table D-1 (Appendix D) is consulted for these values. This table differs from the one originally published by Byrne and Tonisson[8] in the following details: the average earmold correction has been removed because earmold effects are accounted for on an individual basis; ANSI standard frequencies have been used;[1] speech levels used in the derivation of the table were expressed in one-third octave bands at the hearing aid's microphone input; no reserve gain has been added (i.e., this table shows needed gain, not full-on gain). In addition, the gain values for 250 and 500 Hz have been increased by 10 and 5 dB, respectively, as a result of the report by Byrne[6] that the original NAL procedure provided for insufficient gain at these frequencies. It should be noted that the same report indicated that the original NAL procedure prescribes excessive high-frequency gain for sharply sloping audiogram configurations. This problem has not been addressed in Table D-1 but should be kept in mind when selecting hearing aid gain according to an NAL prescription. Table D-1 is entered with the measured threshold at a particular frequency [HTL = threshold measured using TDH39 or TDH49 earphones; eaHL (earmold-hearing loss) = threshold measured using insert earphone coupled to patient's earmold]. To determine the needed gain, the row representing that threshold level is followed to its intersection with the column representing the test frequency.

Block 8 outlines the method for choosing the SSPL90 function when only threshold data are available. The prescription is based on an assumption that the SSPL90 at a given frequency should be equal to the individual's loudness discomfort level (LDL) at that frequency. It is important to note that although it seems reasonable to postulate a monotonic relationship between LDL and appropriate SSPL90, such a relationship has not as yet been empirically demonstrated. In addition, since LDL cannot be directly measured on the patients for whom the threshold-based prescriptive procedure is used, the method relies on a prediction of the individual's LDL at each frequency: the SSPL90 is then set equal to the predicted LDL. Since it has been shown that an individual's LDLs cannot very accurately be predicted from his/her thresholds,[10, 25, 38] it is clear that an SSPL90 prescription based on predicted LDLs can serve only as a first estimate of the necessary values of maximum output. A discussion of the rationale for prediction of LDLs from thresholds is given in Appendix E.

Prescribed SSPL90 values are obtained from Table D-2. This table is entered with the measured threshold at a particular frequency (HTL or eaHL) and the maximum SSPL90 is found at the intersection of the row representing this threshold with the column representing the test frequency. Each column contains two values, identified as "HA1" and "HA2." If the preselection tests utilized a TDH39 or TDH49 earphone for signal delivery, the HA1 value is selected. If the preselection tests utilized the SMW earphone and the patient's earmold for signal delivery, the HA2 value is selected.

It should be noted that these two different prescriptive procedures (loudness-based and threshold-based) adopt fundamentally different approaches to the prescription of SSPL90. In the threshold-based procedure, the guiding principle in the SSPL90 prescription is to protect the hearing aid wearer from potentially intolerable output levels from the hearing aid. Consequently, the SSPL90 is chosen so that it does not exceed the predicted loudness discomfort level. This seems important because the recipients of this prescriptive procedure (usually children) are

often unable to report excessive loudness from the hearing aid. In the loudness-based procedure, the guiding principle in the SSPL90 prescription is to ensure that the maximum output level is high enough to avoid limiting the speech signal when the user is listening at his/her preferred listening level. This approach is primarily concerned with the minimum allowable SSPL90 levels. It is assumed that if the chosen levels are excessive (which happens rarely in practice) this can be detected and corrected in follow-up counseling with the patient.

Aided Threshold Goals Returning to Figure 2, the two prescriptive procedures converge in block 13 in which aided sound field threshold (ASFT) goals are derived in each of the seven tested frequency regions. The specific goals will depend on the prescriptive procedure used to derive the frequency/gain function.

For the loudness-based prescription the goal of the procedure is to amplify speech at 70 dB SPL to a point in the middle of the patient's long-term listening area across the frequency range (for details, see Cox[12]). The ASFT goals for each SPHL/ULCL combination are given in Tables B-1 through B-7.

The threshold-based prescription derived using the NAL procedure attempts to achieve specific amounts of functional gain (FG) at each frequency, assuming that this amount of gain will amplify conversational speech to the patient's most comfortable equal-loudness contour. The ASFT goals are given in Table D-3. This table differs from the one originally published by Byrne and Tonisson[8] in the following respects: ANSI standard frequencies are used, USFTs are expressed in SPL instead of HTL, and speech levels used in the derivation of the table were expressed in one-third octave bands in the free field. In addition, because prescribed gain values were increased at 250 and 500 Hz (see above), the ASFTs at these frequencies have been decreased (i.e., better ASFTs) by 10 dB at 250 Hz and 5 dB at 500 Hz.

The four-tenths prescription rule in block 7 is used in cases where low frequency gain is of paramount importance: in this instance the goal is to reduce the sensitivity loss by four-tenths at these frequencies. Therefore, the ASFT goal at each frequency is six-tenths of the hearing loss above the normal threshold level. For example, if the hearing loss at 500 Hz is 80 dB, the ASFT goal is 48 dB (six-tenths of 80) plus 9 dB (normal sound field threshold), which gives 57 dB SPL.

A comparison of measured aided thresholds with ASFT goals serves as a short-term validation which determines whether the goals of the prescription have been accomplished (this is a separate issue from that of assessing ultimate benefit from amplification which might be conceptualized as long-term validation). This comparison is performed later in the hearing aid fitting process.

COMPARATIVE STAGE

Once the prescriptive stage is completed, the audiologist must decide whether it is appropriate to compare several different hearing aids, all of which satisfy the prescription. This decision is called for in block 14. In some types of evaluations (for example, in fitting an ITE hearing aid or some other previously purchased instrument), comparison of hearing aids is not an appropriate choice. In other instances, however, comparison of similar instruments might be indicated for any of several reasons. First, it is almost never possible to match a frequency/gain prescription exactly. Typically, an excellent match can be achieved between prescription and hearing aid performance at two frequencies (500 and 2500 Hz, for example). If the other tested frequencies differ from the prescribed values, there is usually very little that can be done to remedy this except to eliminate the hearing aid from further consideration. As a result, several hearing aids which all nominally fulfill a prescription can still have different frequency/gain functions. Second, hearing aids which nominally have the same frequency/gain function may differ in other important features: for example, one may be a whole range (syllabic) compressor while another is a linear amplifier. Finally, similar hearing aids from different manufacturers incorporate different circuit designs and patients frequently detect subjectively significant differences among them.

Interaid Comparisons Rejected If it is decided that hearing aid comparisons are not appropriate for this evaluation, the procedure moves on to block 15 which directs the audiologist to select a hearing aid and to configure its gain and SSPL90 performance to match the derived prescription. A procedure for achieving this is given in Appendix F.

The configured hearing aid is then placed on the patient and ASFTs are measured (block 16). The audiologist must then decide (block 22) whether the obtained ASFTs are an adequate approximation of the ASFT goals derived in block 13. Usually the match between ASFTs and ASFT goals is optimal with the hearing aid set according to the derived prescription. However, occasionally the match can be improved by adjusting the hearing aid's tone or volume control (block 23). ASFTs which are within ±5 dB of the goals are considered satisfactory. Sometimes, this condition cannot be met at all seven tested frequencies and a compromise must be reached.

The final step in a strictly prescriptive fitting process (i.e., one which does not incorporate any interaid comparisons) is to ascertain, if possible, whether the patient finds the hearing aid unacceptable in any way (blocks 24 and 25). Certain patients—primarily young children—cannot make this determination. Other patients are able to judge the acceptability of the hearing aid on whatever dimensions are important to them. Typically, if the patient has been properly prepared for the experience of amplification, no problems are encountered at this stage and the hearing aid can be recommended (block 26). Occasionally, it will be discovered at block 25 that the patient has a previously unexpressed objection to the hearing aid, or perhaps to any hearing aid. This situation can usually be avoided by counseling prior to the hearing aid selection procedure.

Interaid Comparisons Elected Returning to block 14, it may be decided that interaid comparisons are desirable in this evaluation. In this event, the flow of the fitting procedure leads to block 17 which directs the audiologist to

choose three hearing aids and to configure all of them to match the derived prescription. These instruments are then compared with each other in terms of some aspect of their performance on the patient (fewer or more instruments could be compared if desired).

ASFT Comparisons Block 18 requires an inspection of the relationship of the USFTs (obtained at block 2) and the long term RMS spectrum for speech at 70 dB SPL. Specifically, it asks whether the patient's unaided sound field thresholds are 20 dB or more below the speech spectrum (shown on the audiogram) through the frequencies 250 to 1000 Hz. If the answer to this question is affirmative then the patient's unaided hearing permits excellent audibility for the low and midfrequency components of speech in a quiet setting. In this event, interaid comparisons are made on the basis of ASFTs rather than speech intelligibility. The rationale for this decision is as follows: this type of individual typically requires amplification only for high-frequency sounds; "similar" hearing aids often differ in the gain they provide above 2500 Hz; these differences are critical to the success or failure of amplification for this type of hearing loss; since the speech intelligibility test used in this procedure (described below) has not been shown to be sensitive to small differences in high-frequency amplification, it seems preferable to expend clinical time in the measurement and optimization of aided threshold performance in the targeted (high) frequencies. As a result of these considerations, the selection process for a patient requiring only high-frequency amplification will proceed from block 18 to block 20. Each hearing aid in turn is placed on the patient and aided thresholds are measured in the sound field. Typically, the hearing aid which can be adjusted to approximate the ASFT goals most closely is the recommended instrument (blocks 21 through 26).

Figure 3 shows two examples of USFT audiograms. The *dashed line* depicts a patient who would be determined to require interaid comparisons based on ASFT measurement. In other words, this patient's USFTs are at least 20 dB lower than the speech spectrum through the low and midfrequencies. The *dash-dot line* depicts a patient with poorer low and midfrequency sensitivity who would be determined, therefore, to be a candidate for speech test comparisons.

Speech Intelligibility Comparisons If the answer to the question posed in block 18 is negative, the selection process proceeds to block 19 which requires another decision. In this block the audiologist must decide whether the patient can perform the task(s) necessary for the interaid comparison based on speech test results. The speech test depicted in Figure 2 is a test requiring ratings of speech intelligibility on a scale from 0 to 10. Most adult patients with average language skills can do this task. If the patient is unable to judge intelligibility, the procedure again goes to block 20 and interaid comparisons are based on ASFTs.

The speech intelligibility rating test has been described elsewhere.[16] Briefly, the stimuli are equalized 35-sec passages of continuous discourse presented in a speech babble background. If the patient can judge intelligibility, the procedure goes to block 28. Blocks 28, 29, and 35 through 45 depict a routine for determining the signal-to-babble (S/B) ratio at which the test is to be given: the test is most likely to discriminate between instruments when the S/B ratio produces scores in the upper half of the scale.[16] The routine encompassed in blocks 35 through 45 results in selection of an S/B ratio to achieve this condition: the required value differs across patients. Once the appropriate S/B ratio has been determined, the patient rates three continuous discourse passages for each hearing aid (block 30). Ratings for three hearing aids can be obtained in 10 min.

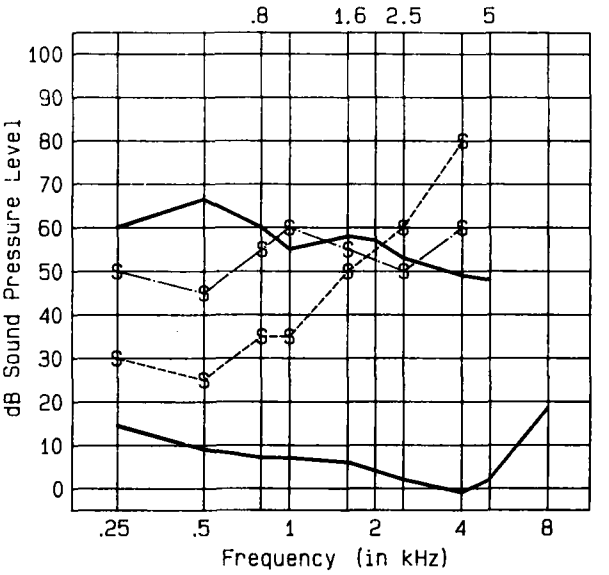

Figure 3. Two unaided sound field threshold (USFT) audiograms. The *dashed line* depicts a configuration for which interaid comparisons would be made on the basis of aided sound field thresholds (ASFTs). The *dash-dot line* depicts a configuration for which interaid comparisons would be made using speech intelligibility ratings. The *upper solid line* shows the long-term one-third octave band RMS level for speech at 70 dB SPL. The *lower solid line* shows the normal, monaural sound field threshold, zero degree azimuth.

The three ratings for each instrument are averaged to produce its final score. When the speech intelligibility ratings indicate a clearly superior hearing aid, this instrument is chosen for further evaluation (blocks 31 and 33). Sometimes the speech intelligibility rating task indicates a clearly inferior hearing aid but produces a tied score between the two better hearing aids. In this case, the patient will usually be able to express a preference for one of these two instruments, based on speech reproduction quality (blocks 31 and 32). In either event, the speech intelligibility ratings serve as the primary basis for the selection of one of the compared hearing aids. Next, the ASFTs are measured for the chosen hearing aid (block 34) and compared to the ASFT goals (block 22). If necessary, minor adjustments may be made to optimize the match between ASFTs and ASFT goals (block 23). Finally, the patient is asked whether the hearing aid is unacceptable in any way (block 25) before the aid is recommended (block 26).

CONCLUSIONS

Hearing aid selection should be a systematic process which applies available knowledge about amplification to the greatest extent possible with each individual patient. Since there are wide variations in patient abilities and needs, a system is required which can encompass selection procedures based on minimal psychoacoustic information as well as those based on a complex of psychoacoustic responses. It is also important that the approach be flexible enough to be readily modified to incorporate new information about desirable amplification properties and more satisfactory procedures when these become available as a result of basic research. This article has described a generic approach which attempts to achieve these goals and has presented one implementation of this approach. Many other implementations are possible.

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APPENDIX A Procedure for ULCL measurement

The upper limit of comfortable loudness (ULCL) is conceptualized as the highest sound pressure level that would be comfortable to listen to for a long period of time. The stimulus is calibrated in SPL and may be frequency-modulated tones (3 to 4 sec long) or pulsed narrow bands of noise with adequately steep filter skirts (5 to 6 pulses per level).

The following instructions may be read by, or spoken to, the patient:

> The purpose of this test is to find the volume of sounds that would be comfortable for you to listen to while you are watching television or listening to the radio. You will hear several sounds which will differ in loudness. Every time you hear a sound that is comfortably loud, please signal immediately by raising your hand.

However, as with most clinical tests, the use of written instructions for ULCL testing does not meet the needs of all patients. The clinician should ascertain that the patient realizes that sounds of several different loudnesses may all be comfortable and that this test is not seeking the "perfect" loudness level: the patient is expected to respond to every level that would be acceptable for long-term listening.

The psychophysical procedure used to measure the ULCL is comprised of two phases for each new test stimulus: there is a "search" phase (during which the approximate location of the ULCL is determined), followed by a "test" phase (during which the level finally recorded as the ULCL is measured).

In the search phase, the stimulus is introduced at a level 20 to 40 dB above threshold. This beginning level should elicit a "comfortable" response. The stimulus is then increased in 10 to 15 dB steps until the subject stops responding (indicating that the stimulus is no longer comfortable). It is assumed that the last stimulus increment has exceeded the ULCL. This concludes the search phase.

In the test phase, the stimulus is introduced at or near the level that concluded the search phase (the level must be higher, i.e., louder, than the ULCL). The stimulus is decreased in 5 dB steps until the subject responds, indicating that the stimulus has entered the comfort zone. Immediately, the level is increased again by 5, 10, or 15 dB and another descending run is begun. The starting point for each descending run should be varied but should not exceed the patient's tolerance for loud sound. A run is terminated when the patient responds. Descending runs are repeated until a decision can be made about the level of the ULCL. The ULCL is defined as the highest level to which the patient responds on two out of three runs during the test phase.

Because the test runs are all descending in level, responses at the upper limit of the comfort range are elicited by this procedure.

APPENDIX B ULCL-Based prescriptions for ITE and OTE hearing aids when preselection tests use a supra-aural earphone

Tables B-1 through B-7 are used to derive loudness-based prescription values for ITE hearing aids.* There is a separate table for each of the seven test frequencies. Within a table, each SPHL/ULCL combination is represented by the square at the intersection of the ULCL-row and the SPHL-column. The square contains two numbers: the *upper, boldfaced, number* is the HA-1 coupler required gain; the *bottom number* is the aided sound field threshold goal (dB SPL). The *column on the extreme right* gives the HA-1 coupler minimum SSPL90 level associated with the ULCL value represented by that row.

For ITE hearing aid prescription (preselection tests use TDH39 or TDH49 earphones for signal delivery): gain, minimum SSPL90, and aided sound field threshold goals may be read directly from the Table for the appropriate frequency.

For OTE hearing aid prescription when the preselection tests have used TDH39 or TDH49 earphones for signal delivery: (1) to find the gain value, add the correction given at the bottom of the table to the ITE gain value obtained from the table; (2) SSPL90 levels and ASFT goals are the same as for ITE prescription; (3) use the patient's custom earmold (with vent plugged) attached to the HA-1 coupler when configuring a hearing aid to match the prescription.

* Tables B-1 through B-7 reprinted from Cox,[14] with permisson.

APPENDIX C ULCL-Based prescriptions for OTE hearing aids when preselection tests use an insert earphone

When the preselection tests have used the SMW insert earphone to deliver the test signal, the hearing aid prescription is derived using tables similar to those given in Appendix B (see Cox[12]). Although the prescription values based on insert earphone data are derived using somewhat different assumptions from those based on supra-aural earphone data, the appropriate values may be obtained by combining the ITE prescription derived from Tables B-1 through B-7 in Appendix B with the correction values given in Table C-1. The prescription obtained by combining the values from Appendix B with those in Table C-1 is several decibels different at some frequencies from the prescription that would be derived from the same SPHL/ULCL data using the tables given in Cox.[12] This discrepancy occurs because the "receiver correction" incorporated into the earlier tables has been found to be unnecessary and has, therefore, been eliminated.

For OTE hearing aid prescription when the preselection tests have used the SMW insert earphone for signal delivery: (1) to find the gain value, add the correction obtained from Table C-1 for the appropriate frequency to the ITE gain for that same frequency obtained from Appendix B; (2) to find the minimum SSPL90 value, add the correction obtained from Table C-1 for the appropriate frequency to the ITE SSPL90 for that

Table B-1

250 Hz
Sound Pressure Hearing Level (SPHL)

250 Hz Upper Limit of Comfortable Loudness (ULCL)	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	SSPL 90
70	**-25** 38	**-23** 40	**-20** 43	**-18** 45	**-15** 48	**-13** 50	**-10** 53	**-8** 55	**-5** 58							71
75	**-23** 35	**-20** 38	**-18** 40	**-15** 43	**-13** 45	**-10** 48	**-8** 50	**-5** 53	**-3** 55	**0** 58						76
80	**-20** 33	**-18** 35	**-15** 38	**-13** 40	**-10** 43	**-8** 45	**-5** 48	**-3** 50	**0** 53	**3** 55	**5** 58					81
85	**-18** 30	**-15** 33	**-13** 35	**-10** 38	**-8** 40	**-5** 43	**-3** 45	**0** 48	**3** 50	**5** 53	**8** 55	**10** 58				86
90	**-15** 28	**-13** 30	**-10** 33	**-8** 35	**-5** 38	**-3** 40	**0** 43	**3** 45	**5** 48	**8** 50	**10** 53	**13** 55	**15** 58			91
95	**-13** 25	**-10** 28	**-8** 30	**-5** 33	**-3** 35	**0** 38	**3** 40	**5** 43	**8** 45	**10** 48	**13** 50	**15** 53	**18** 55	**20** 58		96
100	**-10** 23	**-8** 25	**-5** 28	**-3** 30	**0** 33	**3** 35	**5** 38	**8** 40	**10** 43	**13** 45	**15** 48	**18** 50	**20** 53	**23** 55	**25** 58	101
105	**-8** 20	**-5** 23	**-3** 25	**0** 28	**3** 30	**5** 33	**8** 35	**10** 38	**13** 40	**15** 43	**18** 45	**20** 48	**23** 50	**25** 53	**28** 55	106
110	**-5** 18	**-3** 20	**0** 23	**3** 25	**5** 28	**8** 30	**10** 33	**13** 35	**15** 38	**18** 40	**20** 43	**23** 45	**25** 48	**28** 50	**30** 53	111
115	**-3** 15	**0** 18	**3** 20	**5** 23	**8** 25	**10** 28	**13** 30	**15** 33	**18** 35	**20** 38	**23** 40	**25** 43	**28** 45	**30** 48	**33** 50	116
120	**0** 13	**3** 15	**5** 18	**8** 20	**10** 23	**13** 25	**15** 28	**18** 30	**20** 33	**23** 35	**25** 38	**28** 40	**30** 43	**33** 45	**35** 48	121

(For OTE aid, add 1 dB to Gain)

Table B-2

500 Hz
Sound Pressure Hearing Level (SPHL)

500 Hz Upper Limit of Comfortable Loudness (ULCL)	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	SSPL 90
70	**-24** 44	**-22** 47	**-19** 49	**-17** 52	**-14** 54	**-12** 57	**-9** 59	**-7** 62	**-4** 64							80
75	**-22** 42	**-19** 44	**-17** 47	**-14** 49	**-12** 52	**-9** 54	**-7** 57	**-4** 59	**-2** 62	**1** 64						85
80	**-19** 39	**-17** 42	**-14** 44	**-12** 47	**-9** 49	**-7** 52	**-4** 54	**-2** 57	**1** 59	**4** 62	**6** 64					90
85	**-17** 37	**-14** 39	**-12** 42	**-9** 44	**-7** 47	**-4** 49	**-2** 52	**1** 54	**4** 57	**6** 59	**9** 62	**11** 64				95
90	**-14** 34	**-12** 37	**-9** 39	**-7** 42	**-4** 44	**-2** 47	**1** 49	**4** 52	**6** 54	**9** 57	**11** 59	**14** 62	**16** 64			100
95	**-12** 32	**-9** 34	**-7** 37	**-4** 39	**-2** 42	**1** 44	**4** 47	**6** 49	**9** 52	**11** 54	**14** 57	**16** 59	**19** 62	**21** 64		105
100	**-9** 29	**-7** 32	**-4** 34	**-2** 37	**1** 39	**4** 42	**6** 44	**9** 47	**11** 49	**14** 52	**16** 54	**19** 57	**21** 59	**24** 62	**26** 64	110
105	**-7** 27	**-4** 29	**-2** 32	**1** 34	**4** 37	**6** 39	**9** 42	**11** 44	**14** 47	**16** 49	**19** 52	**21** 54	**24** 57	**26** 59	**29** 62	115
110	**-4** 24	**-2** 27	**1** 29	**4** 32	**6** 34	**9** 37	**11** 39	**14** 42	**16** 44	**19** 47	**21** 49	**24** 52	**26** 54	**29** 57	**31** 59	120
115	**-2** 22	**1** 24	**4** 27	**6** 29	**9** 32	**11** 34	**14** 37	**16** 39	**19** 42	**21** 44	**24** 47	**26** 49	**29** 52	**31** 54	**34** 57	125
120	**1** 19	**4** 22	**6** 24	**9** 27	**11** 29	**14** 32	**16** 34	**19** 37	**21** 39	**24** 42	**26** 44	**29** 47	**31** 49	**34** 52	**36** 54	130

(For OTE aid, add 1 dB to Gain)

Table B-3

750/800 Hz
Sound Pressure Hearing Level (SPHL)

750/800 Hz Upper Limit of Comfortable Loudness (ULCL)	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	SSPL 90
70	**-16** 38	**-13** 40	**-11** 43	**-8** 45	**-6** 48	**-3** 50	**-1** 53	**2** 55	**5** 58							81
75	**-13** 35	**-11** 38	**-8** 40	**-6** 43	**-3** 45	**-1** 48	**2** 50	**5** 53	**7** 55	**10** 58						86
80	**-11** 33	**-8** 35	**-6** 38	**-3** 40	**-1** 43	**2** 45	**5** 48	**7** 50	**10** 53	**12** 55	**15** 58					91
85	**-8** 30	**-6** 33	**-3** 35	**-1** 38	**2** 40	**5** 43	**7** 45	**10** 48	**12** 50	**15** 53	**17** 55	**20** 58				96
90	**-6** 28	**-3** 30	**-1** 33	**2** 35	**5** 38	**7** 40	**10** 43	**12** 45	**15** 48	**17** 50	**20** 53	**22** 55	**25** 58			101
95	**-3** 25	**-1** 28	**2** 30	**5** 33	**7** 35	**10** 38	**12** 40	**15** 43	**17** 45	**20** 48	**22** 50	**25** 53	**27** 55	**30** 58		106
100	**-1** 23	**2** 25	**5** 28	**7** 30	**10** 33	**12** 35	**15** 38	**17** 40	**20** 43	**22** 45	**25** 48	**27** 50	**30** 53	**32** 55	**35** 58	111
105	**2** 20	**5** 23	**7** 25	**10** 28	**12** 30	**15** 33	**17** 35	**20** 38	**22** 40	**25** 43	**27** 45	**30** 48	**32** 50	**35** 53	**37** 55	116
110	**5** 18	**7** 20	**10** 23	**12** 25	**15** 28	**17** 30	**20** 33	**22** 35	**25** 38	**27** 40	**30** 43	**32** 45	**35** 48	**37** 50	**40** 53	121
115	**7** 15	**10** 18	**12** 20	**15** 23	**17** 25	**20** 28	**22** 30	**25** 33	**27** 35	**30** 38	**32** 40	**35** 43	**37** 45	**40** 48	**42** 50	126
120	**10** 13	**12** 15	**15** 18	**17** 20	**20** 23	**22** 25	**25** 28	**27** 30	**30** 33	**32** 35	**35** 38	**37** 40	**40** 43	**42** 45	**45** 48	131

(For OTE aid, add 2 dB to Gain)

Table B-4

1000 Hz
Sound Pressure Hearing Level (SPHL)

1000 Hz Upper Limit of Comfortable Loudness (ULCL)	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	SSPL 90
70	**-11** 33	**-8** 35	**-6** 38	**-3** 40	**-1** 43	**2** 45	**5** 48	**7** 50	**10** 53							80
75	**-8** 30	**-6** 33	**-3** 35	**-1** 38	**2** 40	**5** 43	**7** 45	**10** 48	**12** 50	**15** 53						85
80	**-6** 28	**-3** 30	**-1** 33	**2** 35	**5** 38	**7** 40	**10** 43	**12** 45	**15** 48	**17** 50	**20** 53					90
85	**-3** 25	**-1** 28	**2** 30	**5** 33	**7** 35	**10** 38	**12** 40	**15** 43	**17** 45	**20** 48	**22** 50	**25** 53				95
90	**-1** 23	**2** 25	**5** 28	**7** 30	**10** 33	**12** 35	**15** 38	**17** 40	**20** 43	**22** 45	**25** 48	**27** 50	**30** 53			100
95	**2** 20	**5** 23	**7** 25	**10** 28	**12** 30	**15** 33	**17** 35	**20** 38	**22** 40	**25** 43	**27** 45	**30** 48	**32** 50	**35** 53		105
100	**5** 18	**7** 20	**10** 23	**12** 25	**15** 28	**17** 30	**20** 33	**22** 35	**25** 38	**27** 40	**30** 43	**32** 45	**35** 48	**37** 50	**40** 53	110
105	**7** 15	**10** 18	**12** 20	**15** 23	**17** 25	**20** 28	**22** 30	**25** 33	**27** 35	**30** 38	**32** 40	**35** 43	**37** 45	**40** 48	**42** 50	115
110	**10** 13	**12** 15	**15** 18	**17** 20	**20** 23	**22** 25	**25** 28	**27** 30	**30** 33	**32** 35	**35** 38	**37** 40	**40** 43	**42** 45	**45** 48	120
115	**12** 10	**15** 13	**17** 15	**20** 18	**22** 20	**25** 23	**27** 25	**30** 28	**32** 30	**35** 33	**37** 35	**40** 38	**42** 40	**45** 43	**47** 45	125
120	**15** 8	**17** 10	**20** 13	**22** 15	**25** 18	**27** 20	**30** 23	**32** 25	**35** 28	**37** 30	**40** 33	**42** 35	**45** 38	**47** 40	**50** 43	130

(For OTE aid, add 1 dB to Gain)

Table B-5

1500/1600 Hz
Sound Pressure Hearing Level (SPHL)

1500/1600 Hz Upper Limit of Comfortable Loudness (ULCL)	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	SSPL 90
70	**-16** 36	**-13** 38	**-11** 41	**-8** 43	**-6** 46	**-3** 48	**-1** 51	**2** 53	**5** 56							78
75	**-13** 33	**-11** 36	**-8** 38	**-6** 41	**-3** 43	**-1** 46	**2** 48	**5** 51	**7** 53	**10** 56						83
80	**-11** 31	**-8** 33	**-6** 36	**-3** 38	**-1** 41	**2** 43	**5** 46	**7** 48	**10** 51	**12** 53	**15** 56					88
85	**-8** 28	**-6** 31	**-3** 33	**-1** 36	**2** 38	**5** 41	**7** 43	**10** 46	**12** 48	**15** 51	**17** 53	**20** 56				93
90	**-6** 26	**-3** 28	**-1** 31	**2** 33	**5** 36	**7** 38	**10** 41	**12** 43	**15** 46	**17** 48	**20** 51	**22** 53	**25** 56			98
95	**-3** 23	**-1** 26	**2** 28	**5** 31	**7** 33	**10** 36	**12** 38	**15** 41	**17** 43	**20** 46	**22** 48	**25** 51	**27** 53	**30** 56		103
100	**-1** 21	**2** 23	**5** 26	**7** 28	**10** 31	**12** 33	**15** 36	**17** 38	**20** 41	**22** 43	**25** 46	**27** 48	**30** 51	**32** 53	**35** 56	108
105	**2** 18	**5** 21	**7** 23	**10** 26	**12** 28	**15** 31	**17** 33	**20** 36	**22** 38	**25** 41	**27** 43	**30** 46	**32** 48	**35** 51	**37** 53	113
110	**5** 16	**7** 18	**10** 21	**12** 23	**15** 26	**17** 28	**20** 31	**22** 33	**25** 36	**27** 38	**30** 41	**32** 43	**35** 46	**37** 48	**40** 51	118
115	**7** 13	**10** 16	**12** 18	**15** 21	**17** 23	**20** 26	**22** 28	**25** 31	**27** 33	**30** 36	**32** 38	**35** 41	**37** 43	**40** 46	**42** 48	123
120	**10** 11	**12** 13	**15** 16	**17** 18	**20** 21	**22** 23	**25** 26	**27** 28	**30** 31	**32** 33	**35** 36	**37** 38	**40** 41	**42** 43	**45** 46	128

(For OTE aid, add 1 dB to Gain)

Table B-6

2500 Hz
Sound Pressure Hearing Level (SPHL)

2500 Hz Upper Limit of Comfortable Loudness (ULCL)	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	SSPL 90
70	**-16** 31	**-13** 33	**-11** 36	**-8** 38	**-6** 41	**-3** 43	**-1** 46	**2** 48	**5** 51							77
75	**-13** 28	**-11** 31	**-8** 33	**-6** 36	**-3** 38	**-1** 41	**2** 43	**5** 46	**7** 48	**10** 51						82
80	**-11** 26	**-8** 28	**-6** 31	**-3** 33	**-1** 36	**2** 38	**5** 41	**7** 43	**10** 46	**12** 48	**15** 51					87
85	**-8** 23	**-6** 26	**-3** 28	**-1** 31	**2** 33	**5** 36	**7** 38	**10** 41	**12** 43	**15** 46	**17** 48	**20** 51				92
90	**-6** 21	**-3** 23	**-1** 26	**2** 28	**5** 31	**7** 33	**10** 36	**12** 38	**15** 41	**17** 43	**20** 46	**22** 48	**25** 51			97
95	**-3** 18	**-1** 21	**2** 23	**5** 26	**7** 28	**10** 31	**12** 33	**15** 36	**17** 38	**20** 41	**22** 43	**25** 46	**27** 48	**30** 51		102
100	**-1** 16	**2** 18	**5** 21	**7** 23	**10** 26	**12** 28	**15** 31	**17** 33	**20** 36	**22** 38	**25** 41	**27** 43	**30** 46	**32** 48	**35** 51	107
105	**2** 13	**5** 16	**7** 18	**10** 21	**12** 23	**15** 26	**17** 28	**20** 31	**22** 33	**25** 36	**27** 38	**30** 41	**32** 43	**35** 46	**37** 48	112
110	**5** 11	**7** 13	**10** 16	**12** 18	**15** 21	**17** 23	**20** 26	**22** 28	**25** 31	**27** 33	**30** 36	**32** 38	**35** 41	**37** 43	**40** 46	117
115	**7** 8	**10** 11	**12** 13	**15** 16	**17** 18	**20** 21	**22** 23	**25** 26	**27** 28	**30** 31	**32** 33	**35** 36	**37** 38	**40** 41	**42** 43	122
120	**10** 6	**12** 8	**15** 11	**17** 13	**20** 16	**22** 18	**25** 21	**27** 23	**30** 26	**32** 28	**35** 31	**37** 33	**40** 36	**42** 38	**45** 41	127

(For OTE aid, add 5 dB to Gain)

Table B-7

4000 Hz
Sound Pressure Hearing Level (SPHL)

4000 Hz Upper Limit of Comfortable Loudness (ULCL)	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	SSPL 90
70	**-11** 27	**-9** 29	**-6** 32	**-4** 34	**-1** 37	**2** 39	**4** 42	**7** 44	**9** 47							78
75	**-9** 24	**-6** 27	**-4** 29	**-1** 32	**2** 34	**4** 37	**7** 39	**9** 42	**12** 44	**14** 47						83
80	**-6** 22	**-4** 24	**-1** 27	**2** 29	**4** 32	**7** 34	**9** 37	**12** 39	**14** 42	**17** 44	**19** 47					88
85	**-4** 19	**-1** 22	**2** 24	**4** 27	**7** 29	**9** 32	**12** 34	**14** 37	**17** 39	**19** 42	**22** 44	**24** 47				93
90	**-1** 17	**2** 19	**4** 22	**7** 24	**9** 27	**12** 29	**14** 32	**17** 34	**19** 37	**22** 39	**24** 42	**27** 44	**29** 47			98
95	**2** 14	**4** 17	**7** 19	**9** 22	**12** 24	**14** 27	**17** 29	**19** 32	**22** 34	**24** 37	**27** 39	**29** 42	**32** 44	**34** 47		103
100	**4** 12	**7** 14	**9** 17	**12** 19	**14** 22	**17** 24	**19** 27	**22** 29	**24** 32	**27** 34	**29** 37	**32** 39	**34** 42	**37** 44	**39** 47	108
105	**7** 9	**9** 12	**12** 14	**14** 17	**17** 19	**19** 22	**22** 24	**24** 27	**27** 29	**29** 32	**32** 34	**34** 37	**37** 39	**39** 42	**42** 44	113
110	**9** 7	**12** 9	**14** 12	**17** 14	**19** 17	**22** 19	**24** 22	**27** 24	**29** 27	**32** 29	**34** 32	**37** 34	**39** 37	**42** 39	**44** 42	118
115	**12** 4	**14** 7	**17** 9	**19** 12	**22** 14	**24** 17	**27** 19	**29** 22	**32** 24	**34** 27	**37** 29	**39** 32	**42** 34	**44** 37	**47** 39	123
120	**14** 2	**17** 4	**19** 7	**22** 9	**24** 12	**27** 14	**29** 17	**32** 19	**34** 22	**37** 24	**39** 27	**42** 29	**44** 32	**47** 34	**49** 37	128

(For OTE aid, add 6 dB to Gain)

same frequency obtained from Appendix B; (3) ASFT goals will be the same as given in Appendix B.

APPENDIX D Threshold-Based prescriptions for preselection tests using supra-aural or insert earphone

APPENDIX E Rationale for LDL prediction

Given that prediction of LDLs from thresholds is rather imprecise, the use of an SSPL90 prescription which is based upon predicted LDLs (Fig. 2, block 8), can only be justified because it appears to be the best of the three available options. These are: (1) ignore the SSPL90 and allow it to vary without control, (2) use the same SSPL90 for everyone for whom thresholds are the only available preselection data, (3) use different SSPL90 values for patients who have different hearing thresholds. Option 1 seems unacceptable on professional and ethical grounds. Option 2 is a defensible choice but it ignores data from several sources which establish that, on the average, LDLs increase as hearing thresholds increase (even though the precise relationship between threshold and

Table C-1. Corrections (dB) necessary to derive an OTE prescription based on insert earphone test results from the ITE prescription tables given in Appendix B

	Correction	
Frequency (Hz)	Gain	SSPL90
250	+12	+11
500	+4	+2
800	+3	+1
1000	+3	+2
1600	+5	+4
2500	+9	+5
4000	+10	+4

Table D-1. Required gain (for OTE hearing aids) prescribed from thresholds (HTL or eaHL) using modified NAL procedure.[8] For ITE hearing aids, apply the following corrections: 2500 Hz, −4 dB; 4000 Hz, −5 dB

	Test Frequency						
HTL[a] or eaHL[b]	250	500	800	1000	1600	2500	4000
0	−1	−14	−9	−2	−5	3	−1
5	1	−12	−7	0	−3	5	2
10	4	−9	−4	3	−0	8	4
15	6	−7	−2	5	2	10	6
20	8	−5	0	7	4	12	9
25	11	−3	3	10	7	15	11
30	13	0	5	12	9	17	13
35	15	2	7	14	11	19	16
40	17	4	9	16	13	21	18
45	20	7	12	19	16	24	20
50	22	9	14	21	18	26	23
55	24	11	16	23	20	28	25
60	27	14	19	26	23	31	27
65	29	16	21	28	25	33	29
70	31	18	23	30	27	35	32
75	34	21	26	33	30	38	34
80	36	23	28	35	32	40	36
85	38	25	30	37	34	42	39
90	40	27	32	39	36	44	41
95	43	30	35	42	39	47	43
100	45	32	37	44	41	49	46
105	47	34	39	46	43	51	48

[a] *HTL, hearing loss measured using TDH39 or TDH49 earphone. Gain expressed in HA-1 coupler value.*

[b] *eaHL, hearing loss measured using insert earphone attached to patient's earmold. Gain expressed in HA-2 coupler value.*

Table D-2. Maximum SSPL90 values prescribed from thresholds (HTL or eaHL). If thresholds were measured using TDH39 or TDH49 earphones, SSPL90 is obtained from the "HA1" column. If thresholds were measured using an SMW receiver attached to the patient's earmold, SSPL90 is obtained from the "HA2" column

	250	500	800	1000	1600	2500	4000
HTL[a] or eaHL[b]	HA1/HA2	HA1/HA2	HA1/HA2	HA1/HA2	HA1/HA2	HA1/HA2	HA1/HA2
0	89 100	97 100	98 100	98 100	95 100	95 100	96 100
5	90 101	98 101	99 101	99 101	96 101	96 101	97 101
10	92 103	100 103	101 103	100 103	98 103	98 103	98 103
15	93 104	101 104	102 104	101 104	99 104	99 104	99 104
20	94 105	102 105	103 105	103 105	100 105	100 105	101 105
25	95 106	103 106	104 106	104 106	101 106	101 106	102 106
30	97 108	105 108	106 108	105 108	103 108	103 108	103 108
35	98 109	106 109	107 109	106 109	104 109	104 109	104 109
40	99 110	107 110	108 110	108 110	105 110	105 110	106 110
45	100 111	108 111	109 111	109 111	106 111	106 111	107 111
50	102 113	110 113	111 113	110 113	108 113	108 113	108 113
55	103 114	111 114	112 114	111 114	109 114	109 114	109 114
60	104 115	112 115	113 115	113 115	110 115	110 115	111 115
65	105 116	113 116	114 116	114 116	111 116	111 116	112 116
70	107 118	115 118	116 118	115 118	113 118	113 118	113 118
75	108 119	116 119	117 119	116 119	114 119	114 119	114 119
80	109 120	117 120	118 120	118 120	115 120	115 120	116 120
85	110 121	118 121	119 121	119 121	116 121	116 121	117 121
90	112 123	120 123	121 123	120 123	118 123	118 123	118 123
95	113 124	121 124	122 124	121 124	119 124	119 124	119 124
100	114 125	122 125	123 125	123 125	120 125	120 125	121 125
105	115 126	123 126	124 126	124 126	121 126	121 126	122 126

[a] *HTL, hearing loss measured using TDH39/49 earphone. SSPL90 expressed in HA-1 coupler level.*

[b] *eaHL, hearing loss measured using insert earphone attached to patient's earmold. SSPL90 expressed in HA-2 coupler level.*

Table D-3. Aided sound field threshold goals (dB SPL) prescribed from unaided sound field thresholds (USFT) using modified NAL procedure[8]

	Test Frequency						
USFT (SPL)	250	500	800	1000	1600	2500	4000
0	4	15	10	3	6	4	2
5	6	17	12	6	9	7	4
10	9	20	15	9	12	9	7
15	12	23	18	11	14	12	10
20	14	25	21	14	17	15	12
25	17	28	23	17	20	17	15
30	20	31	26	19	22	20	18
35	23	34	29	22	25	23	20
40	25	36	31	25	28	26	23
45	28	39	34	28	31	28	26
50	31	42	37	30	33	31	29
55	33	44	39	33	36	34	31
60	36	47	42	36	39	36	34
65	39	50	45	38	41	39	37
70	41	52	48	41	44	42	39
75	44	55	50	44	47	44	42
80	47	58	53	46	49	47	45
85	50	61	56	49	52	50	47
90	52	63	58	52	55	53	50
95	55	66	61	55	58	55	53
100	58	69	64	57	60	58	56
105	60	71	66	60	63	61	58

Table E-1. Regression equations and standard errors of estimate Sy·x) for prediction of LDLs (dB SPL) from pure-tone thresholds

Frequency (Hz)	Regression Equation	Sy·x (dB)
500	LDL = 0.24 (hearing loss) + 103	7.8
1000	LDL = 0.29 (hearing loss) + 96	8.2
2000	LDL = 0.21 (hearing loss) + 101	7.9

LDL is different for different individuals).[25,38] If there is a monotonic relationship between LDL and desired SSPL90, then SSPL90 should also increase with increasing hearing loss. As a result of these considerations, the prescriptive method described here attempts to implement option 3.

The proposed relationship between LDL and hearing threshold is a simple one: LDLs (and SSPL90s) are predicted to be at a level of 100 dB plus one-quarter of the hearing loss. This relationship seems to have been observed first by Martin et al.[31] These investigators measured the maximum output at 1000 Hz of 161 hearing aids set to the use-gain setting and correlated the results with hearing loss (HTL) at the same frequency. Their regression equation was: SSPL(dB) = 100.2 + 0.25 (HTL). An essentially identical relationship was observed by Cox and Bisset (unpublished data) in a study of LDLs for 16 hearing-impaired subjects. Table E-1 shows regression equations empirically derived in that study for prediction of LDLs (for one-third octave noise bands) from pure-tone thresholds for three frequencies. Although there are minor differences across frequencies, the similarity between these equations and the equation from Martin et al[31] is quite striking. All four equations produce predictions which do not differ more than 5 dB from each other for any hearing threshold in the range from 35 to 100 dB. These observations provide support for a hypothesis that, on the average, the LDL at a particular frequency (ergo, the SSPL90), occurs at 100 dB plus one-quarter of the pure-tone hearing loss at that frequency.

This hypothesis has been tested using data from two sources. Shapiro[38] reported threshold and LDL data for 20 hearing-impaired subjects at 500, 1000, 2000, and 4000 Hz. Kamm et al[25] reported similar data for 178 ears at 500 and 2000 Hz and for spondee words. Inspection of both sets of data indicated that the median LDL was quite accurately predicted by the proposed rule [LDL = 100 + 0.25 (hearing loss)] for all stimuli. It was concluded that this rule results in a reasonably accurate estimate of the median LDL.

APPENDIX F Procedure for setting a hearing aid to match a prescription

In Figure 2, blocks 15 and 17, hearing aids are configured so that their performance in the 2 cm^3 coupler matches the derived prescription. This is achieved in the following way:

1. An instrument with specifications which would include the prescription values is selected (desired additional features such as induction coil, directional microphone, user-operated low-frequency cut, audio input capability, etc. also figure in instrument selection).
2. The hearing aid is configured to provide the highest SSPL90, the widest frequency response, and full-on gain.
3. While observing the hearing aid's output into the appropriate 2 cm^3 coupler in a hearing aid test box, the SSPL90 control is varied until the SSPL90 performance approximates the prescription as closely as possible.
4. With an input of 2500 Hz at 60 dB, the volume control is varied until the gain is equal to the prescribed value at 2500 Hz.
5. With an input of 500 Hz at 60 dB, the tone control is varied until the gain at 500 Hz equals the prescribed value (the volume control is maintained at the setting determined in step 4).
6. Gain at all tested frequencies is then measured and compared to the prescribed values. Sometimes steps 4, 5, and 6 must be repeated to optimize the match between the hearing aid's performance and the prescribed performance.

All control settings are then noted and the volume control is taped.