# Current Approaches to Hearing Aid Selection

## *Méthodes actuelles pour la sélection des prothèses auditives*

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### Abstract

This paper will review a variety of approaches that are in current use today to select SSPL90 and frequency response, and discuss the advantages and disadvantages of each method. The approaches to be reviewed and discussed include the following: (1) selection based solely on the pure tone audiogram, where gain, frequency response, and SSPL90 are chosen based upon vague or unspecified rationale; (2) a prescription procedure utilizing pure tone thresholds to specify a desired 2 $cm^3$ coupler response using a median CORFIG and SSPL90 based upon a vague or unspecified rationale; (3) a prescription procedure utilizing a pure tone audiogram to specify a desired 2 $cm^3$ coupler response using an individualized CORFIG, with SSPL90 being based upon a suprathreshold measure and specified in coupler values; (4) a pure tone audiogram used to determine appropriate output levels for the long-term spectrum of speech and output limiting levels, with the hearing aid characteristics being specified in a 2 $cm^3$ coupler; and (5) suprathreshold measurements made to determine the residual dynamic range and hearing aid characteristics chosen to amplify a given signal into this range.

### Résumé

*L'auteur examine diverses approches qui sont actuellement utilisées pour choisir le SSPL90 et la réponse aux fréquences. Il mentionne les avantages et inconvénients de chacune des méthodes suivantes : (1) la sélection prothétique basée uniquement sur l'audiogramme tonal, duquel le gain, la réponse aux fréquences et le SSPL90 sont choisis en fonction de critères vagues ou imprécis; (2) une procédure de prescription qui utilise les seuils auditifs pour déterminer une réponse désirée au coupleur 2 $cm^3$ à l'aide d'un CORFIG médian, et dont le SSPL90 est basé sur des critères vagues ou imprécis; (3) une procédure de prescription qui utilise l'audiogramme tonal pour déterminer une réponse désirée au coupleur 2 $cm^3$ à l'aide d'un CORFIG individualisé, et dont le SSPL90 est basé sur une mesure du son supra-liminaire et précisé par les valeurs du coupleur acoustique; (4) une approche dans laquelle l'audiogramme tonal est utilisé pour déterminer les niveaux appropriés de sortie pour le spectre (à long terme) de la parole et pour estimer les niveaux de saturation, les caractéristiques des prothèses auditives étant précisées pour un coupleur 2 $cm^3$; (5) une approche dans laquelle les mesures supra-liminaires sont considérées pour déterminer le champ dynamique résiduel, les caractéristiques des prothèses auditives étant choisies dans le but d'amplifier un signal donné à l'intérieur de ce champ dynamique résiduel.*

## Introduction

Approaches to hearing aid selection have undergone enormous change in the last fifteen years. There has been a clear shift from reliance on speech understanding tests to select the appropriate hearing aid, to concentration on efficient amplification of speech energy into the residual dynamic range of the hearing-impaired person. New acoustic as well as subjective methods of evaluating hearing aids have been developed. The purpose of this paper is to describe some of the current approaches to selecting hearing aids and outline some the advantages and disadvantages of each method. The approaches will be presented in a chronological order of development as well as in a hierarchy of increased sophistication.

## Selection Strategy 1: Use of Only the Pure Tone Audiogram

Use of only the pure tone audiogram to select electroacoustic characteristics is probably the most common approach incorporated today. It is fuelled by the large increase in the in-the-ear (ITE) market share and the lack of sophistication of the typical hearing aid dispenser. In this approach the responsibility is left to the manufacturer to select the gain, frequency response, and SSPL90 of the hearing aid. A recent survey cited by Bratt and Sammeth (1991) indicated that in the Veterans Administration system in the United States approximately 80% of hearing aids were selected by the method of making ear impressions and sending these to the hearing aid manufacturer along with the pure tone audiogram.

In this approach it is uncommon for the dispenser to obtain a measure of loudness discomfort. Therefore, the manufacturer must guess at the appropriate SSPL90, relying upon the degree of hearing loss or the relationship between gain and SSPL90 in the selected circuit. This approach relies upon the sophistication of the manufacturer and their consistency in selection of circuits. Both of these qualities have been called into question in recent years (Angeli, Seestadt-Stanford, & Nerbonne, 1990).

The advantages of this approach are that it is less time-consuming at the beginning of the hearing aid selection process and that it requires little knowledge on the part of the dispenser. While perhaps viewed by different people as an advantage or disadvantage, this approach typically results in a less expensive hearing aid, as those attracted to this method tend to order less controls and often order rather simple linear, peak clipping circuits. The disadvantages include: (1) the lack of a structured approach; (2) the dependence on the manufacturer for sophistication in circuit selection; (3) the possibility of loudness discomfort; (4) the fact that the dispenser has less opportunity to learn; (5) the lack of knowledge about the predicted real-ear response; (6) the removal of responsibility from the dispenser; and (7) the less sophisticated circuits that tend to be utilized. It is this writer's opinion that this approach to hearing aid selection will not best serve the hearing impaired, the manufacturer, or the hearing aid dispenser.

## Selection Strategy 2: Pure Tone Audiogram and Prescription Procedure for Gain/Frequency Response; SSPL90 Approximated

The use of prescription procedures to select gain and frequency response has been popular since the mid 1970s and early 1980s, when selection methods were published by Byrne and Tonisson (1976), Berger, Hagberg, and Rane (1977), Cox (1983), and McCandless and Lyregaard (1983). The use of such prescription schemes has increased in popularity with the advent of probe microphone systems and the availability of software programs to do the calculations. The growth of the ITE market has also led some to wish to specify the desired characteristics of the hearing aid in 2 $cm^3$ coupler values, an option that most of the prescription procedures include.

With the various prescription formulas detailing the recommended gain and frequency response in both real-ear and 2 $cm^3$ coupler terms, many audiologists have focused extensively on the real-ear insertion response (REIR), perhaps to the neglect of the SSPL90. If a measure of loudness discomfort is not obtained, then in the case of an ITE, the manufacturer will select a maximum output that is thought to be acceptable. If loudness discomfort levels (LDLs) are obtained, it is most common to observe the LDL being obtained with speech stimuli presented through standard audiometric earphones. This number is then converted to dB SPL in a 6 $cm^3$ coupler, and the assumption is made that this number is applicable to the 2 $cm^3$ coupler SSPL90 curve. Approximations based upon the audiogram by the manufacturer or the speech LDL approach could result in uncomfortably loud amplified sound.

In using prescription formulas to determine the required 2 $cm^3$ coupler gain and frequency response, conversion values are added to the desired REIR to yield the 2 $cm^3$ coupler values. To make the conversion, a correction figure (CORFIG) is added to the REIR to account for the median REIR/2 $cm^3$ coupler difference. There are several problems with this approach. First, it will be applicable only to the average adult. None of the procedures, with the exception of the Desired Sensation Level approach (Seewald, Zelisko, Ramji, & Jamieson, 1991), have CORFIGs for children as an option. Second, there are a variety of data from behavioral studies that do not agree closely with some of the theoretical CORFIGs that are used by some of the prescription procedures (Hawkins, Montgomery, Prosek, & Walden, 1987). Third, individual variability is quite large with regard to the size of the CORFIG (Hawkins, Montgomery, Prosek & Walden, 1987). The variability can be due to individual variations in middle ear impedance and residual volume of air between the earmold or ITE and the tympanic membrane. Thus, a hearing aid could be ordered assuming the average CORFIG, but it may not provide the desired REIR. A related problem could be that the hearing aid manufacturer may be unable to provide the desired 2 $cm^3$ coupler response, either in a BTE or ITE. Bratt and Sammath (1991) recently showed variations from requested and obtained 2 $cm^3$ coupler values when ordering with the NAL from a manufacturer with whom they "worked closely ... to achieve the desired frequency response (p. 25)." Individual cases commonly showed errors exceeding 10 dB, especially in the higher frequencies.

Advantages to this approach include time efficiency (if software is used), the structure of a documented and published approach to frequency response selection, the presence of stated goals or targets for hearing aid performance, and an approach through real-ear measurement (typically included in this orientation) to verify performance of the hearing aid on the actual person. Disadvantages include the possibility that the dispenser may not obtain the desired REIR due to the use of a mean CORFIG and that loudness discomfort may occur due to the lack of carefully measured LDLs. These disadvantages may diminish if flexible tone and output controls are present and the fitting procedure is done carefully. Finally, suprathreshold measurements typically are not made to verify that appropriate loudness relationships are realized in the hearing aid selection and fitting.

## Selection Strategy 3: Pure Tone Audiogram and Prescription with Customized Values

This approach, while not in common use currently, appears to be gaining interest in the audiological community. Its attractiveness stems from the limitations of the previous approach, that is, the use of median CORFIG values and the lack of attention to the specification of SSPL90. A prescription procedure, such as the National Acoustics Laboratory revised procedure (Byrne & Dillon, 1986), is used to determine a desired REIR. Instead of applying the NAL mean CORFIG to arrive at the desired 2 $cm^3$ coupler response, a CORFIG is determined for the individual person. This idea of an individualized CORFIG was first expressed by Skinner, Pascoe, Miller, and Popelka (1982) and later by Punch, Chi, and Patterson (1990). The CORFIG is generated by obtaining a REIR with a hearing aid and then placing the hearing aid (with the same volume control wheel setting) on a 2 $cm^3$ coupler and subtracting the two gain values. This difference between the obtained REIR and 2 $cm^3$ values, the CORFIG, is added to the NAL target values and 10-15 is added for reserve gain. The result is a full-on 2 $cm^3$ coupler gain curve that can be used to select a BTE from specification sheets or to order an ITE. The hearing aid selected by this method theoretically should have the best chance to provide the desired REIR. Research has not yet demonstrated the superiority of this method for obtaining the desired REIR. The use of programmable hearing aids with very flexible responses may make the need for such an approach less obvious.

Following the more precise nature of the gain and frequency response selection, increased attention is directed toward the selection of SSPL90. The goal is to generate a recommended 2 $cm^3$ coupler SSPL90 curve that is directly related to loudness discomfort measures, with the intention to insure that the hearing aid selected or ordered will not produce uncomfortably loud sounds. The instructions for loudness discomfort measurements are particularly important. The loudness category procedure first described by Pascoe (1978) and modified by Hawkins, Walden, Montgomery, and Prosek (1987) is a structured approach, which provides anchors for the loudness judgments, and has been shown to be reliable. The choice of the transducer is important, and the Etymotic ER-3A has the distinct advantage of being calibrated in a 2 $cm^3$ coupler. It is therefore possible to obtain LDLs and have the value expressed in the appropriate reference for selecting BTEs or ordering ITEs. While obtaining the LDLs, it is also helpful to place a probe tube in the ear canal and determine the SPL present at the tympanic membrane at the point of loudness discomfort. This allows for knowledge of the SPL delivered to the cochlea (useful for overamplification concerns) and the generation of targets for the Real Ear Saturation Response (RESR). The use of probe microphone measurements in this application has been recently described by Stelmachowicz (1991), Stuart, Durieux-Smith, and Stenstrom (1991), and Zelisko, Seewald, and Gagné (1990).

Perhaps as important as where the hearing aid limits the output is how the limiting is accomplished. Although it has been known for years that peak clipping produces large amounts of harmonic distortion, a recent survey by Hawkins and Naidoo (1992) indicated that 82% of hearing aids sold in the United States used peak clipping to limit the output. Hawkins and Naidoo (1992) also conducted a study in which linear circuits, which differed only in the type of limiting (peak clipping or output compression), were compared with a number of stimuli (speech in quiet, speech in noise, and music) for sound quality and clarity at three levels relative to saturation (-12 dB, +5 dB, and +20 dB). Results from twelve hearing-impaired subjects showed a significant preference for compression whenever the hearing aids were being saturated. These results confirm the notion that the undesirable distortion that results from peak clipping can be perceived by hearing aid users and is judged as undesirable.

The importance of selecting an SSPL90 that prevents discomfort may be quite important for acceptance of the hearing aid in everyday life. Users may make maladaptive adjustments to avoid discomfort if the SSPL90 is allowed to exceed the LDLs. They may lower the volume control wheel (VCW), avoid noisy situations, use the hearing aid only in quiet, or simply stop using the hearing aid. The fact that the K-amp circuit returns to unity gain (at typical VCW positions) for higher inputs (essentially becomes transparent) and limits cleanly may well account for some of its recent success.

In summary, this hybrid approach has the advantages of having clear goals and targets for both gain/frequency response and maximum output. All values are expressed in 2 $cm^3$ coupler terms for selecting and ordering, and targets for performance in the real ear are also present for both gain and output. Disadvantages include the greater time commitment in the selection process and the lack of any guarantee that the customizing will produce a hearing aid closer to the desired values.

## Selection Strategy 4: Pure Tone Audiogram and a Desired Amplified Speech Spectrum

This selection strategy utilizes a pure tone audiogram as a reference point for audibility and attempts to amplify the long-term spectrum of speech to specified sensation levels. The approach is described in the literature by Seewald and colleagues (Seewald, 1988; Seewald, 1992; Seewald & Ross, 1988; Seewald, Ross, & Spiro, 1985; Seewald, Ross, &

Stelmachowicz, 1987; Seewald, Zelisko, Ramji, & Jamieson, 1991). The rationale for the particular desired sensation levels is based in part on a large database of adults in which auditory thresholds, most comfortable loudness levels, and LDLs were obtained. One of the most attractive features of such an approach is that all necessary measurements can be made in the ear canal of the hearing aid user, thus eliminating various potentially conflicting reference levels, such as sound field, earphones, and 2 $cm^3$ couplers. Conversions can be applied to the values to express the desired response in 2 $cm^3$ coupler values, and they can be customized using Real Ear to Coupler Differences (RECDs), all of which can be done in commercially available software (Seewald, 1992).

The major advantage of such an approach is that it clearly outlines the entire residual auditory area and provides targets for the amplified speech spectrum and the RESR. It is flexible enough to incorporate user loudness judgments or will predict them based upon known data sets. All measurements can be specified in ear canal SPL, and yet 2 $cm^3$ values are calculated for selection and ordering. The only disadvantage is that the procedure has not been validated as providing successful fittings with a group of hearing-impaired adults. Although the particular approach of Seewald and associates has been described as an application to children, it would be helpful conceptually if the procedure provided gain and output levels that were judged acceptable by adult hearing aid users. Finally, it would be helpful if future versions of this strategy incorporated the use of compression parameters to amplify and compress into a narrow residual dynamic range.

## Selection Strategy 5: Threshold and Suprathreshold Measurements to Define the Dynamic Range and Amplify the Speech Spectrum to Comfortable Loudness

This last strategy is perhaps the least used and potentially the most useful theoretically. An early approach of this type was described by Skinner, Pascoe, Miller, and Popelka (1982). Perceptual judgments of the entire dynamic range are obtained. The purpose is to amplify the long-term speech spectrum to approximately the MCLs and limit the output below the LDLs. The input signal is packaged within the residual dynamic range. An individual CORFIG is obtained to assist in selecting or ordering the 2 $cm^3$ coupler response that will provide the REIR necessary to accomplish the procedure's goals. A more recent similar approach has been advocated by Resound in the programming of their two channel compression hearing aids. Loudness growth is measured in four octave bands, and compression parameters are set for the two channels based on the loudness contours.

The advantage of this approach is that the loudness perception of each individual is measured. This is important due to the large individual variability that is present in such measurements. The approach addresses gain, frequency response, limiting levels, and specifies values in a 2 $cm^3$ coupler. The application of nonlinear concepts to the reduced dynamic range is particularly appealing. The only obvious disadvantages are that most children and some elderly are unable to perform loudness judgment tasks reliably, and it is not clear at this point what the optimal compression parameters should be for various abnormal loudness growth functions.

## Personal Conclusions

Some closing personal conclusions regarding selection methods for hearing aids include the following: (1) the most promise would appear to be in methods that measure suprathreshold functioning of the person with a sensorineural hearing loss; such values should be predicted for children and those incapable of making loudness judgments; (2) the selection process will be easier if all desired specifications are expressed in 2 $cm^3$ coupler values, as this is the metric that the manufacturer understands and can measure; (3) nonlinear processing will prove optimal in the long run for nearly all persons with sensorineural hearing loss; (4) documented advantages should be utilized, such as directional microphones, clean output limiting, strong telecoils, and direct input capability; and (5) initial selection decisions should be validated with acoustic methods, such as probe microphone measurements; long-term adjustments with the capable user should be made using subjective judgments.

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