Critique of Current Approaches to the Selection and Fitting of Hearing Aids

Critique de certaines méthodes de sélection et d'ajustement des prothèses auditives

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Abstract

During the past ten years, several formal methods have been developed for the selection and fitting of hearing aids. Each method comes with its own rationale, set of recommended procedures, and assumptions. Because of new and developing hearing instrument technologies, it may be an appropriate time to re-examine the assumptions and procedures that are presently applied in hearing aid selection and fitting. It is the purpose of this paper to identify and discuss limitations of current approaches to hearing aid selection and fitting. Particular attention is given to the collection and interpretation of audiometric data for the purposes of hearing aid selection/fitting and to the manner in which electroacoustic selection criteria are presently specified. Where potential problems and/or limitations are identified, alternative strategies are described.

Résumé

Depuis dix ans, plusieurs protocoles ont été mis au point pour la sélection et l'ajustement prothétiques. Chacune des méthodes comporte ses propres justifications, procédures et hypothèses. Étant donné l'avènement d'une technologie spécialisée dans le domaine de l'amplification, il devient impératif de réévaluer les hypothèses et procédures qui sont actuellement utilisées lors de la sélection et de l'ajustement des prothèses auditives. Les auteurs délimitent les méthodes actuelles. Ils accordent une attention particulière à la collecte et à l'interprétation des données audiométriques aux fins de la sélection et de l'ajustement prothétiques. Ils notent aussi la façon dont les critères de sélection électro-acoustique sont présentement établis. Enfin, ils identifient des problèmes possibles ou restrictifs, et suggèrent des stratégies alternatives.

During the past decade, there have been several important developments related to the selection and fitting of hearing aids. Clinicians now have formal methods that can be used in the selection of amplification characteristics for their clients. Through software implementations in probe-tube micro-phone systems, these electroacoustic selection strategies can be applied with relative ease within the clinical setting. Alternatively, implementations of several of these formal hearing aid selection methods can be used on personal computer-based systems (e.g., Popelka, 1982; Cox, 1988; Seewald, Zelisko, Ramji, & Jamieson, 1991). A further development relates to the general availability of clinical probe-tube microphone systems. With these systems, clinicians can accurately determine the extent to which the desired real-ear hearing aid performance characteristics have been provided to a given listener. In his paper, David Hawkins has outlined several levels at which hearing aid selection and fitting can be performed. In certain respects, these levels correspond roughly to the evolutionary process that has occurred in hearing aid selection and fitting since the early 1980's.

In this paper, several assumptions and procedural issues that relate to the design and implementation of current approaches to electroacoustic selection and fitting are considered. First, the formal methods for selection and fitting are identified and characterized. Second, issues related to the collection and interpretation of audiometric data, for the purpose of electroacoustic selection, are discussed. Finally, consideration is given to the manner in which current approaches specify desired electroacoustic performance criteria.

Electroacoustic Selection Methods

As a field, we have yet to reach consensus regarding which of the several alternative electroacoustic selection methods should be applied, and under which specific conditions, in clinical decision making. However, there does appear to be an emerging consensus among professionals that it is better to use one of the published hearing aid selection methods than it is to use no method at all. This observation is sup-

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Figure 1. Formal methods that have been developed for the electroacoustic selection and fitting of hearing aids.

BERGER METHOD
(Berger, Hagberg, & Rane, 1984)

CENTRAL INSTITUTE FOR THE DEAF (CID) METHOD
(Skinner, Pascoe, Miller, & Popelka, 1982)

DESIRED SENSATION LEVEL (DSL) METHOD
(Seewald, Ross, & Spiro, 1985; Seewald & Ross, 1988; Seewald,1992)

HAWKINS LOUDNESS DISCOMFORT LEVEL (LDL) METHOD
(Hawkins, Walden, Montgomery, & Prosek, 1987)

MEMPHIS STATE UNIVERSITY (MSU) METHOD
(Cox, 1983; 1985; 1988)

NATIONAL ACOUSTIC LABORATORY (NAL) METHOD
(Byrne & Dillon, 1986; Byrne, Parkinson, & Newall, 1991)

PRESCRIPTION OF GAIN AND OUTPUT (POGO) METHOD
(McCandless & Lyregaard, 1983; Schwartz, Lyregaard, & Lundh, 1988)

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ported by the recently published Vanderbilt/VA Hearing Aid Conference Consensus Statement regarding the recommended components of a hearing aid selection procedure for adults (Hawkins, Beck, Bratt, Fabry, Mueller, & Stelmachowicz, 1991). Although it has taken more than forty years to reach agreement regarding this issue, it appears that order, albeit imperfect, is now preferred to chaos.

Formal methods that have been developed for the purpose of electroacoustic selection are shown in Figure 1. Despite the known differences that exist among these methods, they all have certain characteristics in common. It is, in fact, this set of shared characteristics that allows for their general classification as *methods*. Specifically, the original publications that are associated with each of these hearing aid selection methods provide: (1) a statement of rationale; (2) a description of how the audiometric data are to be collected; (3) an operational definition of the assumed input speech signal; (4) a description of which electroacoustic performance criteria are specified; and (5) a description of the procedures that are to be used to verify electroacoustic performance.

An analysis of the original publications reveals that the degree to which each of these factors were considered varies somewhat across the methods. For example, issues related to the operational definition of average conversational speech for the purpose of electroacoustic selection have been given more attention in the development of some of these methods (e.g., Byrne & Dillon, 1986; Cox, 1988; Seewald et al., 1991; Skinner, Pascoe, Miller, & Popelka, 1982) than it has in

others (e.g., McCandless & Lyregaard, 1983). Each hearing aid selection and fitting method comes with its own rationale, assumptions, and set of recommended procedures. For this reason, both clinicians and researchers alike need to familiarize themselves with these characteristics before attempting to implement any particular method. Informative discussions of issues related to the design and application of contemporary hearing aid selection methods can be found in Bratt and Sammeth (1991), Humes (1991), Pascoe, (1988), and Skinner (1988).

As noted earlier, one major development that has occurred during the past decade relates to the availability of clinical probe-tube microphone systems. The introduction of these systems into clinical settings has had a major impact on the evolution and general acceptance of hearing aid selection methods. One primary advantage of these systems is that they provide an efficient means for implementing the formulae associated with several selection methods. By simply entering the client's threshold values into the software and selecting the method of choice, a prescription is derived for the client within a matter of seconds. It is likely that the efficiency and convenience that these systems provide has accelerated clinician acceptance of theoretical approaches to selection. However, use of these systems has not been without compromise.

It is important to differentiate between prescriptive formulae and selection methods. Each of the selection methods incorporates a unique set of formulae from which the desired or target electroacoustic performance criteria are derived. However, these formulae represent only one component of the method. Thus, it is possible to apply a set of the equations associated with a particular method, yet not use the method. For example, several of the current methods require both threshold and uncomfortable listening level (UCL) values to derive a complete set of electroacoustic performance criteria for a listener (e.g., Berger and POGO methods). However, most probe-tube microphone system implementations simply have omitted the output limiting component associated with these methods. Thus, in the final analysis, when a clinician selects an option from the probe-tube microphone system's menu, they have chosen only one component (i.e., insertion gain equations) of a particular method. Unfortunately, this piecemeal approach to electroacoustic selection has provided limited information regarding the usefulness of specific methods.

Presently, a common approach to electroacoustic selection and fitting includes the use of threshold values that have been obtained with conventional audiometric procedures to derive a prescription for the desired Real Ear Insertion Response (REIR). The hearing aid is subsequently fitted to provide a reasonable approximation to the target REIR. Some

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degree of "fine-tuning" may be required to conclude the electroacoustic selection and fitting process. With this approach, it is assumed that: (1) the audiometric threshold data that are obtained using conventional procedures are both sufficient and valid for the purposes of electroacoustic selection, and (2) the REIR is the most useful way in which to specify the desired real-ear hearing aid performance characteristics for the purposes of clinical fitting. Because of new and developing hearing instrument technologies, it may be an appropriate time to pause and to re-examine the assumptions and procedures that are presently applied in hearing aid selection and fitting.

Audiometric Measures for Hearing Aid Selection

The purpose of audiological assessment is to describe the nature of an auditory impairment and its consequences in a manner that will facilitate appropriate audiologic and/or otologic intervention. By viewing assessment in this way, the clinician needs to: (1) determine the information that will be required for the purposes of informed clinical decision making; (2) consider the available measurement options; and (3) develop a set of audiological assessment protocols accordingly.

As noted earlier, a common approach to the clinical problem of electroacoustic selection incorporates the use of audiometric threshold data only, obtained using conventional procedures, to derive estimates of the electroacoustic characteristics that will be required by a given hearing impaired listener. The use of this general approach assumes that threshold values provide both sufficient and valid data upon which to base all clinical decision making related to the selection of appropriate hearing aid performance characteristics. The validity of this assumption can be questioned for several reasons.

If the original publications associated with most of the formal hearing aid selection methods are consulted, it will be observed that each contains specific details regarding how the audiometric data are to be collected for the purpose of hearing aid selection. For example, most of the articles provide a description of the: (1) signal type; (2) signal transducer(s); (3) psychophysical methods; (4) type of measurements (e.g., threshold, MCL, UCL); (5) instructional set; and (6) calibration procedures that are to be employed to properly implement the method. It will be observed also that the details related to audiometric assessment procedures have received a greater degree of consideration in the development of several of the methods than they have in others. Nonetheless, one is left with the impression that for all current methods, the collection of audiometric data is viewed as an important and integral part of the hearing aid selection and fitting process.

Audiometric Signal Delivery Considerations

Regardless of the strategy employed, the accuracy of the fitting will depend, in part, on the reliability and validity of the audiometric data that are applied in selecting amplification characteristics. One threat to the validity of the audiometric data collected for electroacoustic selection purposes relates to the manner in which the signals are transduced and delivered to the listener. By convention, most audiometric data are presently obtained using the TDH-series supra-aural earphone, regardless of the purpose for which the measurement is being made. Although it is convenient to use the same signal transducer for multiple purposes in audiometric data collection, there are several problems associated with this approach.

All audiometric data obtained using the TDH-series earphone are, by convention, specified in decibels Hearing Level (dB HL). For the purposes of hearing aid selection, however, there are certain advantages to specifying audiometric data in dB sound pressure level (SPL) as measured in a 2 cm^3 coupler or in the real-ear (Erber, 1973; Hawkins, 1980; Cox, 1981; Libby, 1985; Skinner, 1988; Hawkins, Cooper, & Thompson, 1990; Seewald, 1991). For example, by specifying audiometric data in terms of the SPL developed in a 2 cm^3 coupler, the metric is the same as that used to characterize the electroacoustic performance of hearing aids. In this way, direct comparisons can be made between electroacoustic performance of a hearing aid and the relevant auditory characteristics of a listener.

Within the aided condition, the important relationships include: (1) the levels of amplified speech delivered into the ear canal relative to the listener's threshold levels across frequencies (i.e., amplified speech sensation levels), and (2) the maximum hearing aid output relative to the levels of sound at which the listener experiences discomfort. Unfortunately, when hearing is measured using a conventional audiometric earphone, it is impossible to know what the precise relationships among these relevant auditory and electroacoustic variables will be within the listener's ear canal. This is because the listener's auditory characteristics are defined relative to the SPL measured in a 6 cm^3 coupler. Thus, when the listener's thresholds and LDLs that are measured in dB HL are converted to reference SPL values in a 6 cm^3 coupler, the SPLs measured under these conditions cannot be compared directly to the output of a hearing aid within a listener's ear canal.

There are several options with regard to how auditory characteristics might be defined so that these important interrelationships can be known. The preferred option is to use a probe-tube microphone to determine the SPL of the test signal within the ear canal at a listener's threshold and at LDL

Figure 2. Monaural air conduction thresholds (o) and LDLs (□) obtained from a listener with a sensorineural hearing impairment. These audiometric findings, plotted in dB HL, were obtained using a conventional audiometric supra-aural earphone.
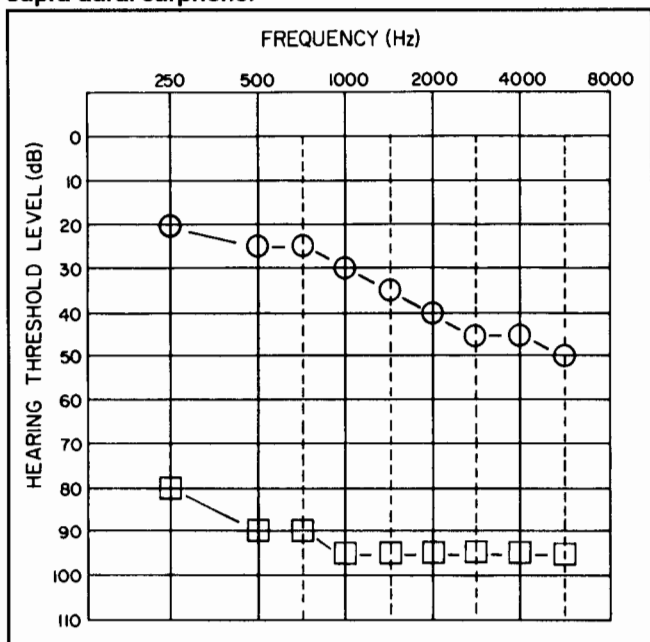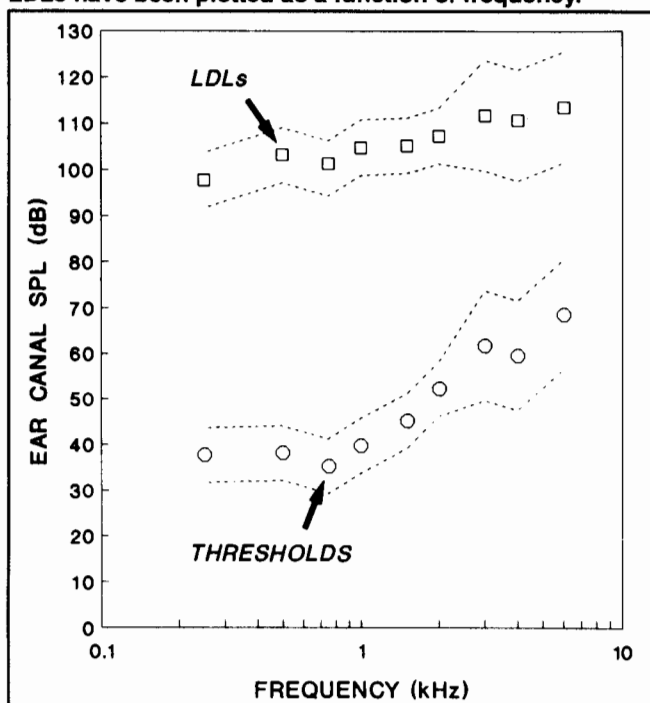

Figure 3. Monaural air conduction thresholds (o) and LDLs (□) that have been transformed (Cox, 1986) to dB SPL (ear canal level) from the dB HL values plotted in Figure 2. The 95% confidence intervals (Cox, 1986) for the predictions of ear canal SPL for both thresholds and LDLs have been plotted as a function of frequency.


(Gagné, Seewald, Zelisko, & Hudson, 1991a; Stelmachowicz, 1991; Stuart, Durieux-Smith, & Stenstrom, 1991). In this way, the manner in which the auditory characteristics are defined will be the same as that applied in quantifying the ear canal levels of the measured or predicted real-ear hearing aid performance characteristics. Alternatively, the auditory characteristics of a listener can be defined in reference to the SPL developed in a 2 cm^3 coupler (Cox, 1981; Erber, 1973; Hawkins, 1980; Hawkins et al., 1987). Although somewhat less precise, another option is to predict the ear canal SPL, at threshold and LDL, by using a set of average transformation values.

The literature suggests that for TDH-series earphones, the dB difference between the signal level at the entrance to the ear canal and the level that is measured in a 6 cm^3 coupler varies substantially across listeners (Erber, 1968; Shaw, 1966; Cox, 1986). These inter-subject differences have been attributed to variations in coupling the earphone to the pinna and to ear canal resonances and antiresonances which are not present in the 6 cm^3 coupler measurement (Skinner, 1988). Based on her analysis of the literature, Skinner (1988) concluded that average 6 cm^3 coupler to tympanic membrane transformation values can be used to predict the SPL at the eardrum with a reasonable degree of accuracy for frequencies between 750 and 2000 Hz, but not at higher and lower frequencies. Furthermore, on the basis of her findings, Cox (1986) concluded that an average 6 cm^3 coupler to tympanic membrane transformation could be used to predict the SPL at the eardrum to within 6 dB between 250 and 2000 Hz and to within 12 dB at frequencies above 2000 Hz for 95% of the adult subjects in her study.

The following example will be used to illustrate the limitations of conventional audiometric earphones for the purposes of electroacoustic selection and fitting. A listener's thresholds and LDLs are shown in Figure 2. These audiometric data were collected in dB HL using conventional TDH-49 supra-aural earphones. By using a set of average values, it is possible to predict the SPL at the tympanic membrane for the thresholds and LDLs plotted in Figure 2. For this example, we have taken the 6 cm^3 coupler to tympanic membrane transform reported by Cox (1986) and plotted the predicted ear canal SPLs associated with this listener's thresholds and LDLs in Figure 3.

Unfortunaltely, because we have used a set of *average* values to perform this transformation, it can be anticipated that the predicted values that have been plotted in Figure 3 will be somewhat in error. To illustrate the degree of accuracy with which the ear canal SPLs can be predicted from the audiometric data collected for this listener, we have plotted the 95% confidence intervals reported by Cox (1986) around the mean transformed threshold and LDL values. It can be seen that at an alpha level of 0.05, we can expect this listener's

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Figure 4. Monaural air conduction thresholds (o) and loudness discomfort levels (□) measured using an in situ audiometric procedure. The projected levels of the amplified long-term average spectrum of speech and real-ear saturation response that are provided by a hearing aid are also shown.
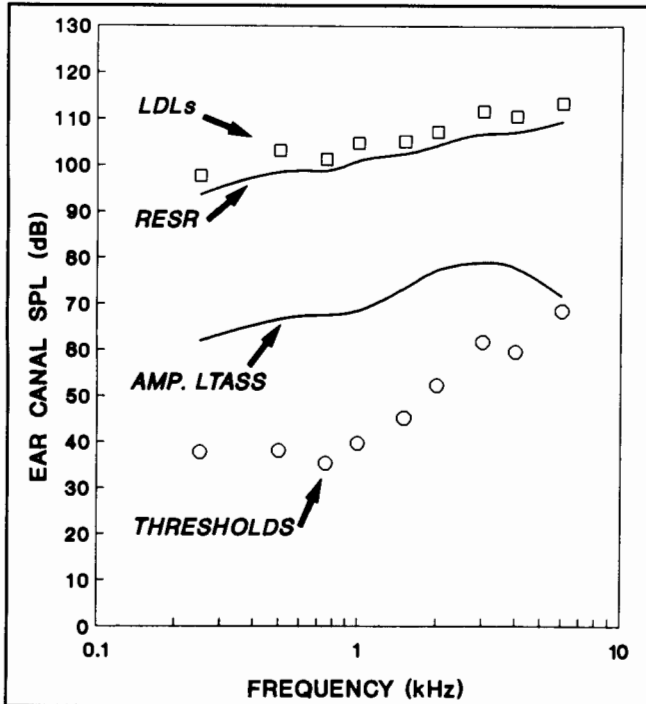
threshold and LDL values, expressed as dB SPL at the tympanic membrane, to fall within a range of 12 dB from between 0.25-2 kHz and within a range of 24 dB at frequencies above 2 kHz.

It can be assumed that the LDL measurements were made to select an appropriate output limiting characteristic for this listener. Because the conventional supra-aural earphone was employed, however, the clinician can only predict that this listener's LDL at 4000 Hz, for example, lies somewhere within a 24 dB range from between 97-121 dB SPL (see Figure 3). From our perspective, this level of accuracy in estimating the ear canal SPL associated with auditory variables is inadequate for the purposes of precise electroacoustic selection and fitting. Because audiometric data serve as the primary basis upon which electroacoustic selection and fitting decisions are made, serious consideration should be given to using alternative audiometric signal delivery/real-ear measurement options that allow for a more precise definition of auditory variables in a manner compatible with the electroacoustic characterization of hearing aids (Gagné et al., 1991a; Hawkins & Schum, 1991; Stuart et al., 1991; Stelmachowicz, 1991).

Consider the audiometric and electroacoustic data that have been plotted in Figure 4. Assume that the threshold and LDL values were obtained using an in situ audiometric ap-

proach (e.g., Gagné et al., 1991a). Because the ear canal SPL for these variables has been directly measured, and not predicted by using a set average values, we can have a greater degree of confidence in their validity for the purposes of electroacoustic fitting. In theory, this approach to audiometric assessment should facilitate a more accurate fitting of amplification to meet the requirements of each unique listener. We have attempted to illustrate this by plotting the projected levels of the amplified long-term average spectrum of speech along with the real-ear saturation response (RESR) that might be provided by a particular hearing aid. Note that by measuring all four variables at a common point of reference and in the same metric (i.e., ear canal SPL), their important inter-relationships can be studied and evaluated for electroacoustic fitting purposes.
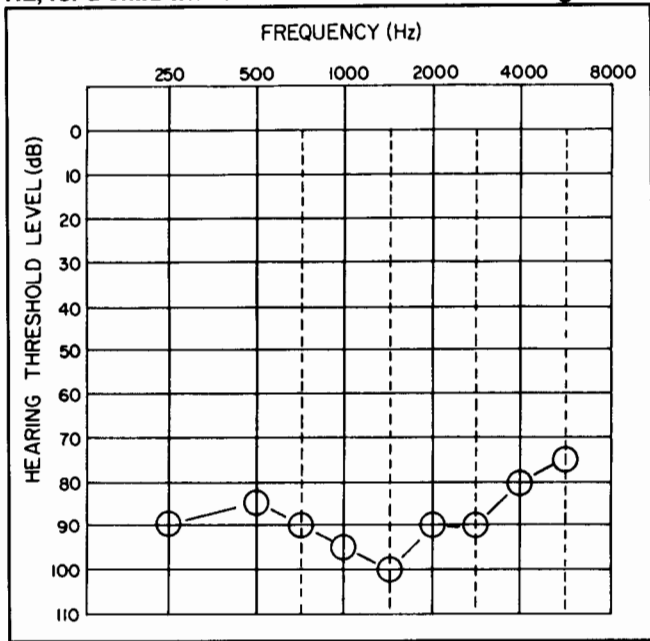
Within many clinical settings, audiometric thresholds are used exclusively to select the amplification characteristics of hearing aids. With this approach, it is assumed that thresholds provide a sufficient basis for making all electroacoustic selection decisions. This assumption will be considered briefly within the following section.

Supra-Threshold Audiometric Measures

Few if any hearing health care professionals would argue with the position that the maximum acoustic output produced by a hearing aid should be limited to a level below which a user will experience loudness discomfort. Rarely, however, are *systematic* clinical approaches presently applied to ensure that this condition has been accomplished. For some elusive reason, the measurement of supra-threshold audiometric variables continues to be an unresolved and somewhat controversial issue (e.g., Hawkins & Schum, 1991). In view of this controversy, it is of particular interest to note that, of the seven hearing aid selection methods listed in Figure 1, five recommend and describe specific procedures for supra-threshold measures. In fact, one of the methods that has been listed (i.e., Hawkins et al., 1987) was developed specifically for the purpose of selecting the output limiting characteristic of hearing aids for adult listeners. Furthermore, it should be noted that in their Consensus Statement regarding the recommended components of a hearing aid selection procedure for adults, Hawkins et al. (1991) stated that "some acceptable type of supra-threshold judgement (e.g., loudness discomfort level, uncomfortable listening levels, highest comfortable levels) should be used to determine an appropriate maximum output of the hearing aid" (p.321). Thus, the incongruity continues between that which is recommended and that which is routinely practiced.

When supra-threshold audiometric measurements are not made, it is assumed that loudness discomfort can be accu-

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Figure 5. Monaural air conduction thresholds (o), in dB HL, for a child with a severe sensorineural hearing loss.

Figure 6. Monaural air conduction thresholds (o) and loudness discomfort levels (□), measured in dB SPL (ear canal level), for a child with a severe sensorineural hearing loss. The audiometric procedures that were employed with this child are described in Gagné et al., (1991a,b).

rately predicted on the basis of threshold values alone. At the present time there are no data to support this assumption. In fact, all substantial data sets concerning the relationship between threshold and loudness discomfort in persons with sensorineural hearing impairment (e.g., Kamm, Dirks, & Mickey, 1978; Pascoe, 1988) suggest that these two variables are, at best, only slightly related. Obviously, there will be a proportion of the population (e.g., young children) with whom it is not possible to obtain reliable measures of loudness perception. For these individuals, Hawkins et al. (1991) have recommended that data-based predictions (e.g., Cox, 1985; Pascoe, 1988; Skinner, 1988; Seewald, 1991) should be used to determine the output limiting characteristic of a hearing aid. However, it cannot be assumed that such predictive approaches will provide the same degree of electroacoustic fitting accuracy as direct supra-threshold measurements. Descriptions of procedures for measuring LDLs and highest comfortable loudness levels (HCLs) in adults (e.g., Cox, 1985; Hawkins et al., 1987; Pascoe, 1988) and school-age children (Gagné, Seewald, Zelisko, & Hudson, 1991b; Kawell, Kopun, & Stelmachowicz, 1988; Stuart et al., 1991) are available to anyone who might be interested in performing these measures within their own clinical practice.

The following case example may serve to illustrate several limitations associated with the exclusive use of conventional threshold measurement procedures for the purposes of electroacoustic selection and fitting. The case to be described is a severely hearing impaired 12 year old child who was referred to our facility for an evaluation of her hearing aid fitting. Reportedly, the child persisted in turning down the
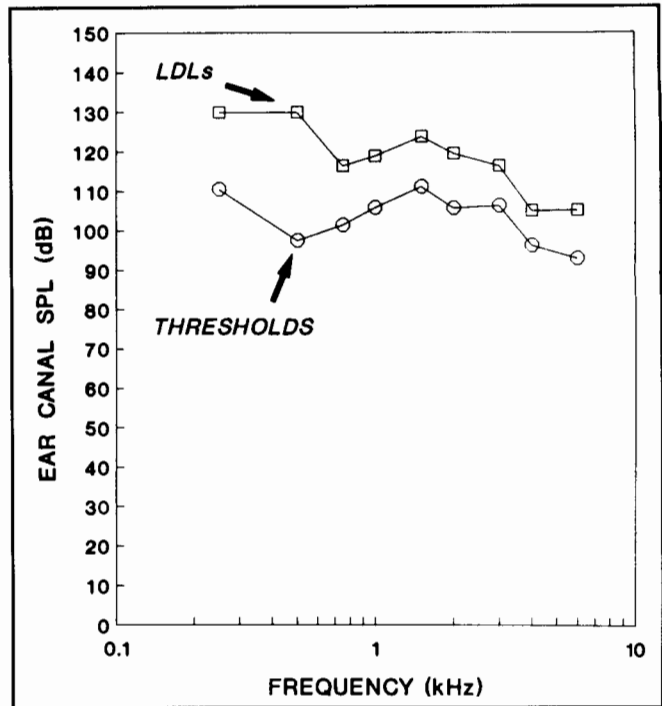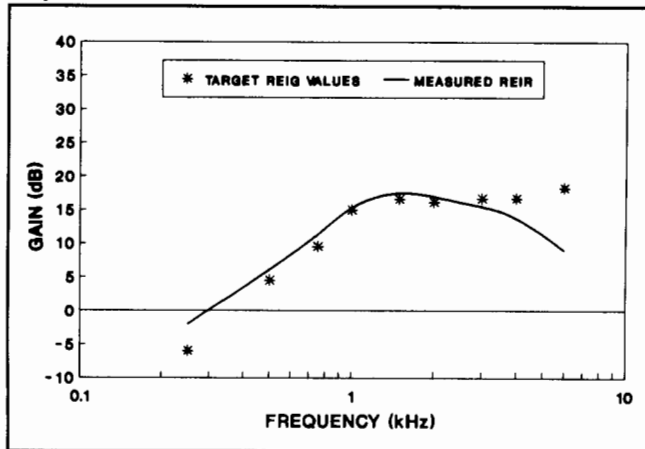
volume control of her hearing aid well below the recommended setting regardless of the electroacoustic adjustments that were made. The pure tone air conduction thresholds that were obtained for this child's right ear using standard procedures are shown in Figure 5.

As a first step, we chose to measure this child's thresholds and LDLs using in situ audiometric procedures (see Gagné et al., 1991a, 1991b). The results of this audiometric assessment are shown in Figure 6. Note that both the threshold and the LDL values have been plotted in dB SPL (ear canal level) in this figure. The nature of this particular electroacoustic fitting problem can be understood by carefully examining the relationship between the threshold and LDL values across frequencies. Most notable is the narrow range between the thresholds and LDLs at frequencies above approximately 750 Hz. For this child, the average dynamic range of hearing for the octave and inter-octave frequencies above 750 Hz is 12 dB with a minimum threshold/LDL difference of 8.7 dB at 4000 Hz. By defining this child's auditory characteristics in the manner shown in Figure 6, it is possible to select a set of electroacoustic characteristics that are optimally compatible with this unique audiometric profile. For this child, the audiometric thresholds obtained by conventional procedures (see Figure 5) did not provide sufficient information upon which to base the selection and fitting

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Figure 7. Target real-ear insertion gain values derived for a hearing impaired listener using the N.A.L.-Revised equations (Byrne & Dillon, 1986). The real-ear insertion response that was measured for this listener is also shown.
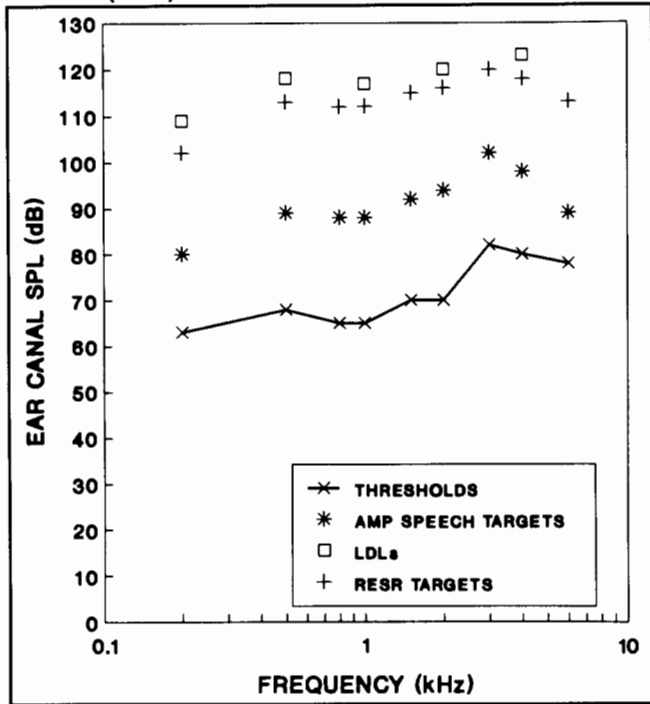

equations to be implemented and enter the client's threshold values into the software of the probe-tube microphone system.

To a certain extent, the specification of electroacoustic performance criteria, in terms of real-ear gain, is a result of history. Before clinical probe-tube microphone systems became generally available, desired real-ear performance criteria were specified, in the formal selection methods, as target aided sound field thresholds (e.g., Berger et al., 1984; Byrne & Tonnison, 1976; Cox, 1982; Popelka, 1982). These target aided sound field thresholds were derived by subtracting the desired real-ear gain (i.e., functional gain) from the unaided threshold values. With the introduction of clinical probe-tube microphone systems, it was both a natural and logical step to convert real-ear performance criteria as specified previously by the various methods (i.e., prescribed functional gain) into the electroacoustic analogue (i.e., prescribed insertion gain).

The use of insertion gain selection criteria, in conjunction with clinical probe-tube microphone measures of hearing aid performance, represents a significant step in the evolution of clinical practice in the selection and fitting of hearing aids. The general approach that is taken in using REIG target values to specify desired real-ear electroacoustic performance is illustrated in Figure 7. Specifically, the target REIG values that were derived for a given hearing impaired listener, using the N.A.L.-Revised equations (Byrne & Dillon, 1986), have been plotted in this figure as a function of frequency. Observe that the REIR that was measured for a hearing aid fitted to this listener is also shown. The main advantage of this general approach is that some criteria are available to the clinician against which the measured real-ear performance can be compared. Thus, with this approach, theoretical selection and real-ear verification have been effectively interfaced in a manner that can be implemented easily in routine clinical activity.

Despite the important role that insertion gain selection criteria have played in the evolution and validation of current selection methods, it must be acknowledged that the REIR is limited in several ways when viewed as the sole basis upon which the adequacy of a hearing aid fitting is evaluated. It is important that these limitations be acknowledged and understood particularly in view of some of the recent as well as several anticipated developments in hearing aid technology. From our perspective, one major limitation of the insertion gain approach to performance criteria specification is that the criteria, and the results of any subsequent measurements that relate to these criteria, exist apart from any meaningful and/or relevant context. Without being able to compare *directly* how the desired real-ear hearing aid response relates to a listener's auditory characteristics, it is virtually impossible to know, for example, where the amplified spectrum of speech will be placed within the listener's auditory area. In

decisions that were necessary to ensure the maximum use of residual hearing and comfort simultaneously. Unfortunately, because audiometric measures such as those obtained with this child are not performed routinely, we do not know how many of our clients receive only limited benefit from their hearing aids or, more seriously, have rejected the use of amplification altogether.

Specification of Electroacoustic Selection Criteria

The desired electroacoustic performance characteristics of hearing aids can be specified in several ways. These performance criteria, against which actual performance will be subsequently evaluated, can be expressed in terms of the desired or target performance in the real-ear or, alternatively, in terms of performance characteristics that can be measured in a 2 cm^3 coupler. Furthermore, for both the real-ear and coupler, there are now several options regarding how electroacoustic performance criteria can be specified. For example, real-ear hearing aid performance criteria can be specified in terms of target aided sound field thresholds (i.e., functional gain), the real-ear insertion response (REIR), the real-ear aided response (REAR), and/or the real-ear saturation response (RESR).

Common to most, but not all, contemporary hearing aid selection methods is the specification of real-ear hearing aid performance criteria in terms of the desired (i.e., target) real-ear gain as a function of frequency. Consequently, all clinical probe-tube microphone systems implement the real-ear insertion gain (REIG) equations that are associated with several of the electroacoustic selection methods. To derive the target REIR for a client, the clinician need only select the set of
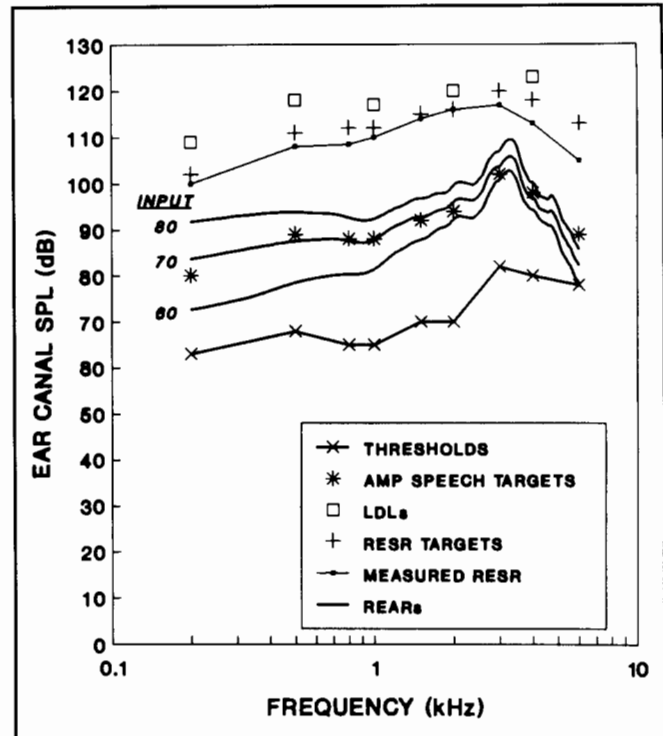
Figure 8. Monaural air conduction thresholds and loudness discomfort levels, measured in dB SPL (ear canal level), for a listener with a moderate sensorineural hearing loss. The target levels for the long-term average spectrum of speech and the target values for the real-ear saturation response (RESR) of the hearing aid are also shown. The electroacoustic selection criteria were derived for this listener using the method described by Seewald (1992).

Figure 9. Monaural air conduction thresholds and loudness discomfort levels, measured in dB SPL (ear canal level), for a listener with a moderate sensorineural hearing loss. The target levels for the long-term average spectrum of speech and the target values for the real-ear saturation response (RESR) of the hearing aid are shown. In addition, three real-ear aided responses (REARs), in dB SPL, that were obtained from an input compression hearing aid in response to a speech-weighted complex signal presented at overall signal input levels of 60, 70, and 80 dB SPL and the real-ear saturation response (RESR) of the hearing aid are shown.

this regard, the earlier specification of real-ear hearing aid performance criteria that were stated in terms of aided sound field threshold values (i.e., desired functional gain) provided the relative advantage of being able to relate the theoretically derived criteria directly to other variables within a familiar context (i.e., the audiogram). Unfortunately, however, target insertion gain values are, at the least, one step removed from this familiar and tangible reality.

Consider, for example, the information that is presented in Figure 7. It can be observed that, at most frequencies, the measured response provided a reasonably good approximation to the N.A.L.-Revised target insertion gain values. However, one might ask if the differences that are observed between the target and measured values at 4 and 6 kHz mean that the speech signal at frequencies above approximately 3 kHz will be inaudible under average listening conditions. Unfortunately, it is not possible to answer this important question on the basis of the information that is presented in Figure 7. This issue of context will likely become more significant as we attempt to select and fit the new generation of hearing instruments that incorporate more sophisticated signal processing schemes (i.e., beyond linear gain). With the

capability to adjust the compression thresholds and compression ratios within several independent channels, it will be necessary to re-formulate the manner in which the electroacoustic selection criteria are expressed. This might include a shift back to an auditory-based context.

An alternative to the insertion gain approach in which the performance criteria are expressed in terms of the REAR and RESR hearing aid selection criteria is presented in Figure 8. The variables that have been plotted in this figure include: (1) a listener's monaural thresholds and LDLs; (2) the REAR target values for the amplified long-term average spectrum of speech having an assumed overall level of 70 dB SPL; and (3) the target values for the real-ear saturation response (Seewald et al., 1991; Seewald, 1992). Note that all four variables have been plotted in dB SPL (ear canal level) as a function of frequency. More importantly, observe that the electroacoustic performance criteria have been stated within the context of this listener's auditory area.

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In addition to the variables shown in Figure 8, the variables presented in Figure 9 include the REARs that were measured for an input compression hearing aid in response to a speech-weighted complex signal presented at three different overall signal input levels of 60, 70, and 80 dB SPL. In addition, the RESR of this instrument, as measured with a 90 dB SPL pure tone sweep, is also shown. The advantages of this general approach to specifying hearing aid performance criteria in combination with probe-tube microphone measures should be apparent, relative to the more conventional insertion gain approach (see Figure 7). From the data that are presented in Figure 9, for example, it is possible to develop predictions regarding the audibility of speech as a function of input signal level. Furthermore, it is possible to be more confident that comfortable listening will be provided to this listener within the aided condition. From our perspective, this general approach to electroacoustic selection and fitting will assist us in meeting the more complex fitting challenges that lie ahead.

Summary

Several issues related to clinical hearing aid selection and fitting practices have been discussed. The formal methods that have been developed for hearing aid selection were identified and characterized. Several concerns regarding current implementations of available methods were raised. First, the need to differentiate between hearing aid selection methods and prescriptive formulae was discussed. Second, a concern was expressed regarding the limited nature of current probe-tube microphone system implementations of these methods. Third, because each of the formal methods comes with its own rationale, recommended procedures, and assumptions, clinicians were encouraged to consult the original publications associated with any method before attempting to implement the method with their clients.

Consideration was given to the collection and interpretation of audiometric data for the purposes of hearing aid selection and fitting. It was observed that threshold data only, collected using standard audiometric procedures, provide a very limited basis upon which to base electroacoustic selection and decision making. For this reason, the collection of audiometric data for electroacoustic selection and fitting must be viewed as more than a simple extension of the diagnostic process. Finally, consideration was given to the manner in which current hearing aid selection methods specify electroacoustic performance criteria. We now have a variety of options for characterizing real-ear hearing aid performance. Therefore, there is a need to reconsider how to express the criteria against which measured performance will be evaluated. A brief case example was presented to illustrate the potential value of stating electroacoustic performance criteria in terms of the real-ear aided response and the real-ear saturation response. It is anticipated that this general approach will become particularly useful as we attempt to fit the newer generation of hearing instruments to our clients.

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