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The Effect of Using Averaged Versus Custom Real-Ear to Coupler Difference Values in the Desired Sensation Level Approach to Prescribing Hearing Instrument Gain

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THESIS APPROVAL

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Abstract

An abstract of the thesis of John Aaron Coverstone for the Master of Science in Speech Communication: Speech and Hearing Science presented January 20, 2000.

Title: The Effect of Using Averaged versus Custom Real-Ear to Coupler Difference Values in the Desired Sensation Level Approach to Prescribing Hearing Instrument Gain.

Because there are many variables and much missing information when fitting young children with hearing instruments, it is necessary to rely on prescriptive procedures such as the Desired Sensation Level (DSL) Method to create target 2cc gain values for ordering and fitting hearing instruments. Inherent in creating 2cc targets is a conversion process known as a real-ear to coupler difference (RECD) measurement. The DSL algorithms make allowances for averaged data to be used in lieu of this measurement.

The purpose of this study is to evaluate the validity of using averaged real-ear to coupler difference values included in the DSL computer program in its calculation of target 2cc coupler gain for hearing instruments. The results of applying those values when fitting hearing instruments, as opposed to using custom values, was determined. To achieve a measure of the impact of any

observed deviation from the DSL's RECD values, both custom RECD values and the averaged values used by the DSL Program were used to predict real-ear response curves from measurements of each subject's hearing instrument(s) on a 2cc coupler.

RECD values were calculated for twelve children (twenty ears) with normal outer ears and intact tympanic membranes, as determine by the researcher. These values were compared against published values and analyzed for inter-subject variability.

Analysis of the data demonstrated a wide variability of RECD values between subjects, even though the average of all ears reasonably approximated published averaged data. When individual RECDs were used to create 2cc targets, it was discovered that there is potential for targets generated using average data to significantly over-amplify some patients and under-amplify others.

THE EFFECT OF USING AVERAGED VERSUS CUSTOM REAL-EAR TO COUPLER DIFFERENCE VALUES IN THE DESIRED SENSATION LEVEL APPROACH TO PRESCRIBING HEARING INSTRUMENT GAIN

by

JOHN AARON COVERSTONE

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Introduction

The importance of hearing to a child's development can not be overemphasized. Children with significant hearing loss are at a disadvantage for acquiring speech and language and for learning social and academic skills. The greater the hearing loss, the greater the impact on the child. Research shows that the earlier hearing losses are identified in children and remediation is begun, the greater a child's level of speech production and linguistic competence in the early years of life (Davis & Wood, 1992).

Early intervention programs have been developed to provide habilitation to young children in attempts to minimize the effects of hearing loss on their overall development. These programs concentrate on improving communication skills through effective modeling and focusing on everyday situations. Although this is an important part of the process of habilitation of children with hearing loss, efforts to improve the auditory signal should accompany habilitation programs for the majority of children with hearing impairment (Matkin, 1987). The method used to provide adequate auditory input for children with hearing impairments is, therefore, an important consideration.

Traditionally, hearing instrument fitting procedures have followed a trial-and-error method, relying solely on an audiogram for a guideline and providing necessary adjustments as the child ages and can provide more feedback (Eisenberg & Levitt, 1991). This poses problems in attempting to meet the goal of providing appropriate amplification that allows a child the maximum benefit that can be derived from his or her residual hearing. Very young children (i.e. - preverbal or those with minimal expressive skills) cannot provide feedback about the sound of a hearing instrument and do not have the listening experience upon which to base such feedback. This leaves the clinician with little idea as to how effective the amplification characteristics are for the child. This means that this method potentially falls far short of the goal.

Prescriptive fitting procedures have been developed by various researchers in efforts to provide an objective means of estimating ideal gain for hearing instruments. Prescriptive procedures attempt to prescribe the amount of gain an individual will need, based on formulas derived from certain assumptions and readily available test data. If both the formulas and their underlying assumptions are sound, this provides a method of fitting hearing instruments

that is potentially much less time consuming and much easier than comparative fittings.

The availability of prescriptive procedures for fitting children holds immediate potential for taking much of the guesswork out of projecting how much amplification a child will need. Unfortunately, prescriptive procedures have largely been formulated for adults (Seewald et al., 1987). Because of the enormous importance of achieving an optimal fit on children, a premium must be placed on formulating prescriptive procedures for children. A prescriptive procedure for children needs to account for the particular amplification needs and physical characteristics of pediatric patients.

The Desired Sensation Level (DSL) is one such procedure that is targeted toward children (Seewald et al, 1992). The DSL is a prescriptive procedure that uses hearing thresholds to estimate the gain a hearing instrument needs to provide to make speech clearly audible to a patient.

Typically, dispensers analyze hearing instruments with a 2cc coupler in a hearing instrument test chamber. This practice allows a standard measurement to be used by anyone who needs to analyze the function of a hearing instrument. This is usually done to periodically ascertain whether the hearing instrument is functioning within tolerance limits of

the reference measurement provided by the manufacturer. Analyses are sometimes peformed to approximate fitting a hearing instrument on a patient's ear.

Although the 2cc coupler is designed to approximate the volume of an adult ear canal, it neither approximates the volume of a child's ear canal nor provides resonance characteristics consistent with children's ears (Jirsa & Norris, 1978; Fikret-Pasa & Revit, 1992). To allow comparisons of hearing instrument output as measured on a 2cc coupler and output as measured in an individual's ear, real-ear to coupler difference (RECD) values have been developed to allow conversions between the two measurements (Burnett & Beck,1987; Nelson Barlow et al, 1988; Feigin et al,1989; Zelisko, Seewald, & Gagne, 1992). Real-ear to coupler difference values are a product derived by subtracting the stimulus measured through a 2cc coupler from the same stimulus measured in a subject's ear. The DSL algorithms provide real-ear to coupler difference conversion capabilities so that a hearing instrument dispenser can specify 2cc coupler gain when choosing a hearing instrument (Seewald, Ross, & Spiro, 1985; Seewald et al, 1993).

RECD values are used to convert desired real-ear gain values to a target hearing instrument response on a 2cc coupler. If the dispenser wishes, custom RECD values can be

calculated for each patient. Using custom RECD values presumably helps to reduce the possibility of error introduced by variations in individuals' ear canal resonances. This would theoretically result in maximum accuracy of coupler response values, but would increase the amount of time that must be spent in evaluation. If the canal resonance characteristics of most children do not vary significantly from the averaged data, use of averaged data provides an acceptable method for performing the real-ear to coupler conversion. If there is significant variation in canal resonances from the averaged data, the only way to maintain acceptable validity of measurements may be to generate patient-specific RECDs.

This study was designed to assess whether a hearing instrument dispenser can use averaged data in real-ear to coupler conversions for pediatric patients with certainty that the result will be accurate for each child's ears, or whether RECD values need to be generated for each patient. The size of a child's ear canal is significantly different from that of most adults and from that of other children, especially when there is a difference in age (Dempster & Mackenzie, 1990). From this observation, it is predicted that the ear canal resonances of most children will vary from one to another and from any averaged values that have

been generated. This would result in actual amplification received from hearing instruments (as measured in the ear canal) varying from predicted amplification values. It may even result in grossly inappropriate fittings, should the difference in RECD values prove great enough.

The main purpose of this study is to evaluate the validity of using average real-ear to coupler difference values included in the Desired Sensation Level computer program in its calculation of target 2cc coupler gain for hearing instruments. The results of applying those values when fitting children with hearing instruments, as opposed to using custom values, will be determined. To achieve a measure of the impact of any observed deviation from the DSL's RECD values, both the custom RECD values and the average values used by The Desired Sensation Level Program will be used to predict real-ear response curves from measurements of each subject's hearing instrument(s) on a 2cc coupler.

Literature Review

THE ROLE OF HEARING IN DEVELOPMENT

Hearing is an extremely important part of a child's development. A hearing loss can result in severe delays in communicative, cognitive, and social development. It is unquestionably in a hearing impaired child's best interest to receive amplification as early as possible after identification of a hearing loss. There is also increasing support of the belief that a hearing impaired child's rate of development is directly linked to the age at which he or she receives amplification (Matkin, 1987; Tannahill & Smoski, 1985; Nowell, 1985).

Of the various aspects of a child's development, communication skills may be one of the most important. Schum (1991) supports the belief that language and communication ability are key to social and behavioral development. From this persective, the importance of providing a child with amplification cannot be overstated. As pointed out by Schum (1991), deaf or hard of hearing children display patterns of speech and language development similar to normally hearing children. This allows us to conclude that efforts to address hearing loss may help to limit the delays in the development of hearing-impaired

children. Stated most simply, the main problem hearing impaired children face is simply that they cannot hear.

THE IMPORTANCE OF EARLY IDENTIFICATION AND INTERVENTION

Early intervention programs have been implemented in attempts to identify children with disorders and provide help as early in a child's development as possible. These efforts are aimed toward increasing a child's chances of developing more closely to normal children. It is widely supported that amplification should be made available to children as early as possible (Matkin, 1987), a theory that is supported by a study by Stokes and Bamford (1990). They found that the subject identified and fit with amplification earliest most closely followed the normal pattern of development. They discovered that infants diagnosed as hearing impaired in their first year may make a transition from pre-linguistic to linguistic communication that follows the normal pattern of linguistic development.

APPROACHES TO HEARING INSTRUMENT SELECTION AND MEASUREMENT

Many problems arise when addressing the issue of amplification for the pediatric population. Infants, toddlers, and very young children are unable to perform the behavioral tasks that result in high confidence auditory

thresholds across an adequate range of frequencies. Young children, and some older children, can be expected to tire of the task well before the full range of audiometric frequencies have been covered. Therefore, estimates of gain and frequency response may be based on limited and unreliable data.

Once auditory data has been obtained, the audiologist must decide what means of amplification is appropriate for a child if this course of action is to be pursued. It is especially important that the amplification provided by a hearing instrument will appropriately provide a child with the necessary auditory input. The means by which this may be accomplished are varied. A paired comparison approach, as used with many adult patients, is not appropriate for many older children and especially for very young children (Eisenberg & Levitt, 1991). Young children are most often unable to provide adequate feedback about the quality of input provided by amplification devices. Eisenberg and Levitt(1991) suggested that paired comparison techniques can be used with many children 6.5 years and older and occasionally with younger children.

A method used by many clinicians is comparison of aided to unaided hearing thresholds, or functional gain measurements. As stated by Schwartz and Larson (1977),

evaluations of threshold information are inadequate for assessing the benefit to a child with respect to speech recognition occurring at intensities well above thresholds. Determining a child's relative ability to detect pure tone stimuli may also have little correlation to a child's reception of a complex speech signal. Furthermore, this procedure is potentially fallible and is not a trivial undertaking when dealing with young children. The problems encountered in a threshold search are increased by the addition of hearing instruments. The child must endure further testing, only a few frequencies are tested, and the possibility exists that the noise floor will be amplified to levels audible in a sound field testing situation. All these factors can combine to create an undesirable environment for evaluating hearing instrument fittings.

Methods of determining target hearing instrument output based on formulas derived from a large number of subjects' preferences, called prescriptive procedures, have become increasingly popular in recent years (Byrne & Dillon, 1986; Humes, 1986; Fikret-Pasa & Revit, 1992; Stelmachowicz et al, 1993). Many of these methods use auditory threshold data as a basis for the formulas and provide as output target hearing instrument gain values. As pointed out by Seewald, Ross, and Stelmachowicz (1987) however, these procedures can

be grossly inadequate for fitting children. The primary goal of fitting hearing instruments on adults, for whom these procedures were intended, is to provide a comfortable amplified signal. As young children do not have an established language system, the primary goal of fitting hearing instruments on children is to make as much of the long-term speech spectrum (LTSS) audible, comfortable, and undistorted across as many speech frequencies as possible. This is to assist in developing language and allowing the child to function in educational, social, and home environments. Therefore, the goals of fitting hearing instruments on children differ from that of fitting adults and prescriptive procedures designed with adults in mind are inappropriate for use with children.

SIGNIFICANCE OF PEDIATRIC PRESCRIPTIVE PROCEDURES

Prescriptive procedures designed for adults simply cannot be directly applied to pediatric fittings and be expected to provide acceptable amplification (Seewald et al, 1985; Seewald et al, 1987). The level of acoustical input that serves as a basis for many calculations of gain for adult hearing instruments is not the same as that for children. In a study by Stelmachowicz, et al. (1993), typical speech inputs at the microphone of the hearing

instrument on children were found to be up to 20 dB higher than the level typically measured when using the one-meter speaker distance often associated with adult conversation and used by those formulating prescriptive procedures. Stelmachowicz attributes this to the closer proximity within which parents interact with children. Additionally, current prescriptions of hearing instrument gain that is targeted for adults are seemingly inadequate for prescribing gain for children. Snik and Hombergen (1993) found that, on the average, present prescriptive procedures resulted in a greater insertion gain with children than adults, as measured with a real-ear system.

In fitting hearing instruments, the audiologist must rely on experience, electroacoustical data, listening to the instrument, and observation of the child to determine the appropriateness of the fit. This area of hearing instrument fitting becomes especially crucial when fitting an instrument on a child with a mild to moderate hearing loss, for whom a wider (and more variable) range of intensities may be prescribed. The restricted dynamic range of those with severe to profound impairments allows the prescription of only a limited amount of gain before maximum allowable output levels are reached. Children with mild to moderate hearing impairments can more easily be prescribed gains that

fall within their dynamic range and stay well below sound pressure levels that are considered damaging. However, because large amounts of gain can be provided with relative ease from modern hearing instruments, this population is presented with the greatest possibility of overamplification should thresholds be overestimated.

For these reasons, a separate group of criteria must be formed for prescribing amplification for children. This is no easy task, as the criteria must be almost universal while taking into account the specific needs and characteristics of children.

THE DESIRED SENSATION LEVEL METHOD

Seewald, Ross, and Spiro (1985) have developed a procedure for prescribing hearing instrument gain named the Desired Sensation Level (DSL). This procedure was designed using research results describing the specific listening needs and practical aspects of hearing instrument fittings on children.

The DSL is a set of calculations that uses hearing thresholds obtained using pure tone stimuli and predicts desired gain for a hearing instrument as measured in the user's ear (called a real-ear measurement) or in a hearing instrument test chamber with a 2cc coupler. As described by

Seewald et al. (1987), the desired sensation levels, derived from calculations based on a person's hearing thresholds, are added to the individual's hearing thresholds, in dB SPL, to produce the amplified speech targets, also in dB SPL. This is the desired level for the individual to receive speech, usually through an amplifying device, and is called the amplified speech spectrum (often referred to as the long-term amplified speech spectrum, or LTASS). To calculate the gain needed to achieve these targets (desired real-ear gain), Seewald's speech spectrum is subtracted from the target amplified speech spectrum. This results in the amount that speech needs to be amplified to meet the targets.

Seewald has made the DSL procedure available via computer (Seewald et al. 1993). The computer program uses pure tone thresholds obtained via headphones, insert receivers, or sound field to produce prescribed use gain, full-on gain (FOG), and saturation sound pressure level (SSPL), as measured on a 2cc coupler. The significance of generating predicted values for a 2cc coupler is that it allows the dispenser to use the 2cc coupler and test chamber to estimate the amount of amplification that the child will receive once the hearing instrument is fit. Additionally, hearing instrument orders are placed using a 2cc reference

and the dispenser must be able to estimate the 2cc gain needed to achieve the desired gain when the instrument is fitted on the child's ear. Also supplied are predictions of in situ gain, DSL real-ear saturation response (RESR), insertion gain, and aided sound field thresholds in decibels Hearing Level (dB HL). These values are used to prescribe the gain that the child should receive, as measured with the hearing instrument fit on the ear.

One of the benefits of the computer program is the flexibility it allows the clinician. Because the calculations are performed on a computer, the DSL program easily allows the clinician to input custom information. Clinicians can input measurement variables including stimulus transducer type, stimulus calibration reference - HL or SPL, and custom stimulus conversion values such as real-ear to dial difference or real-ear to coupler difference measurements. Clinicians can also input hearing instrument variables such as circuit type, shell characteristics, and, when appropriate, earmold type and plumbing. Finally, clinicians can choose to use the DSL's averaged RECD data or input custom values.

CLINICAL SIGNIFICANCE OF REAL-EAR MEASUREMENT SYSTEMS

Real-ear measurement can serve as an important part of the hearing instrument fitting process in children, as it gives us a tool for eliminating some of the guesswork in prescribing hearing instrument gain. As found by Feigin et al. (1989), Lewis and Stelmachowicz (1993), Dempster and Mackenzie (1990), and Nelson Barlow et al. (1988), the resonances of children's ears vary significantly from those of adults and other children, even those in the same age group. These findings lend increased importance to obtaining individual real-ear measurements from each child who is a hearing instrument candidate.

With the advent of real-ear measurement systems that are both feasible and affordable for clinical use, it is now possible to quickly provide a direct measure of the sound pressure level (dB SPL) at the eardrum with a hearing instrument in place. Real-ear systems can quickly measure a large range of frequencies and obtain a reliable and complete measurement of what a hearing instrument is delivering to a person's ear. This has drastically eased the chore of performing evaluations of hearing instruments on the wearer. The significance in clinical use is that we can measure both the resonance of a patient's ear and a hearing instrument's output while it resides in the

patient's ear. This brings to hearing instrument fitting procedures a dimension of verification not previously available.

Measuring hearing instrument performance at the eardrum not only provides a more accurate measure of a hearing instrument's output, but also provides a common point of reference for all clinical measurements (Skinner, 1988). Conversion factors have been described which allow for measurements from instruments calibrated in a sound field or on 2cc or 6cc coupler to be expressed in SPL at the eardrum (Lewis & Stelmachowicz, 1993; Skinner, 1988; Barlow et al, 1988; Feigin et al, 1989; Burnett & Beck, 1987; Cox, 1986). Direct comparisons of these measurements (with the addition of conversion values) can be performed, provided that the conversion values are accurate.

The conversion of measurements to SPL at the eardrum takes on added significance when prescribing gain for hearing instruments. If the frequency response of a hearing instrument is prescribed in terms of measurement on a 2cc coupler, the clinician can evaluate the hearing instrument and make initial adjustments without the patient present by adding the values to convert from the 2cc coupler to real-ear measurement.

The RECD can be calculated for each individual, but this adds time and work to the process. If an averaged measurement of RECD is used, the clinician can omit this extra step from the real-ear evaluation process, permitting again that the conversion values are accurate and the variance is insignificant.

REAL-EAR MEASUREMENT PROCEDURES

Real-ear measurement systems consist of a microphone connected to a probe tube to be inserted into the patient's ear, a microphone that resides outside the patient's ear and serves as a reference microphone, a speaker for signal presentation, and a computer system for signal generation, measurement, and analysis. The procedure for performing real-ear measurements involves six steps. The terminology and procedures are taken from Mueller (1990) and Preeves (1987). First, the probe tube is inserted into the patient's ear, with the reference microphone positioned just outside the ear, and a leveling signal is presented from the speaker to calibrate the microphones to each other. Next, the real-ear unaided response (REUR) is measured by presenting a signal to the ear. This signal may be any of a number of sounds, but, as recommended by Preeves (1987), is usually a composite noise signal as this most closely

approximates the complex signals that will be processed by a hearing instrument (This measurement may even be used before the hearing instrument fitting. If any significant deviations are noted from averaged unaided responses, the clinician may submit a copy of the real-ear response to the hearing instrument manufacturer so that this consideration may be used during the manufacturing process.).

Next, the hearing instrument is inserted into the patient's ear and set at use level, with the probe tube in place, and a second measurement is made with the same stimulus. This measurement is the real-ear aided response (REAR) and reflects the actual output of the hearing instrument while in the patient's ear. From these two measurements, the real-ear insertion gain (REIG) and in situ gain can be calculated. Insertion gain is a description of how much amplification is provided to the user by the hearing instrument. It is calculated by subtracting the REUR from the REAR. Insertion gain may be compared to gain as measured in a test box on a 2cc coupler to determine that amount of amplification a person's ear is providing from natural resonance. In situ gain is a measure of the amount of amplification a person is receiving from a hearing instrument in reference to that individual's environment, taking into account the resonance of the person's ear. In

situ gain is calculated by subtracting the response of the reference microphone from the REAR.

From this data, the real-ear to coupler difference (RECD) values can be calculated. The RECD is an important part of hearing instrument fitting, because some prescriptive procedures, and the DSL in particular (Seewald et al, 1993), use this value in calculating target gain. If the clinician is to avoid having to input into the DSL program custom RECD values for each patient, averaged data must be used in these procedures. As with any other averaged data, this allows for the potential for significant variations from the average and, therefore, variations from the prescribed gain.

PEDIATRIC REAL-EAR TO COUPLER DIFFERENCE VALUES

The volume of a child's ear canal is smaller than that of an adult, from which the 2cc value for hearing instrument couplers was derived. This size discrepancy in a child's ear canal and pinna results in a different frequency shaping for sound stimuli, most notably in an altered resonant frequency (Dempster & Mackenzie, 1990). A study by Barlow et al.(1988) found real-ear to coupler differences between children and adults of 10-15 dB at some frequencies. Jirsa and Norris(1978) found that significant differences existed

between adult and child ear canal volume measurements and state that "2-cc coupler measures are not appropriate guidelines for the fitting of hearing aids to young children."(p.351) This difference in resonance frequencies creates a difference in the frequency shaping of the signal delivered by the hearing instrument and potentially invalidates the RECD values when applied to children.

Although Lewis and Stelmachowicz(1993) found little differences in real ear to 6cc coupler measurements (those used in calibrating supra-aural headphones) between children and adults, the intersubject variability was substantial. These substantial differences between subjects supported findings by Nelson Barlow et al. (1988). These findings collectively point out the need for individualized assessment in fitting hearing instruments on children and complicate the task of providing a universal prescriptive procedure. Nelson Barlow et al. (1988) called for "a more direct measure of SPL, such as probe tube microphone measures" (p.247) in determining the real-ear output of hearing instruments, and SSPL90 values in particular, in comparison to a 2cc coupler.

SIGNIFICANCE OF USING CUSTOM RECD VALUES

The DSL method for prescribing target hearing instrument gain uses averaged RECD values to convert from real-ear insertion gain (REIG) to gain on a 2cc coupler (Seewald, 1992), which must be used for selection of a hearing instrument, as manufacturers have standardized on reporting hearing instrument specifications in this fashion. The ability to perform this calculation and store the RECD values was actually a breakthrough in Seewald's procedure, as only one measurement must now be made on a child. That value is then stored and can be used to evaluate hearing instrument performance in a test box using a 2cc coupler. This eliminates the need for repeated measurements of insertion gain on a child and provides a method of conversion deemed "crucial" by Nelson Barlow et al. (1988).

Hawkins, et al.(1989) found it appropriate to utilize a real ear measurement system to verify target gain values that have been created in order to amplify as much of the speech spectrum as possible for children. The incorporation of this functionality into the DSL procedure has allowed for individualized prescription of hearing instrument gain based on formulas designed to provide targets specifically for children.

Methods

In this study RECD values were measured for a group of children for comparison to the values used by the DSL computer program and to other published values. This was achieved by measuring a stimulus presented to the subjects' ears and comparing it to the same stimulus measured in a 2cc coupler. The individual RECD values were also analyzed for inter-subject variability and for deviation from the averaged values generated from the subjects' measurements. In addition, calculations were made to assess the potential impact of clinical use of these measurements by determining the difference in prescribed hearing instrument gain when various RECD values were used in the DSL computer program.

SUBJECTS

15 children (30 ears) 4 to 12 years of age were included in the study. The children were recruited through requests for participation from parents with children in the speech and hearing clinics at Portland State University and from an open request to parents at the University. Requirements for candidacy were that subjects 1) had normal pinnae and auditory canal structures, as determined via otoscopy, and 2) had no history of ossicular abnormalities or recent procedures involving the tympanic membrane (such

as insertion of PE tubes), as determined by case history. Hearing levels were not used as criterion for candidacy as our objective was to measure canal resonance, which is not dependant on normal functioning cochlear or neural structures. Subjects were inspected via otoscopy for presence of cerumen and any other conditions that could alter canal resonances. Seven individual ears were disqualified due to excessive cerumen. In addition, one ear was disqualified due to noted redness of the tympanic membrane and surrounding tissues and the subject's complaint of discomfort in his ear. Two ears were disqualified due to one subject's refusal to participate in the procedure. The remaining twenty ears were used in the study.

EQUIPMENT

All presentations were made using a Tascam cassette recorder/player using a Maxell UDXL-II cassette tape. Measurements were made using the Frye Electronics Fonix 6500 Hearing Instrument and Real-Ear Analyzer. At the time this study was performed, the Fonix 6500 did not allow for the automatic generation of RECD values. This limitation was due to the inability of the Fonix 6500 to generate a stimulus through a single transducer and record it with both the real-ear microphone and hearing instrument test chamber

microphones (via 2cc coupler)[1]. In order to accomplish this task, a modification to the standard real-ear measurement procedure was necessary. Therefore, recordings were achieved by coupling the real-ear output from the Fonix 6500 to the audio input of the tape recorder and recording a 70 dB SPL speech-weighted composite stimulus (a wide-band noise stimulus).

The stimulus was played back through an E.A.R. 3A insert receiver coupled to the headphone jack of the tape recorder for all stimulus presentations. The headphone jack was used to prevent the need for adapters (RCA to 1/4") to couple the insert receiver to the line output and thereby risk degrading the signal. The headphone volume control dial was taped in place to prevent any alteration of the output.

The earplug of the insert receiver was coupled to the HA-1 2cc coupler with *Fun Tak* putty, with the receiver tubing centered over the coupler opening. The insert receiver was calibrated according to ANSI s3.6 (1989) proposed standards for insert earphone calibration. The probe tube was calibrated according to the procedure

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1 A RECD kit is now available from Frye Electronics which allows clinicians to create these values using the Fonix 6500.

recommended by Hawkins and Mueller (1992). A diagram of the equipment is provided in Figure 1.

PROCEDURES

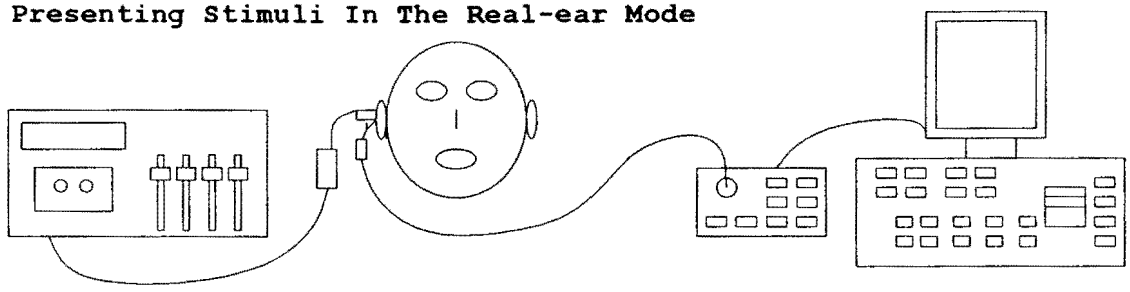
Seven measurements were made on 6 separate days with the insert receiver coupled to the 2cc coupler. These measurements were performed prior to each session with subjects. All aspects of the project were performed at the Portland State University Audiology Clinic.

Real-Ear To Couple Difference Measurement

A 2cc coupler response measurement was taken prior to each session of real-ear response measurements. The 2cc measurements were performed by securing the insert phone to the 2cc coupler with putty and measuring the output with the Fonix test chamber microphone. To obtain frequency-specific values, the curve displaying the measurement was frozen on-screen and the *Data* button was pressed to numerically display the data for printing. This also allowed the opportunity to review the stimulus to ensure that the section of tape being used for that group of subjects contained a stable stimulus (i.e., had not degraded from previous use).

Figure 1

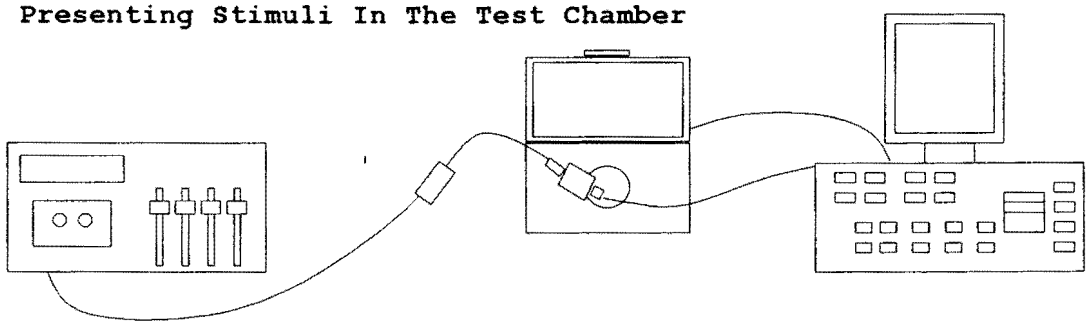
Presenting Stimuli In The Real-ear Mode



Tascam with EAR-3A Insert Phone

Fonix 6500 Real-ear System

Presenting Stimuli In The Test Chamber



Tascam with EAR0-3A Insert Phone

Fonix 6500 with 2cc Coupler in Test Chamber

All RECD values were generated using whichever 2cc coupler measurement had been recorded prior to the session in which a particular subject was included. This ensured that the same section of tape was being used for each measurement, accounting for minute variability that may arise from tape wear, potential variations in tape integrity and any other source of day-to-day variability in the stimulus source.

Real-ear measurements were taken once in each ear with the real-ear probe tube and insert earphone present simultaneously in the ear canal. Frequency specific values were obtained using the same method as with the 2cc coupler measurement. Acoustical measurements were taken in the real-ear and 2cc coupler conditions using the speech weighted noise originally generated by the Fonix 6500 and recorded and played back by the cassette recorder.

The probe tube was inserted into the external auditory canal to a depth of approximately 15 - 20 mm, as recommended by Lewis and Stelmachowicz (1993). The depth of insertion was determined by positioning the probe tube so that the tragus was located between marks at 15mm and 20mm. Response values measured at the beginning of each session with the insert receiver on the 2cc coupler were subtracted from

values measured in the real-ear condition during that session to obtain the RECD for each subject.

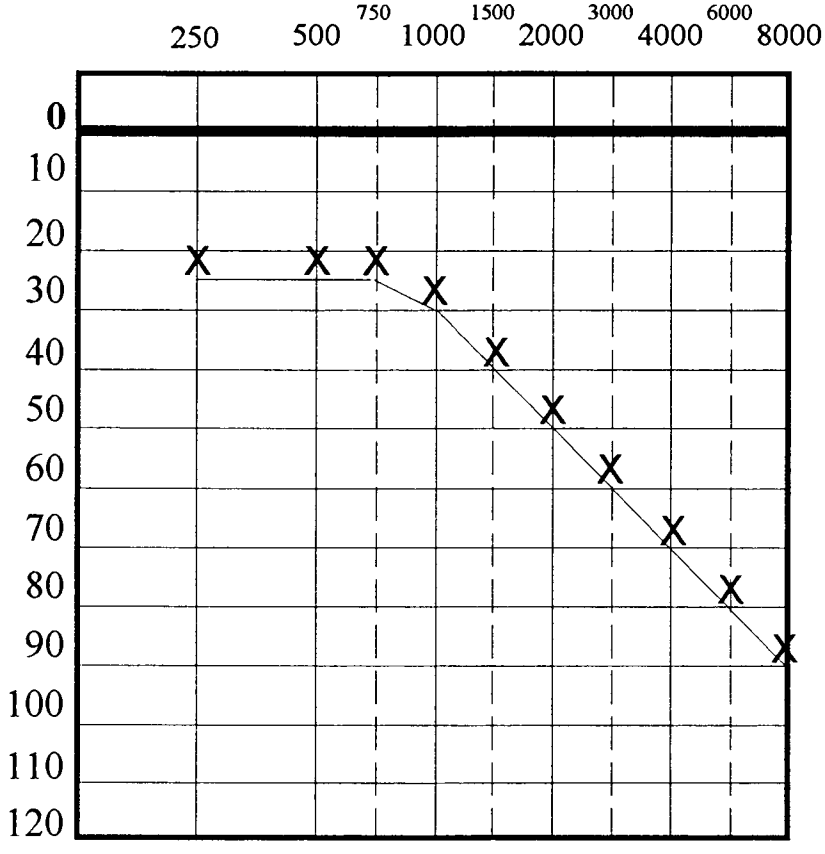
Calculation and Significance of RECD Values

A comparison of real-ear to coupler difference values calculated from this data was made to published values and to the values used within the DSL program. A comparison was also made of the DSL's RECD values to each of 2 subjects. Real-ear to coupler difference values were obtained from *The DSL, version 4.1* (Seewald et al, 1996) and verified with data from Seewald(1993).

In order to determine the effects of using normative RECD values, rather than a patient's custom RECD values, in calculating target hearing instrument gain, target hearing instrument gain values were created and compared for a fictitious hearing loss. Using the audiogram depicted in Figure 2, target 2cc gain values were calculated using the DSL RECD values, averaged RECD values from all of our subjects, and actual RECD values from two of our subjects. The two subjects used for this calculation were those with the largest deviation from the mean RECD values for the group. The age used in each case was 6 years, which approximates the age of both actual subjects as well. The theoretical hearing aid characteristics chosen within the

Figure 2

Audiometric thresholds used for sample hearing loss.



DSL software were as follows: A behind-the-ear hearing aid coupled to a full-shell earmold with SAV venting with #13 standard tubing.

Target gain calculations were compared to actual gain calculations using the same two subjects' RECD values to plot the long-term amplified speech spectrum and real-ear saturation response when the DSL's RECD values were used to prescribe gain.

Results and Discussion

COMPARISON OF RECD VALUES

The mean RECD values from all subjects are presented in Table 1 and compared to other published values in Figure 3. It should be noted that, because the Fonix 6500 does not provide data for 750 Hz, our values for 200 Hz and 700 Hz are compared with values for 250 Hz and 750 Hz, respectively, from the DSL and other published data. The mean RECD values from our subjects compare well with DSL values, as well as to values from Feigin et al. (1989). Their mean RECD values all fall within one standard deviation of our mean RECD values with the exceptions of 4000 Hz and 6000 Hz, which deviate by 0.9 and 4.8 dB, respectively (Feigin et al, 1989).

As an indication of variability in RECD values across subjects, the overall largest and smallest RECD values from actual subjects are also shown in Figure 3. Both subjects have normal outer ear structure, defined by a normally developed pinna, auditory canal, and tympanic membrane structures, as determined by otoscopy and observation. However, the RECD values at each frequency for Sample Subject #1 are much greater than one standard deviation below the mean values from our study(negative relative to mean). Additionally, the RECD values for all frequencies

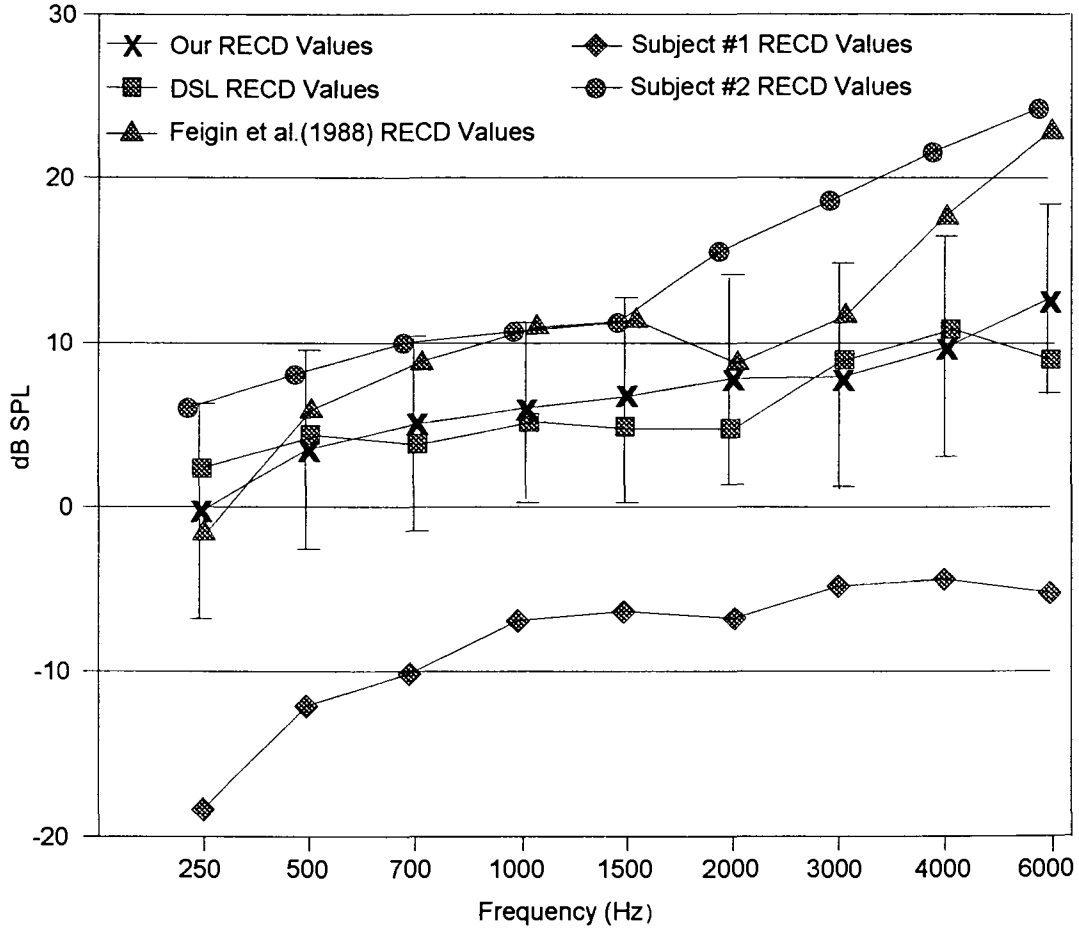
Table 1

Summary of Averaged Real Ear to Coupler Difference Values from This Study

	Frequency, Hz								
RECD Values	200	500	700	1000	1500	2000	3000	4000	6000
Mean RECD Values (dB)	-0.3	3.5	4.6	5.7	6.5	7.8	8.0	9.8	12.7
S.D. (+/- dB)	6.5	6.1	5.9	5.4	6.3	6.4	6.8	6.8	5.8

Figure 3

Averaged and individual RECD values compared with other published values.



above 1500 Hz for Sample Subject #2 are greater than one standard deviation from the mean. Those values at 1500 Hz and below from Sample Subject #2 fall just inside one standard deviation from the mean.

APPLICATION OF RECD VALUES IN THE DSL PRESCRIPTIVE PROCEDURE

Table 2 displays the 2cc coupler hearing instrument gain prescribed by the DSL program for the hearing loss portrayed in Figure 2, a mild, sloping to severe, hearing loss. Prescribed gain values are provided using the DSL's RECD values, averaged RECD values from this study, and the custom values from the two subjects, as shown in Figure 3.

At most frequencies, the 2cc coupler gain prescribed when using our averaged RECD values varied slightly from the 2cc coupler gain prescribed when using the DSL values. This again indicates good agreement between the data sets.

When RECD values generated from actual subjects were used in the DSL program calculation, some results demonstrated significantly different target 2cc coupler responses. Using the RECD values from subject #1, the resulting DSL 2cc coupler gain prescription was at least 11 dB greater at each frequency than when using the DSL's own values and reached deviations of up to +21 dB (at 250 Hz).

Table 2

Comparison of Prescribed Hearing Aid Gain Using Different RECD Values

RECD Values Used to Generate Targets	Frequency (Hz)								
	250	500	750	1000	1500	2000	3000	4000	6000
DSL Values[a]									
Target 2cc Gain	7	8	9	12	20	31	37	45	52
Target 2cc SSPL	93	100	99	99	103	110	110	110	111
Mean Values[a]									
Target 2cc Gain	11 (+4)	8 (0)	9 (0)	10 (-2)	17 (-3)	27 (-4)	37 (0)	45 (0)	49 (-3)
Target 2cc SSPL	97	100	98	98	100	106	110	110	108
Subject #1 Values[a]									
Target 2cc Gain	29 (+22)	24 (+16)	23 (+14)	23 (+11)	30 (+10)	42 (+11)	50 (+13)	59 (+14)	67 (+14)
Target 2cc SSPL	115	116	113	111	113	121	123	124	126
Subject #2 Values[a]									
Target 2cc Gain	5 (+3)	4 (-4)	3 (-6)	5 (-7)	13 (-7)	19 (-12)	27 (-10)	33 (-12)	38 (-14)
Target 2cc SSPL	91	96	93	93	96	98	100	98	97

Note: 2cc coupler target values are listed with deviation (in parentheses) from the values obtained using DSL averaged data

[a]All targets were calculated using the DSL procedure in the DSL v4.1 software

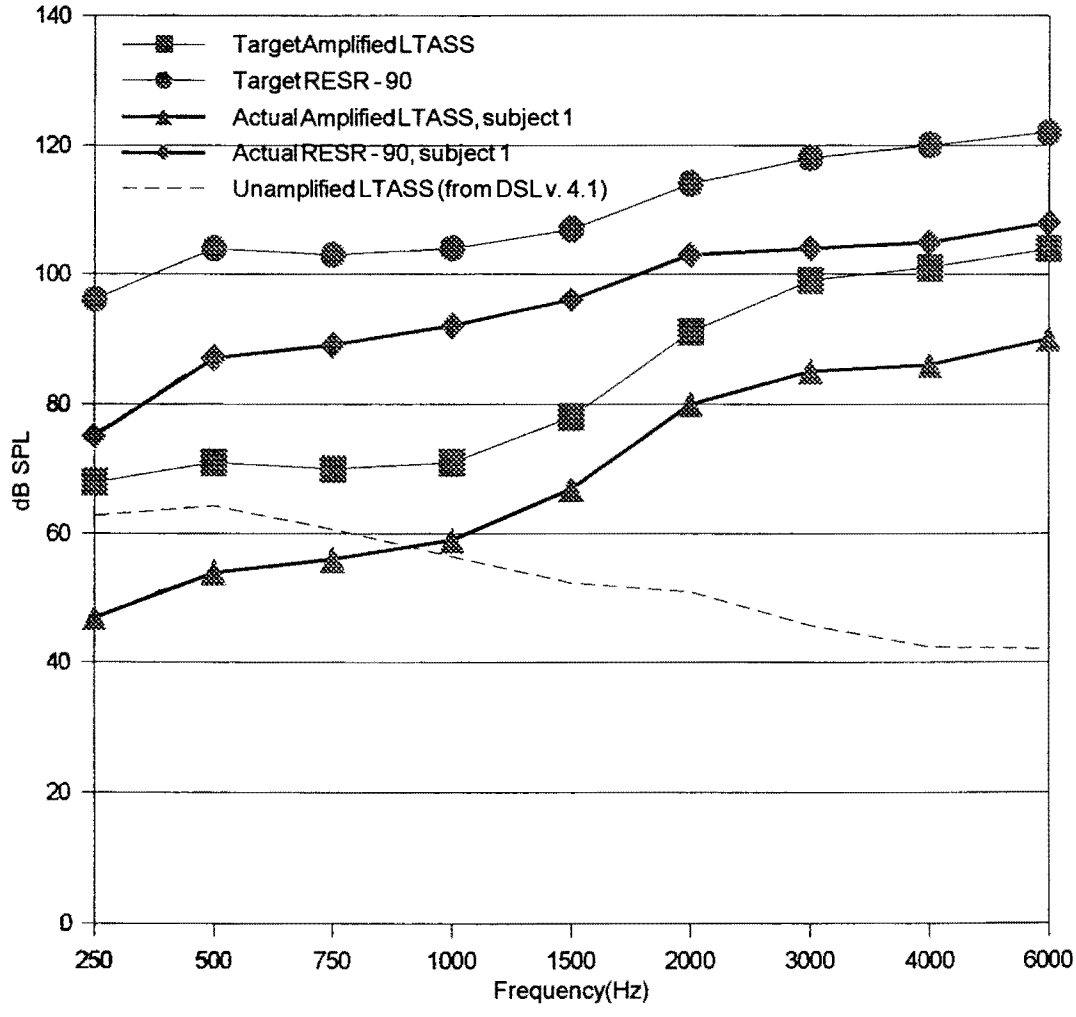
In order to calculate the actual (predicted) amplified *long-term average speech spectrum* (LTASS) for each subject, the RECD in each condition was added to the prescribed 2cc target. This is a reverse-engineering of the DSL method. Essentially, the DSL program has subtracted its averaged RECD data, then we added our custom RECD data, resulting in an amplified LTASS that reflects the difference between our subjects' and the DSL's RECD values.

The actual amplified LTASS values were plotted against the target amplified LTASS generated by the DSL program and the (unamplified) LTASS used by the DSL for its prescriptive procedure. The results are plotted in Figures 3 and 4 using the RECD values from the two sample subjects. The audiometric thresholds used for this illustration are displayed in Figure 2.

Because the RECD values calculated for subject #1 are considerably lower than the DSL values, the actual amplified LTASS resulting from fitting this patient with a hearing instrument set to 2cc coupler targets (using DSL RECD values) is substantially lower as well, as seen in Figure 4. When the audiometric thresholds represented in Figure 2 are used in *The DSL, version 3.1*, to prescribe hearing instrument gain, the intensity of the resulting actual amplified LTASS is less than the intensity of the

Figure 4

DSL target gain vs. actual gain calculation using subject #1 RECD values.



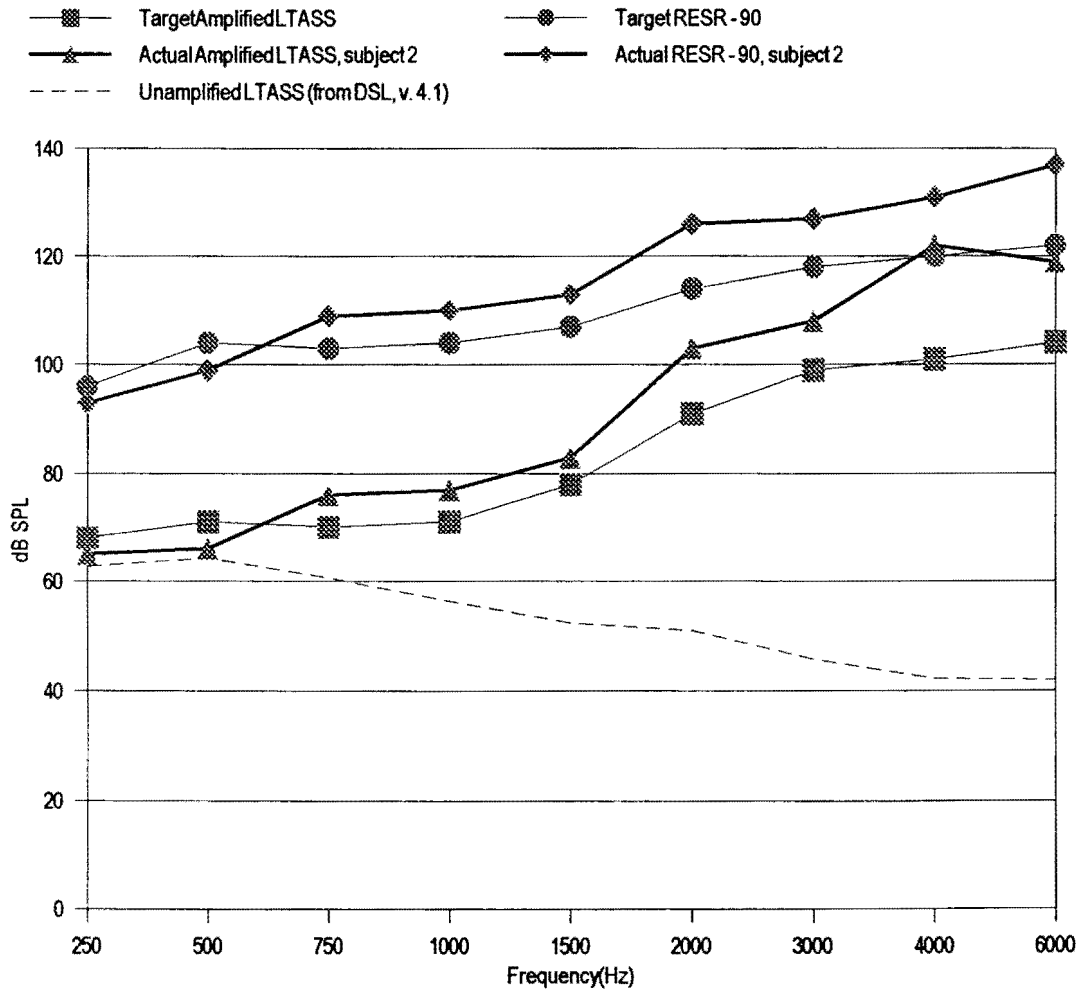
unamplified LTASS from 250 Hz through 1500 Hz. This results from the fact the subject's canal resonance is such that SPL is reduced in the ear canal, requiring additional gain at all these frequencies to match the target LTASS. This means that, at these frequencies, should the DSL prescription be followed closely and the hearing instrument fit without real-ear verification, the device could act as an attenuator at those frequencies.

Additionally, high frequency speech information will be extremely soft for this patient. At any frequency, this patient would not receive sufficient amplification should the hearing instrument gain be limited to the low levels prescribed by the DSL. This example clearly shows that fitting a hearing instrument on this child without the benefit of using custom real-ear to coupler difference values or real-ear verification techniques would be a potentially serious impediment to the child's auditory and speech development.

When the RECD values from subject #2 were used, the gain resulting from the DSL prescription ranged from 5 dB greater than when using DSL values (250 Hz) to 15 dB less than when using DSL values (6000 Hz), as seen in Figure 5. When analyzing the target and actual LTASS for example subject #2, the effects of fitting a hearing instrument

Figure 5

DSL Target gain vs. actual gain calculations using subject #2 RECD values.



using the DSL prescriptive procedure with the DSL RECD values is not so pronounced in the low and middle frequencies as with subject #1. Even in these areas, however, the LTASS deviates enough to warrant concern: as much as 5 & 6 dB through 1500 Hz. In the high frequencies (2000 Hz and above), this child would be amplified to the extent that the LTASS exceeds the target real-ear saturation response. If we assume that the DSL targets are appropriate, then in this instance it is certainly likely that the output of a hearing instrument fit strictly to the DSL prescription using DSL RECD values would be uncomfortably loud for the child and potentially damaging to the child's hearing. In amplifying speech to these levels, the benefit the child would receive may be reduced also.

Summary and Implications

In general, the mean RECD values calculated from subjects in this study compare favorably with averaged RECD values from other sources, including the DSL. The intersubject variation and individual subjects' variation from the mean values, however, do not support the use of these averaged values in clinical practice. We can conclude from this that using averaged RECD values to prescribe hearing instrument gain or estimate the real-ear response of a hearing instrument when fit to a child could potentially fail to maximize the benefit that a child could be receiving from a hearing instrument. Although we have used the DSL Method to demonstrate calculations, we can construe from the magnitude of the inter-subject variations that this could be true of any presciptive formula.

The sample prescriptions from Table 2 demonstrate the extreme variation in prescribed hearing instrument gain that is possible in potential hearing instrument candidates. In the cases of both subject #1 and subject #2, a completely different hearing instrument may be required, given the same audiogram, in order to meet the DSL prescription when based on DSL RECD values or our averaged RECD values.

In the cases of both Example Subject #1 and Example Subject #2, analysis of the actual amplification the

children would receive demonstrates the importance in measuring the acoustical characteristics of each individual child's ear(s) when fitting hearing instruments. Failure to do so will potentially result in a severe under-fitting or over-fitting for a patient, either of which may compromise the benefits of amplification.

In addition to the effects of over- or under-amplification of the child, an error in the prescribed output could potentially disrupt the fitting process. Hearing instrument circuitry is manufactured to perform within certain specifications, including a minimum and maximum acceptable gain range. Should a clinician use averaged data to predict the real-ear performance of an instrument, the discovery of significant over- or under-amplification of the child, when real-ear measurement is performed later, could result in a setback of the fitting process while the clinician returns the instrument for a more appropriate device.

FEASIBILITY OF RECD MEASUREMENTS FOR EACH PATIENT

Although the focus of this study was analysis of RECD values and the importance of those values in prescribing hearing instrument gain using the DSL (or any other prescriptive procedure), the more general point is that

audiologists must take into account the individuality of each patient. Generating RECD values is a multiple-step procedure. It can be quite time consuming and may involve a greater time commitment than a clinician is willing to invest in the hearing instrument fitting process. A more expedient approach would certainly be more clinically feasible than creating RECD values for each patient.

With the relative pervasiveness of real-ear measurement systems in audiology clinics today, there is at most clinician's disposal a very adequate means for ensuring properly fit hearing instruments. If a clinician were to need to fit a hearing instrument on either of the two example subjects, the DSL is an excellent means for prescribing target hearing instrument gain for an individual. However, instead of relying completely on the averaged measurements inherent to the DSL calculations (such as RECD values), a clinician can use real-ear measurement equipment during the hearing instrument fitting to customize the process.

If real-ear measurements have been made prior to the fitting, the clinician can accurately adjust the hearing instrument on a 2cc coupler by generating custom RECD values. Regardless of whether the instrument has been preset, a clinician can measure real-ear gain with the

instrument on the child and adjust the settings to meet the target real-ear output. This ensures that the child is receiving the most benefit possible from the hearing instrument, given current means of prescribing and measuring amplification characteristics. This method of hearing instrument fitting provides a clinician with a fast, easy, and readily accessible option for maximizing the potential of a hearing instrument.

NEED FOR FURTHER RESEARCH

Although, the sample size in this study was somewhat small, the results of averaged data compare well with those of both the DSL (from Seewald, 1993) and Feigin et al (1989). The standard deviations from our data, however, were larger than those from Feigin et al(1989) at most frequencies. The standard deviations from a larger data set would likely compare more closely with those from Feigin et al. There is still a need for further research in this area to support current and past findings.

To fully assess the impact of using averaged RECD data versus individualized measurements, further research is needed to study the outcomes of generating target hearing instrument gain using the DSL and other popular prescriptive procedures. Again, a larger number of subjects would

greatly help to assess, not only the possible differences in outcomes when using averaged or custom data, but the amount of variability created by the two data sets and the prevalence of hearing instrument gain prescriptions being significantly over- or under-estimated.

Most hearing instrument and real-ear analysis systems in the market today come with or have the ability to be upgraded to RECD generation software. This makes the procedures outlined in this study accessible and easily performed in a quick and efficient manner. With both the DSL and RECD procedures being added to the software in hearing instrument analyzers, more dispensers will take advantage of these procedures and implement them in fitting hearing instruments. As the technology becomes more readily obtained by dispensers, the need to perform further research to ascertain the importance of performing custom measurements grows.

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