

Prescriptive Procedures for Infants and Children

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In the context of early intervention, infants will wear their hearing aids at fixed, **clinician-determined settings for months or years** before they are able to clearly express their preferences. Therefore, the validity of the clinician-determined hearing aid settings may be of crucial importance for auditory development in the early years of life. In this chapter the validity of prescriptive approaches for determining initial settings of infants' hearing aids will be examined.

The Recommended Approach

Recent consensus statements have recommended that hearing aid prescription should be done in an *objective* manner (AAA 2003; ASHA 1998; Pediatric Working Group (PWG) 1996). Objective hearing aid prescription uses computational algorithms that *prescribe* specific amplification characteristics, typically based on the diagnostic status of the hearing aid wearer. These prescriptions are used to compute recommended electroacoustic settings for the hearing aids that should result in appropriate detection, loudness, and intelligibility of amplified speech. Because prescriptions are defined electroacoustically, they are meant to be verified using specific electroacoustic measures to ensure that the prescription is achieved by the hearing aid within a reasonable tolerance. The use of this objective approach is important for several reasons. First, it results in a consistent treatment across children, clinicians, and clinics. This consistency not only facilitates communication and collaboration between clinical sites, but

also allows individual clinicians to see trends of successful and/or unsuccessful outcomes.

The objective approach to hearing aid prescription also facilitates growth and knowledge accumulation in the field of infant hearing aid fitting. Specifically, research studies that have developed and/or evaluated pediatric hearing aid prescriptions have typically been conducted in controlled laboratory environments (e.g., Ching, Newall and Wigney 1997; Jenstad, Seewald, Cornelisse and Shantz 1999; Jenstad, Pumford, Seewald and Cornelisse 2000; Scollie, Seewald, Moodie and Dekok 2000). This type of evaluation determines the *efficacy* of a prescription. Application of objective prescriptions in clinical practice facilitates direct comparison between clinical treatment and experimental findings. This facilitates the development of clinical experiences and cases that informally or formally evaluate the *effectiveness* of a prescriptive algorithm. In the long term, both efficacy and effectiveness data are necessary in the comprehensive evaluation of a prescription's validity. It may also be possible to harness the advantages of both efficacy and effectiveness methodologies, when conducting controlled case-based research in the clinical environment. In this methodology, clinicians apply an objective prescription, and monitor the outcomes using both highly controlled outcome measures (e.g., loudness perception, speech recognition testing using calibrated stimuli) and measures of real-world effectiveness (e.g., questionnaires). Further, we can document any necessary deviations from the objective prescription that are made in response to outcomes data, and thereby learn about the validity of a given prescription.

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Table 1. Characteristics of validity in hearing aid prescription procedures.

| Characteristic | Definition | Research Questions for Hearing Aid Verification |
|----------------------|--|---|
| Content Validity | The items in the measure are comprehensive, and logically represent the concept. | Does the prescription comprehensively consider all relevant psychoacoustic and electroacoustic factors? Can the targets be used with a realistic range of actual hearing aids? |
| Concurrent Validity | Two instruments designed to measure the same concept produce the same result. | Do independently derived prescriptive formulae produce similar targets? |
| Predictive/ Validity | The measure is successful in predicting a future state or behavior. | Do hearing aid users receive more benefit from hearing aids fitted to the prescription than to an alternative? If the prescription has specific goals for aided outcomes, are the goals met? Is the fit to prescribed targets related to treatment decisions? |
| Construct Validity | The measure does what it was designed to do. | Does the prescription provide an accurate, comprehensive, electroacoustic prescription of a theoretically optimal hearing aid? Should it be used clinically? |

How can a “valid” prescription be defined?

Many clinicians will have learned about the various forms of validity in their clinical training. These include such concepts as “predictive validity” and “concurrent validity.” However, these validity criteria are typically taught and applied with regard to measurement tools, such as standardized tests. The next section of this paper will explore whether we can modify these concepts to consider the validity of prescriptive algorithms. Although this is a largely academic exercise, it may be an important concept to consider. Without a solid theoretical foundation, and perhaps consensus, it is difficult for those who conduct research, write preferred practice guidelines, and/or make clinical treatment decisions to ensure that these activities have a shared underlying framework. The link between a unifying theory and the testing of an application of that theory is a hallmark of good science. Our field will evolve and mature as we increase the rigor with which we evaluate the validity of our own practices. Several schemes for performing such evaluations have been suggested in the literature (Ottenbacher 1997; Portney and Watkins 2000). From these, I have modified the traditional definitions of content validity, concurrent validity, predictive validity, and construct validity for application to hearing aid prescriptions for discussion in this

paper. These modifications and their logically associated research questions are presented in table 1. The next several sections of this paper will discuss each modification.

Content Validity: Prescriptions Should be Comprehensive

Content validity reflects the comprehensiveness of a tool. For questionnaires, we typically ask whether the questions thoroughly cover all of the logical and relevant aspects of the topic. For hearing aid prescriptions, we could ask instead whether the prescription considers and/or computes all of the psychoacoustic and electroacoustic variables known to impact outcomes of hearing aid fitting. Which, therefore, are the variables that should be considered relevant? The following section will propose a set of variables that have been shown to relate to speech and loudness perception in a variety of real-world listening environments.

Audiometric Thresholds

Listeners with different degrees and configurations of hearing loss require different levels of amplification in order to detect signals and recognize speech. Prescriptive targets (gain, output limiting, etc.) are computed using thresholds as the primary,

if not the only, data source. Further, the listener's auditory thresholds can be used to predict supra-threshold variables such as the loudness discomfort level (LDL) (Dillon and Storey 1998; Seewald 1991). The accuracy of threshold-based predictions of LDL can be questioned on the basis of large between-subjects variability of LDL in relation to threshold (Bentler and Cooley 2001). However, predictions of LDL developed for use with the pediatric population are designed to be conservative (Seewald 1991). Furthermore, predicted LDLs are typically the only option when fitting hearing aids in early infancy. For this reason, the importance of threshold data is higher for infant hearing aid fitting than it is for fittings with older listeners who can also complete suprathreshold assessments.

Infant hearing sensitivity is assessed using a unique set of procedures. Specifically, infants under six months of developmental age are typically not able to participate in behavioral evaluation of auditory thresholds. Therefore, we assess hearing sensitivity by measuring electrophysiologic responses to sound and use these data to predict auditory thresholds (e.g., Stapells, Gravel and Martin 1995). A comprehensive pediatric hearing aid prescriptive algorithm must take into account the calibration and response properties of this assessment approach. Specifically, the computations in the hearing aid prescription are typically designed to use true auditory thresholds, rather than estimated thresholds. Also, some electrophysiologic threshold estimation procedures recommend that specific, evidence-based corrections be applied to facilitate accurate estimation of behavioral threshold (Stapells et al. 1995; Stapells 2000). Typically, these corrections *reduce* the estimated threshold level, in order to express the threshold estimates in the dB HL scale. Omitting the corrections, therefore, may overestimate the amount of gain actually required in the hearing aid. A prescriptive formula intended for use with infants should make specific recommendations for how such data are to be entered, and which, if any, corrections have been applied prior to calculation of targets. Currently, generic prescriptive methods take audiometric thresholds in the dB HL format, requiring the clinician to correct electrophysiologic thresholds, if necessary, prior to prescribing hearing aids. Clinicians are encouraged to prescribe infants' hearing aids based on electrophysiological evaluations, in order to meet the goals of early intervention programs. However, clinicians should familiarize

themselves with the issues of non-standardized calibration, and ensure that appropriate corrections are applied if required.

Infant hearing thresholds are also affected by the unique properties of the highly variable, small, and growing external auditory canal and middle ear system. These properties are known to affect the values of auditory thresholds and/or threshold estimates that are calibrated in dB HL (Seewald and Scollie 2003). Two specific approaches have been recommended when accounting for external ear canal acoustics in assessment data. The first approach is to convert the assessment data from dB HL to dB SPL in the ear canal using a measurement of the ear canal's acoustic properties (Scollie, Seewald, Cornelisse and Jenstad 1998). The second approach is to use a measurement of the ear canal's acoustic properties to correct the assessment data to the dB HL values that would have been obtained in an average adult ear. Over the years, this approach has been labeled "derived HL," "predicted HL," or "equivalent adult hearing level" (Seewald, Ramji, Sinclair, Moodie and Jamieson 1993; Seewald et al. 1997; Ching and Dillon 2003; Marcoux and Hansen 2003). If the ear canal SPL approach is used, then the prescription must be calculated using the dB SPL thresholds. If the second approach is used, then the prescription must be calculated using the equivalent adult HL thresholds. If neither approach is applied, then the prescription cannot be considered comprehensive for the purposes of pediatric hearing aid fitting.

Effects of Competing Signals

Hearing aids are used in a variety of listening environments, ranging in the levels of background noise, the amount of reverberation, and the distances and levels of the signal sources. All of these factors will affect the degree and nature of amplified sound that will be received by the infant through his or her hearing aids. Most prescriptions are specifically designed to predict the frequency response, gain, and compression that will be appropriate for speech recognition in a quiet and non-reverberant environment. Therefore, they may not comprehensively address an infant's listening needs in a noisy car, or a child's listening needs in a reverberant classroom. Clinicians who provide amplification to infants and young children may need to modify and/or supplement prescribed amplification to span a range of listening environments. One common modification is the

fitting of a lower-gain noise program for use in high-noise environments such as the car, the school bus, or the movie theatre. One common supplement is an FM system for use in conjunction with personal hearing aids, either in the home or school environment (Gabbard 2003; Lewis and Eiten 1998; Moeller, Donaghy, Beauchaine, Lewis and Stelmachowicz 1996). Gabbard (see Chapter 11) describes a program of FM use in the toddler/preschool years. FM systems are known to address the effects of both distance and reverberation. Comprehensive protocols for setting the electroacoustic properties of the FM system for use with personal hearing aids have been developed (ASHA 2002).

Effects of Audibility

Prescriptive formulae essentially define a mathematical relationship between acoustic and electroacoustic variables (speech acoustics, gain, frequency response, compression, output limiting) and psychoacoustic variables (speech recognition, loudness perception). Prescriptive formulae use this electroacoustic/psychoacoustic relationship to compute a set of electroacoustic parameters that should facilitate successful suprathreshold perception. A comprehensive prescriptive formula will consider a wide range of electroacoustic hearing aid parameters, including frequency response, compression threshold and ratio, channel structure, time constants, and output limiting levels (assuming that experimental evidence exists to make specific, quantitative recommendations for each). However, current prescriptive formulae vary significantly in their theories regarding the relationship between electroacoustic variables and psychoacoustic outcomes. One aspect of these differences may be important to consider in infant hearing aid fitting: what is the goal of providing audibility via hearing aid amplification? Two approaches to defining this goal currently exist: (a) the habilitative audibility approach and (b) the effective audibility approach.

The Habilitative Audibility Approach

Advocates of the habilitative audibility approach recommend providing a complete acoustic representation of all incoming sounds to the infant's developing auditory system. The goal of providing audibility is to allow access to the full bandwidth and envelope of conversational-level speech so that phonemic patterns can be learned. Inherent in this approach is the

assumption that that infant has some potential to learn to recognize sound elements and patterns despite suprathreshold deficits in frequency and/or temporal resolution. The habilitative nature of this approach was first advocated by aural-oral theorists (e.g., Ling 1989). In this approach, the goal of an amplification system is to provide audibility of the acoustic segments of speech that are important for speech understanding, so that intensive aural therapy is supported and warranted. This type of hearing aid fitting is viewed as a starting point, and is intended to be followed by evaluations of whether the audible speech is beneficial, and whether the "quality" of the child's suprathreshold hearing can support speech recognition (Ling 1989).

Provision of audible speech cues for habilitation is one goal of the Desired Sensation Level (DSL) family of prescriptive algorithms. Computationally, the DSL method attempts to make audible the entire long term average spectrum of conversational speech, and to place it at a suprathreshold level that is associated with listening comfort and best speech recognition scores in children with permanent hearing losses. Target levels were derived from published values that described the speech sensation levels associated with comfortable listening (Kamm, Dirks and Mickey 1978), ceiling speech recognition performance in children with sensory hearing loss (Erber 1973; Erber and Witt 1976; Macrae 1986), and avoidance of loudness discomfort (Pascoe 1988), in a comprehensive prescription of both frequency response and maximum output (Seewald, Ross and Spiro 1985). Often, wide-dynamic range compression processing (e.g., Cornelisse, Seewald and Jamieson 1995) is applied with the goal of providing audibility of as many inputs as possible, again so that the developing infant may learn to attribute meaning to sound. Over time, the habilitative approach has led DSL-related research and application to focus on relatively low compression thresholds, somewhat higher gains compared to other prescriptions, and evaluation of procedures that promote accurate electroacoustic fits to target electroacoustic performance for individual infants and children. Numerically, the DSL targets are best viewed as target levels that should provide the highest sensation level of speech that is associated with comfortable long term listening. Higher overall sensation levels are intentionally prescribed in order to allow audibility, if possible, of meaningful but low-level segments within the speech signal. Recent laboratory studies of children's perception of

high-frequency fricatives indicate that children require a broad audible bandwidth in order to perceive low-level speech sounds such as /s/ (Stelmachowicz, Pittman, Hoover and Lewis 2001).

The Effective Audibility Approach

In contrast, advocates of the effective audibility approach argue that provision of full audibility may not be an appropriate goal. Studies of effectiveness have measured whether increments in audibility result in increments in intelligibility. *Lack* of effectiveness is assumed to exist when further increases in audibility no longer cause improvements in speech recognition scores (Ching, Dillon, Katsch and Byrne 2001). The relationship between audibility and effectiveness can be predicted, in part, by the listener's unaided auditory thresholds. Listeners with severe hearing losses, for example, tend to have poorer performance in speech recognition than do listeners with normal hearing or mild hearing losses. This is essentially the same concept as Ling's assertion that evaluation of the aided, suprathreshold, "quality" of hearing is an essential follow-up to the provision of amplified speech (Ling 1989).

Individual variation around this audibility-effectiveness trend is considerable. Put differently, while some listeners with a severe hearing loss do not benefit from audibility, others receive significant benefit. Because of this, the average trend predicts a gradual decrease in audibility as hearing level increases. In clinical practice, this compromise between individuals with and without effectiveness limits may not describe a given individual's audibility needs. Just as the habilitative approach assumes that audibility is effective until proven otherwise, the effective audibility approach assumes that audibility may be less than fully effective until proven otherwise.

Limits of effective audibility have been proposed and implemented in the NAL-NL1 prescriptive formula (Ching et al. 2001). In applying this formula to infants and young children (e.g., Ching, Dillon, Britton and Agung 2001), it is assumed that adult-derived limits of effectiveness also apply to the pediatric population. This assumption has not been evaluated, nor were the original effectiveness data gathered on children.

Effects of Age

In early intervention, many practical and theoretical challenges exist that change how we must practice when prescribing hearing aids. Some of these practical challenges transcend an infant's later years in toddlerhood and childhood. The pediatric population is audiologically distinct in several important ways. Pediatric assessment data are different and require additional measurements. Also, pediatric listening requirements are unique and differ from those of adults, with or without hearing impairment.

Assessment Requirements

First, compared to adults with hearing losses, infants and children are more likely to have asymmetrical, unusually configured, progressive, or fluctuating hearing losses (Pittman and Stelmachowicz 2003). Second, infants and young children have growing external ear canals to roughly age five, and this growth significantly affects their external ear canal acoustics (Bagatto, Scollie, Seewald, Moodie and Hoover 2002). Growth is rather rapid in the first year of life, and generally continues until five or six years of age. Throughout this time, the acoustic properties of the ear canal are changing, with a general trend toward decreasing levels of ear canal resonances, and a lowering of resonant frequencies. These general findings and trends have been demonstrated for both the open ear resonance, or Real Ear Unaided Response (Kruger 1987; Westwood and Bamford 1995), and the occluded ear resonance, or Real Ear to Coupler Difference ([RECD] Feigin, Kopun, Stelmachowicz and Gorga 1989; Bagatto et al. 2002).

Ear canal growth has significant implications for infant hearing aid prescription. The smaller size of the infant ear means that less coupler gain is required from the hearing aids, but also that the gain requirement needs revision as the ear grows. In general, an efficient solution to this problem is to adopt a prioritized set of clinical goals in which individualized real ear transforms are measured whenever possible, but that age-appropriate average values are also used as a secondary option. The most widely validated measurement for this purpose is the RECD (Seewald, Moodie, Sinclair and Scollie 1999; see also Munro, Chapter 5 in this volume), which may be measured efficiently and reliably in the pediatric population (Bagatto, Seewald, Scollie and Sinclair-Moodie 2004; Sinclair et al. 1996; Tharpe, Sladen, Huta and

Rothpletz 2001) or predicted using age-appropriate values (Bagatto et al. 2002). However, the routine use of age-appropriate values is not typically encouraged by most practice guidelines, because ear canal acoustics vary substantially from individual to individual (AAA 2003; PWG 1996). Even in adults, between-individual variance in ear canal acoustics exceeds 30 dB (Saunders and Morgan 2003).

Both the DSL v4.1 and NAL-NL1 prescriptive approaches integrate the infant's RECD data into the prescriptive process, allowing targets to be updated as the infant or child grows. The common approach now used with both prescriptions entails completing the assessment of thresholds, measurement of the RECD, electroacoustic prescription, and transformation of the prescribed real ear targets to the 2cc coupler. Hearing aid fitting is then completed by measuring and adjusting the hearing aid response or gain on the 2cc coupler, and achieving a good match to prescribed target performance. This approach ensures both accuracy and consistency and does not require the child to participate or cooperate in prolonged probe-microphone measurement sessions.

Listening Requirements

Finally, infants and young children acquire hearing loss either before or during the acquisition of language. For children who are raised in a spoken language environment, prelingual hearing impairment means that speech cues must be learned through aided hearing rather than remembered from a prior period of normal hearing. These factors play a much smaller role in the adult population.

Research indicates that children, particularly those with hearing losses and/or learning difficulties, require better speech signals than do adults in order to achieve a given level of performance in speech recognition. A corollary of this is: children perform more poorly than adults for the same speech signal, as long as ceiling or floor effects are not present. This is true for monosyllabic words in quiet, in which children younger than ten years of age require a higher SPL than adults to achieve 71% correct (Elliot et al. 1979). It is also true for sentences in noise (Elliott 1979; Gravel, Fausel, Liskow and Chobot 1999), sentences in reverberation (Nábilek and Robinson 1982), phonemes in reverberation (Neuman and Hochberg 1982), phonemic contrasts (Hnath-Chishold, Laipply and Boothroyd 1998), words with/without sentence context (Nittrouer and Boothroyd 1990), and fricatives

across bandwidths (Kortekaas and Stelmachowicz 2000).

In addition, children with hearing losses have different speech signal requirements than their age-matched peers, even when compensation is provided with frequency-dependent amplification. Studies comparing children with normal and impaired hearing have shown age-related interactions with level, bandwidth, and sensation level in the perception of fricatives or the use of semantic context in recognizing words (Stelmachowicz, Hoover, Lewis, Kortekaas and Pittman 2000; Pittman and Stelmachowicz 2000; Stelmachowicz, Pittman, Hoover and Lewis 2001; 2002). Also, children's hearing levels interact with the audibility, sensation level and bandwidth of speech in fricative recognition (Pittman and Stelmachowicz 2000; Stelmachowicz et al. 2001; Stelmachowicz et al. 2002). In summary, a large body of research supports the conclusion that children and adults have different listening requirements, and that children require greater auditory access to a speech signal in order to achieve adult-like performance levels.

Several clinical implications may be drawn from adult-child distinctions. It may be argued that a habilitative audibility approach is warranted with the prelingually impaired population, and that children require more gain, a higher signal-to-noise ratio, and a broader audible bandwidth of speech. It can also be argued that we should apply a prescriptive approach and hearing instruments that can be flexible to accommodate changing listening requirements over time in order to maintain audibility. Accommodation to changes over time requires high-quality and regular follow-up. This must include regular re-measurement of auditory thresholds and external ear canal acoustics, *and* the incorporation of these new measurements in readjusting the performance of the hearing aids. Follow-up schedules vary with the age of the child: infants typically require more frequent follow-up than do older children. Another important implication for follow-up is the use of information regarding the success of the amplification system in supporting the development of auditory skills (Harrison 2000). Continued fitting to a given prescriptive approach is only warranted if the child is developing appropriate skills in the areas of sound awareness, device use, and speech and language development. Otherwise, the clinician should employ informed problem solving in assessment and fitting, rather than continuing to apply the original assessment and fitting strategy. Electroacoustic tools and

functional assessments exist that may assist in this process (Anderson and Smaldino 2000; Kopun and Stelmachowicz 1998; Stelmachowicz 2000; Stredler-Brown and Deconde Johnson 2001)

Are Current Prescriptions Comprehensive?

The previous several sections may be best summarized by recalling that prescriptive formulae have been designed to consider speech recognition and/or loudness perception for a speech signal in an otherwise quiet environment. Within this context, prescriptions are generally comprehensive in their approaches, taking into account the effects of hearing level, ear canal acoustics, signal level and frequency, and amplitude compression processing. Infant-specific prescription can and should proceed based on electrophysiologic estimates of hearing thresholds, bearing in mind that corrections from nHL to HL (and/or SPL), if required, should precede computation of prescribed gain or output. Once gain and output targets are derived, a comprehensive pediatric prescriptive approach should support infant-friendly verification by generating coupler-based targets that have been corrected for the individual infant's ear canal characteristics.

Concurrent Validity: Do Current Prescriptions Agree?

Concurrent validity addresses the ability of two different test instruments to produce essentially the same result. This form of validity is highly relevant to clinical hearing aid prescription, because a variety of prescriptive formulae exist for clinical use, and may prescribe somewhat different targets for the same hearing loss. Concurrent validity in prescription is generally presented from two perspectives: (1) whether a new and an old version of the same prescription provide similar targets; and (2) whether two different prescriptions provide similar targets. Currently, two prescriptive approaches are actively recommended for use in pediatric hearing aid fitting: the Desired Sensation Level (DSL) method, and the National Acoustic Laboratories' (NAL) prescription (Byrne, Dillon, Ching, Katsch and Keidser 2001; Seewald et al. 1997). Their intra- and inter-prescription similarity will be discussed below.

Intra-Prescription Similarities

Both the DSL and NAL formulae have been revised several times. Within each revision, explicit comparisons to the previous version are made. Between-version similarities demonstrate concurrent validity if a new, *independently derived*, computational algorithm prescribes targets that are similar to those from the previous algorithm. Both the DSL and NAL nonlinear prescriptions were explicitly compared to the previous linear prescriptions at a fixed input level of 70 dB SPL. For example, Cornelisse et al. (1995) found that DSL[i/o] agreed with the DSL 3.1 targets to within 5 dB. A similar NAL-NL1 vs. NAL-RP study has also been published (Byrne et al. 2001).

Inter-Prescription Similarities

Target-to-target agreement between prescriptions is perhaps a more complex issue, particularly when the comparison is done from the perspective of pediatric audiology. Most published target-to-target comparisons have been done in the Real Ear Insertion Gain (REIG) format, which is not recommended for use with children. This may seem trivial, but is in fact an issue of key importance for pediatric hearing aid prescription. The REIG format typically employs an average adult Real Ear Unaided Gain (REUG), and subtracts some assumed input target signal in its computation. For pediatric prescription, average adult REUG values are likely inappropriate. Also, specific estimates of the speech spectrum for pediatric application have been described in the literature (e.g., Cornelisse, Gagné and Seewald 1991; Pittman, Stelmachowicz, Lewis and Hoover 2003). Therefore, adult-derived REIG comparisons may not accurately reflect true inter-prescription similarities, nor accurately predict the aided responses that could result in the ear of a particular infant or child when hearing speech. For this reason, inter-prescription agreement should be evaluated also from a pediatric perspective, using normative data and measurement formats that reflect normal clinical practice in pediatric audiology.

A further issue with published comparisons is the modification of the original target prior to evaluation of agreement. One strategy for target modification is the "normalization" of target responses at 1000 Hz (e.g., Keidser, Brew and Peck 2003). In applying this strategy, the researcher increases or decreases each target response, mathematically, so that all responses are forced to meet at 1000 Hz regardless of the actual

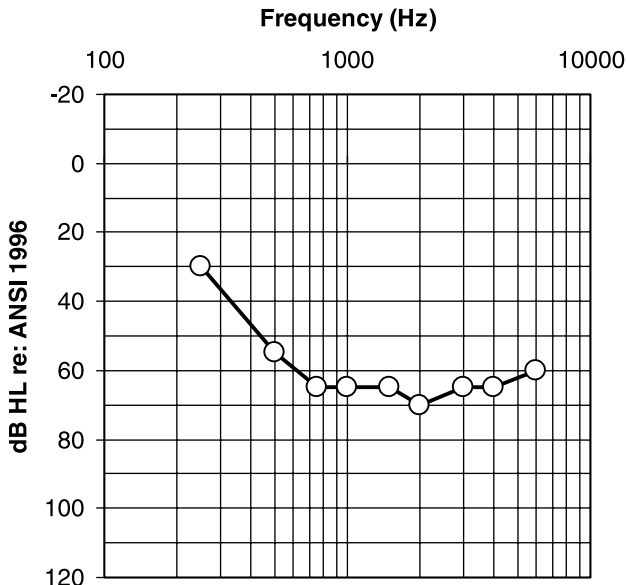


Figure 1. Right ear air conduction thresholds, in dB HL, for a ten-year-old child.

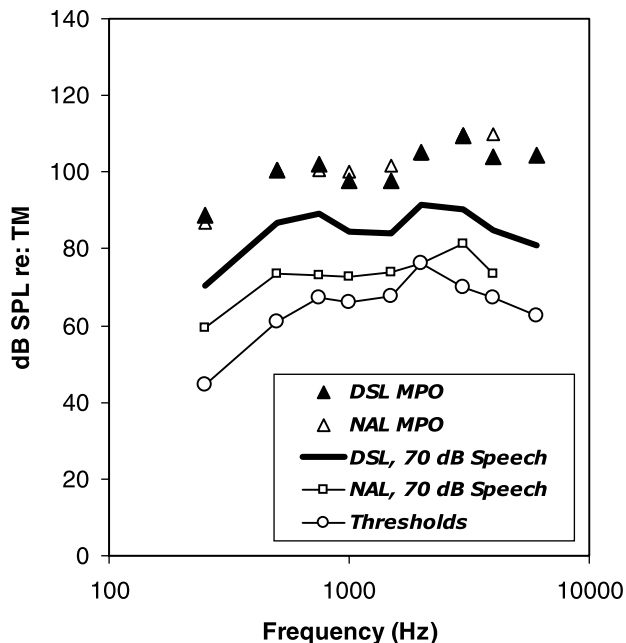


Figure 2. Hearing aid verifications for a 70 dB SPL speech input for the case example shown in figure 1.

prescribed level. Given that many prescriptions can differ markedly at 1000 Hz, and that infants and young children typically wear hearing aids with locked volume controls, the normalization approach may not provide accurate estimates of inter-

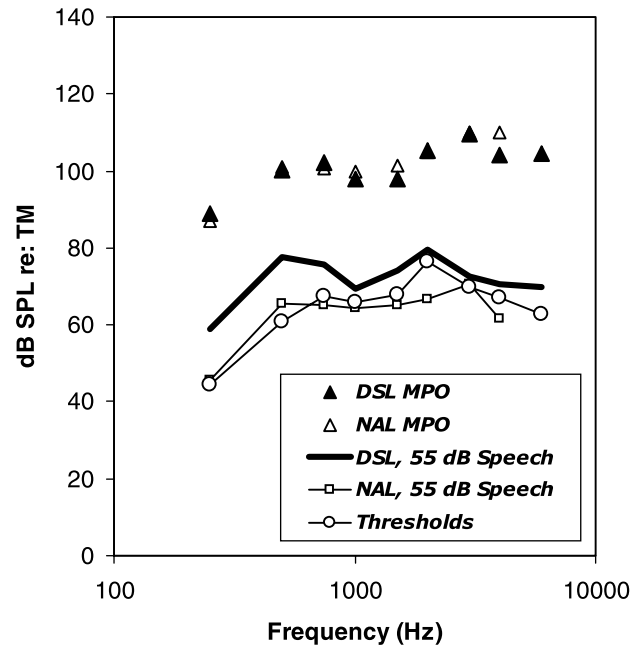


Figure 3. Hearing aid verifications for a 55 dB SPL speech input for the case example shown in figure 1.

prescription agreement in pediatric hearing aid prescription. A further issue is the omission of maximum output targets in the comparisons of prescriptive formulae. This important variable is essential to a complete pediatric prescription, and is therefore an important element of a valid inter-prescription comparison for pediatric applications.

It is beyond the scope of this paper to provide a comprehensive evaluation of inter-prescription differences. However, a case study may serve to illustrate the differences in prescription that can be attained if different prescriptive strategies are employed. Figure 1 shows the right ear audiometric thresholds of a ten year-old child. This ear was fitted with a multi-channel wide dynamic range compression hearing aid, and was verified using the child's measured RECD. The alternative hearing aid fittings that resulted from using the DSL[i/o] and the NAL-NL1 fitting algorithms are shown in figures 2 and 3. Verification measures are shown for a 90 dB pure tone sweep and either a 70 dB SPL speech input[†] (see

[†] The speech estimates shown were derived by adding the measured coupler gain from 70 dB and 55 dB speech-weighted noise to normative estimates of conversational free field speech (Byrne et al. 1994), the child's RECD, and microphone location effects for a BTE hearing aid. The same derivation procedure was applied to both DSL and NAL verification data.

figure 2) or a 55 dB SPL speech input (see figure 3). Expectations based on older target comparison studies might lead one to assume that the main difference between the targets should be that DSL provides more high frequency amplification than NAL. However, this is not the case for this individual child's comparison, which uses the most recent version of each formula and makes the comparison in dB SPL for the same input signal. Compared in this way, the inter-prescription difference is roughly a 10 dB overall level difference, in which the DSL prescription provides more overall gain than the NAL prescription. Also, the prescriptions for maximum output are remarkably similar, indicating potential concurrent validity. These observed patterns for this case may or may not be typical of what can be expected for other children with differing levels and configurations of hearing loss.

Predictive Validity: Prescriptions Should Provide Benefit

Predictive validity in a hearing aid prescription implies that hearing aid users will benefit more from their hearing aids if the prescription is used than if the prescription is not used. In a more specific question, one prescription may have higher predictive validity than an alternative if it provides either higher levels of benefit, or more consistent benefit. Predictive validity implies that a prescriptive procedure is clinically useful, if we assume (a) that clinicians choose prescriptive formulae that have been proven beneficial in a target population that is similar to the individual at hand, and (b) that clinicians can accurately verify that they have replicated the prescribed targets in the fitted devices (see Scollie and Seewald 2002 for more information on verification). Inherent in this process is an implicit hypothesis: the hypothesized and/or demonstrated benefit of this amplification scheme will generalize to this individual. For pediatric audiology, it is perhaps important to remember that laboratory and clinical trials of predictive validity in *adults* may not generalize to the infant/toddler/child population.

In evaluating predictive validity, several approaches have been taken in the literature. Some studies have evaluated whether the goals of a given prescription are actually attained in samples of children. For example, the DSL 4.1 prescription has been shown to meet its goal of providing a comfortable,

preferred overall listening level (Scollie et al. 2000), normalized loudness for speech (Jenstad, Pumford, Seewald and Cornelisse 2000), and high levels of speech recognition for both linear and WDRC hearing aids (Jenstad et al. 1999). In these studies, children were previous users of the DSL prescription.

An alternative approach to evaluating predictive validity is to compare prescriptive alternatives to determine whether different outcomes result. This type of research can be considered intra-prescription or inter-prescription, and can be based on either preference or performance outcomes. In an inter-prescription study of preference, Ching et al. (1997) found that children with severe to profound hearing loss preferred the NAL-RP prescription to the DSL 3.0 prescription. The children in this study were previous users of the NAL prescription. In an intra-prescription study of performance, Jenstad et al. (1999) found that children with mild to moderately severe hearing loss recognized speech at high performance levels across a greater input range when fitted with the WDRC version of DSL [i/o] than with the linear version of the same prescription.

A further alternative is to compare prescribed frequency responses to the measured responses of long-term successful hearing aid wearers. Snik and colleagues conducted a series of such studies in the early 1990s, comparing then-current versions of several prescriptions to the fittings that resulted from many years of fine-tuning by experienced clinicians, in response to the developmental outcomes of the children in the studies. For children with mild to profound losses, the half-gain and DSL 3.1 prescriptions tended to be similar to current use settings (Snik and Stollman 1995). For children with profound losses, NAL-RP and DSL 3.1 were within 6 dB of current use settings (Snik, van den Borne, Brokx and Hoestra 1995). These studies indicate that use of a systematic prescription produces fittings that are in general agreement with the fittings of experienced clinicians who have knowledge of a child's functional communication status. This conclusion may speak to a consistency advantage to applying an objective prescription as a common starting point for pediatric hearing aid fittings.

Condie, Scollie and Checkley (2002) evaluated a sample of children with moderate to profound hearing losses, both with their own hearing aids and with trial WDRC hearing aids. Electroacoustic verification measures revealed that their own hearing aids had been fitted using a variety of fitting strategies. The

trial hearing aids were fitted to DSL[i/o]. On average, the children were able to understand significantly more PBK words in quiet with the DSL-fitted devices. More interesting was the change in consistency of this outcome: the children who performed most poorly with their own aids received the most benefit from changing to the trial aids. Scores with own aids ranged from 0% correct to 94%, while trial aids scores ranged from 46% to 98%. Given that testing was completed at a conversational level, we did not expect that this improvement was mainly due to the effects of WDRC. Our verification results indicated that a broader bandwidth, and in some cases a more appropriate listening level, was provided more consistently in the trial devices. For example, children's own aids were up to 30 dB below target at 2000 Hz, while the DSL-fitted devices were within 2 dB of this target for all children in the study. Increases in speech audibility at 250 Hz were in the range of 20 dB for many children. This indicates that the consistency of fitting to target may relate to the consistency of outcome. We can examine this relationship in more detail by comparing the degree of gain changes to the degree of performance changes that these children experienced. The largest single-ear, single-frequency changes for each child, measured at a test level of 70 dB SPL, are plotted against changes in PBK-50 scores in figure 4. The linear regression line indicates that 50% of the variance in speech recognition is accounted for by changes in frequency response. The

issue of consistent benefit is perhaps as important as the issue of differential benefit, when evaluating predictive validity.

Construct Validity: Not only which prescription should we use but how should we use it?

It is well understood that construct validity is the most difficult form of validity to demonstrate. This makes good sense, as the definitions of construct validity are typically meant to denote overall, or true, validity in a very complete sense. For a prescriptive formula to hold construct validity, it would need to provide an accurate, comprehensive, electroacoustic prescription of a theoretically optimal hearing aid. Our field is likely not yet at the point where all potential research questions related to prescriptive formulae have been exhausted. Therefore, I will instead speculate that even the best-validated prescriptive calculation is entirely meaningless unless it is successfully and accurately replicated by the user's hearing aids. We have increasing data to show that relying upon (a) manufacturer's automatic fittings rather than manually verified and fine tuned hearing aids (Hawkins and Cook 2003), and (b) age-predicted estimates of external ear canal resonances rather than probe-microphone measurements both contribute substantially to inconsistent fittings. I hope that

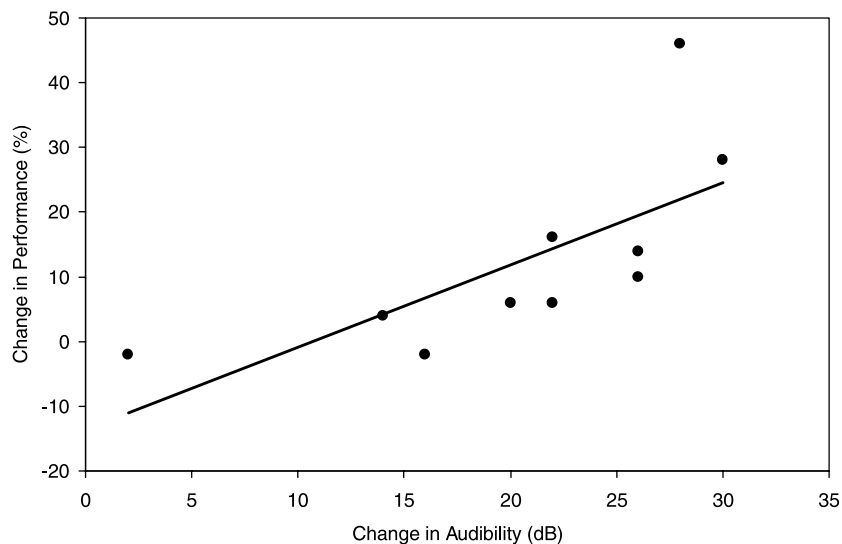


Figure 4. Relation between changes in audibility versus changes in performance for a sample of children fitted using a systematic prescriptive approach.

this paper demonstrates that the pediatric population requires access to consistently prescribed, accurately fitted hearing aids. This requires our profession to not only apply well-validated prescriptions, but also to select beneficial technologies, set them appropriately, and verify each fitting electroacoustically. This philosophy has been echoed repeatedly in professional practice guidelines for the last decade (AAA 2003; PWG 1996) yet finds inconsistent application in clinical practice. It behooves those of us who work in pediatric audiology to ensure that we not only develop, but also apply and evaluate the validity of our prescriptive and fitting procedures. This requires work and integration by both clinicians and researchers, acting as a team in the best interests of the infants and children whom we serve.

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