Fitting Preschool and Primary School Children with Hearing Instruments: An Evaluation of Hearing Aid Prescription Rules

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Introduction

Hearing Aid Fitting in Children

Although the knowledge about hearing aid fitting in children has accumulated steadily over the past three decades, the fitting of hearing aids in young preverbal children is still often a trial-and-error process. Common reasons are that only limited audiometric data are available, and that as a rule, young children are unable to express their preferences. In addition to objective evaluations (using couplers or a microphone in the auditory canal), repeated behavioral observations are necessary to determine whether the hearing aid provides the child with appropriate information to derive meaning from acoustic events, and to verify whether amplified speech is sufficiently audible while uncomfortable levels are avoided.

An additional problem is that little is known about the desired gain in children. Studies have indicated that young children with normal hearing need higher presentation levels to be able to discriminate speech sounds as well as adults can (e.g., Nozza, Rossman, and Bond 1991).

Furthermore, it is not known whether the optimal frequency response, thus the gain as a function of frequency for a given hearing loss, in children who are still at the beginning of their speech-language development is the same as that in children who have acquired some language. Finally, as pointed out by Stelmachowicz et al. (1993), the input levels to the infant’s hearing aid microphone may be high because of the way the parent holds the child.

The important progress made in forming a scientific basis for hearing aid fitting in children was partly driven by the introduction of real-ear measurements, by the development of nonlinear hearing aids, and by the introduction of the cochlear implant. The latter obliged us to evaluate the efficiency of well-fitted conventional hearing aids in young children in a relatively short period as part of the selection procedure for cochlear implantation.

Studies showed that when hearing aid fitting is optimal in children with profound hearing impairment, their residual hearing capacity plays a significant role or even a primary role in language acquisition (Brookhouser, Worthington, and Kelly 1990; Marlowe 1994). Therefore, hearing aid fitting in those children must be evaluated thoroughly before decisions can be made about enrolling them in sign language programs or cochlear implantation programs.

Threshold-Based Prescription Rules

Theoretical insights have led to the development of hearing aid prescription rules. These rules help in the selection of hearing aids and are especially useful in young, preverbal children. However, the rules must be based on relatively simple audiometric inputs such as hearing thresholds. Several rules have been developed for adults and/or validated in adults. Probably the oldest rule is the half-gain rule. It states that the real-ear desired gain should be equal to half the hearing loss at all frequencies (Leijon et al. 1990). Several modifications have been published (Byrne and Cotton 1988; Hawkins 1992; McCandless and Lyregaard 1983). Another approach, originally developed for the electroacoustic selection of hearing aids for young children, is the desired sensation level (DSL) method (Seewald 1995; Stelmachowicz and Seewald 1991). All these rules aim to amplify speech at normal conversation level either to the subject’s presumed most comfortable listening levels or to the middle of the subject’s dynamic range. Nevertheless, the prescribed values may vary significantly from rule to rule (Hawkins 1992).
Over the past few years, we have evaluated three commonly used rules for hearing aid fitting in young children, namely, the POGO, NAL, and DSL. The POGO is the half-gain rule with corrections for the gain at 250 Hz and 500 Hz to minimize upward spread of masking (McCandless and Lyregaard 1983). The advantage of the POGO procedure is its simplicity. More than ten years ago, the POGO procedure was revised because it was found that subjects with severe and profound hearing loss demand higher gain than prescribed (revision called the POGO-II; Schwartz, Lyregaard, and Lundh 1988). If the uncomfortable loudness levels are known, which is not usually the case in young children, the desired maximum output of the hearing device is also prescribed.

Byrne and coworkers, from the National Acoustic Laboratories in Australia, developed the NAL rule. By studying the results of a large number of subjects who were hearing impaired with hearing aids (Byrne and Cotton 1988; Byrne and Tonisson 1976), they optimized their rule. Because of the way they optimized their rule, the prescriptions are directly influenced by the characteristics of contemporary hearing aids. This rule was also adapted for subjects with profound deafness. It is referred to as the NAL-RP (Byrne, Parkinson, and Newall 1990).

The NAL rule has been updated with desired maximum output values (Storey et al. 1998). These prescribed values are based on (unaided) hearing thresholds.

Early work that, in time, led to the development of the DSL method started in the seventies (Gengel, Pascoe, and Shore 1971), but the most important contributions were made over the past ten years (Seewald 1995; Stelmachowicz and Seewald 1991). Data from several psychophysical studies were used. Therefore, this rule does not depend on the characteristics of current hearing aids.

From the start, apart from the desired gain, the desired maximum output of the hearing device was a central item (Gengel, Pascoe, and Shore 1971). The limited maximum output of a hearing device is often referred to as the saturation sound pressure level (SSPL). If the SSPL is set at too low a level either by peak clipping or by output compression, amplified normal speech may be distorted and therefore less recognizable. If on the other hand the SSPL is set too high, loud sounds may cause discomfort, and there is the risk of damaging the patient’s residual hearing (Macrae 1994).

The best way to measure the SSPL is with a 2cc coupler. In young children with small ear canals, the SSPL measured in the ear will be considerably higher than that measured with the coupler. Thus in children, corrections of the calculated SSPL values are needed related to the size of the ear canal. The DSL has tackled this problem by introducing generalized age-related corrections to the desired SSPL values (Seewald 1995).

Hearing Aid Measurements

To compare desired gain as a function of frequency to measured values, several tests are available. Mostly, objective tests are advocated, such as the so-called real-ear insertion gain (REIG) measurement. The REIG is measured with a microphone in the ear canal by subtracting the unaided sound pressure levels from the aided sound pressure levels (Libby 1991; Snik and Hombergen 1993; Stelmachowicz and Seewald 1991). In addition, evaluations on a 2cc coupler are important, first, to see whether the technical performance of the device is in accordance with the manufacturer’s data and, second, to measure the SSPL at the settings used daily by the child.

Often, the functional gain or the difference between aided and unaided thresholds is determined. Functional gain measurements are time-consuming and less informative than REIGs. Therefore, functional gain measurements are often replaced by REIG measurements.

The Value of Prescription Rules

In the early nineties, we studied the hearing aid settings in young successful users of linear behind-the-ear hearing aids by analyzing their results in retrospect. The studies concerned:

1. Retrospective REIG measurements in young children with hearing impairment who were fitted with hearing aids in a well-organized expert system (with a structured auditory training program). These children were fitted during the eighties before the development of REIG evaluations (Snik and Hombergen 1993).

2. Comparison of measured gain and output in young children with target values obtained using several prescription rules (Snik and Stollman 1995; Snik et al. 1995).

3. Aided thresholds, studied in children with conductive hearing loss using either air- or bone-conduction hearing aids (Snik, Mylanus, and Cremers 1994).

These studies and other similar studies are reviewed below.

Real-Ear Gain in Children and Adults
When we started our study in 1989, real-ear measurements were not yet being performed on a regular basis; 2cc coupler measurements were performed only to check the proper functioning of the hearing aids. At that time, hearing aids (linear devices) were selected based on experience, not on prescriptive rules. They were provided on a trial basis and optimized during the child’s stay at the Pediatric Audiology Department’s therapeutic kindergarten for children who are hearing impaired. Children of up to 4 years of age attended the kindergarten one or two days a week. Besides social activities, the children were trained individually and in groups in sound awareness, localization and discrimination, listening and speech, and language acquisition. For this purpose, a structured auditory program was developed, based on the work by Erber (1982). During the training sessions, the auditory performance with the hearing aids was tested informally and also at regular intervals formally by measuring aided thresholds. The results were evaluated monthly by the therapist, audiologist, psychologist, and parents. If necessary, the volume setting and/or control settings were changed, or other hearing aids were tried. After the child had become accustomed to the hearing aids and was found to be progressing well with the therapy, the trial period was ended. Typically, the trial period lasted six months.

In retrospect, we performed objective measurements in children who were fitted successfully according to this expert system (Snik and Hombergen 1993). Only the results of children with symmetrical sensorineural hearing loss who were using binaural hearing aids were analyzed. Children with predominant high-frequency hearing loss were excluded, as well as children with hearing thresholds that exceeded 120 dB HL. In addition, children with acquired deafness after the age of 2 years were excluded. Results were available from 60 primary school children whose age ranged from 4.1 to 12 years, and 35 young preschool children whose age ranged from 2 to 4 years. REIGs were measured 0.5 to 9 years after the first fitting.

The REIG curve was separated into two components: the “frequency response” (the shape of the curve) and the “mean gain” (the overall amount of amplification). As a rule, preschool children are not capable of adjusting the volume of their hearing aids properly. Therefore, both the mean gain and the frequency response are important when fitting young children with hearing aids. The mean gain or mean REIG was determined by averaging the insertion gain at 0.5, 1, 2, and 4 kHz. First, the mean REIG values are presented, and then the results for frequency response will be considered.

Figure 1a shows the individual mean REIG values (of only one ear: the ear with the best aided response). For reference purposes the results of 40 adults are presented in figure 1b. At first sight, the mean REIG values appear to be spread around straight lines. Linear regression analysis showed that the data from the preschool and school children were comparable. Therefore, these results were pooled. To compare the children’s results to those of the adults, the regression line calculated from the adult group is also shown in figure 1a. The analysis revealed that on the average, the mean REIG in the children was 5 to 7 dB higher than in the adults.

![Figure 1a and 1b](image-url)
Next, we calculated the articulation index (AI). The AI is an expression of the proportion of the speech signal that is audible and therefore useful in the evaluation of hearing aid fitting. This is especially so in young children because standardized speech recognition testing is not always reliable. Speech recognition scores are related to the AI, but discrimination abilities also play a major role. AI calculation assumes that the dynamic range with the hearing aid is wide enough that normal speech can be processed without distortion because of output limiting.

In figures 2a and 2b, the AI is presented for the children and adults as a function of hearing loss. The AI decreased with increasing hearing loss, while the AI values in the children were significantly higher than those in the adults. This means that a greater portion of the spectrum of normal speech was audible in the children that was ascribed to the 5 to 7 dB difference in mean gain.

In conclusion, according to our expert system (with a structured auditory training program), children need a higher gain than adults. This results in higher AI values and is in accordance with the results of studies showing that young children need higher speech levels to discriminate speech sounds as well as adults can (Nozza, Rossman, and Bond 1991; Palmer, Sheppard, and Marshall 1991). Furthermore, the findings suggest that fitting strategies based on results obtained in adults are probably inappropriate for children.

Comparison of Measured Gain and Output with Target Values

Children with Moderate or Severe Hearing Loss

In the second study, the frequency response was studied in relation to the prescribed gain (Snik and Stollman 1995). A retrospective comparison was made between measured and calculated REIGs and SSPL90 values using prescription methods on a group of young children who, according to our evaluation protocol, were successfully fitted with linear behind-the-ear hearing aids. We chose the POGO-II, NAL, and DSL methods. The SSPL90 refers to the output, in dB SPL, measured on a 2cc coupler with a 90 dB SPL input and the settings used daily by the child. Results were analyzed of 24 young children of up to 6.5 years of age who were hearing impaired and fitted with hearing aids at our clinic between July 1989 and September 1991.

Results of the children who fulfilled the same criteria as listed above were included except that their age was 6 years or younger and that their mean hearing threshold at 0.5, 1, 2, and 4 kHz was 75 dB HL or less. Results of children with more severe hearing loss are described separately in the next section.

All the children were considered to be successful hearing aid users on the basis of successive audiologic evaluations during at least three years of follow-up. For this study, the procedure at the kindergarten was further standardized as follows. Initially, the maximum output (SSPL90) of the hearing aids was set at 105 dB SPL. It was gradually increased during successive training sessions until discomfort was observed. After the trial period was ended, real-ear measurements were performed as well as an SSPL90 measurement on a 2cc coupler.

Figure 3 shows the measured REIGs minus the calculated REIGs as a function of frequency using the three rules. The result of the ear with the highest AI was used for this analysis. The figure indicates that on the average, the NAL prescribed 3 to 7 dB less gain than that mea-
sured. For the POGO-II and the DSL there was a good correspondence, except for the DSL at 4 kHz. In the majority of children the individual differences between the prescribed and measured values, averaged over 0.5, 1, 2, and 4 kHz, using the DSL, POGO-II, or NAL, were between +5 and −5 dB (in 68%, 81%, and 54% of the chil-
dren, respectively).

Figure 4 shows the difference between the age-cor-
corrected SSPL90 values calculated with the DSL method and the measured values. The mean difference values were spread around zero, but the curve was not smooth. This was ascribed to the well-known resonance peak of behind the ears around 1500 Hz. The close similarity between the calculated and measured values suggests that the age-related output prescriptions of the DSL method are adequate. The mean prescribed output was more than 3 dB above the measured value in only one case (4%).

Children with Severe/Profound Hearing Loss

In a third study (Snik et al. 1995) we analyzed the results of children with profound hearing loss (a mean hearing loss at 0.5, 1, 2, and 4 kHz of 90 dB HL or higher). The set-up of this study differed from the other studies in that the children were selected. The study group comprised 16 children who were prelingually deaf selected on their well-developed aural-oral communication skills that were clearly above average and had resulted in mainstreaming. At the time of evaluation, their age was between 8 and 13 years. It was assumed that hearing aid fitting in these children was probably close to optimal. All the children were fitted with linear devices. In the classroom they all used additional personal FM systems.

All the children had measurable hearing thresholds from 0.25 to 4 kHz. Thresholds of worse than 115 dB HL were not found in any of the children at any of the frequencies. Aided speech recognition testing at 70 dB SPL showed that the mean open set phoneme recognition score was 71% (range 30% to 100%), which was clearly (31%) above the mean of a reference group (which comprised 22 unselected children aged between 4 and 12 years with hearing thresholds between 90 and 115 dB HL; unpublished results).

In retrospect, we compared the measured and pre-
scribed gain and output using the POGO-II, DSL, and NAL-RP rules.

Figure 5 presents the average measured REIG minus the calculated value using the three rules for 0.5, 1, 2, and 4 kHz. Poor agreement was seen at 4 kHz. Similar findings have been reported by others (Byrne, Parkinson, and Newall 1990; Libby 1991) and were ascribed to the fact that most high-power hearing aids have insufficient gain in this frequency region (Libby 1991), partly to prevent feedback. The long length of tubing in the relatively long earmolds might have played a part (Snik and Hombergen 1993).

Figure 5 shows that the POGO-II produced the most discrepancies; it prescribed too much gain. At 0.25, 1, and 2 kHz, a discrepancy of more than 10 dB was found. Dyrlund and Lundh (1990) found a similar result.
Compared to the higher frequencies, the POGO-II prescribed little gain at 0.25 and 0.5 kHz. This was caused by the prescribed reductions in the gain in this frequency range, to minimize upward spread of masking. Although such reductions are beneficial in persons with mild to moderate hearing loss, research has shown that in subjects with severe or profound hearing loss, amplification in the low-frequency region seems to be of great importance for speech recognition (Brokx et al. 1997; Byrne et al. 1990; Dyrlund 1988; Von Wedel and Von Wedel 1993).

Studies have shown that in children who depend primarily on lipreading, placing special emphasis on amplification in the low-frequency range is highly beneficial (Dyrlund 1988; Franck 1991). However, there was no positive or negative effect on speech recognition in an auditory-only presentation mode. Ross (1975) and Diller (1991) stated that the low frequencies should be deemphasized if a child has functional hearing over a broad frequency range (to minimize upward spread of masking that might influence the audibility of consonants) but not if functional gain is restricted to the low-frequency range.

Individual differences were studied by taking each child’s RMS (root-mean-square) difference between the measured and calculated values. Figure 6 depicts the RMS values. The best result was found for the NAL-RP, followed closely by the DSL and POGO-II.

The prescribed age-corrected SSPL values using the DSL minus the measured values are depicted in figure 7 as a function of frequency. Values of close to zero were found. This is in accordance with the results from another study on unselected young children with profound hearing impairment (Snik and Stollman 1995); their results are also included in the figure. In 2 out of the 16 children, the calculated SSPLs were more than 3 dB higher than the measured values.

In summary, although the number of subjects was limited and only the results of a selected group of children were included, some conclusions can be drawn. The NAL-RP proved to be the most adequate rule to obtain the desired insertion gain, followed closely by the values prescribed by the DSL method.

On average, the SSPL values calculated using the DSL method can be considered adequate.

Ching, Newall, and Wigney (1997) also compared the measured and prescribed gain using the NAL-RP and DSL procedures. They studied 21 children between 6 and 16 years old with severe or profound deafness. The hearing aids were fitted according to the NAL-RP rule. The mean measured gain at 0.5, 1, and 2 kHz was in fair agreement with the NAL-RP prescriptions, but also with the DSL prescriptions. A problem in the study by Ching and coworkers, as they discussed, was that the children were fitted according to the NAL-RP rule. If they had been fitted according to the DSL rule with appropriate time to become accustomed to the amplified sound prescribed by the DSL method, the results may have been different.
Amplification for Children with Conductive Hearing Loss

In young children, conductive hearing loss is commonly caused by congenital malformations of the middle ear and/or auditory canal, chronic otitis media with effusion, or chronic draining ears. If surgical intervention is not (yet) an option, the fitting of hearing aids has to be considered. Generally, air-conduction hearing aids are the first choice, but if occlusion of the ear canal by an earmold cannot be tolerated or if the ear canal or the auricle is severely malformed, a bone-conduction hearing aid is the only option.

In our study, aided thresholds were determined in a group of 43 young children with conductive hearing loss who were using air- or bone-conduction devices (Snik, Mylanus, and Cremers 1994). Cases with mixed hearing loss and unilateral cases were excluded. For reference purposes, the results were compared to those of a group of adults (with the same audiometric inclusion criteria).

The subjects were divided into four subgroups. The first group comprised subjects who were using a conventional transcutaneous bone-conduction hearing aid (transducer connected to a behind-the-ear or body-worn hearing aid: 10 children, 20 adults); the second group used a percutaneous bone-anchored hearing aid, or BAHA (10 children, 24 adults); the remaining group, using air-conduction hearing aids, were subdivided into a group with binaural hearing aids (16 children, 10 adults) and a group with monaural amplification (7 children, 10 adults). The reason for monaural amplification was either contralateral otorrhoea or unwillingness to use two hearing aids.

Figure 8a shows the average aided hearing thresholds as a function of frequency in the four groups of children. Figure 8b shows the results for the adults. Statistical analysis revealed that per subgroup, the differences between the adults’ data and the children’s data were not significant at any of the four frequencies (0.5, 1, 2, or 4 kHz). However, there was a tendency toward lower, thus better, thresholds in the children than in the adults. Nevertheless, for further analysis, data from the children and adults were pooled. Compared to the other subgroups, significantly poorer thresholds were found only for the subgroup of patients who were using a conventional bone-conduction device. Among other things, this means that the aided thresholds with the BAHA were better than with the conventional bone conductor. A similar result in children was reported by Powell et al. (1996).

Next, the relationship was studied between the aided threshold and the hearing threshold obtained with headphones. Correlational analysis for each subgroup showed that these relationships were not statistically significant. This suggests that prescriptive rules based on hearing thresholds are not suitable for subjects with conductive hearing loss. It was not an unexpected result.

The results shown in figure 8 suggest that when fitting a conventional bone-conduction hearing aid, the volume and control settings should be set so that the aided hearing thresholds are between 20 and 25 dB HL for the frequencies 1, 2, and 4 kHz. For fitting a BAHA or air-conduction hearing aid whether it is applied monaurally or binaurally, the aided thresholds should be between 15 and 20 dB HL.

Conclusions

A comparison was made between clinical experience and prescriptive rules for fitting hearing aids to young children with hearing impairment. Hearing aid fitting was optimized in a structured auditory training program. Although the number of children was limited, some conclusions can be drawn.

In children with moderate-to-severe hearing loss, the POGO-II and DSL prescribed REIG values that were in satisfactory agreement with the measured data according to the mean REIG and frequency response. The gain prescribed by the NAL was about 4 dB too low. In children with more severe hearing loss, the POGO-II prescribed too much gain, while the NAL-RP prescriptions were ade-
quate, as was the case with the DSL prescription. The DSL prescribed more gain than the NAL-RP for the highest frequency (4 kHz). This is most probably due to the fact that NAL prescriptions, in contrast to DSL prescriptions, were optimized in studies using contemporary powerful hearing aids, which have limited gain in that frequency range. This suggests that from a scientific point of view, DSL targets are preferable.

An important advantage of the DSL over the other rules is that the calculated values are available as age-corrected 2cc coupler values and that desired output limiting characteristics are also given. This is useful for the preselection of hearing aids and for the evaluation of infants who reject the measuring probe for REIG measurements. Instead of using the generalized age-related 2cc coupler corrections, clinicians are advocated to determine the child’s own real-ear-to-coupler difference or RECD (Seewald 1995).

Prescription rules are definitely helpful for fitting hearing aids in children. For linear devices, DSL values seem to be a good place to begin when fitting young children. However, it should be realized that prescription methods cannot replace structured audiologic evaluations of a child’s aided hearing by experienced personnel.

Finally, prescription rules based on unaided hearing thresholds are not suitable for patients with conductive hearing loss. Our data suggest that for contemporary hearing devices, the target aided thresholds should be near 20 dB HL.

References


