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**Hearing-aid Fitting in Profoundly Hearing-impaired Children**

Comparison of Prescription Rules

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Generally, the performance of a hearing-impaired child with his or her hearing aids is the major criterion in selection programmes for cochlear implantation. Thereto, it has to be considered whether the hearing-aid fitting is optimal. For this purpose, methods which prescribe hearing-aid gain are valuable, especially in young preverbal children. Three of these methods were evaluated by comparing the calculated and measured gain as a function of frequency in a selected group of profoundly hearing-impaired children (n = 16), all of whom were successful users of hearing aids. Fair agreement was found for the modified NAL rule applicable in profoundly hearing-impaired subjects and the DSL method (desired sensation level method).

**Key words:** Children, hearing-aid fitting, insertion gain measurements, prescription rules, profound deafness

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**Introduction**

In most paediatric cochlear implant (CI) selection procedures, the absence of functional hearing with hearing aids is the most important criterion for CI candidacy (Radcliffe, 1994). However, it is difficult to be sure that the hearing-aid fitting is optimal or, more specifically, whether the gain and maximum output of the hearing aid are adequate. It is necessary to find out whether the hearing aid provides the child with appropriate information to derive meaning from acoustic events and this can be a great problem in young children. It is well known that for profoundly hearing-impaired children (hearing loss exceeding 90 dB HL) with appropriate hearing-aid fitting and training, residual hearing can play a significant role, or even a primary role, in language acquisition (Brookhouser et al., 1990; Marlowe, 1994). Erber & Alencewicz (1976) showed that functional hearing can be assumed if the hearing loss was no worse than 90 dB HL, whereas functional hearing can be assumed to be absent if the hearing loss exceeds 110 dB HL. In between, a large spread in speech recognition abilities was found ranging from chance to almost 100% scores. Therefore, evaluating the hearing-aid fitting in profoundly hearing-impaired children, before considering them as CI candidates, needs an aggressive approach (Marlowe, 1994).

Unfortunately, it is generally the rule with young children that only limited audiological data are available at the time of the initial fitting. Therefore the selection of hearing aids is often a 'trial and error' process. As soon as hearing aids are fitted, the preverbal child needs structured training to become accustomed to hearing and listening, and basic auditory skills have to be developed. Repeated observations of the child's responses to sounds are used to evaluate his or her functional use of hearing with the hearing aids. It is necessary to evaluate whether or not amplified speech is audible, while avoiding discomfort levels and ensuring that the hearing aid is functioning optimally without any distortion due to saturation of the hearing-aid amplifier. For this purpose, methods which calculate the desired gain and maximum output of the hearing aid (target formulae) are a great help (Snik & Hombergen, 1993; Marlowe, 1994). The desired, calculated gain can be verified with real ear measurements which are nowadays considered to be indispensable for fitting hearing aids to young children.
Several prescription rules have been described in the literature, but only a few of them have been developed or adapted for application to patients with profound hearing loss. POGO (Prescription of Gain and Output, McCandless & Lyregaard, 1983) and NAL (National Acoustics Laboratories’ procedure, Byrne & Dillon, 1986) are examples of such rules. The reasoning behind these rules is that the frequency-insertion gain characteristics can be predicted from hearing threshold levels and the rules are based on research into adults.

POGO and NAL have been adapted for application to severely and profoundly hearing-impaired patients. POGO prescribes additional gain for all frequencies if the hearing threshold exceeds 65 dB HL (Schwartz et al., 1988); this revision of POGO was called POGO-II. From a study on the applicability of the NAL rule to severely and profoundly hearing-impaired adults, it was proposed to decrease the low frequency slope of the prescribed frequency-gain curve by 4 dB/octave if the hearing threshold at 2 kHz was between 95 and 110 dB HL, and by 8 dB/octave if the threshold exceeded 110 dB HL (Byrne et al., 1990). Furthermore, the desired overall gain should be 10 dB above that calculated with the original NAL rule. In the present article the modified NAL rule is referred to as the NAL-PD rule.

Although the desired gain of a hearing aid is of great importance, the desired maximum output is at least as important. If a patient’s loudness discomfort levels (LDLs) are known, which is not usually the case in young children, both rules provide information on the desired maximum output of the hearing aids.

A more sophisticated method, originally developed for the electroacoustic selection of hearing aids for young children, is the DSL method (Desired Sensation Level method, Stelmachowicz & Seewald, 1991; Seewald, 1992; Seewald et al., 1993). DSL is based on studies in which hearing thresholds, most comfortable loudness levels and LDLs were obtained from adults. It outlines the residual auditory area and provides the so-called desired sensation levels for the amplified speech spectrum. From the desired sensation levels, e.g. the desired real ear gain and/or the desired electroacoustical (i.e. 2 cm³ coupler) gain can be calculated. Desired electroacoustical maximum output levels are also calculated and most importantly, corrections are applied for age-related variables, such as the size of the ear canal (Seewald, 1992; Seewald et al., 1993). Therefore, this method is especially suitable for children. An important advantage of DSL is that if real ear measurements are unsuccessful, DSL allows evaluation on the 2 cm³ coupler, without the participation of the child.

Dyrlund & Lundh (1990) used POGO-II in 21 children with profound hearing loss which ranged from 90 to more than 120 dB HL. They studied hearing in the frequency range of up to 1 kHz. At the time of the initial fitting, the measured and calculated gains with POGO-II at 250 and 500 Hz were in good agreement. However, at 1 kHz the measured insertion gain was more than 10 dB below the calculated value. The authors reported that at follow-up visits the children had reduced the volume by an average of 10 dB.

The NAL-PD is a direct consequence of applying the NAL rule to severely and profoundly hearing-impaired adults. Modifications of the NAL rule were introduced to minimize discrepancies between calculated and measured insertion gain values (Byrne et al., 1990). No evaluation studies by other groups applying NAL-PD are known. Studies on the use of DSL in profoundly hearing-impaired patients are unknown too.

This article presents a retrospective comparison between the measured and calculated insertion gain using POGO-II, DSL and NAL-PD in a selected group of children with profound hearing loss who were successful hearing-aid users. The children were selected from our database on the following criteria: early onset of deafness (before age 2 years), born between 1975 and 1986, at least 6 years of hearing-aid use and attending a normal school. In The Netherlands, the majority of profoundly hearing-impaired children attend special schools for the hearing impaired. Most of the children in the present study were initially placed at such special schools, but owing to adequate oral-aural communication skills, special education was no longer needed, or was even contraindicated because of the higher verbal demands at regular schools.

In this investigation on successful prelingually hearing-impaired hearing-aid users, conclusions will be derived concerning the desired gain and the maximum output levels of hearing aids for profoundly hearing-impaired children who were candidates for cochlear implantation.
Material and Methods

Subjects

From our records, 16 children with profound sensorineural hearing loss, i.e. a pure-tone average at 0.5, 1, 2 and 4 kHz (PTA) of at least 90 dB HL, fulfilled the criteria. The age at the first hearing-aid fitting ranged from 0.3 to 3.8 years (mean 2.2 years); the duration of hearing-aid use varied from 6 to 16 years (mean 10 years). After kindergarten for hearing-impaired children, 7 of the children went directly to regular schools. The other 9 children were initially referred to special schools for the deaf, but were transferred to regular schools later on when they were on average 8.6 years of age (range 6–12 years). The children underwent regular psychological and educational assessments. Thirteen out of the 16 children had normal non-verbal intelligence, while 3 children were above average (exceeding 120 IQ points).

All the children were fitted binaurally with linear behind-the-ear hearing aids with peak clipping to limit the maximum output. In the classroom they all used additional personal FM systems.

Fitting Procedure

In Nijmegen, the initial hearing-aid fitting was done while the children were attending a therapeutic kindergarten for hearing-impaired children. In longitudinal evaluative studies, functional hearing with the hearing aids was assessed. The results were discussed regularly with the teacher, audiologist, psychologist and the parents. If necessary, the volume setting and/or control settings of the hearing aids were changed or other hearing aids were tried. Special attention was paid to the maximum output (quantified by the saturated sound pressure level or SSPL) of the hearing aids. As a rule, the SSPL was initially set at 110 dB SPL. It was gradually increased (steps of 5 dB) during successive observations until discomfort was noted. After the child had become accustomed to the hearing aids and, according to the multidisciplinary team supervising the child, was found to be progressing well with the auditory training programme, the trial period with hearing aids was ended. The trial period lasted an average of 20 weeks. Afterwards, the training continued and the child’s hearing and the hearing aids were monitored at longer intervals, at least twice a year.

After about 5 years, the children were refitted with new hearing aids. After pure-tone and speech audiometry, hearing aids were tried in a test session using the child’s own ear moulds. (Hearing aids were selected by experience, and, as a standard, ear moulds with horn-borings were prescribed.) Speech recognition was tested and had to be equal to or better than that obtained with earphones. The child’s opinion was noted. Based on the first results, hearing aids were selected for the trial period, which lasted for at least 6 weeks. After the trial period an evaluation was made which included speech recognition tests. If the result was not satisfactory according to the child, the parents or the audiologist, a second trial period was started with other hearing aids, or the same hearing aids were used with different control settings, depending on the types of complaint.

Measurements

Audiometry was performed using standard procedures and equipment (Interacoustics AC-5, calibrated according to ISO 389). Thresholds were obtained at the frequencies 0.25, 0.5, 1, 2 and 4 kHz. For all of the children, audiograms were available which were considered to be reliable. Insertion gain measurements were performed with the CAS system (Danavox); the measurement protocol and results of a reproducibility study have been described in more detail elsewhere (Snik & Hombergen, 1993). The electroacoustical characteristics of the hearing aids were measured with a 2 cm³ coupler incorporated into the CAS system, according to IEC 118.

The aided articulation index was used to select the child’s best aided ear (Snik & Hombergen, 1993). The results of this ear were used in the analysis.

To make a comparison with the calculated values, the difference score viz. the measured minus the calculated insertion gain (MIG – CIG) at 0.25, 0.5, 1, 2 and 4 kHz, was calculated for each child. The difference scores of the children were averaged and are presented as a function of frequency. This was done to derive general conclusions on too much or too little calculated gain as a function of frequency. Individual differences were studied by taking each child’s RMS (root-mean-square) difference between the MIG and CIG values; RMS was used to prevent cancelling too much calculated gain in one frequency region and too little in another.

In some children, high target values for the insertion gain were calculated, even in excess of 80 dB HL (with POGO-II). As such high target values cannot be achieved with contemporary hearing aids, we reduced all the calculated values which exceeded 70 dB to 70 dB in the evaluations.

Aided speech recognition tests were administered by live voice presentation without lipreading. The tests were presented with a slightly raised voice volume so that the level at the child’s ear was approximately 70 dB SPL. An open set spontaneous recognition test (20 items) was used in 14 of the 16 children (standard test for children older than 6 years). The Dutch version of the picture identification test described by Erber & Alencewicz (1976; 24 items) was used in 6 children: normative values for this test were available (Coninx et al., 1994). Results from speech recognition tests, insertion gain and SSPL measurements, as obtained at the last hearing-aid evaluation, were used. At that moment, the children were 8.8 years of age on the average (range 5 to 14 years).

Results

Fig. 1 presents the average puretone hearing thresholds and aided thresholds, calculated by subtracting the insertion gain from the unaided thresholds, as a function of frequency. It should be mentioned that all the children had measurable hearing thresholds from 0.25 to 4 kHz; remarkably, thresholds of worse than 115 dB HL were not found in any of the children, at any of the frequencies. In Fig. 2, the children’s aided speech recognition scores are presented as a function of their average hearing loss. Six of the children who were tested with the picture identification test had scores which were clearly above average. The same figure shows that the
majority of the children had open-set scores which were above or near to the mean normative score for the picture identification test. This means that these children had favourable speech recognition scores with their hearing aids.

Fig. 3 presents the average measured insertion gain minus the calculated insertion gain (MIG − CIG) using POGO-II, DSL and NAL-PD. Poor agreement was seen at 4 kHz (sudden decrease in the curves). This has also been reported by others (Byrne et al., 1990; Libby, 1991; Snik & Hombergen, 1993) and can be ascribed to the fact that most high-power hearing aids have insufficient gain in this frequency region (Libby, 1991). The large tubing length in the relatively long ear moulds might also have played a part (Snik & Hombergen, 1993). Therefore, the insertion gain results at 4 kHz will not be considered in further interpretations and discussions.

Fig. 3 shows that most of the data points obtained with the DSL and NAL-PD methods were between +5 dB and −5 dB, while only one of the data points obtained with POGO-II was within this range.

Therefore, POGO-II is the rule with the most deviation. At 0.25, 1 and 2 kHz, a discrepancy of more than 10 dB was found between the CIG and MIG. Fig. 4 depicts the RMS difference between the MIG and CIG of each child, in histogram form. It can be seen that the smallest differences between MIG and GIG were found for NAL-PD followed by DSL and
POGO-II. Averaged over all the children, RMS difference values were found of 5.6, 8.1 and 12.0 dB, respectively. Pearson’s correlational analysis showed that the RMS difference values for the three prescription methods were nonsignificantly related to the PTA (tested at the 5% level), which suggests that the level of agreement between the measured and calculated insertion gain values did not depend on the size of the hearing loss.

Compared to the NAL-PD and POGO rules, DSL has the advantage of giving a prescription of the maximum output characteristics. The age-corrected SSPL values as prescribed by DSL compared to the measured values are depicted in Fig. 5 as a function of frequency. When the average value per child is considered, 12 out of the 16 average values deviated by 3 dB or less from zero. Only in two of the remaining children were the calculated SSPL values higher than the measured ones by 4 and 6 dB, respectively. On average, the SSPL values calculated by DSL can be considered as adequate.

Fig. 5. The measured minus the calculated saturated sound pressure level (MSSPL - CSSPL) by DSL as a function of frequency for the whole group. Standard deviations (not indicated) ranged from 3.6 dB at 1 kHz to 6.4 dB at 0.25 kHz.

Discussion and Conclusions

The children in this study were selected on their well-developed aural-oral communication skills, which were clearly above average and had resulted in mainstreaming. It was assumed that hearing-aid fitting in these children was probably close to optimal. Although the hearing aids were not directly optimized for speech recognition, recognition scores as presented in Fig. 2 proved to be favourable compared to those obtained in a normalization study on an unselected group of profoundly hearing-impaired children in the same age range. Nevertheless, it cannot be excluded that further optimization with speech recognition tests might have been beneficial to some of the children. Comparing retrospectively measured hearing-aid characteristics with those calculated by three different prescription methods showed that POGO-II gave the most deviation in results (see Figs. 3 and 4). At 1 and 2 kHz, a discrepancy of 12 dB or more was found between the calculated and measured insertion gain (Fig. 3), which is in agreement with the observations reported by Dyrlund & Lundh (1990). Compared to the higher frequencies, 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 patients with mild to moderate hearing loss, research has shown that for patients with a severe or profound hearing loss amplification in the low frequency region is of great importance for speech recognition (Dyrlund, 1988; Von Wedel & Von Wedel, 1993) and it has been suggested that the corrections in the low frequency region may be superfluous for these patients (Byrne et al., 1990; Snik & Hombergen, 1993).

The (adequate) prescription of maximum output characteristics (Fig. 5) is an advantage of DSL over the other two rules. A further advantage of DSL is that desired electroacoustical gain and maximum
output characteristics can be obtained, which are very useful for the preselection of hearing aids and for evaluation purposes if the child rejects the probe for real-ear measurements.

Although the number of patients in this study was limited and only the results of a very select group of children were included, some conclusions can be drawn. Prescription rules may be very helpful in fitting profoundly hearing-impaired children with hearing aids. NAL-PD proved to be the most adequate rule for obtaining the desired insertion gain, immediately followed by the DSL method. DSL is the most practical rule because it supplies adequate target values for both gain and maximum output. Therefore, it is concluded that the DSL values seem to be a good place to begin when fitting children. However, prescription methods cannot substitute for behavioural evaluations by an experienced staff. In preverbal profoundly hearing-impaired children, repeated structured long-term observations and training of auditory functions are of primary importance in documenting the child's progress with hearing aids and to assess his or her suitability for cochlear implantation.

References


