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Preferred Listening Levels of Children Who Use Hearing Aids: Comparison to Prescriptive Targets

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Abstract

The preferred listening levels (PLLs) of children with sensorineural hearing loss were elicited using conversation-level speech, heard through the children's own hearing aids. All hearing aids were fitted using the desired sensation level (DSL) method. Comparisons were made between the PLL and targets from the following prescriptive formulae: DSL version 4.1 and two versions of the National Acoustic Laboratories (NAL) procedure, including NAL revised for severe-profound losses (NAL)-RP and NAL nonlinear NAL/NL1. Results for this sample of children indicated that the PLL was similar to the DSL targets, and that, on average, NAL-RP/NL1 targets recommended less gain than that preferred by the majority of children in this study. The implications of factors such as acclimatization, test levels, and clinical procedures on these results are discussed.

Key Words: Amplification, children, desired sensation level, frequency response, hearing aids, National Acoustic Laboratories NL1, National Acoustic Laboratories RP, preferred listening level, prescription gain formulas, real-ear-to-coupler difference

Abbreviations: ANOVA = analysis of variance, BLS = binaural loudness summation, BTE = behind the ear, DSL = desired sensation level, LDL = loudness discomfort level, MCL = most comfortable level, NAL = National Acoustics Laboratories, PLL = preferred listening level, POGO = prescription of gain and output, RECD = real-ear-to-coupler difference, SPL = sound pressure level, SSPL = saturation sound pressure level, WDRC = wide dynamic range compression

The provision of appropriate amplification is an important early step in the treatment plan for children with sensorineural hearing losses. The audiologist must ensure that amplified sound is consistently audible at comfortable listening levels (Pediatric Working Group, 1996). One way to assess whether a prescribed frequency response is acceptable to the child is to compare it to the child's preferred listening level (PLL). The PLL is considered a measure of "optimal" amplification characteristics when measured on experienced hearing aid users because it is assumed that their chosen listening level will strike the best possible compromise between comfort, intelligibility, and other factors such as distortion and background noise (Cox, 1982). The PLL is typically measured by presenting a speech stimulus to a listener, allowing the listener sufficient time to adjust the volume control to his or her preference, and then measuring the electroacoustic characteristics of the aid at that setting. Therefore, the PLL can be used to evaluate if a recommended volume control setting is in accordance with the listener's preference. This is an important issue for pediatric hearing aid fitting since volume control covers are a typical consideration in hearing aid selection, particularly in the infant and toddler age range (Beauchaine et al, 1996).

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Extensive study of the PLL has been completed with adult listeners using a wide range of stimuli, instructional sets, response paradigms, and amplification systems. Specifically, increased background noise levels cause listeners to choose lower PLLs (Cox and Alexander, 1991, 1994; Neuman et al, 1995). It is unclear whether the stimulus level affects the PLL because some studies have shown an effect for input level (Cox and Alexander, 1994; Newman et al, 1995) whereas others have not (Walden et al, 1977). Generally, it may be expected that volume control adjustments and/or level-dependent compression would be necessary to accommodate to listener preference across the listening environments and levels that would typically be encountered in daily life (Cox and Alexander, 1991; Neuman et al, 1995).

The PLL corresponds closely to the level at which children with severe to profound hearing losses achieve their best speech perception/categorization performance (Erber and Witt, 1977). Typically, the children with severe hearing losses displayed PLLs that were 32 dB above threshold, whereas the children with profound hearing losses preferred speech to be 19 dB above threshold. These findings are similar to a study of the most comfortable level (MCL) in children, in which the MCL was typically 6 to 10 dB below the uncomfortable level and moved closer to threshold as the degree of hearing loss increased (Erber and Alencewicz, 1976). These studies demonstrate that the PLL is related to level of hearing loss and that the PLL can predict the listening range at which comfort and intelligibility are high, even in children.

Because the PLL is related to both comfort and intelligibility, it is an appealing tool to use in the evaluation of prescriptive formulae. That is, if a given prescriptive formula can predict the electroacoustic characteristics that are preferred by a group of children, it may lend validity to the application of that formula in pediatric hearing aid fittings. This approach was taken by Ching et al (1997), who compared the National Acoustics Laboratories (NAL-RP: Byrne and Dillon, 1986; Byrne et al, 1990) and the desired sensation level (DSL 3.0: Seewald et al, 1985) in a group of 21 children with severe to profound hearing losses. These children were asked to choose the most intelligible of two audiovisual stimuli, which differed in spectral shape, while wearing their own hearing aids set to NAL-RP. The frequency shaping of the stimuli was varied to be either flat, a 6-dB/octave low-frequency reduction, a 6-dB/octave low-frequency boost, or a 12-dB/octave low-frequency boost. Each frequency response was presented at the MCL for pairwise comparison testing. Thus, although Ching et al (1997) did not assess the PLL per se, they assumed that the children would prefer the frequency response with the highest intelligibility rating since they had controlled for the comfort of the overall level.

Ching et al (1997) concluded that the NAL-RP formula predicted preferred hearing aid gain and slope more closely than the DSL 3.0 prescription. However, they noted that because the children had been using hearing aids fitted to the NAL-RP prescription, it was not possible to assess whether their acclimatization to such a response influenced their preferences. Given that acclimatization may be both level and frequency dependent (Gatehouse, 1993), it is possible that listener preference could be higher for a response that has been worn for an extended period of time. In fact, Gatehouse (1993) cautions against evaluating listener preferences immediately following the selection of a frequency response.

A somewhat different approach was taken by Snik and colleagues (Snik and Hombergen, 1993; Snik and Stollman, 1995; Snik et al, 1995), who compared prescriptive formulae to the hearing aid responses used by children who had been carefully fitted over time and were deemed "successful" hearing aid users by their rehabilitative team. The first of these studies determined that preschool and school-aged children used 7 dB more gain than did adults, indicating that different prescriptive formulae may be required for the adult and pediatric populations (Snik and Hombergen, 1993). Snik and Stollman (1995) compared the half-gain rule and the DSL 3.0 frequency responses to the used frequency responses of 34 children with mild to profound hearing losses. They found that both prescriptive rules were in close agreement with user gains for the majority of children and that DSL-prescribed saturation sound pressure level (SSPL)-90 was in agreement with the majority of used SSPL-90 measurements. In a further study, the DSL 3.1 and NAL-RP prescriptions and the Prescription of Gain and Output (POGO II) (Schwartz et al, 1988) were compared to the used insertion gains of children with profound sensorineural hearing loss (Snik et al, 1995). These researchers concluded that both NAL-RP and DSL were successful in prescribing insertion gains that were within 5 dB of the used insertion gains of the majority of children. The NAL-RP targets were somewhat closer to used gain values than DSL 3.0 targets, and the POGO II targets were not in agreement with use gain values for the majority of children.

Binaural Loudness Summation and the PLL

In normal-hearing listeners, a given stimulus will be perceived to have greater loudness if it is presented binaurally rather than monaurally. This phenomenon has been termed "binaural loudness summation" (BLS). Hawkins et al (1987) assessed BLS in adult listeners with normal and impaired hearing sensitivity. When subjects performed either a loudness matching task or a fixed loudness level search, BLS was apparent for both speech noise stimuli and pure tones. Loudness summation decreased in magnitude, with higher input level stimuli eliciting smaller amounts of BLS. When loudness discomfort levels (LDLs) were measured using a clinical loudness rating procedure (Hawkins et al, 1987), no evidence for BLS was found. The authors concluded that correction for binaural loudness summation is not necessary when selecting the output limiting characteristic of hearing aids.

It is not known if the presence or size of BLS in hearing-impaired adults similarly exists in children with hearing loss. The hearing-impaired adults in the Hawkins et al study showed roughly 6 dB of BLS for a mid-level speech-noise stimulus. It is possible that exposure to real speech may result in similar amounts of BLS in children with hearing loss.

Purpose and Hypotheses

The literature on PLLs indicates that the PLL varies with the stimulus, environment, hearing threshold level, and type of hearing aid circuitry. There are still several unknown factors that may affect PLLs, especially in children. It is possible that monaural and binaural listening tasks may produce different PLLs due to binaural loudness summation. It is possible that prescriptive formulae may be used to predict the PLL or that acclimatization to a specific frequency response may affect the PLL (Byrne and Dirks, 1996; Ching et al, 1997). No study has yet been published that examines the PLLs of children who have acclimatized to DSL-fitted hearing aids.

The purpose of the present study was to determine if hearing aids fitted using version 4.1a of the DSL method (Seewald et al, 1997) would amplify conversation-level speech to children's PLLs. A second purpose was to compare the children's PLLs for average conversational speech to the prescriptive targets generated by the NAL formulae (Byrne and Dillon, 1986; Byrne et al, 1990; Dillon et al, 1998). A third purpose was to assess the presence or absence of binaural loudness summation in the PLL in a sample of children with sensorineural hearing loss.

It was hypothesized that DSL targets would be similar to the PLLs of the majority of children with hearing loss. Based on the numeric differences between the DSL 4.1 and NAL-RP/NL1 targets, it was also hypothesized that the NAL-RP/NL1 prescription would recommend less gain than that preferred by the majority of children in this study. For monaural versus binaural PLL measures, it was hypothesized that binaural loudness summation would cause binaural PLLs to be lower than monaural PLLs.

METHOD

Stimulus Delivery

Testing was completed in a double-walled sound-treated audiometric test chamber. A single loudspeaker was located in the corner of the sound booth and was 1 meter away from the test subjects at 0° azimuth. A GSI 16 audiometer was used to attenuate the test signal and deliver it to the loudspeaker. The ambient noise level within the test environment was 44.6 dBA SPL. The test stimulus was list 4 from the Hearing in Noise Test compact disk (Nilsson et al, 1994), which was digitally filtered to simulate the long-term average speech spectrum measured for children's speech by Cornelisse et al (1991) at an overall level of 60 dB SPL.

Hearing Aid Assessment and Fitting

Children in this study were assessed for hearing sensitivity prior to the study. Pure-tone thresholds were measured using insert phones coupled to the children's personal earmolds.[1] Real-ear-to-coupler differences (RECDs) were measured at the time of assessment using the child's earmolds and standard protocols for either

[1]The earmold is coupled to the insert phone for three reasons: (a) it provides good retention and seal, (b) the child is familiar with the feeling of his or her own earmold, (c) it allows the RECD measured with the earmold to be used in converting HL thresholds to real-ear SPL prior to target calculation (Seewald and Scollie, 1999), in an individualized and accurate fashion (Scollie et al, 1998).

the Fonix 6500 (Seewald et al, 1997) or the Audioscan RM500 (Cole and Sinclair, 1998). Thresholds and RECDs were entered into DSL 4.1a for Windows. Software calculations converted HL thresholds to values in real-ear SPL using the child's own RECD. Targets for hearing aid performance were calculated from the real-ear SPL thresholds using the DSL [input/output] algorithm (Cornelisse et al, 1995) and converted to 2-cc coupler format (Seewald et al, 1999). Hearing aids were adjusted to meet targets for 2-cc coupler performance for mid-level signals and a 90-dB pure-tone sweep. The recommended volume control setting was provided to parents.

On average, hearing aids in this study met gain targets to within ±5 dB from 500 to 3000 Hz, with 95 percent of hearing aids meeting targets within ±5 dB from 750 to 2000 Hz. All children were experienced, regular users of hearing aids set using DSL targets and assessment protocols.

Electroacoustic Measurement

Each hearing aid was placed in the test chamber of an Audioscan RM500, and the 2-cc coupler gain for a 50 dB SPL 2-kHz pure tone was measured. As shown in Figure 1, this measurement was sensitive to changes across a wide range of volume control settings, for both moderate- and high-power hearing aids. This measurement was made at the audiologist's recommended volume control setting (i.e., the volume control setting at which the aid best met DSL targets). Then, the child was told that she/he would hear "a man talking" and that she/he should adjust the volume control of the hearing aid(s) until the talker sounded "the best to you." The volume control on the hearing aid(s) was reduced to minimum, and the stimulus was delivered via the loudspeaker. At this point, the experimenter visually indicated to the child that the stimulus had begun, and the child would begin adjusting the volume control.

Once the child had adjusted the volume control(s) to the preferred level, the hearing aid(s) were removed and the 2-cc coupler gain was measured. Each child completed two trials of the PLL task while listening binaurally. For the one child who wore only one hearing aid in daily life, two monaural PLLs were tested rather than the binaural PLL. Children who were 8 years or older were also asked to complete right and left ear monaural PLL trials. During monaural trials, one aid was turned off but left in place, and the other aid was used while listening to the stimulus. Measures of 2-cc coupler gain were completed as in previous trials.

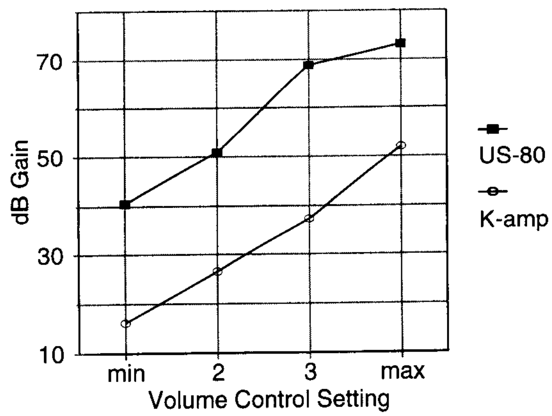

Figure 1 Variation in measured gain with volume control manipulation across the full range of settings. Measures are shown for a high-power aid (US-80) and a moderate-power aid (K-amp).

Subjects

Prior to inclusion in the study, subjects were screened for normal middle ear function and the ability to independently manipulate the volume controls of their hearing aids. Twenty-one subjects participated in this study. Of the 21 subjects, 3 were excluded from data analysis. Two were excluded due to poor test–retest reliability. The third subject was excluded because she was having frequent feedback problems due to loosely fitting earmolds, which had not yet been

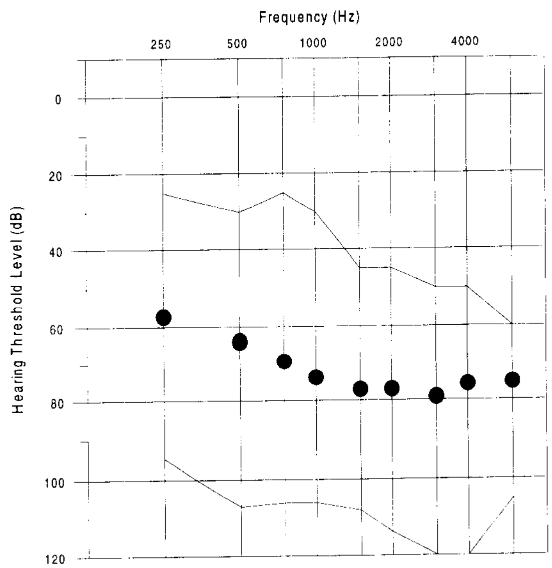

Figure 2 Pure-tone thresholds of the subjects in this study. Shown are the average and range of thresholds at each frequency, across ears of subjects.

replaced. The remaining 18 subjects (8 male, 10 female) had a mean age of 10.8 years, ranging from 4.8 to 19 years.

All subjects were clients at the Speech and Hearing Clinic at the University of Western Ontario. Based on pure-tone threshold averages, the degree of hearing loss of subjects in this study ranged from moderate to profound. Figure 2 shows the average and range of hearing losses by frequency across all subjects. All subjects but one were binaural hearing aid users.

RESULTS

Comparisons to Prescriptive Targets

PLL measurements were compared to prescriptive targets from the DSL 4.1 and NAL-RP formulae as follows. First, the PLL measures for the two binaural trials were averaged together for each ear. In the case of the monaural hearing aid user, monaural data were used and data from only one ear are reported. Using measured hearing aid responses for 35 ears from 18 subjects, the PLL gain setting was used to calculate the three-frequency average (3FA) of the hearing aid gain setting at PLL as follows. The 2-cc coupler gain at the recommended volume control setting was measured across frequencies. Then, the gain at 2000 Hz was measured during the PLL trials. The difference between the PLL gain and the recommended gain at 2000 Hz was added to recommended gain at 500 and 1000 Hz, and the average gain at 500, 1000, and 2000 Hz was calculated.

The 3FA of prescribed 2-cc coupler gain targets was also calculated for each of the NAL-RP and DSL 4.1 formulae for each ear. For DSL targets, thresholds and RECDs were entered into DSL 4.1, and targets for gain in the 2-cc coupler were calculated by the software, using corrections for linear gain versus wide dynamic range compression (WDRC) circuitry. For NAL-RP targets, NAL-RP equations were implemented in a spreadsheet to calculate real-ear insertion gain values for any hearing aids that used linear gain circuitry. In calculations of the NAL-RP targets, the severe-to-profound correction (Byrne et al, 1990) was applied if appropriate, and individually measured RECDs were used in conversions of insertion gain targets to coupler gain. For nonlinear hearing aids, NAL-NL1 software (Dillon et al, 1998) was used to generate targets from thresholds and RECDs for each test ear.

The targets from DSL 4.1 and NAL-RP/NL1 are plotted against the PLLs in Figure 3. Linear regressions of each prescriptive formula onto the PLL are also shown. These data indicate that both formulae tended to underestimate the amount of gain preferred by most

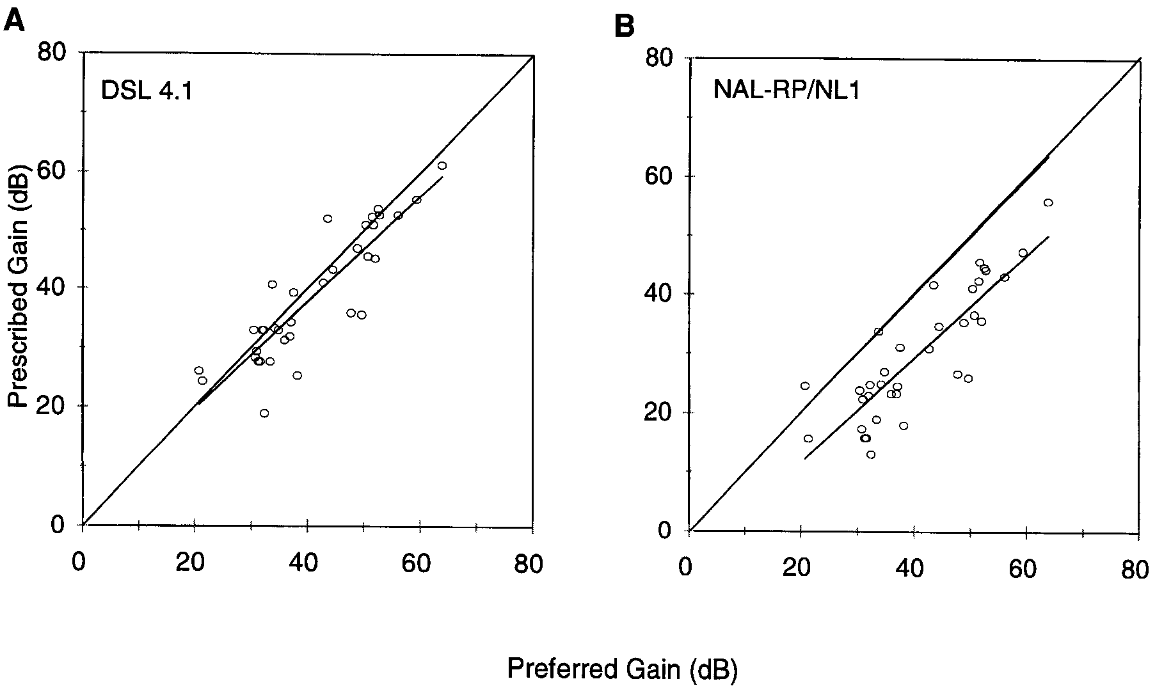

Figure 3 DSL 4.1 and NAL-RP/NL1 recommended listening levels plotted against preferred listening levels, for individual ears, in the binaural listening condition. Linear regressions are also shown for each prescriptive formula.

subjects, and that this underestimation was greater for the NAL-RP/NL1 formula than for the DSL formula.

A repeated-measures analysis of variance (ANOVA) was performed on the average PLLs measured in the binaural listening condition, as well as the DSL and NAL-RP/NL1 targets, with left and right ears considered a within-subjects variable. Results of the ANOVA procedure indicated that significant differences existed between the PLL, DSL, and NAL-RP/NL1 levels, accounting for 65 percent of the variance in the data ($F[1.04,16.7] = 29.5$, $p < .001$). No effect for left versus right ear was found, nor was there any interaction between test ear and measured levels of PLL, DSL, and NAL. Because the test ear did not have an effect on the data, individual ear data were collapsed for each subject for subsequent analyses.

Post hoc two-tailed t-tests indicated that there were no significant differences between the PLL and DSL target gains ($t[17] = -1.24$, $p = 0.23$). A significant difference was found between the PLL and NAL-RP/NL1 target gains ($t[17] = -5.86$, $p = .00$). In order to evaluate the clinical implications of these findings, 95 percent confidence intervals around the target values were calculated. These confidence intervals show that DSL targets will result in recommended listening levels that range from 5 dB below the PLL to 1.3 dB above the PLL in 95 percent of children, with 66 percent of PLLs falling within ±5 dB of target. For NAL targets, 95 percent of fittings will range from 14 dB below to 6.7 dB below the PLL, with 9 percent of PLLs falling within ±5 dB of target.

Monaural vs Binaural Preferred Listening Levels

In addition to the binaural PLL task, 14 children were also able to complete a monaural PLL trial in each ear. All 14 children were binaural hearing aid users. Figure 4 displays the monaural PLLs scattered about the binaural PLL for all 28 ears tested. It may be seen that the regression line through the monaural PLLs is nearly identical to the binaural PLL data. A repeated-measures ANOVA on left and right ear data across monaural and binaural PLLs indicated that no significant difference existed between the monaural and binaural PLLs measured in this study ($F[13,1] = .668$, $p = .428$). These results demonstrate no clear evidence for the phenomenon of binaural loudness summation for amplified speech under the conditions of this experiment.

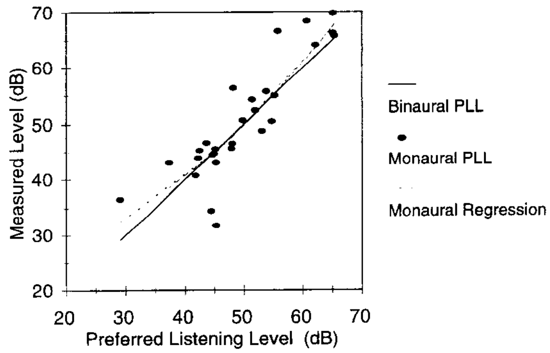

Figure 4 Monaural vs binaural preferred listening levels for 28 ears from 14 subjects. A curvilinear regression of the monaural data onto the binaural data is shown as a dashed line.

DISCUSSION

The results of this study indicate that the recommended volume control settings derived from DSL fittings are similar to the PLLs of children who are (a) experienced users of DSL-fitted hearing aids and (b) listening either binaurally or monaurally to speech at conversational levels. These findings indicate that the recommended user volume control settings that result when a clinician uses the DSL method to fit hearing aids should be acceptable to the majority of children.

The correspondence between the DSL-recommended listening level and the PLL may be dependent on the unaided hearing level. The regression of the recommended levels from DSL 4.1 against the PLL is shown in Figure 3A. The slope of this regression may indicate that the DSL targets' underestimation of preferred gain is not substantially different across hearing levels. A slightly larger discrepancy between PLL and DSL is noted for those subjects with higher target values. That is, as hearing loss increased, children in this study were more likely to prefer slightly more gain than DSL 4.1 would recommend. However, this effect is rather small, and across hearing levels, these data indicate that the use gain settings resulting from DSL fittings are similar to children's PLLs for average speech.

The findings of the present study generally agree with those of the Snik et al studies (Snik and Stollman, 1995; Snik et al, 1995). These papers compared the user frequency responses of children who were successful hearing aid users to various prescriptive formulae. In both studies, the DSL target gains were within 5 dB of the use gains of the majority of the children's hearing aids across a range of hearing losses from moderate to profound.

In contrast to the present study, Snik et al (1995) found a high level of agreement between NAL-RP and children's use gains than was found in the present study. Similarly, Ching et al (1997) found that NAL-RP agreed more closely with children's preferred gain than did DSL. These findings are not replicated in the present study, which found that listening levels recommended by the NAL-RP procedure may be significantly lower than the PLLs measured in this study. The role of acclimatization must be considered in interpreting the differences in findings between the studies.

As Ching et al (1997) suggest, it is possible that children will prefer the frequency response and listening level to which they have become acclimatized. This could have been one reason why the NAL-fitted children in the Ching et al study preferred the NAL-RP response, whereas the DSL-fitted children in the present study preferred the DSL 4.1 response. Although past research on preference for an acclimatized frequency response is not yet conclusive on this topic, some authors have suggested that acclimatization is both level and frequency dependent, and that the frequency response of the hearing aid affects acclimatization (Gatehouse, 1993; Byrne and Dirks, 1996). This has implications for the evaluation of a changed frequency response in that broader bandwidth responses may be initially rejected only to be preferred later once acclimatization has occurred (Byrne and Dirks, 1996). These suggestions are consistent with the differences between the findings of the present study and the previous studies (Snik and Stollman, 1995; Snik et al, 1995; Ching et al, 1997). The DSL responses in both data sets generally recommended more high- and low-frequency amplification and a higher overall listening level than the NAL-RP responses. This suggests that the children in the Ching et al and possibly some children in the Snik studies would need an acclimatization period in order to prefer or use a DSL response. In contrast, the children in the present study were already acclimatized to the DSL listening level.

Clinically, these findings should be interpreted after considering two factors: (a) how DSL is used and (b) the role of varying input levels. In this study, the most current version of the DSL method was used (Seewald et al, 1997), and no peak clipping hearing aids or unfiltered earhooks were fitted. All fittings employed insert phones coupled to personal earmolds during audiometry, and individually measured RECDs on each ear fitted. Because the shape and magnitude of individual ear canal resonance varies considerably (Kruger, 1987; Feigin et al, 1989) and applies to both audiometric (Scollie et al, 1998; Seewald and Scollie, 1999) and hearing aid data (Seewald et al, 1999), hearing aid fittings that use DSL without these individualized measures may have greater variance around the PLL than observed in these data.

The second factor that should be considered is that these children were tested at only the level of conversational speech in order to facilitate the testing of very young children. Therefore, we did not evaluate children's PLLs for softer and louder speech levels or for nonspeech stimuli. However, other studies have indicated that DSL fittings provide acceptable and normalized loudness ratings for speech across a wide range of input levels when WDRC circuitry is fitted to DSL [input/output] targets (Jenstad et al, 1999, 2000). If linear hearing aid circuitry is used, soft speech is typically perceived as softer than with WDRC (Jenstad et al, 1999), the overall loudness contour is not normalized (Jenstad et al, 2000), and speech intelligibility is somewhat reduced (Humes et al, 1999; Jenstad et al, 1999). At average speech input levels, both linear and WDRC circuitry fitted to DSL targets provide high levels of speech intelligibility and comfort (Jenstad et al, 1999; Humes et al, 1999). Assuming that comfortable loudness and high speech intelligibility are the primary components of the PLL, it may be speculated that DSL fittings of either linear or WDRC instruments will provide children with comfortable loudness of aided conversational speech near the preferred listening level for a majority of fittings.

SUMMARY AND CLINICAL IMPLICATIONS

The purpose of this study was to determine the nature of the relationship between prescriptive targets and user PLLs. Based on the results of the present study, it was found that the DSL 4.1 prescription, when used with the described procedures, appears to more closely approximate pediatric user PLLs than does NAL-RP/NL1 in children who are users of DSL-fitted hearing aids regardless of the level of hearing loss. Past studies have indicated that the DSL method successfully provides high levels of speech intelligibility and comfortable loudness levels to children with moderate to severe hearing losses (Jenstad et al, 1999). Therefore, it seems that the DSL method may be a reasonable approach to use when fitting infants and children with amplification. As well, the currently common practice of providing children with binaural fittings, using fixed or absent volume controls, does not seem to pose a risk to listening comfort or preference, at least for conversational speech.

It is more difficult to determine whether NAL-RP/NL1 or DSL 4.1 would result in preferred and/or improved speech intelligibility, loudness perception, or sound quality in children. A major obstacle to answering such a question is the obvious need to allow acclimatization to new amplification prior to assessment of the fitting, particularly when changes are made to aided levels and/or bandwidths. Clearly, these design issues are not trivial when considering the rehabilitative and developmental context of the young hearing-impaired child. Nonetheless, the relative success of alternative amplification strategies for young children with hearing loss is a key issue, deserving of further study.

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