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Key Words

Real-ear-to-coupler difference

Hearing aid prescriptions

Gain

Frequency response

Maximum output

Children

Real-ear difference

Coupler gain

Abbreviations

CT: Compression thresholds

DSL: Desired sensation levels

NAL-NL1: National Acoustic

Laboratories' prescription for
non-linear hearing aids, version 1

OSPL90: Maximum power output

RECD: Real-ear-to-coupler differences

The National Acoustic Laboratories in Australia and the University of Western Ontario in Canada collaborated in a comparison of the NAL-NL1 (Dillon, 1999; Byrne et al, 2001) and DSL 4.1 (Seewald et al, 1997) prescriptions for children. This paper reviews the differences in prescribed gain-frequency responses and maximum power output and examines the extent to which the prescribed differences were preserved in hearing aids fitted to children.

Byrne et al (2001) summarized differences between the two prescriptions in terms of frequency response slope, overall gain, and compression parameters. For a flat loss, DSL v.4.1 prescribes more low-frequency gain than NAL-NL1, and for a sloping high-frequency loss, DSL v.4.1 prescribes more high-frequency gain than NAL-NL1. For all hearing losses, DSL v.4.1 prescribes more overall gain than

Prescribed real-ear and achieved real-life differences in children's hearing aids adjusted according to the NAL-NL1 and the DSL v.4.1 prescriptions

Abstract

This paper examined how hearing aids adjusted for comparing NAL-NL1 with DSLv.4.1 prescription formulas matched prescriptive targets. The real-ear-to-coupler differences (RECD) of 48 children (24 in Australia and 24 in Canada) were measured and used to derive coupler gain targets. Verification of gain and output were carried out in an HA2-2cc coupler. Electroacoustic measurements revealed a minimal difference between NAL-NL1 and DSLv.4.1 frequency-response slopes due to practical limitations of the devices, even though the prescribed differences were large (up to 13 dB/octave). The difference in overall gain was generally achieved in the hearing aids, with DSLv.4.1 prescribing higher overall gain than NAL-NL1. The mean RECD at 4 kHz was 5 dB higher for children in Australia than in Canada. As the same RECDs were used in deriving targets for both prescriptions, this is unlikely to affect the results of the comparison. The impact of a gain difference between prescriptions on children's performance and preferences in real life is reported in separate papers.

Sumario

Este trabajo examinó cómo los auxiliares auditivos ajustados para comparar las recetas NAL-NL1 y DSLv.4.1 se ajustaron a las metas de prescripción. Se midieron las diferencias de oído-real a acoplador (RECD) de 48 niños (24 de Australia y 24 de Canadá), y se utilizaron para derivar las metas de ganancia por acoplador. La verificación de la ganancia y la salida se realizó en un acoplador HA2-2cc. Las mediciones electroacústicas revelaron una diferencia mínima entre las curvas de respuesta frecuencial de la NAL-NL1 y la DSLv.4.1, debido a limitaciones prácticas de los dispositivos, aunque las diferencias de prescripción eran grandes (hasta de 13 dB/octava). La diferencia en ganancia global fue generalmente lograda en los auxiliares auditivos, con el DSLv-4.1 indicando una ganancia global más alta que la del NAL-NL1. La RECD a 4 kHz fue 5 dB más alta para los niños de Australia que para los de Canadá. Dado que se usaron los mismos RECD para derivar las metas en ambas recetas, es improbable que éstas afecten los resultados de la comparación. El impacto de la diferencia de ganancia entre las recetas, para el desempeño de los niños y sus preferencias en la vida real se reporta en trabajos separados.

NAL-NL1. The difference in the frequency response slope becomes more substantial with greater degrees of hearing loss and steeper audiometric configurations. NAL-NL1 also prescribes a lower compression ratio than DSL v.4.1.

These differences can be explained in terms of the rationale underlying each prescription. The NAL-NL1 procedure aims to maximize speech intelligibility (as predicted by the speech intelligibility index model modified to allow for the effects of hearing loss desensitization) while constraining overall loudness to be the same or less than that experienced by a normal-hearing person. The balance of loudness between low and high frequencies is determined by the principle of maximizing effective audibility (Ching et al, 2001). Therefore, the amount of gain prescribed at each frequency region depends

on the contribution of an audible signal at that region to speech intelligibility. The range of frequencies that contributes to speech intelligibility varies with audiogram and input level. Because NAL-NL1 applies loudness normalization only to the overall loudness of sounds, it prescribes lower compression ratios than procedures that aim to normalize loudness.

On the other hand, the DSL procedure prescribes gain-frequency responses that were originally derived to amplify speech to certain 'desired' sensation levels (i.e. a specific suprathreshold level). The desired sensation levels were based on a review of evidence from a variety of sources, including comfortable listening levels (Kamm et al, 1978; Pascoe, 1978) and speech recognition performance in children (Erber & Witt, 1977; Gengel et al, 1971; Macrae, 1986; Smith & Boothroyd, 1989). These desired sensation levels were later merged with a loudness normalization algorithm to create a nonlinear version of DSL known as DSL v4.1 (Cornelisse et al, 1995, see also review in Seewald et al, 2005). The procedure is based on a variation of frequency-specific loudness normalization in that it maps an extended dynamic range of inputs rather than a normal dynamic range into the dynamic range of the hearing-impaired person (Cornelisse et al, 1995).

Notwithstanding the differences in targets prescribed by the NAL-NL1 and the DSL v.4.1 procedures (Byrne et al, 2001), hearing aids adjusted to match targets of the respective procedures may differ less than the prescribed targets. It is not possible to evaluate a prescriptive procedure directly, only the results of applying that procedure can be evaluated; therefore, it is pertinent to consider how closely prescriptive targets are achieved in commercial hearing aids. This paper examines the extent to which real-ear differences prescribed by the two procedures were preserved in hearing aids fitted to children. The performance and preference of children using the hearing aids are presented in companion papers (2010).

Method

Participants

Twenty-four children in Australia (46 aided ears) and twenty-four children in Canada (48 aided ears) between 6 and 19 years of age

participated in this study. Descriptions of subject characteristics are detailed in Ching et al (2010).

Hearing threshold levels

The hearing threshold levels were measured by using ER3A insert earphones coupled to the children's own earmoulds. In Australia, a Madsen Aurical system was used for hearing assessment, and a Grason-Stadler (Model GSI 37) auto tympanometer was used to evaluate middle-ear status. In Canada, a Grason-Stadler (Model GSI 16) audiometer was used for hearing assessment, and a Starkey Admittance Audiometer (Model A226) screening tympanometer was used to perform acoustic impedance measures. Figure 1 shows the audiometric thresholds of participants at the two sites, and Table 1 gives the summary descriptive statistics.

On average, neither the audiogram slope from 0.5 to 4 kHz nor the averaged hearing level over the same frequency range was significantly different between sites (Slope: $F(1,92) = 1.1, p = 0.29$; hearing level: $F(1,92) = 0.7, p = 0.38$). However, the variance between sites was different (Slope: $F = 0.53, p = 0.02$; hearing level: $F = 0.6, p = 0.04$). This suggests that there was a greater spread in audiogram configurations and threshold levels among participants in Canada than in Australia.

Hearing aid fitting procedure

Hearing aid fitting procedures were established so that individual ear canal acoustics were considered in deriving coupler gain and output limiting targets, and prescriptive targets were matched as closely as possible (Bagatto et al, 2005; Ching et al, 2002). Behind-the-ear hearing aids with multiple channels that allowed adjustments of compression thresholds and compression ratios in each channel were selected.

REAL-EAR-TO-COUPLER DIFFERENCE MEASUREMENT

Real-ear-to-coupler differences (RECD) were measured for each ear. The real-ear portion of the measurement used a custom earmould driven by the Aurical ME insert earphone. The coupler portion of the measurement used the same earphone connected to an HA2-2cc coupler (Moodie et al, 1994). The real-ear and coupler measurements carried out at both sites utilized a Madsen Aurical system.

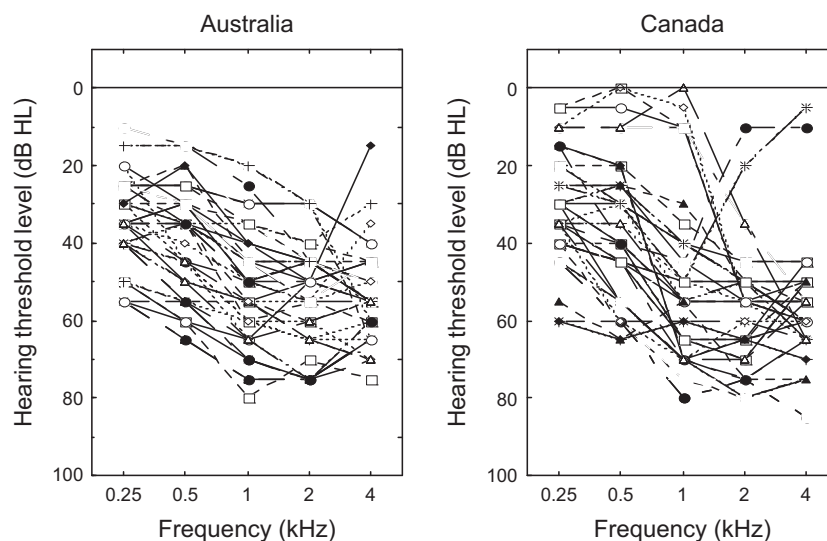


Figure 1. Audiometric thresholds of participants in Australia (left panel) and in Canada (right panel).

Table 1. Mean, standard deviation (SD), and range of four-frequency average (4FA) hearing threshold levels in dB HL, and audiogram slope (dB/octave) for children in Australia and children in Canada.

	<i>4FA (0.5–4 kHz)</i> <i>dB HL</i>	<i>LF slope (0.25–1 kHz)</i> <i>dB/octave</i>	<i>HF slope (1–4 kHz)</i> <i>dB/octave</i>	<i>Slope (0.5–2 kHz)</i> <i>dB/octave</i>
Australia				
Mean	48.7	8.1	1.5	7.2
SD	11.7	4.6	7.3	4.2
Range	31.3 to 71.3	2.5 to 22.5	–20 to 22.5	–5.0 to 15.0
Canada				
Mean	51.2	10.0	2.8	9.2
SD	15.2	7.4	11.6	8.4
Range	26.3 to 78.8	–5 to 27.5	–22.5 to 32.5	–15.0 to 27.5

For the real-ear measurements, there was a variation in the methods used for determining the insertion depth of the probe tube between sites. In Australia, a 6-kHz-notch method was used (Ching & Dillon, 2003). Because of standing waves in the ear canal, it is important that the probe tube is placed within a known distance of the eardrum (Dirks & Kincaid, 1987). The probe tube should theoretically be located within 9 mm of the eardrum to prevent errors greater than 2 dB caused by standing waves for measurements up to 4 kHz, (Dillon, 2001, pp.91–94). The desired probe tube location can be found by presenting a warble tone at 6 kHz in the sound field and finding a minimum in the ear canal at a region about 15 mm from the eardrum (Storey and Dillon, 2001; Sullivan, 1988). In this study, this region was located by smoothly inserting a probe tube into the ear canal while observing the probe-tube output display. Using the insertion depth for the 6 kHz minimum as a guide, the probe tip was then positioned 9 mm from the eardrum by inserting it an extra 6 mm. RECDs were then measured with this depth for each ear. In Canada, the insertion depth of the probe tube was determined by the clinicians' judgement (Sinclair et al, 1996) based on an optical method (Zemplenyi et al, 1985) of placing the end of the probe tube relative to landmarks of the ear canal as viewed through an otoscope. Care was taken to ensure that the probe tube extended at least 5 mm from the medial tip of the earmould, regardless of which method was used in placing the probe tip.

TARGET DERIVATION

The hearing thresholds and individual RECDs were used to derive amplification targets in an HA2-2cc coupler by using the NAL-NL1 software (Dillon, 1999) and the DSL v.4.1 software (Seewald et al, 1997).

To control for the possible confounding differences in compression thresholds (CT) and maximum power output (OSPL90) on the evaluation of gain-frequency responses, the CT and OSPL90 were assigned common values for both prescriptions. The compression threshold was set so that broadband speech at 50 dB SPL rms would just activate compression. Individual RECDs were used to derive coupler gain values by subtracting the RECD value from the real-ear aided gain (REAG) target for input levels of 55, 70, and 80 dB SPL. The OSPL90 targets of the two prescriptions, which were very similar, were averaged, and these averaged values were applied to both prescriptions for each ear.

HEARING AID ADJUSTMENT AND VERIFICATION

All 24 children in Australia and 14 of the 24 children in Canada were fitted with Bernafon Smile 110 behind-the-ear hearing aids.

This device is a digital hearing aid with dual channels, dual memory, and wide-dynamic-range compression with adjustable compression thresholds and compression ratios in each channel. Ten children in Canada were fitted with Siemens Prisma hearing aids to maintain compatibility with their personal FM systems. The Prisma is a four-channel, dual-memory digital hearing aid with wide-dynamic-range compression capability. Because the same hearing aid model was used for both prescriptions, any effect it may have on performance would have been similar for both prescriptions.

Hearing aids were adjusted in an HA2-2cc coupler to match the coupler gain targets and OSPL90 targets for each prescription. The pure-tone compression threshold was set to 54 dB SPL (± 3 dB) for the low-frequency channel(s) and to 45 dB SPL (± 3 dB) for the high-frequency channel(s) for both prescriptions. When fitting the same ear, the cross-over frequencies in hearing aids were held constant between prescriptions.

For verification of hearing aid gain-frequency responses at different input levels, a broadband speech-weighted noise generated by the Aurical system was used as a stimulus, and the hearing aids were measured in an HA2-2cc coupler. Verification was achieved by comparing the measured 2cc coupler gain or output to target values calculated using the individually measured RECD.

Verification of the achieved OSPL90 was carried out by measuring the output of hearing aids in an HA2-2cc coupler by using a swept tone at 90 dB SPL generated by the Aurical system. For a two-channel hearing aid with adjustable maximum output for each channel, the target low-frequency OSPL90 was calculated by averaging the prescribed values at 0.5 and 1 kHz, and the target high-frequency OSPL90 was calculated by averaging the prescribed values at 2, 3, and 4 kHz. For a four-channel hearing aid, the targets at 0.5, 1, 2, and 4 kHz were used. When the OSPL90 was sufficiently low that it precluded achieving the gain prescription, the OSPL90 target was raised such that it was no more than 2 dB above the higher of the NAL and DSL OSPL90 prescription. The hearing aids were adjusted in an HA2-2cc coupler to approximate the prescriptions as well as could be achieved. At the time of fitting, the maximum output of hearing aids was checked to ensure that it was not set too high to result in loudness discomfort for each participant. This was carried out by presenting babble noise at a high sound pressure level and by making loud sounds such as clapping hands and rattling a spoon in a mug when the hearing aids were worn. No further adjustment was found to be necessary for either prescription.

To confirm that hearing aid characteristics were stable over the entire duration of the study, the gain and OSPL90 of the hearing aids

were measured in an HA2-2cc coupler prior to each test session at every trial period for every participant.

Results

RECD

Figure 2 shows the average RECD measurements of all ears fitted with hearing aids at both sites and Table 2 gives the descriptive statistics. A two-factor analysis of variance with one grouping factor (site) and one repeated factor (frequency) revealed a statistically significant interaction between site and frequency ($p < 0.001$). Post-hoc analyses using the Bonferroni test showed that on average, the RECD at 4 kHz was 5 dB higher for participants in Australia than those in Canada ($p < 0.001$).

Coupler gain

Figure 3 shows the gains averaged across 0.5 to 4 kHz for a medium input level as prescribed by the NAL and the DSL prescriptions (left panel) together with the gains achieved in hearing aids (right panel) for individual participants at the two sites. The diagonal line represents complete agreement and the broken lines on either side denote ± 5 dB. As shown, DSL prescribed higher gain than NAL for all participants.

The extent to which DSL differed from NAL in terms of gain (DSL minus NAL gains) for low, medium, and high input levels at low and high frequencies is summarized in Figure 4. Difference in target gain was presented with difference in achieved hearing-aid gain, averaged across participants in Australia and Canada. At the low frequencies (Figure 4, left panel), the achieved difference matched the prescribed difference for a low input level but was less than prescribed at medium and high input levels. At the high frequencies (Figure 4, right panel), achieved difference matched prescribed difference at low and high input levels, but was reduced at a medium input level. Descriptive statistics for all input levels across frequencies at each site are summarized in Table 3. The reduction of real-life difference in gain between NAL and DSL is a consequence of underachieving DSL targets in hearing aids. This is consistent with having to limit gain so as not to exceed the maximum output target. Because the gain for DSL is higher, it has a greater effect for that prescription.

As Table 3 shows, prescribed differences were generally larger than achieved differences, with gain differences greater at low (0.25–1 kHz) than at high frequencies (2–4 kHz). For instance, the difference in gain prescribed by DSL and NAL at 70 dB SPL input was, on average across frequencies, 9.6 dB in Australia and 10.5 dB in Canada. In hearing aids, these differences were reduced to 7.2 dB and 6.9 dB respectively. Across different input levels, the mean difference in hearing-aid gain (0.5–4 kHz) between prescriptions ranged from 4 to 7 dB in Australia and from 4 to 8 dB in Canada.

Frequency response slope

Figure 5 shows the frequency response slope (0.5–4 kHz) as prescribed by NAL and DSL for a 70 dB SPL input level (left panel) together with the achieved slopes (right panel) for individual participants. The broken lines denote ± 3 dB/octave from the diagonal line of agreement. As expected from the greater variability in audiometric thresholds of participants in Canada than in Australia, there were a larger number of ears for which the prescribed slopes differed by more than 3 dB/octave in Canada. At 70 dB SPL input level, there were four ears in Australia and 11 ears in Canada for which

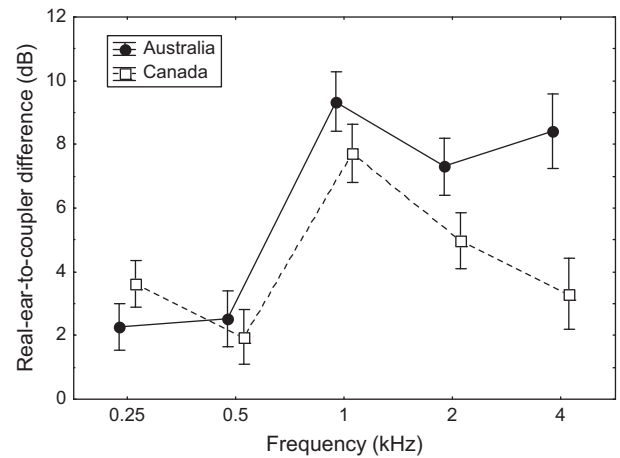


Figure 2. Mean real-ear-to-coupler difference of participants in Australia (filled circles) and Canada (open squares). Vertical bars denote 95% confidence intervals.

the responses prescribed by NAL and DSL differed by more than 3 dB/octave. At 55 dB SPL input, 10 ears in Australia and 21 ears in Canada had target slopes that differed by > 3 dB/octave, and at 80 dB SPL input, the corresponding numbers were 8 and 25 respectively.

The mean difference in frequency response slopes between NAL and DSL (NAL–DSL slopes) at low, medium, and high input levels across both sites is shown in Figure 6. Filled circles represent prescribed slopes and open squares represent achieved slopes. At low frequencies (Figure 6, left panel), the difference in prescribed slopes was greater at low and high input levels (5 dB/octave) than at medium input levels (1 dB/octave). The achieved difference matched the prescribed difference only at a medium input level. This mean difference in achieved slopes was within 3 dB/octave. At high frequencies (Figure 6, right panel), the mean difference between slopes was within 1 dB/octave of each other.

Table 4 summarizes the prescribed and achieved slope differences for low and high frequencies, showing that the target slope difference was greater at low frequencies (0.25 to 1 kHz) than at high frequencies (1 to 4 kHz). The slopes prescribed by DSL and NAL could differ by up to 13 dB/octave in the low frequencies, and up to 10 dB/octave in the high frequencies for individual ears. Over the range from 0.5 to 4 kHz, the prescribed slopes for individual ears differed by up to 9 dB/

Table 2. Mean and standard deviation of RECDs measured at five frequencies for children in Australia and Canada.

	Frequency (kHz)				
	0.25	0.5	1	2	4
Australia					
Mean	2.3	2.5	9.3	7.3	8.4
SD	2.8	2.9	2.9	2.0	3.5
Canada					
Mean	3.6	1.9	7.7	5.0	3.3
SD	2.1	3.1	3.5	3.8	4.3
Aus-Can					
Mean	-1.3	0.6	1.6	2.3	5.1

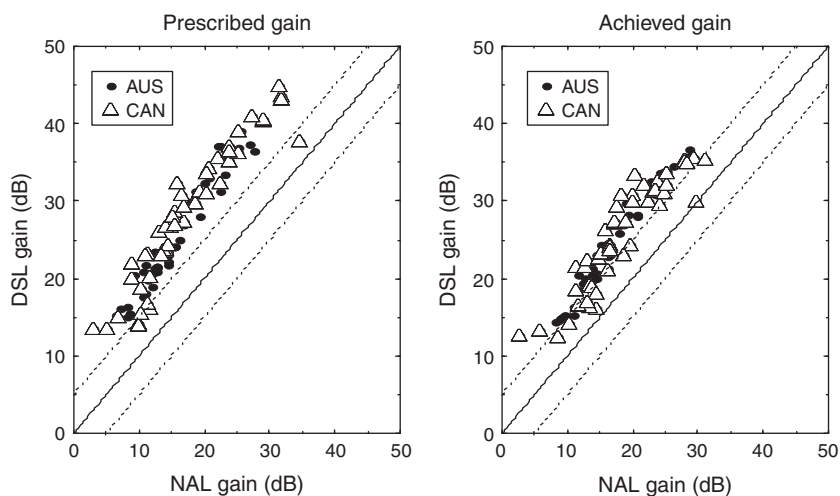


Figure 3. Coupler gain averaged over 0.5 to 4 kHz for NAL in relation to DSL for participants in Australia (filled circles) and in Canada (open triangles). The left panel shows prescribed gain, and the right panel shows the gain achieved in hearing aids.

octave, but the achieved slope difference was at most 6 dB/octave for individual ears. Across low and high input levels, the mean difference in hearing-aid frequency-response slope (0.5 to 4 kHz) between prescriptions was within 2 dB/octave at both sites.

Maximum power output

Table 5 gives the OSPL90 targets as prescribed by the NAL and DSL prescriptions, showing that the targets were very similar to each other. As described previously, the averaged targets were used for fitting to both prescriptions. Figure 7 shows the achieved values for both prescriptions.

Even though the DSL procedure prescribes higher gains than the NAL procedure, the OSPL90 targets of the respective procedures were very similar (see Table 5). The use of a common OSPL90 target was designed to control for the possible confounding of maximum output with gain-frequency responses. Although the same targets were applied for both prescriptions, the achieved values for the DSL prescription were higher than those for the NAL prescription by 3 dB ($p < 0.0001$), possibly as a consequence of matching the higher gain targets of the DSL prescription. The achieved values approximated the targets at low frequencies but deviated considerably from the targets at 1 and 2 kHz due to the limited capability of the devices in shaping OSPL90 values across frequencies.

For both prescriptions, the OSPL90 targets effectively limit the gain that can be prescribed for 80 dB SPL sounds, increasingly so as hearing thresholds increase. As DSL prescribes higher gains than NAL, the impact of OSPL90 on the ability to achieve the target gain for 80 dB SPL input levels is greater for DSL.

Discussion

This paper reports RECD data used in deriving coupler gain targets and presents measurements of coupler gain and output of hearing aids fitted to 48 children in Australia and Canada according to NAL and DSL prescription methods. The results indicated that, firstly, even though the two prescription methods prescribed large differences in frequency response slopes, the slope difference achieved in the hearing aids was minimal. Secondly, the DSL procedure

prescribed higher overall gain than the NAL procedure on average by 10 dB for a medium input level, 7 dB for a low input level, and 6 dB for a high input level. Although the gain difference achieved in the hearing aids was reduced, there was on average a 7 dB difference in gain at medium input level, and a 7 dB and 4 dB difference in gain at low and high input levels respectively. Thirdly, the mean RECD at 4 kHz was 5 dB higher for children in Australia than in Canada.

Why was it not possible to achieve the slope difference?

Although the NAL and DSL procedures prescribed different frequency response slopes, up to 13 dB/octave in the low frequencies and 9 dB/octave in the high frequencies, minimal difference was left after the prescriptions were applied in hearing aids. Although one might suspect that this was a result of intentional reduction of hearing aid gains at some frequencies by clinicians to avoid feedback, this was rarely the case. More commonly, the output limiting and constant compression ratio across levels prevented target gain levels from being achieved, thereby affecting the response slope. The target low-frequency response slope difference between prescriptions was therefore significantly reduced in hearing aids for input levels of 55 and 80 dB SPL. Examination of the prescribed and achieved gains as a function of input levels revealed that when adjusting hearing aids to match DSL targets, unless a higher compression ratio is applied to the 70 to 80 dB SPL range than to the 55 to 70 dB SPL range of input levels, either the 55 or the 80 dB SPL gains in hearing aids has to be greater than prescribed. In Canada, the achieved low-frequency gains were close to prescribed targets at 55 dB SPL but were significantly lower than prescribed at 80 dB SPL input. Conversely, the achieved high-frequency gains were significantly higher than prescribed at 55 dB SPL input but were close to prescribed targets at 70 and 80 dB SPL input levels. The slope at low input levels would be reduced when a single compression ratio was applied. Consequently, a higher compression ratio than prescribed by the DSL procedure was used in hearing aids for children in Canada. The effect of a higher-than-prescribed compression ratio on children in this study is unknown.

Comparing the fitting of children who received the Bernafon 2-channel Smile 110 hearing aids to those who received the Siemens

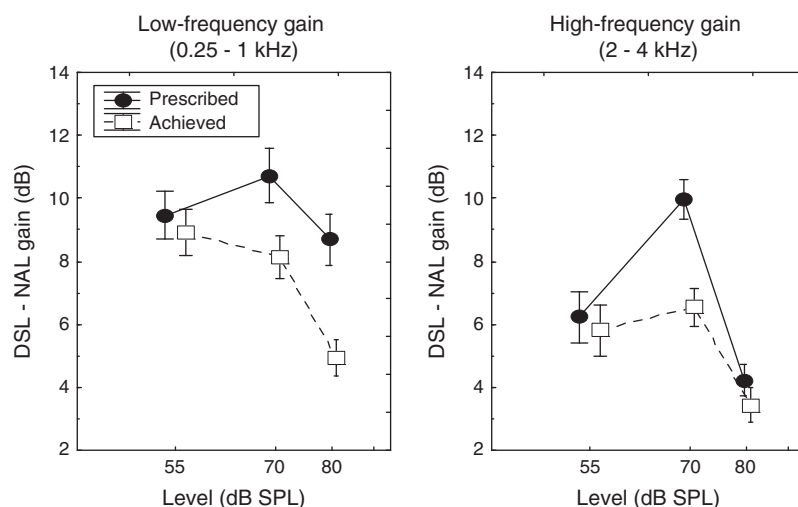


Figure 4. DSL minus NAL gain (DSL – NAL gain) at 55, 70 and 80 dB input levels, averaged across Australia and Canada. Prescribed differences are depicted by filled circles, and achieved differences by open squares. The left panel shows gain differences at low frequencies (0.25 – 1 kHz) and the right panel shows differences at high frequencies (2–4 kHz). Vertical bars denote 95% confidence intervals.

4-channel Prisma hearing aids did not reveal any difference in fitting accuracy between hearing aid types, even though the latter has more channels for adjustments.

Why were the RECDs different between sites?

The mean RECD at 4 kHz was on average 5 dB higher for children in Australia than in Canada. The average difference between repeated

measurements in Australia (Ching & Britton, 2008) was less than 1 dB, consistent with the test-retest differences reported in previous studies (Sinclair et al, 1996; Tharpe et al, 2001). As the intra-subject variability is smaller than the inter-subject variability, the difference between RECDs measured in Australia and in Canada reflects real differences between data from the two groups of children rather than random measurement error. This apparent divergence may be due to a difference in the location of the probe tip relative to the eardrum

Table 3. Mean, standard deviation (SD), and range of gain differences between the NAL and DSL (DSL – NAL) target values and achieved values in hearing aids of children in Australia and in Canada. Low frequency (LF), high frequency (HF), and four-frequency average (4FA) gains at three input levels are shown.

Level	Prescribed gain (dB)			Achieved gain (dB)				
	LF	HF	4FA	LF	HF	4FA		
	(0.25–1 kHz)	(2–4 kHz)	(0.5–4 kHz)	(0.2–1 kHz)	(2–4 kHz)	(0.5–4 kHz)		
Australia	55	Mean	9.5	6.1	6.4	8.9	3.7	5.7
		SD	2.9	3.4	1.9	2.8	3.3	1.9
		Range	3.4 to 16.1	–0.3 to 15.0	3.6 to 11.7	3.0 to 14.7	–1.5 to 15.0	2.3 to 11.8
	70	Mean	10.8	9.2	9.6	9.2	6.1	7.2
		SD	3.2	2.8	2.0	2.4	2.5	1.5
		Range	4.4 to 17.3	5.0 to 15.1	6.7 to 14.7	4.3 to 13.7	1.0 to 12.0	4.3 to 10.8
	80	Mean	8.7	3.5	4.9	5.9	2.4	3.9
		SD	3.2	1.8	1.3	2.2	2.1	1.4
		Range	2.1 to 14.4	0.8 to 8.2	2.5 to 7.9	2.3 to 10.7	–2.0 to 8.0	1.5 to 7.5
Canada	55	Mean	9.4	6.4	6.9	8.9	7.9	8.2
		SD	4.4	4.5	2.9	4.2	3.4	3.1
		Range	0.0 to 18.8	–3.7 to 19.5	–0.2 to 13.2	–2.4 to 15.2	–0.8 to 16.5	–1.1 to 13.5
	70	Mean	10.7	10.7	10.5	7.2	6.9	6.9
		SD	4.9	3.2	2.9	3.8	3.2	2.8
		Range	0.0 to 19.9	3.2 to 16.4	2.9 to 16.4	–1.0 to 14.8	0.7 to 12.9	0.1 to 12.8
	80	Mean	8.7	4.9	5.9	3.9	4.5	4.4
		SD	4.6	2.7	2.2	2.9	2.7	2.2
		Range	0.0 to 19.0	–0.8 to 14.1	–2.1 to 9.9	–0.6 to 11.5	–0.6 to 11.8	–0.1 to 9.4

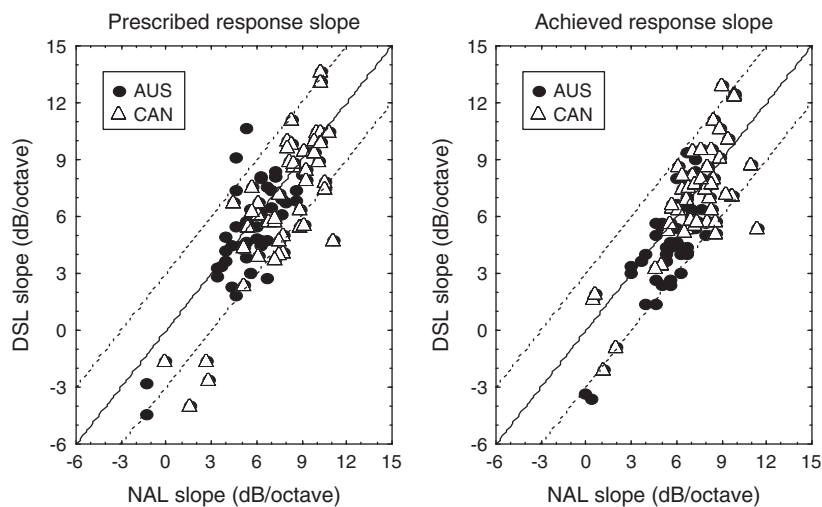


Figure 5. Frequency response slope between 0.5 to 4 kHz for NAL in relation to the response slope for DSL, expressed in terms of dB/octave, for participants in Australia (filled circles) and in Canada (open triangles). The left panel shows prescribed response slopes, and the right panel shows the response slopes achieved in hearing aids.

(Chan & Geisler, 1990) when measuring RECD in the two countries. In Canada, clinicians used an optical method to adjust the placement of a probe tube in the ear canal, and the actual distance of the probe tip relative to the eardrum was unknown. In Australia, clinicians used an acoustic method that incorporated the use of the quarter-wave anti-resonance property of the ear (Dirks & Kincaid, 1987) to place the probe tube at 9 mm from the ear drum. Alternatively, if the earmoulds used by children in Australia were deeper than those in Canada, the insertion depth of the probe would be greater, and the residual ear-canal volume would be smaller. Both factors would result in a greater RECD, particularly at 4 kHz.

A third reason may be related to a difference in the internal diameter of the sound bore used in fitting children at the two sites. If a sound bore has a constriction along its length in the earmould, it would reduce the high-frequency power delivered to the ear canal. Conversely, if the internal diameter of the sound bore increases along its length, a boost in frequencies above 3 kHz would result (Dillon, 2001). Although that was the case for two Australian children (4 ears) who had 3-mm Libby horns, all other children had #13 standard tubing. The small number of earmoulds with Libby horns in Australia does not explain the observed divergence. Unless the sound bores were accidentally constricted for children in Canada, the

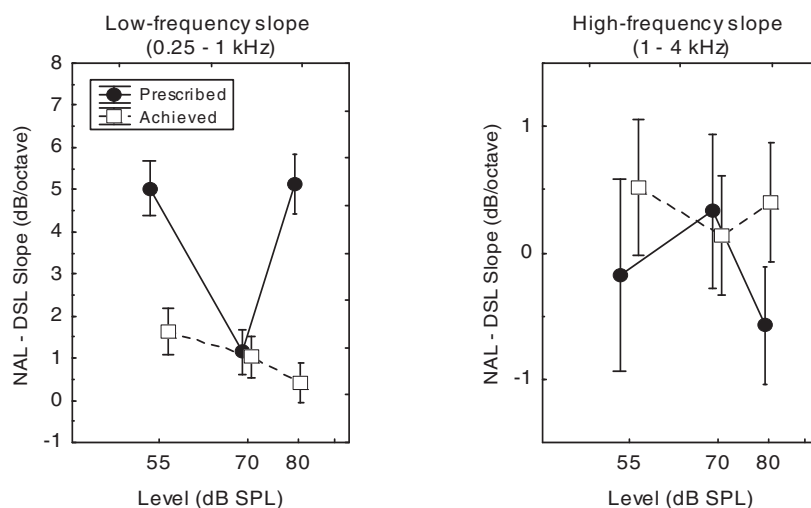


Figure 6. NAL minus DSL frequency response slope (NAL – DSL slope) at 55, 70 and 80 dB SPL input levels, expressed in terms of dB/octave. Prescribed differences are depicted by filled circles, and achieved differences by open squares. The left panel shows differences at low frequencies (0.25 – 1 kHz), and the right panel shows differences at high frequencies (1–4 kHz). Vertical bars denote 95% confidence intervals.

Table 4. Mean, standard deviation (SD), and range of frequency response slope differences between the NAL and DSL (NAL slope – DSL slope) for target values and achieved values in hearing aids of children in Australia and in Canada. Low frequency (LF), high frequency (HF), and total slope (Total) at three input levels are shown.

Level	Prescribed slope (dB/octave)			Achieved slope (dB/octave)				
	LF (0.25–1 kHz)	HF (1–4 kHz)	Total (0.5–4 kHz)	LF (0.25–1 kHz)	HF (1–4 kHz)	Total (0.5–4 kHz)		
Australia	55	Mean	5.7	-1.1	1.4	2.5	1.0	1.7
		SD	2.6	3.2	2.1	2.6	2.5	1.9
		Range	-0.2 to 12.0	-9.4 to 6.9	-4.5 to 5.8	-3.0 to 8.0	-4.0 to 5.0	-2.3 to 5.0
	70	Mean	1.7	-0.4	0.3	1.6	0.4	1.0
		SD	2.2	2.7	1.7	2.1	2.0	1.6
		Range	-2.9 to 7.5	-8.3 to 5.1	-5.3 to 3.9	-2.5 to 7.0	-3.5 to 4.5	-2.7 to 4.0
	80	Mean	5.7	-1.4	2.0	1.2	0.9	1.1
		SD	2.9	1.9	1.4	2.1	1.9	1.6
		Range	-0.4 to 11.7	-6.4 to 2.2	-2.5 to 5.5	-3.0 to 6.0	-2.5 to 6.5	-2.7 to 5.3
Canada	55	Mean	4.3	0.7	2.4	0.8	0.1	0.5
		SD	3.5	3.9	3.0	2.5	2.7	2.2
		Range	-3.9 to 11.9	-9.9 to 8.9	-3.6 to 8.9	-7.2 to 6.8	-6.4 to 5.1	-4.0 to 5.6
	70	Mean	0.6	1.1	1.0	0.5	-0.2	0.2
		SD	2.8	3.1	2.3	2.4	2.5	2.0
		Range	-7.2 to 6.7	-5.0 to 7.0	-3.3 to 6.4	-5.3 to 5.4	-5.5 to 5.8	-3.8 to 6.1
	80	Mean	4.5	0.2	2.7	-0.4	-0.1	0.1
		SD	3.9	2.3	3.3	2.2	2.5	1.9
		Range	-2.0 to 12.9	-6.5 to 5.6	-3.1 to 8.2	-6.2 to 4.5	-4.5 to 8.2	-2.9 to 6.2

significant reduction of RECD at 4 kHz could not be explained on the basis of earmould acoustics. There remains a fourth reason that the ear canals of children in Canada are truly different from those in Australia. Although such a difference is highly unlikely, there is no evidence to rule it out.

What impact did the variable RECD have on the comparison of prescriptions in real life?
If the RECDs at 4 kHz for children in Canada were spuriously low because of shallower insertion depth, then using the apparent RECD (as measured) to derive coupler gain targets for individual ears would

Table 5. Mean, standard deviation (SD), and range of maximum power output targets of the NAL and the DSL prescription.

Site	Prescription		Frequency (kHz)				
			0.25	0.5	1	2	4
Australia	NAL	Mean	89.6	96.0	95.5	100.4	98.3
		SD	3.3	3.7	5.4	4.4	4.8
		Range	83.0 to 97.0	90.0 to 103.0	84.0 to 109.0	93.0 to 113.0	88.0 to 108.0
	DSL	Mean	91.8	95.2	93.2	100.6	98.9
		SD	2.7	3.4	5.3	4.5	4.0
		Range	85.7 to 98.7	89.8 to 101.5	83.0 to 105.1	93.2 to 111.8	90.8 to 107.1
	Averaged targets	Mean	90.7	95.6	94.3	100.5	98.6
		SD	2.9	3.5	5.3	4.3	4.4
		Range	84.4 to 97.9	89.9 to 101.9	83.5 to 107.1	93.1 to 111.6	89.4 to 107.4
Canada	NAL	Mean	87.9	95.8	97.7	103.4	107.9
		SD	4.4	6.4	8.0	6.8	8.0
		Range	80.0 to 99.0	83.0 to 110.0	80.0 to 112.0	91.0 to 115.0	90.0 to 122.0
	DSL	Mean	90.0	96.1	95.2	103.5	104.1
		SD	3.7	5.6	6.5	5.2	4.8
		Range	84.1 to 100.9	84.8 to 109.4	80.2 to 105.4	93.5 to 114.3	94.2 to 114.9
	Averaged targets	Mean	89.2	95.9	96.4	103.4	106.0
		SD	3.9	5.9	7.0	5.6	6.1
		Range	82.1 to 99.5	84.9 to 109.7	80.1 to 108.7	93.8 to 113.7	94.1 to 117.9

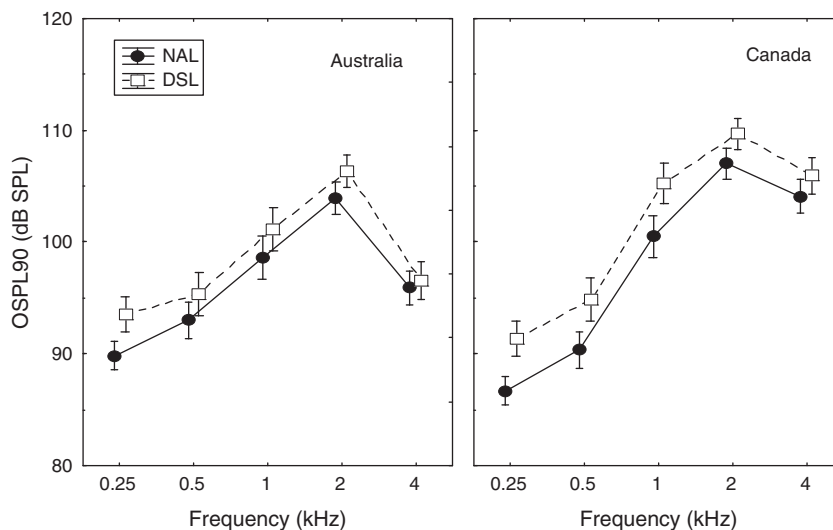


Figure 7. Achieved OSPL90 values in hearing aids for NAL-NL1 (filled circles) and DSL v.4.1 (open squares). The left panel shows data from Australia and the right panel shows data from Canada. Vertical bars denote 95% confidence intervals.

result in higher REAG than prescribed. On the other hand, the use of these same RECDs in determining the children's hearing thresholds will cause the thresholds at 4 kHz to be under-estimated. The resulting error in the prescription will partially offset the error in deriving the coupler gain targets. The remaining error will, however, have been applied to both the NAL and the DSL prescriptions and is unlikely to have affected the results of this experiment.

Conclusions

Although NAL and DSL procedures prescribed different average gains and different response slopes, the limitations in fitting hearing aids resulted in the achieved gain-frequency responses differing substantially in overall gain but very little in response slope. Limitations on achieving the desired slope arose principally from the hearing aids having only a single compression ratio from 55 to 80 dB SPL input levels, and because the prescribed OSPL90 limited the amount of gain that could be achieved at high input levels. These limitations had a greater effect on the DSL fittings because DSL prescribes a greater range of slopes than NAL.

Even though a gain difference can be created or removed by adjusting the hearing aid volume control, it is very important to prescribe and achieve the optimal gain for children. Because audiologists who fit hearing aids to children would invariably be guided by either the NAL or the DSL prescription, the achieved gain in hearing aids would be used by children over the first few years of life when they are not able to operate controls or provide verbal feedback about the comfort and effectiveness of amplification. This joint evaluation of the two prescriptions allowed an examination of the influence of prior hearing aid prescription experience on the performance and preferences of children.

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