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Key Words

hearing aid prescription
children
NAL-NL1
DSL v.4.1
cross-over comparison
double-blind study
amplification

Abbreviations

3FA: Three-frequency average, across 0.5, 1, 2 kHz
3FA HTL: Three-frequency average hearing threshold level
DSL: Desired sensation level
DSL v.4.1: Desired sensation level procedure version 4.1
FOM: Figure of merit
HTL: Hearing threshold level
NAL: National Acoustic Laboratories
NAL-NL1: National Acoustic Laboratories' hearing aid prescription procedure for non-linear hearing aids
NAL-RP: National Acoustic Laboratories' hearing aid prescription procedure for linear hearing aids
PEACH: Parents' evaluation of aural/oral performance of children
RECD: Real-ear-to-coupler difference
SELF: Self evaluation of listening function
SRT: Speech reception threshold
TEACH: Teachers' evaluation of aural/oral performance of children

A cross-over, double-blind comparison of the NAL-NL1 and the DSL v4.1 prescriptions for children with mild to moderately severe hearing loss

Abstract

The relative effectiveness of the NAL-NL1 and the DSL4.1 prescriptions for 48 children with mild to moderately severe hearing loss was studied using a double-blind, four-period, two-treatment cross-over design in Australia and in Canada. Evaluations included speech perception tests, loudness ratings, reports from parents and teachers on functional performance in real life, children's self-reports, paired-comparison judgements of intelligibility, and children's preferences in real-world environments. Electroacoustic measures of hearing aids revealed that gain differences dominated the comparison. Across trials and measures, individual Australian children consistently preferred either the NAL-NL1 or the DSL v.4.1 prescription. An overall figure of merit (FOM), calculated by averaging the standardized difference scores between prescriptions for all measures, revealed that the strongest prescription-related differences were found in Australia. On average, an advantage and preference for the NAL-NL1 prescription was associated with lesser degrees of hearing loss. This research provides evidence on the effectiveness of the NAL-NL1 and DSL v.4.1 prescriptions, and highlights the need for evaluating and fine-tuning amplification to meet the diverse needs of individual children in real life.

Sumario

Se estudió la relativa efectividad de las prescripciones NAL-NL1 y DSL 4.1 en 48 niños con pérdidas auditivas de leves a moderadamente severas, usando un estudio doble ciego, en cuatro períodos y con un diseño cruzado de dos tratamientos en Australia y en Canadá. Las evaluaciones incluyeron pruebas de percepción de la palabra, tasas de reclutamiento, autoreportes de los niños, juicios de inteligibilidad comparados por pares y preferencias de los niños en ambientes de mundo real. Las mediciones electroacústicas de los auxiliares auditivos revelaron que las diferencias en ganancia dominaron la comparación. En todas las pruebas y mediciones, los niños Australianos individualmente prefirieron de manera consistente tanto la prescripción NAL-NL1 como la DSL v.4.1. Una figura global de mérito (FOM), calculada al promediar las puntuaciones de diferencias estandarizadas entre prescripciones de todas las medidas, revelaron que las diferencias más fuertemente relacionadas con la prescripción, se encontraron en Australia. En promedio, la ventaja y preferencias hacia la prescripción NAL-NL1 se asoció con grados menores de pérdida auditiva. Esta investigación proporciona evidencia de la efectividad de las prescripciones NAL-NL1 y DSL v.4.1 y pone de relieve la necesidad de evaluar y de afinar la amplificación para alcanzar las diversas necesidades individuales de los niños en la vida real.

The NAL-NL1 (Dillon, 1999; Byrne et al, 2001) and the DSL v4.1 (Seewald et al, 1997) prescriptive procedures are widely used for prescribing non-linear hearing aids to children. Although both procedures adopt a common approach in incorporating individual real-ear measurements for prescribing amplification (as devised for the DSL method, see Seewald et al, 2005), different formulae were used to relate gain to hearing thresholds, thereby leading to markedly different prescriptive real-ear targets for many audiometric configurations (Byrne et al, 2001). Not only does DSL v4.1 prescribe higher overall gain than NAL-NL1 for all hearing losses, it also provides

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more low-frequency emphasis than NAL-NL1 for flat losses and more high-frequency emphasis than NAL-NL1 for sloping high-frequency losses. A detailed comparison of the targets calculated by the two prescriptions and the gain and maximum output of hearing aids adjusted to match the respective prescription targets for children in this study is described in a companion article (Ching et al, 2010a).

Previous research on children's gain requirements is inconclusive, with some studies showing that required gain is closer to the Desired Sensation Level (DSL) prescription whereas others indicate that required gain is closer to the National Acoustic Laboratories (NAL) prescription. Scollie et al (2000) reported findings from 18 children (35 ears) with moderate to severe hearing loss (mean three-frequency average hearing threshold levels of about 72 dB) in an experiment in which the children were asked to adjust their hearing aid volume control(s) to a preferred level while listening to sentences presented at 60 dB SPL in an acoustic booth. On average, the preferred gain averaged across 0.5, 1, and 2 kHz (3FA) was not significantly different from that prescribed by DSL v4.1, but was significantly higher than the NAL-RP/NAL-NL1 prescriptions (the NAL prescription for linear and non-linear hearing aids respectively). On the other hand, Ching et al (1997, 1999) showed that the required 3FA gain of 43 severely or profoundly hearing-impaired children (71 ears; mean 3FA hearing threshold level (HTL) = 95 dB HL) for listening to speech at 65 dB SPL at a comfortable level was not significantly different from the NAL-RP target gains.

A subsequent comparison of the hearing aid gain required by children to the NAL-RP and DSLv4.1 targets (Ching et al, 2001) indicated that 65% of the children used gains within 5 dB of the NAL targets, 30% used more gain, and about 5% used less gain. Compared to the DSL targets, about 33% used gain within 5 dB of the DSL targets, 58% used less gain and 9% used more gain than prescribed. Whereas the Scollie et al (2000) study suggests that the DSL prescriptive targets are close to the preferred listening levels of children with moderate to severe hearing losses (fitted using a DSL prescription), the Ching et al studies reveal that the required gain of children with severe or profound hearing loss who were fitted with a NAL-RP prescription are closer to the NAL than to the DSL targets. The varied findings on gain requirements of children in different studies may be partly due to dissimilarities in subject characteristics, including degree of hearing loss and listening experience. The different findings may also be due to the use of dissimilar signal presentation levels for determining listeners' preferred gain. The required real-ear gain to achieve an optimal level for speech intelligibility would be expected to vary with speech input levels.

As against a laboratory-based approach to assessing required gain, Snik et al (1995) conducted a retrospective comparison of prescriptive targets with children's used gains in hearing aids that had been individually adjusted over an extended period of aural habilitation. The data were drawn from 16 profoundly hearing-impaired children (mean 3FA HTL > 90 dB HL) who were successful hearing aid users attending normal schools. Their data showed that used gain was within ± 5 dB of the targets of the NAL-RP and the DSL 3.0 prescriptions, with the average deviation for DSL targets being 2 dB further away from used gain than were the NAL targets. The DSL targets for output limiting were within 3 dB of limiting actually used in 12 of 16 cases. These results largely agreed with earlier results from Snik and Stollman (1995), which showed agreement between DSL 3.0 and used gain, as well as output limiting within ± 5 dB in most cases, across hearing levels from mild to profound. These comparisons have greater face validity than laboratory-based tests in that everyday listening and speech perception were considered in adjusting hearing aids. However, the basis for initial fitting is unknown, and the extent to which that may have influenced subsequent adjustments is uncertain (Stelmachowicz et al, 1998).

In regard to frequency response requirements of children, Ching et al (2001) showed that preferred frequency response slope (0.5 to 2 kHz), in 43 severely or profoundly hearing-impaired children (71 ears), was not significantly different from that prescribed by the NAL-RP, but was significantly less in high-frequency emphasis than that prescribed by the DSL v.3.0 (an earlier version of the DSL v.4.1). Most children (89%) preferred the NAL slope within 6 dB/octave, with the preference of the remaining children equally split between more or less low-frequency emphasis. When children's preferred slopes were compared to the DSL prescribed slopes, about half (51%) agreed within ± 6 dB/octave; the remaining children preferred less high-frequency emphasis. In a similar vein, the data from Snik et al (1995) revealed a closer approximation of the used frequency response slope to the NAL than to the DSL targets. In another study, Snik and Stollman (1995) compared measured hearing aid gains in 34 children with mild to profound hearing loss with targets calculated using either a half-gain rule or the DSL method. They concluded that the half-gain rule matched the measured values better than the DSL method. Although the used frequency response approximated the DSL targets for children with mild or moderate hearing loss (3FA HTL < 50 dB HL), children with more severe hearing loss used much less high-frequency emphasis than that prescribed by the DSL formula. The question remains as to whether the NAL or the DSL prescriptions better meet the requirements of child users of hearing aids.

In terms of performance, Jenstad et al (2000) showed that hearing aids fitted according to the wide-dynamic-range compression (WDRC) version of the DSL prescription (DSL v.4.0) normalized loudness for warble tones, environmental sounds and speech more closely than could be achieved with the linear version of the same prescription for 10 subjects. The same subjects also attained high levels of speech perception scores across five speech spectra that varied in level between 48 dB SPL and 83 dB SPL in quiet (Jenstad et al, 1999). There were no studies on the effects of hearing aid prescription on functional performance in the everyday life of children with amplification. No studies directly compared the relative effectiveness of the NAL-NL1 and DSL v.4.1 prescriptions for children.

Given that both prescriptions have been used extensively around the world for many years, why has it not been obvious from clinical application which prescriptive targets bring more benefits for children? This is partly due to the limited extent to which targets were achieved in conventional hearing aids that generally had a restricted range of response slopes between 2 and 4 kHz. Several reports (Snik et al, 1995; Snik & Stollman, 1995; Jenstad et al, 2000; Scollie et al, 2000) have attested to the under-achievement of DSL target gains at 4 kHz, especially so when hearing loss was more severe. Typically, target gains were matched within ±5 dB between 0.5 and 2 kHz, with greater deviations from targets outside this frequency range. Fitting conventional hearing aids according to either prescription would therefore result in real-ear gains that were not very different, with the difference most likely to be further reduced once volume controls were adjusted by individual hearing-aid users to an equated loudness at a preferred listening level.

With access to the enhanced flexibility in advanced hearing instruments, it would be possible to match prescriptive targets over a wider frequency range more closely than it has been possible previously. This allows for a direct comparison of the real-ear prescriptions in real life to identify the optimal amplification characteristics for children. The need for increased understanding of children's amplification requirements is important not only for theoretical interest but also of practical necessity for providing effective amplification to children soon after hearing loss has been diagnosed through newborn hearing screening programs. Because the small amount of data published to date was inconclusive, being confounded by subject characteristics, methodological limitations and non-blinded assessments, the National Acoustic Laboratories and the University of Western Ontario have joined efforts in conducting an evaluation of the NAL-NL1 and the DSL v.4.1 prescriptions for children.

The present study was designed to evaluate preference and performance in laboratory and in real-world settings for children with mild to moderately severe hearing loss by using a double-blinded protocol in a cross-over design. The collaboration enabled the examination of the effect of prior experience with hearing aid prescription on preferences and performance. The objectives were: (1) to compare the performance and preferences of children who used hearing aids fitted with the NAL-NL1 and the DSL v.4.1 prescriptions; and (2) to determine whether prior experience with one prescription affected what children preferred and/or performed better with.

This paper describes the design of the study together with an overview of the findings on different measures (related papers in this special issue give detailed accounts of each dimension assessed). Here, we focus on examining the relationship among all measures with the aim of identifying the relative merit of each prescription, and to determine potential factors, including previous auditory experience, which might have affected children's performance and preference ratings.

Method

Design of the study

A four-period, two-treatment crossover design was implemented in Australia and in Canada (see Table 1 for an overview). At each of the two test sites, half of the participants received the NAL-NL1 and the other half the DSL v.4.1 prescription for fitting at the first trial period. After experiencing one prescription for eight weeks, each participant received the other prescription for the second trial period of another eight weeks. During the third and fourth trial periods, the two prescriptions were put into separate programs in hearing aids for access via a remote control by the participants at all times. Each of the third and fourth trial periods lasted for four weeks. The allocation of prescription to programs was counterbalanced across participants and trial periods. At the end of each trial period, a battery of assessments was administered. A double-blind protocol was implemented so that neither the audiologist who administered the tests nor the child participants (including their parents and teachers) knew which prescription was used in each hearing aid program during each trial.

Participants

Forty-eight hearing-impaired children (24 in Australia and 24 in Canada) participated in the study. This sample size permits detection of an effect size of 0.35 within-group standard deviation with a power of 80%, for an alpha level of 0.05. To ensure that gain-frequency responses were sufficiently different between prescriptions for comparison purposes, and to comply with the requirements for approval by the Human Research Ethics Committee in Australia, the audiometric criterion for inclusion was set so that the difference in target gains between prescriptions for an average speech input of 70 dB would not be less than 5 dB or greater than 15 dB at two or more audiometric frequencies between 0.25 and 4 kHz. Children with tympanometry within normal limits (0.7 mL < equivalent

Table 1. An overview of study design.

	Trial 1(8 weeks): Single prescription		*Trial 2(8 weeks): Single prescription*	*Trial 3(4 weeks): Both prescriptions*	*Trial 4 (4 weeks): Both prescriptions*
	NAL or DSL		NAL / DSL	DSL and NAL	NAL and DSL
	Pre-trial	*Post-trial*	*Post-trial*	*Post-trial*	*Post-trial*
Laboratory-based tests: performance		Sentence in noise, Consonants in quiet: 55, 70, 80 dB	Sentence in noise, consonants in quiet	Sentence in noise, consonants in quiet	Sentence in noise, consonants in quiet
	Loudness rating: speech from 55 to 80 dB	Loudness rating	Loudness rating		
Laboratory-based tests: preference	Paired comparison judgment: speech at 70 dB in quiet	Paired comparison judgment	Paired comparison judgment	Paired comparison judgment	Paired comparison judgment
Real life: Performance and preference		PEACH TEACH SELF	PEACH TEACH SELF	Children's diary	Children's diary

volume < 1.5 mL) were included. The air-bone gap was restricted to ≤ 15 dB at each audiometric frequency or ≤ 10 dB at two or more consecutive audiometric frequencies.

Children who had a history of fluctuating hearing loss, evidence of middle ear or retro-cochlear pathology, known auditory processing deficit, known language impairment, abnormalities of the external ear canal, or who had disabilities in addition to hearing impairment, were excluded.

In Australia, the participants were 12 boys and 12 girls. The age at participation ranged from 6.6 to 19.8 years (mean = 11.6 years). In Canada, the participants were 17 boys and seven girls. Their age at participation ranged from 6.7 to 17.3 years (mean = 11.2 years).

All children had bilateral sensori-neural hearing loss. Their hearing threshold levels were measured by using ER3A insert earphones coupled to the children's personal earmolds. Descriptive statistics are shown in Table 2. In Australia, 22 children were bilaterally aided; two wore hearing aids in one ear only (one child had mild hearing loss; the other child had no measurable hearing in the unaided ear). Prior to enrolment in the study, all children wore hearing aids that provided linear amplification with output compression limiting, fitted according to the NAL-RP prescription (Byrne & Dillon, 1986; Byrne et al, 1991). In Canada, all children were aided bilaterally. Two children had linear hearing aids with peak clipping or diode clipping, twelve had linear hearing aids with output compression limiting, and ten had non-linear hearing aids with wide-dynamic-range compression. Their own hearing aids were fitted with some approximation to the DSL v.4.1 prescription (Cornelise et al, 1995).

Hearing aid fitting

A detailed account of the protocols for deriving targets, adjusting and verifying hearing aids, and the extent to which real-ear differences between prescription methods were preserved in hearing aids, is presented in a companion article (Ching et al, 2010a). Briefly, the hearing thresholds and individual real-ear-to-coupler differences (RECD) were used to derive amplification targets by using the NAL-NL1 software (Dillon, 1999) and the DSL v.4.1 software (Seewald et al, 1997). All 24 children in Australia and 14 of the 24 children in Canada received the Bernafon Smile 110 hearing aids. The remaining 10 children in Canada were fitted with Siemens Prisma hearing aids to ensure compatibility with their personal FM systems. Hearing aids were adjusted and verified in an HA2-2 cc coupler.

In Australia, close monitoring over the phone after initial fitting was implemented as partial fulfilment of the requirements of the Australian Hearing Ethics Committee for approval of the study. The audiologist performing the monitoring by phone was blind to the prescription used in hearing aids. A trial period would continue for eight weeks only with participant consent. When a participant was unwilling to continue using the hearing aids as set, the participant was counselled and persuaded to continue for one week, with an agreement that the trial would be terminated on request at the end of the week. If a trial was terminated at the end of the first two weeks, all evaluations as would normally be carried out at the end of a trial period were conducted. This occurred for three children, one who was commencing with the NAL prescription after completing a trial with the DSL prescription, and two who were commencing with the DSL prescription after completing a trial with the NAL prescription. The monitoring procedure was not required in Canada, and children completed the eight-week trials for each of the two prescriptions. Following trials 1 and 2 with single prescriptions, all children completed two four-week trials with dual prescriptions. During all four trial periods, the volume control(s) of hearing aids were locked.

Evaluation measures

Loudness rating

Children's ratings of loudness of speech amplified using each prescription were determined immediately after hearing-aid fitting and subsequently at the end of an eight-week trial period for each prescription. A detailed description of the test procedure is provided in Scollie et al (2010a Briefly, the Rainbow Passage was used as stimulus, and was presented at 55, 60, 65, 70, 75, and 80 dB SPL in the sound field for loudness rating on a seven-point scale. In each test, four repetitions of each level were presented in a random order.

Speech tests

Children's speech perception was assessed at the end of each of the four trial periods, giving two measures for each prescription. A detailed description of the test procedures has been provided in Scollie et al (2010a). Briefly, sentence perception in noise was assessed by presenting recorded sentences in speech-shaped noise in the sound field. Speech was presented at 70 dB SPL, and the level of noise was adjusted to determine the speech reception threshold for 50 % correct (SRT) by using an adaptive procedure. In Australia, the BKB/A sentences were used (Bench & Doyle, 1979; NAL recording). In Canada, the HINT sentences were used (Nilsson et al, 1994).

In addition, recognition of consonants presented at 55, 70, and 80 dB SPL in quiet was assessed. Each consonant was embedded in a

Table 2. Mean, standard deviation (SD), and range of hearing threshold levels in dB HL for children in Australia and children in Canada.

		Frequency (Hz)				
		250	*500*	*1000*	*2000*	*4000*
Australia	Mean	33.9	38.7	50.1	53.2	53.0
	SD	11.7	14.0	14.6	11.6	12.6
	Range	10.0 to 55.0	15.0 to 65.0	20.0 to 80.0	30.0 to 75.0	15.0 to 75.0
Canada	Mean	31.9	39.7	52.3	57.6	57.6
	SD	14.2	18.8	20.8	16.1	17.6
	Range	5.0 to 60.0	0 to 75.0	0 to 80.0	10.0 to 80.0	5.0 to 85.0

VCV context, where C was one of the 21 English consonants /p b t d k g f v ð s z ʃ tʃ d m n l r j w h/. Two replications of each consonant were used in each test and the number of consonants correctly identified at each input level was scored.

Paired-comparison judgment of intelligibility

The children's intelligibility judgments were obtained by using a paired-comparisons test (Studebaker, 1982) with audio-visual presentation of a children's story (Ching et al, 1999). A detailed description of the test procedures has been provided in Ching et al (2010b). Briefly, the two prescriptions were implemented in a child's hearing aids on-line via a programming unit connected to a computer. The child compared a recorded story amplified with each of the two prescriptions in pairs and chose the one that made the story easier to understand. This was carried out immediately after hearing aid fitting, and subsequently at the end of each of the four trial periods. The number of preferences for each prescription was recorded.

Real-life functional performance in single-prescription trials

Parents' and teachers' observations of children's functional performance in real-life settings together with children's own reports were used to obtain real-life functional performance ratings at the end of each of the first two trial periods. A detailed description of the test procedures has been provided in Ching et al (2010b). Briefly, three questionnaires were used, the Parents' Evaluation of Aural/oral performance of CHildren, or PEACH (Ching & Hill, 2007), the Teachers' Evaluation of Aural/oral performance of CHildren, or TEACH, and the Self Evaluation of Listening Function, or SELF (Ching et al, 2008). Structured interviews were conducted at the end of each trial separately with the parents, teachers, and children based on the respective questionnaires. Each questionnaire yielded an overall score, a 'Quiet' and a 'Noise' subscale score, and an overall rating with comments.

Children's real-life comparative ratings in dual-prescription trials

At the third and fourth home trial periods during which each child had access to both programs (prescriptions) via a personal remote control, children's preferences in different real-life situations were assessed by a questionnaire that was adapted from the PEACH and the SELF. Detailed description of the test procedure has been provided in Scollie et al (2010b). The children were given a diary to record their experience, and they were interviewed at the end of each trial period. Their comments and ratings were used for scoring.

Statistical analyses

Percentage scores were arcsine transformed before statistical analyses (Studebaker, 1985). Tests of variance with repeated measures were used to compare the two prescriptions for each of the performance and preference measures. Within-subject effects were adjusted by using the Greenhouse-Geiser epsilon correction. Where significant interaction effects were found, post-hoc analyses were carried out by using the Bonferroni procedure with adjusted significance level for multiple tests. Spearman rank order correlations were performed to examine the relationship among performance and preference measures, and multi-linear forward stepwise regression analyses were used to determine the factors that affected performance and preferences of children in Australia and Canada.

Results

Summary of findings on individual dimensions

Prescribed and achieved hearing aid gain and output

A detailed account of the prescribed real-ear differences and the achieved differences between prescription methods in hearing aids has been presented in Ching et al (2010a). Briefly, the results indicated that even though the two prescription methods prescribed large differences in frequency response slopes (up to 13 dB/octave), the slope difference achieved in hearing aids, on average, was within ± 3 dB/octave due to practical limitations of the hearing devices. Generally, there was under-achievement of high-frequency gain targets for children with sloping losses and low-frequency gain targets for children with flat losses. These limitations applied most strongly when attempting to achieve the DSL targets. Individual hearing aids differed by −4.0 to 8.0 dB/octave between prescriptions over the frequency range from 0.25 to 4 kHz.

On the other hand, the difference in prescribed gain (up to 20.0 dB) was generally maintained in hearing aids. On average, the achieved gains in hearing aids differed by 7 dB between prescriptions. Individual hearing aids differed by −2.0 dB to 15.0 dB between prescriptions.

It was also found that the mean RECD at 4 kHz was, on average, 5 dB higher for children in Australia than in Canada. Because the same RECD was applied in adjusting hearing aids for both prescriptions, any effect it may have on real-ear gains at 4 kHz would have been similar for both prescriptions.

Loudness rating

Detailed results have been presented in Scollie et al (2010a). Children rated speech amplified with the DSL procedure to be louder than that amplified with the NAL procedure immediately after fitting, but rated sounds amplified by both prescriptions similarly after eight weeks familiarization with each prescription. These results indicated significant acclimatization effects in loudness ratings. On average, children's ratings were within the range of normal loudness, despite differences in hearing-aid gains of up to 15 dB between prescriptions. Both in Australia and in Canada, children rated speech amplified by both prescriptions to be less than average normal loudness for low input levels, but similar to normal for medium and high input levels.

Speech perception

Detailed results have been presented in Scollie et al (2010a). The results suggest that on average, speech intelligibility in noise was little affected by differences between prescriptions. The SRT for sentence perception in speech-shaped noise among Australian children, with both prescriptions, was equivalent to performance of normal-hearing listeners (Keidser et al, 2002). Across trial periods, there was no significant difference in SRT for children in Australia, but a significant improvement in SRT over time with the NAL prescription for children in Canada.

Consonant perception was equally good, on average, with both prescriptions at all input levels for children at both sites. Over the range of presentation levels from 55 to 80 dB SPL, performance increased with increase in presentation level for children in Australia, but not in Canada.

Paired-comparison judgment of intelligibility

Detailed results on paired-comparison intelligibility judgments of speech presented at 70 dB SPL in quiet have been presented in Ching et al (2010b). Seventeen Australian children (70%) and sixteen Canadian children (66%) had significant preferences for one prescription over the other. Of these, the Australian data showed that 59% of children preferred the NAL prescription whereas the Canadian data showed that 50% preferred the NAL prescription. On average, neither prescription was significantly preferred over the other.

Real-life functional performance in single-prescription trials

Detailed results from parents', teachers' and children's reports (PEACH, TEACH and SELF questionnaires) have been presented in Ching et al (2010a). These questionnaires were completed while children wore hearing aids with only one prescription. On average, children wore hearing aids for 79% or more of their waking hours during the trials. Children in Australia complained about being bothered by loud sounds more often when they used the DSL than the NAL prescription ($p < 0.001$). A similar but insignificant trend was observed in Canada. On average, the parents' and teachers' reports did not reveal a significant effect of prescription ($p > 0.05$) whereas the children's reports indicated that NAL was significantly better than DSL in noise. On an individual basis, there were significant differences in functional performance between prescriptions, based on reports from parents and children.

A blinded analysis of comments from parents and children obtained at the end of trial 2 revealed that 32 of the 48 children (66%) expressed a preference for one of the prescriptions, 13 for DSL and 19 for NAL. Consistently across trials 1 and 2, and across sites, more negative comments about intrusiveness of noise was associated with DSL than with NAL, and more positive comments about loudness comfort was associated with NAL than with DSL.

Children's real-life comparative ratings in dual-prescription trials

Detailed results on children's preferences in real life have been presented in Scollie et al (2010b). These preferences were measured when children had both prescriptions, one per memory, in the hearing aids. The overall preference scores of Australian children were split between prescriptions (11 preferred NAL and eight preferred DSL, the remaining five had no preferences). For specific listening environments, Australian children preferred DSL for soft speech or speech from behind, but preferred NAL in four noisy listening environments that typically occur outside home or school. The majority of the Canadian children reported an overall preference for the DSL prescription (three preferred NAL and 17 preferred DSL, the remaining four had no preferences). They also preferred DSL for soft speech, speech from behind, and five other communication situations in the home and school. Analyses of individual comments indicated that children had clearly stated reasons for preference, often reporting on the loudness and/or clarity of speech, and the presence of background noise as reasons for their preference. They often reported the DSL prescription to be better for listening to softly spoken speech or speech from behind, and the NAL prescription to be better for listening to speech in situations with competing noise.

Relationship among evaluation measures in the laboratory and in real life

The relationship among speech performance measures, intelligibility judgments, functional performance measures, and preference measures obtained at different trial periods and from different respondents (including parents and children) was examined by calculating Spearman correlation coefficients, separately for the Australian children and the Canadian children. The variables included the difference between the SRTs for the NAL and DSL prescriptions (NAL−DSL), the difference between the consonant scores for the two prescriptions at three presentation levels, the paired-comparison intelligibility judgments, the difference in PEACH quiet subscale scores between the two prescriptions, the difference in PEACH noise subscale scores between prescriptions, the difference in parents' overall ratings, the difference in the SELF quiet subscale scores between the two prescriptions, the difference in SELF noise subscale scores between prescriptions, the difference in children's overall ratings between prescriptions, the stated preferences at the end of the second trial, the children's overall preference based on real-life comparisons at the end of the third and fourth trials, and the children's situational ratings averaged across the third and fourth trials. The findings for each site are reported separately (see Tables 3 and 4).

In Australia, children's paired-comparison judgements of intelligibility in the laboratory were significantly correlated with preference ratings based on functional performance in real life. This is evidenced by significant correlations between intelligibility judgments and SELF rating differences and stated preferences at the end of the first two trials, as well as preferences at the end of the third and fourth trial periods. Perception of consonants presented at 70 dB SPL was also positively related to preference and ratings in real-life situations, suggesting that children preferred the prescription that provided better speech perception. Parents' ratings at the end of trials 1 and 2 were significantly correlated with children's ratings and preferences in real life at the end of all trials, suggesting that parents and children agreed on which of the prescriptions was more effective in real life. This is further supported by significant correlations between the PEACH quiet subscale scores and the SELF quiet subscale scores. The consistency of children's ratings is supported by the significant correlations between children's overall ratings at the end of trials 1 and 2, the program preferred in real life and the situational ratings by children at the end of trials 3 and 4. The children's preferred prescription in real life based on comments at the end of trial 2 was consistent with their preferred program and situational ratings at the end of trials 3 and 4 (see Table 3).

In Canada, the children's ratings were correlated with the parents' ratings at the end of trials 1 and 2. The children's preferred program during trials 3 and 4 was significantly correlated with their averaged situational ratings during the same period (see Table 4).

What affected performance and preference

The main interest in the present study was to determine whether children's performance and preferences varied with prescription, and if so, whether degree of hearing loss and prior auditory experience affected children's performance and preferences. This was investigated by using regression analyses. To characterize children's preference and performance with each prescription, an overall figure of merit (FOM) was calculated by averaging the standardised difference scores between prescriptions for sentence perception in

Table 3. Data from Australia showing significant correlation coefficients at 5% level (based on 24 children). The variables include three-frequency average hearing loss in the better ear (HL3FA), three-frequency average hearing loss slope in the better ear (HL3FSL), difference in SRT between prescriptions (SRT Diff), difference in consonant scores between prescriptions at 55, 70, and 80 dB stimulus level (C55: Diff, C70: Diff, C80: Diff), paired comparison judgment scores averaged across all trials (PC_mean), difference in PEACH ratings (P: Diff_R), difference in PEACH scores in Quiet between prescriptions (P: Diff_Q), difference in PEACH scores in Noise between prescriptions (P: Diff_N), and the same sequence for the child's questionnaire (C: Diff_Q, C: Diff_N, C: Diff_R), real-life preferences at the end of trials 1 and 2 (Pref: T1&2), and the children's preferred program and averaged situational ratings at the end of trials 3 and 4 (Pref: T3&4, SitR: T3&4). Single asterisks mark correlations with $p < 0.01$.

	HL3FA	*HL3FSL*	*SRT Diff*	*C55: Diff*	*C70: Diff*	*C80: Diff*	*PC_mean*	*P: Diff_R*	*P: Diff_Q*	*P: Diff_N*	*C: Diff_R*	*C: Diff_Q*	*C: Diff_N*	*Pref: T1&2*	*Pref: T3&4*	*SitR: T3&4*
HL3FA							−0.41	−0.47		−0.63*		−0.42	−0.50*			
HL3FSL		-														
SRT: Diff			-													
C55: Diff				-												
C70: Diff					-						0.44				0.43	0.45
C80: Diff						-										
PC_mean							-				0.43			0.64*	0.73*	0.64*
P:Diff_R								-	0.42		0.47	0.44				0.52*
P:Diff_Q										0.44		0.59*				
P:Diff_N										-	0.44					
C:Diff_R											-	0.48		0.66*	0.54*	0.53*
C:Diff_Q												-	0.68*		0.42	0.51*
C:Diff_N													-			
Pref:T1&2														-	0.55*	0.46
Pref:T3&4															-	0.89*
SitR:T3&4																-

Table 4. Data from Canada showing significant correlation coefficients at 5% level (based on 24 children). The variables were the same as those described in Table 3. Single asterisks mark correlations with $p < 0.01$.

	HL3F A	*HL3F SL*	*SRT: Diff*	*C55: Diff*	*C70: Diff*	*C80: Diff*	*PC_ mean*	*P: Diff_R*	*P: Diff_Q*	*P: Diff_N*	*C: Diff_R*	*C: Diff_Q*	*C: Diff_N*	*Pref: T1&2*	*Pref: T3&4*	*SitR: T3&4*
HL3FA	-			−0.42												
HL3FSL		-														
SRT: Diff			-	−0.43						−0.45	0.41					
C55: Diff				-											0.41	
C70: Diff					-									−0.47		
C80: Diff						-										
PC_mean							-									
P:Diff_R								-			0.45					
P:Diff_Q									-							
P:Diff_N										-						
C:Diff_R											-		0.46			
C:Diff_Q												-				
C:Diff_N													-			
Pref:T1&2														-		
Pref:T3&4															-	0.85*
SitR:T3&4																-

noise, consonant perception in quiet at three levels, intelligibility judgments, difference scores between prescriptions for PEACH scores and rating, SELF scores and rating, children's real-life overall preference and comparative ratings for different situations. Prior to averaging, the dispersion of all quantities to be averaged was equalized by dividing all values by the standard deviation of the respective distributions. As shown in Table 5, the spread of merit is greater in Australia than in Canada, suggesting that the strongest overall advantages for both NAL and DSL were found in Australia.

Multi-linear forward stepwise regression was performed with the FOM as a dependent variable on data from 24 children in Australia and 20 children in Canada (data on old hearing aids were not available for four children in Canada). The stability of findings reported was confirmed by repeating the analysis using backward stepwise regression with the same variables. The independent variables comprised three-frequency average hearing loss in the better ear, difference between the achieved NAL and DSL gain in hearing aids, difference between old hearing aid gain and achieved NAL gain, and the difference between old hearing aid slope and achieved DSL slope. Analyses of the total data from both sites revealed that children with lesser hearing loss were more likely to favour the NAL prescription (Beta = −0.41, p = 0.005). Further, children whose old hearing aids had response slopes that were more similar to the DSL achieved response slope favoured the DSL prescription (Beta = 0.28, p = 0.05). Inspection of the data revealed that this latter result might have been confounded by site, because children in Australia had old hearing aids fitted with some approximation to the NAL response that generally had steeper slopes than the DSL prescription whereas children in Canada had old hearing aids fitted with some approximation to the DSL prescription with equal or flatter slopes than those achieved in the new hearing aids for this study. For this reason, and also to examine the reliability of findings, stepwise regression analyses were performed separately for the Australian and the Canadian data.

The analyses revealed that children with lesser three-frequency average hearing loss were more likely to have a figure of merit in favour of the NAL prescription (Beta = −0.49, p = 0.01) in Australia. A similar though insignificant trend was found in Canada (Beta = −0.38, p = 0.1). Figure 1 shows the FOM as a function of hearing loss, separately for the two sites.

To identify which measures most consistently lead to the same prescription being judged as superior for an individual, each measure was correlated with the FOM, using item-total correlations to preserve independence. Table 6 shows the item-total correlations, separately for each site. The reliability analysis of data from

Table 5. Descriptive statistics of the overall figure of merit. Positive values indicate a greater than average advantage for the NAL prescription, and negative values indicate a greater than average advantage for the DSL prescription.

	Mean	*Median*	*Minimum*	*Maximum*	*SD*
Australia	0.36	0.46	−1.09	1.38	0.56
Canada	0.13	0.11	−0.70	0.78	0.37

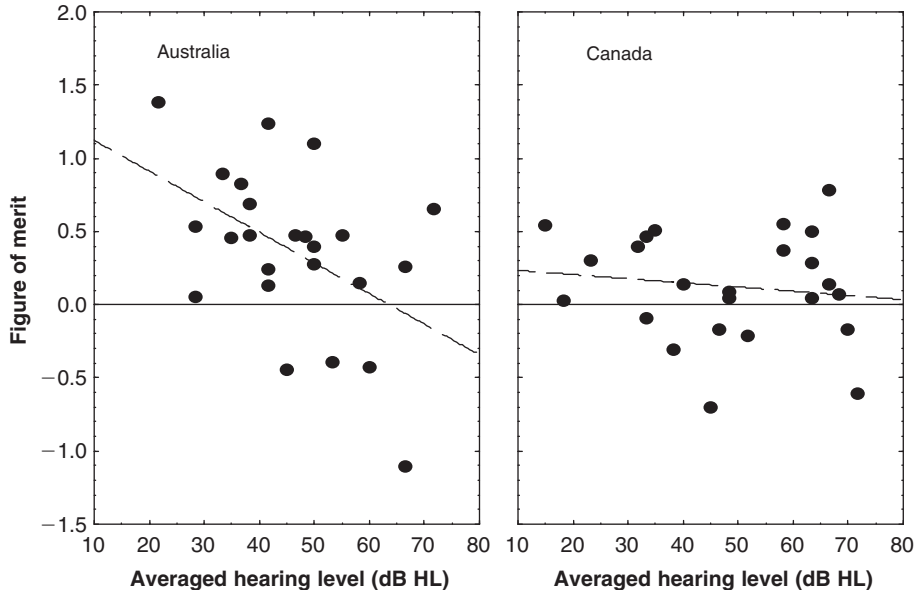

Figure 1. Three-frequency average hearing level in the better ear in relation to the overall figure of merit.

Australia indicated that the speech perception measures (SRT in noise and VCV consonants at three input levels) had very low item-total correlations (< 0.2). Once these items were removed, the standardized Cronbach's alpha for the remaining four measures was 0.84. In a similar vein, the analysis of data from Canada indicated that the two speech measures had low reliability. Once removed, the standardised Cronbach's alpha was 0.34. These results suggest that children's intelligibility judgments, parents' and children's real-life functional performance ratings, and children's real-life comparative ratings for different situations produced consistent conclusions about which prescription was better for each child, though this conclusion is stronger for the Australian data than for the Canadian or the combined data.

Table 6. Item-total correlations ($Corr_{i-t}$) for measures used in calculating the overall figure of merit (FOM). The measures include paired-comparison intelligibility judgments averaged across all trials (PC_Mean), difference in SRT between prescriptions (SRT Diff), difference in consonant scores between prescriptions averaged across presentation levels of 55, 70, and 80 dB SPL (AVC: Diff), difference in PEACH overall scores between prescriptions (P: Diff), difference in SELF overall scores between prescriptions (C: Diff), and children's situational ratings averaged across trials 3 and 4 (AVSitR).

Item no.	*Description*	*$Corr_{i-t}$ (Australia)*	*$Corr_{i-t}$ (Canada)*	*$Corr_{i-t}$ (Overall)*
1	PC_mean	0.54	0.22	0.46
2	SRT Diff	−0.16	−0.9	−0.09
3	AVC: Diff	0.24	−0.13	0.07
4	P: Diff	0.64	0.04	0.34
5	C: Diff	0.66	0.17	0.49
6	AVSitR	0.73	0.21	0.51

Discussion

Amplification requirements of children

This paper examined the findings from a range of performance and preference measures conducted in laboratory and real-life environments to determine the relative effectiveness of the NAL-NL1 and the DSL v.4.1 prescription for children. Because gain differences between targets for the two prescriptions were preserved in hearing aids whereas slope differences were not, despite the different slopes prescribed by the two procedures, the comparisons in all trials were dominated by overall gain differences.

Speech perception results indicated that children performed equally well with both prescriptions when listening to speech over the range of 55 to 80 dB SPL in quiet and when listening to medium-level speech in noise, despite gain differences of 7 dB between prescriptions. The finding that the choice of prescriptions has no impact on speech perception, under laboratory conditions, is consistent with other research showing that similar speech recognition scores can be obtained by different gain-frequency responses as long as speech sounds are audible (van Buuren et al, 1995). However, this laboratory-based performance was not entirely compatible with real-life experience. Children reported difficulty listening to speech in different real-life situations even though their speech perception in noise in the laboratory was on par with normal-hearing children. Unlike the laboratory setup where speech and noise originated from the front, target sounds and distracting sounds in real life frequently arrive from different directions. If children with hearing loss have reduced ability to stream sounds based on direction of arrival (Ching et al, in preparation), as occurs for many children with auditory processing disorders (Cameron et al, 2006), the discrepancy between laboratory and real-life speech performance would be at least partially explained. Also, the children's real-world preferences from the dual-memory trials indicated a significant preference for using DSL

for soft speech and speech from behind. Children's comments in these and other situations (e.g. listening to the teacher in the classroom) are consistent with improved speech understanding and/or ease of listening with DSL than with NAL. The discrepancy between laboratory-based test results and real-life experience may also be partially explained by the selection of test level for the laboratory measures: speech recognition scores were tested at 55 dB SPL as the lowest test level, which was above the compression threshold of the hearing instruments. It is likely that children encountered lower levels than this when listening to soft or distant speech for which the higher gain provided by DSL would be even more beneficial. It is also likely that children's comments and preferences reflected ease of listening differences that were not measured in the laboratory tests of speech recognition. Across both sites, there were more positive comments about hearing and understanding softly spoken speech as well as speech from a distance or behind with the DSL prescription than with the NAL prescription.

In a similar vein, loudness ratings obtained after the children had eight weeks familiarization with each prescription revealed that both prescriptions amplified speech between 55 and 80 dB SPL to a loudness range that is within the range of normal loudness, and that there were no significant difference in ratings between prescriptions following an eight week period of acclimatization with each prescription. Unlike loudness judgments based on connected speech in the laboratory, real-world difference in perceived loudness between prescriptions was substantial for sounds in different environments. In real life, children reported that background sounds were intrusive in passive listening situations and complained about excessive loudness. Some of these comments occurred during the acclimatization period, and others occurred following it. Across both sites, there were more negative comments about loudness of sounds with DSL than with NAL and more positive comments about loudness comfort with NAL than with DSL.

The functional performance ratings by parents and children during single prescription trials (trials 1 and 2) showed significantly lower ratings (poorer performance) for the Noise subscale compared to the Quiet subscale across both prescriptions. This serves to reinforce the need for enhancing signal-to-noise ratio (SNR) for children. Not only is there evidence to indicate the benefits of directional microphone technology in some classroom situations (Ricketts et al, 2007), there is now evidence to show that directional microphone technology enhances SNR for young children in real life (Ching et al, 2009).

During dual-prescription trials (trials 3 and 4), children at both sites had significant preferences for the DSL prescription for listening to softly spoken speech and speech from behind. Children in Australia also had significant preferences for the NAL prescription when listening in noisy environments (playground, restaurant, transport, shopping mall). These findings suggest that the optimal gain for low-level inputs is closer to DSL than to NAL, and the optimal gain for use in noisy situations is closer to NAL than to DSL. The provision of increased gain for low-level inputs while maintaining the gain for medium-level and reducing gain for high-level inputs may be accomplished by the use of a higher compression ratio than is currently used in either prescription, or by manually switchable multiple programs, or by the use of adaptive noise suppression that decreases gain in noisy environments. However, while there is a prima facie case for using directional microphones and noise-reduction systems with children, the real-world efficacy and outcomes from using these technologies have not been thoroughly investigated in children. Especially for young children who are still developing their spatial hearing abilities and language skills, and who require access to learning via overhearing, the maintenance of hearing from various locations is important. Furthermore, the findings suggest that children require different amplification characteristics for different listening conditions. Options for children who are able to select their personal preferences in different situations include the provision of multiple programs or trainability in hearing aids (Zakis et al, 2007). For children who are unable to manually switch between programs, automated amplification schemes that vary gain-frequency responses with detected changes in listening environments may be an option.

Examination of predictors for the overall merit of a prescription suggests that Australian children who have lesser three-frequency average hearing loss significantly preferred and performed better with the NAL prescription, on average. For Canadian children, a similar trend was indicated although the effect was not significant at the 0.05 probability level. This may be because the lower correlations in Canada between the measures comprising the FOM made the FOM a less reliable indicator of prescription superiority in Canada than in Australia.

Does auditory experience affect preference and performance?

There were differences between the findings in Australia and those in Canada. Across trial periods, the Australian children consistently preferred one prescription to another, with neither prescription being dominantly preferred over the other. On the other hand, the Canadian children had preferences that were equally split between prescriptions during the first two trials (eight for NAL and eight for DSL), but the majority of preferences were for DSL (three for NAL and 17 for DSL) at the end of the last two trials. Across methods of evaluation in laboratory settings and in real life, the Australian children tended to consistently prefer one prescription to the other, whereas the Canadian children varied in preference across measures. The Australian children did not show significant difference in speech perception in noise across all trials. On the other hand, the Canadian children showed poorer initial performance with the NAL prescription that improved across trials, but equally good performance across trials when using the DSL prescription. As the Australian children had experience of some approximation of the NAL prescription and the Canadian children had experience of some approximation of the DSL prescription prior to the study, the present findings are consistent with a bias in preference towards the prescription to which the children were accustomed. The findings obtained over extended trial periods reveal a potential change or improvement in performance when children used the prescription with which they had less familiarity.

Caveat

This evaluation of prescriptive procedures for children with mild to moderately severe hearing loss was dominated by differences in gain. Hence, the effect of gain variations on performance of children with more severe hearing loss remains to be investigated. Furthermore, variations in frequency response slope are known to affect functional performance of children with severe or profound hearing loss (Ching et al, 2008). The extent to which such differences affect performance of mild or moderately hearing impaired children will have to be addressed in future research.

Summary and Conclusions

In summary, the findings of this cross-over comparison of the two prescriptions are:

1. There were large differences in frequency response slope prescribed by the two prescriptions (up to 13 dB/octave). However, the practical limitations of hearing aids resulted in a reduction of difference in slope between prescriptions to within ±3 dB/octave of each other, both in Australia and in Canada.
2. The DSL v4.1 procedure prescribed higher gain (0.5 to 4 kHz) than the NAL-NL1 prescription on average by 10 dB, and the achieved gain difference was 7 dB on average. This difference in gain dominated the comparison of prescriptions.
3. Children in both sites mapped speech presented at 55 to 80 dB SPL to the loudness range from 'too soft' to 'too loud'. The children rated the loudness of both prescriptions to be less than average normal loudness for low input levels, but similar to normal for medium and high input levels. Although the different prescriptions led to predictable differences in loudness rating at fitting, this difference largely disappeared with only a few weeks of listening experience.
4. Speech perception in quiet and in noise with both prescriptions was equally good, both for children in Australia and in Canada. The SRTs and consonant scores were similar to the performance level of normal-hearing children.
5. Based on intelligibility judgments of speech presented at 70 dB SPL in the laboratory, about 70% of Australian children and 66% of Canadian children had significant preferences for one or the other prescription. On average, the judgments were equally split between prescriptions, both in Australia and in Canada.
6. Intelligibility judgments in the laboratory were significantly correlated with children's ratings and preferences in real life for children in Australia but not for children in Canada.
7. On average, parents and teachers' reports (PEACH and TEACH) did not reveal a significant effect of prescription, but children's reports (SELF) indicated that NAL-NL1 was significantly better than DSL v4.1 in real-world noisy situations.
8. Consistently across trials 1 and 2, more negative comments about intrusiveness of noise was associated with DSL v.4.1 than with NAL-NL1, and more positive comments about loudness comfort was associated with NAL-NL1 than with DSL v.4.1. This was found in both Australia and Canada.
9. Consistently across trials 3 and 4, more positive comments about listening to softly spoken speech as well as speech from a distance or behind were associated with DSL v.4.1 than with NAL-NL1. This was found in both Australia and Canada.
10. Both quantitative and qualitative measures used in trials 3 and 4 provided insights into the children's real world preferences. Both prior experiences (i.e., test site) and listening environment were found to influence overall preference for a given prescription. Averaged across sites and trials, 33% of children preferred NAL-NL1, 56% preferred DSL v.4.1, and the remaining 10% had no preference.
11. In Australia, preferences of children and parents (intelligibility judgments, SELF scores and PEACH scores) for the NAL-NL1 prescription increased with lesser severity of hearing loss.
12. Individual children in Australia consistently preferred either the NAL-NL1 prescription or the DSL v.4.1 prescription across trial periods and across different preference measures. Those children preferring the NAL-NL1 prescription did so because they were less troubled by loud sounds and reported hearing speech better in situations where there were competing noises. Those children preferring the DSL v.4.1 prescription did so because it enabled them to hear speech more loudly and/or clearly. They also reported better hearing for soft and distant speech as well as sounds within the environment.
13. The overall figure of merit revealed that the strongest overall advantages for both NAL-NL1 and DSL v.4.1 were found in Australia. Across sites, an advantage and preference for the NAL-NL1 prescription was associated with lesser degrees of hearing loss, on average.

In conclusion, the findings imply that the gain requirements of children in real-life environments differ from those prescribed by either the NAL-NL1 or the DSL v.4.1 prescription. To achieve optimal audibility of soft speech, children need more gain than is prescribed by NAL-NL1. However, to achieve listening comfort in noisy places, they need less gain than is prescribed by DSL v.4.1. This combination can be achieved by using a higher compression ratio than is currently prescribed by either prescription, or by manually switchable programs, or perhaps by automatically adaptive noise-reduction algorithms in hearing aids although this later option has yet to be fully evaluated for application with infants and children. Whereas prescription of overall gain is less important for older children who have access to a volume control in their hearing aids, it is most important for infants and young children who wear their hearing instruments at settings determined by clinicians for at least the first few years of life. This research provides evidence regarding the effectiveness of the NAL-NL1 and the DSL v.4.1 prescriptions, and highlights the need for evaluating and fine-tuning amplification to meet the diverse needs of individual children in real life.

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Note

1. The participants ranged in age from 6.6 to 19.8 years. The terms 'children' or 'child' are used in this and other manuscripts in this issue to describe the samples, in accordance with the National Institutes of Health policy of defining 'children' as 'individuals under the age of 21 years'.

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