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## Original Article

# Evaluation of real-world preferences and performance of hearing aids fitted according to the NAL-NL1 and DSL v5 procedures in children with moderately severe to profound hearing loss

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## Abstract

**Objective:** The study aims to compare the performance of hearing aids fitted according to the NAL-NL1 and DSL v5 prescriptive procedure for children. **Design:** This is a crossover four period trial. **Study sample:** Sixteen school-aged children with moderately severe to profound hearing losses participated in the study. The children were fitted with Phonak Naida V SP hearing aids according to the two prescriptive procedures. **Results:** The results showed that children performed significantly better with DSL v5 than with NAL-NL1 prescription for sentence perception in quiet. The paired-comparison judgments of speech intelligibility showed seven children significantly preferred the DSL v5 prescription while two children preferred the NAL-NL1 prescription. The average scores on functional and ratings by parents and teachers performance of children in real life were significantly better for the DSL v5 prescription. At the end of all trials, nine children preferred the DSL v5 prescription, four preferred the NAL-NL1 prescription, and two had no preference. **Conclusions:** Hearing aids fitted based on the DSL v5 procedure would seem to be more appropriate than the NAL-NL1 procedure for children with moderately severe to profound sensorineural hearing loss, at least in quiet listening environments.

**Key Words:** NAL-NL1; DSL v5; children; hearing performance; paired-comparison; speech test; PEACH; TEACH; severe to profound hearing loss

The National Acoustic Laboratories (NAL) and desired sensation level (DSL) procedures are widely used by clinicians to fit hearing aids to children with hearing impairment. Studies on children who used hearing aids fitted according to the different procedures have yielded mixed results, with some studies showing a preference for the NAL procedure (Snik et al, 1995; Ching et al, 1997, 1999, 2001a) and some studies showing a preference for the DSL procedure (Snik & Stollman, 1995; Jenstad et al, 1999, 2000; Scollie et al, 2000).

A recent study conducted by the National Acoustic Laboratories (NAL) together with the University of Western Ontario (UWO) compared the performance and preferences of children who used hearing aids fitted according to the NAL-NL1 and DSL v4 procedures (Ching et al, 2010a). The NAL/UWO study used a crossover, double-blind and four-period design to evaluate hearing performance of 48 school-aged children with mild to moderately severe hearing loss in Australia and in Canada. The children were fitted with new

hearing aids adjusted to meet targets prescribed by the NAL-NL1 and DSL v4 procedures. After extended periods of familiarity with each procedure, the children were assessed using a loudness rating test, speech tests, paired-comparison judgments of intelligibility tests, and functional performance scales. On average, there was no significant difference between the procedures for speech perception. In real life, children preferred the DSL v4.1 prescription for listening to soft speech and the NAL-NL1 prescription for listening in noisy situations. The study also found that on average, preference for the NAL-NL1 prescription was associated with lesser degrees of hearing loss for children in Australia. Thus the question remains as to whether the NAL-NL1 or the DSL v4.1 procedures is more effective for children with severe to profound degree of hearing loss. The aim of the present study was to compare the performance of the NAL-NL1 procedure and the latest version of DSL procedure (DSL v5) among school-aged children with moderately severe to profound hearing loss.

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Abbreviations	
4FA	Four frequency average
COMADAS	Computer-based Malay auditory discrimination assessment
DSL	Desired sensation levels
HINT	Hearing in noise test
HTL	Hearing threshold level
MPO	Maximum power output
NAL-NL1	National Acoustic Laboratories' prescription for non-linear hearing aids, version 1
PEACH	Parents' evaluation of aural/oral performance of children
RECD	Real-ear-to-coupler difference
SELF	Self-evaluation of listening function
SNR	Signal to noise ratio
SRT	Sentence reception threshold
TEACH	Teacher's evaluation of aural/oral performance of children
UKM	Universiti Kebangsaan Malaysia
UWO	University of Western Ontario

**Method**

*Participants*

Sixteen children aged between 7 and 17 years (mean = 12.7 years; SD = 2.8) were recruited from the audiology clinics of Universiti Kebangsaan Malaysia (UKM) and the General Hospital in Kuala Lumpur. The participants comprised of two girls and 14 boys with degree of hearing losses that ranged from moderately severe to profound (four frequency average (4FA) at 0.5, 1, 2 and 4 kHz = 81.9 dB HL; SD = 17.7; range = 51.9 to 115 dB HL). The children's hearing threshold levels were measured using the ER3A insert earphone coupled to the child's own earmold, at 0.25, 0.5, 0.75, 1, 1.5, 2, 3, 4, 6, and 8 kHz. Table 1 shows the age, 4FA hearing threshold level (HTL),

duration of hearing aid experience, types of hearing aids used, and educational settings for each child. All children had bilateral sensorineural hearing loss except for one child who had a mixed hearing loss in one ear and an unaidable hearing loss in the other ear. There were four children with asymmetrical audiograms, two of whom used hearing aids only in one ear (the better ear). Except for two children, all were experienced hearing-aid users. Eleven children were in mainstream schools, with three of them receiving special support in classroom (inclusive program). The other five children were in a unit for deaf children or special program.

*Location of study*

The study was conducted at the Audiology and Speech Sciences Clinic, School of Rehabilitation Sciences of UKM in Kuala Lumpur. All tests were carried out in double-walled, sound treated rooms.

*RECD measurement*

The audiometric hearing threshold in dB HL and individual real-ear-to-coupler-difference (RECD) values were used to derive coupler gain targets using the NAL-NL1 (Dillon, 1999) and DSL v5 (Scollie et al, 2005) stand alone software. The individual RECD was measured on the fitted ears using the Siemens UNITY probe microphone system. To measure SPL in the ear canal, the probe tube was placed inside the ear canal and the receiver tube was connected to the child's own earmold. In order to determine the insertion depth of the probe tube placement, the probe tube was placed beside the child's earmold and its marker was adjusted so that it was flush with the outside surface of the earmold and the tip extended 5 mm beyond the earmold tip. When inserting the probe tube, the marker was placed at the inter-tragal notch.

*Hearing-aid fitting*

All children were fitted with new Phonak Naida V SP Standard hearing aids. This behind-the-ear hearing aid has 16 channels, four

**Table 1.** Information on age, 4FA HTL, duration of hearing-aid experience, type of hearing aids used, and education for each child.

Child	Age (years)	4FA HTL		Hearing-aid experience (years)	Hearing aid		Education
		left	right		left	right	
1	11	63.3	63.3	9	Canta 770-D	Canta 770-D	Mainstream
2	10	66.3	65.0	8	Siemens Artist e2e	Siemens Artist e2e	Mainstream
3	12	71.3	73.8	0	*	*	Mainstream
4	15	62.5	71.3	13	Supero 411	Eartone	Inclusive
5	12	105.0	86.3	9	Supero 412	Supero 412	Mainstream
6^	15	52.5	51.3	9	Phoenix 203	Phoenix 203	Inclusive
7	17	92.5	92.3	11	Audinet PPCL	Audinet PPCL	Inclusive
8^	16	72.5	71.3	14	Picoforte PPCLP	SuperFront PPSC	Special
9	7	98.8	95.0	5	Siemens Prisma	Naida III UP	Mainstream
11@	16	NR	115.0	10	PPCL 4+	No hearing aid	Mainstream
12@ #^	15	72.5	NR	7	Siemens Music Pro	No hearing aid	Special
13	11	70.0	70.0	0	*	*	Mainstream
14	13	98.8	106.3	11	Widex Brava	Widex Brava	Special
15	9	108.8	78.8	8	Widex B32	Widex B12	Special
16	13	110.0	95.0	11	Siemens 2D Prisma	Siemens Triano SP	Mainstream

\*non-experienced hearing-aid users, @monaural hearing-aid user, #sign language as primary language, ^not using hearing aids prior to study

memory programs, and data logging feature. Advanced features such as noise reduction, feedback manager, and sound recover (frequency compression) were disabled for the purpose of this study. The hearing-aid gain and frequency response were adjusted to match the gain targets prescribed by the NAL-NL1 and DSL v5 formula at 50, 65, and 80 dB SPL input levels, and verified in an HA2-2cc coupler. The maximum power output (MPO) at each frequency was also adjusted to match the prescribed MPO by the respective prescriptive methods. Prior to each test session in the clinic, the hearing aid MPO and gain-frequency response were checked in an HA2- 2 cc coupler.

#### Test procedure

This is a crossover, four period trial of prescriptions study. During the first two periods, each lasting six weeks, children had access to one prescription only. During the third and fourth trial period, each lasting three weeks, children had access to both the prescriptions via their hearing aid remote controls. The research procedure followed closely the procedure used in the NAL/UWO study (Ching et al, 2010a). The following section describes the test procedure.

#### TRIAL PERIOD 1

Half of the children were randomly assigned to receive the NAL-NL1 prescription while the other half were fitted according to the DSL v5 prescriptive procedure. After the fitting, the children underwent a six week home trial with the hearing aids. During the trial period, children were instructed to fill in the self evaluation of listening function (SELF) scale, and their parents were asked to complete the parents' evaluation of aural/oral performance of children (PEACH) scale (Ching & Hill, 2007). The children's school teachers were also invited to take part in this study by completing the teacher's evaluation of aural/oral performance of children (TEACH). The purpose was to evaluate the children's functional hearing in real life with the hearing aid prescriptive procedure assigned to them. At the end of the first home trial period, children returned to the clinic to complete the following tests: paired-comparison judgments of speech intelligibility tests and speech perception tests using both the NAL-NL1 and DSL v5 prescriptions. The completed PEACH, SELF, and TEACH questionnaires were collected.

#### TRIAL PERIOD 2

At the end of the first home trial, children's hearing aids which had been fitted according to NAL-NL1 prescription in the previous trial, were switched to the DSL v5 prescription and vice versa. This was followed by another six weeks of home trial with the hearing aids. The same evaluations as for the first trial period were conducted at the end of the second period of home trial.

#### TRIAL PERIOD 3

Both the NAL-NL1 and DSL v5 prescriptions were activated in the hearing aids so the children could access both prescriptions via the tactronics push-button on the hearing aids. The default memory program was set to the same as the prescriptive formula assigned to the child in the first trial. The children were allowed to switch between these two programs whenever they wished in the third trial period. During this trial, children were also required to fill in a short diary which allowed them to compare the performance of the two programs in different listening situations. By the end of the three weeks trial, the children returned to the clinic to complete a paired-comparison judgments test as well as a speech perception test.

#### TRIAL PERIOD 4

To avoid bias among children towards the prescription set as the default memory program during the third trial, the default program was counterbalanced in the fourth trial session. This means the relative positions of the two programs in trial 3 were reversed. The paired-comparison tests and speech perception tests were repeated at the end of the trial session. Throughout the entire study, the children and parents were blinded to the hearing-aid prescription in each program of hearing aids fitted to the children.

#### NAL-NL1 and DSL v5 performance evaluation

##### SPEECH TESTS

A consonant discrimination test was administered to the children involved in the study, using the computer-based Malay auditory discrimination assessment, or COMADAS (Ting et al, 2005). The test consists of 18 Malay consonants recorded from a male talker in a VCV context, where V represents the carrier vowel /a/. Each consonant is replicated giving a total of 36 items in a test list. The speech material was presented from a computer laptop connected to a digital equalizer, an amplifier, and a loudspeaker. During the test, the children were seated 1 m from the loudspeaker at 0 degree azimuth. The speech material was presented at 65 dBA in quiet. The children responded to the stimulus by pointing to the possible consonant on a laminated template that displayed all the tested consonants. The responses given by the children were entered into the computer by the tester to calculate the scores. The consonants were presented in a randomized order within each test list.

The pediatric Malay hearing in noise test (HINT) was used to test sentence perception. It consists of 13 phonemically balanced lists with 10 short sentences in each list. During the test, stimuli were presented from a loudspeaker located 1 m away and at 0 degree azimuth from the child. The child's task was to repeat the sentences. The test was conducted first in quiet and then in noise. The sentence lists presented in quiet and noise were counterbalanced for both prescriptions. For each test condition, the sentence reception threshold (SRT) was measured. The SRT is defined as the signal level or the signal to noise ratio (SNR), at which the children correctly repeated 50% of the sentence was obtained.

Prior to the consonant discrimination test and HINT for every test condition, the child was presented with one practice list for familiarization purposes. At each test session, one list was used for each prescription. In trials 1 and 2, the children were always tested with the prescription that they were using in the home trial, followed by the other prescription. In trials 3 and 4, they were always tested with the prescription that was set as the default program.

##### PAIRED-COMPARISON JUDGMENTS OF SPEECH INTELLIGIBILITY TESTS

Paired-comparison tests of speech intelligibility were administered after the speech tests. Children were presented, audio-visually with Malay children's stories read by a male native speaker at 65 dB A. The stories were popular children stories selected with help from a speech pathologist. A 14-inch television monitor was positioned next to a speaker which was placed 1 m away from the child and at 0 degree azimuth. The children were instructed to listen to the stories with one prescription and then with the other one. A switch box was given to the child for him/her to 'select' the prescriptive procedure while listening to the story. The children were able to switch back and forth as many times as they liked before deciding which prescription provided them maximum speech intelligibility. The children's hearing aids were connected

to the fitting software and the tester could activate either the NAL-NLI or DSL v5 prescription, each time the children switched the button. This process was repeated 10 times and the prescriptions were counterbalanced to avoid bias preference towards any one switch position.

FUNCTIONAL PERFORMANCE EVALUATION

The effect of the two prescriptive procedures on the child’s real life functional performance was assessed using the PEACH, SELF, and TEACH scales. The PEACH and TEACH scales were developed to evaluate the effectiveness of amplification for infants and children with hearing impairment by a systematic use of parents’ and teachers’ observations, and the SELF was adapted from the PEACH and was administered to the children to obtain their feedback with regard to the hearing aid performance (All scales can be freely downloaded from the NAL website, www.outcomes.nal.gov.au). The three assessment scales were translated and adapted into Malay. Normative data for PEACH in Malay language are available (Quar et al, 2012).

The translated versions of PEACH, TEACH, and SELF were administered to the parents, teachers, and children at the end of the first two trials. All the respondents were given instructions by the tester to complete the questionnaires. At the end of each trial, an interview was conducted between the tester and respondents to clarify responses given and also to obtain further information regarding the performance of each prescription. All scales were scored using a five-point scale ranging from 0 to 4. An item was given a score of zero if the child did not demonstrate auditory response; a score of 1 was given if one or two examples were given or the behavior occurred 25% of the time; a score of 2 was given if three or four examples were given or the behavior occurred 50% of the time; a score of 3 was given if five or six examples were given or the behaviors occurred 75% and a score of 4 was given if more than six examples could be supplied by the parents or if the parents observed that the auditory behavior occurred more than 75% of the time (see Ching & Hill, 2007). The item scores were combined into two subscale scores, one for listening in quiet, and one for listening in noisy environments. Item scores were summed to derive an overall score.

As part of the PEACH and TEACH questionnaires, parents and teachers were also requested to compare the children’s performance between prescriptions by completing a difference rating for using a five-point scale (− 2 = much worse; − 1 = a bit worse; 0 = no difference; + 1 = a bit better; + 2 = much better). The comparative rating was completed at the end of the second trial period. For the third and fourth trial when the children had access to both prescriptions via their hearing-aid remote controls, they were required to complete a short diary which compared the performance of the two programs in different listening situations. The diary included questions that asked if the children found the prescriptions to be different, which prescription they preferred more, and by how much. In addition, six items relating to different listening conditions were also included in the diary. For each item, the children needed to compare the performance of the two prescriptions on a five-point scale as described above. The children were reminded to try both of the prescriptions in different listening environments, so that they could compare their performances.

The PEACH, TEACH, and SELF also examined hearing-aid usage and loudness discomfort. These items were analysed separately and thus were not included in the functional hearing assessment presented above. The item on hearing-aid usage was scored based on a five-point scale (0 - Never; 1 - Seldom; 2 - Sometimes; 3 - Often; 4 - Always) and the scale was reversed for loudness discomfort.

DATA LOGGING

The data logging feature was used to investigate the duration of hearing-aid usage for each prescription in trial 1 and 2, and the frequency of using each prescription when the child could switch between prescriptions in trial 3 and 4. The duration of hearing-aid usage was presented by the data logging system as the average hours of use per day while the frequency of using either the prescription was defined as a percentage.

Results

Prescribed and achieved gain

To examine how well prescribed targets were achieved in the hearing aids, the mean prescribed gain was subtracted from the mean achieved gain at all the tested frequencies, respectively for the NAL-NLI and DSL v5 procedures. For the NAL-NLI fittings, the mean difference between the achieved and prescribed gain at each frequency was small for soft and medium input levels (within ± 3 dB). For the DSL v5 fittings, the mean difference between the achieved and prescribed gains was within ± 2 dB for frequencies up to 2 kHz, but the achieved gain was below the prescribed gain by 7 dB at 4 kHz for soft and medium input levels. Individual data suggested that seven children with profound sensorineural hearing losses had hearing aids which were underamplified at 4 kHz for the DSL v5 fittings. For the other children, the mean achieved gain were either in good or fair agreement (0.2 to − 8 dB) with the gain prescribed by DSL v5 at 4 kHz.

Performance evaluation

CONSONANT DISCRIMINATION TEST

The results were obtained from 15 children, as one child had difficulty completing the evaluation test. Table 2 shows the mean consonant scores in percentage, the standard deviations (SD), as well as the range of scores for both prescriptions obtained at the end of each of the four trials.

Using the general linear model, repeated measures analysis with prescription and trial as the independent variables, the results indicated that the main effect of prescription was not significant (p = 0.18). However, the main effect of trial was significant (F(3, 36) = 5.159, p = 0.03). The interaction between prescription and trial was not significant (p = 0.13)

SPEECH RECOGNITION TEST

The sentence reception threshold (SRT) of the Malay HINT was measured from seven children. Other children were not able to complete this task due to high linguistic demands. For each trial

**Table 2.** Mean consonant scores (% correct), standard deviation (SD), and range of consonant scores by prescription and trial.

	<i>Trial 1</i>	<i>Trial 2</i>	<i>Trial 3</i>	<i>Trial 4</i>
NAL-NLI				
Mean	50.2	49.3	52.4	51.8
SD	26.5	28.9	29.1	28.2
Range	16.7–94.4	19.4–100	13.9–100	13.9–97.2
DSL v5				
Mean	49.4	51.0	52.8	58.5
SD	29.6	29.5	28.9	28.6
Range	11.1–100	2.8–97.2	16.7–97.2	11.1–100

session, the mean SRT was calculated for both prescriptions. The results are displayed in Figure 1 (a), for SRT measured in quiet, and Figure 1 (b), for SRT measured in noise. In quiet, the mean SRTs for DSL v5 procedure were slightly lower/better than the NAL-NL1 procedure for all test trials. The general linear model repeated measure analysis revealed a significant main effect of prescription ( $F(1,6) = 17.130, p < 0.01$ ) and trial ( $F(3, 18) = 6.765, p = 0.01$ ). No significant interaction between prescription and trial was found ( $p = 0.44$ ). In noise, a significant main effect of trial was found ( $F(3, 18) = 6.285, p < 0.01$ ). Unlike the SRT in quiet, there was no significant difference between the NAL-NL1 and DSL v5 procedure for SRT in noise ( $p = 0.81$ ).

#### PAIRED-COMPARISON TEST

Paired-comparison judgments of speech intelligibility tests were completed by 15 children at the end of each of the four trials. For each trial, children were required to perform the paired-comparison task 10 times making a total of 40 comparisons for each child. The binomial distribution was used to determine the criterion for defining the preference of one prescription over the other as significant and not due to chance. Based on the calculations, if one prescription is chosen 26 times or more, the probability of it happening by chance is

4%. Hence, results where children chose one prescription 26 times or more over the other prescription were considered significant. Based on this criterion, it was found that nine children (60%) had a significant preference and that, of these, seven children preferred the DSL v5 procedure and two children preferred the NAL-NL1 procedure. The proportion of children who had significant preferences was similar to the results in NAL/UWO study on Canadian children (66%) (Ching et al, 2010d).

#### PEACH, TEACH, AND SELF

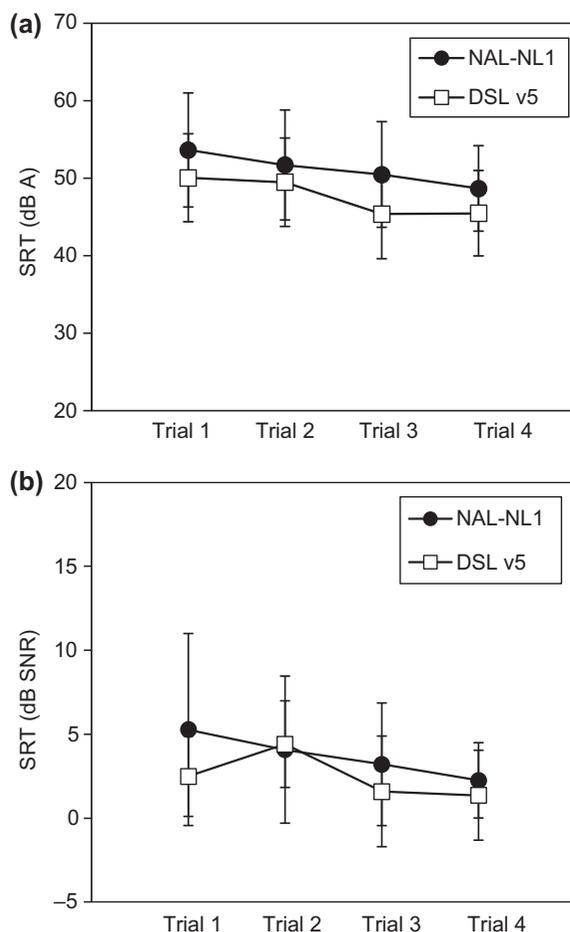
The scales were completed by 14 parents for PEACH, 15 teachers for TEACH, and all 16 children for SELF. For each scale, the mean total scores as well as the quiet and noise subscale scores were calculated (Ching & Hill, 2007). In calculating the scores, the item regarding telephone usage was not included since many of the children reported not using or rarely using the telephone. The results are displayed in Figure 2 (a) for PEACH, Figure 2 (b) for TEACH, and Figure 2 (c) for SELF. On average, the DSL v5 had higher scores than NAL-NL1 for all the subscales and scales evaluated. The differences of mean scores between prescriptions were small for PEACH and TEACH, but relatively bigger for SELF. The quiet subscale scores were consistently higher than the noise subscale scores suggesting the functional performance of children was better in quiet than in noise. The general linear model repeated measures analysis was used to analyse the data with scale (PEACH, TEACH, and SELF) as dependent variable and prescription (NAL-NL1 and DSL v5) and listening condition (quiet and noise) as independent variables. The results showed a significant main effect of prescription for PEACH ( $F(1, 13) = 6.869, p = 0.02$ ), TEACH ( $F(1, 14) = 5.533, p = 0.03$ ), and also SELF ( $F(1, 15) = 10.339, p < 0.01$ ). The main effect of listening conditions was also significant for PEACH ( $F(1, 13) = 24.698, p < 0.01$ ), TEACH ( $F(1, 14) = 20.423, p < 0.01$ ) and SELF ( $F(1, 15) = 6.062, p = 0.03$ ). No significant interactions between prescriptions and listening conditions were found in all the scales ( $p > 0.05$ ). Spearman's rank-order correlation was conducted to analyse the relationships among the scales. Results showed that the PEACH scores were significantly correlated with the TEACH scores ( $r(13) = 0.616, p = 0.03$ ) but no significant correlations were found between the SELF scores with either PEACH ( $p = 0.08$ ) nor TEACH scores ( $p = 0.16$ ).

The parents and teachers were also asked to rate the relative performance of the two prescriptions for each item in the scales. The mean ratings for each item are shown in Figure 3 (a) for the parents and Figure 3 (b) for the teachers. On average, DSL v5 were perceived by parents and teachers as either the same or slightly better than NAL-NL1 for all items with the largest difference (0.5 of a rating category) being observed for the item on 'respond to name in quiet'. Spearman's rank-order showed the ratings provided by parents and teachers to compare prescriptions were significantly correlated with each other ( $r(13) = 0.675, p = 0.01$ ).

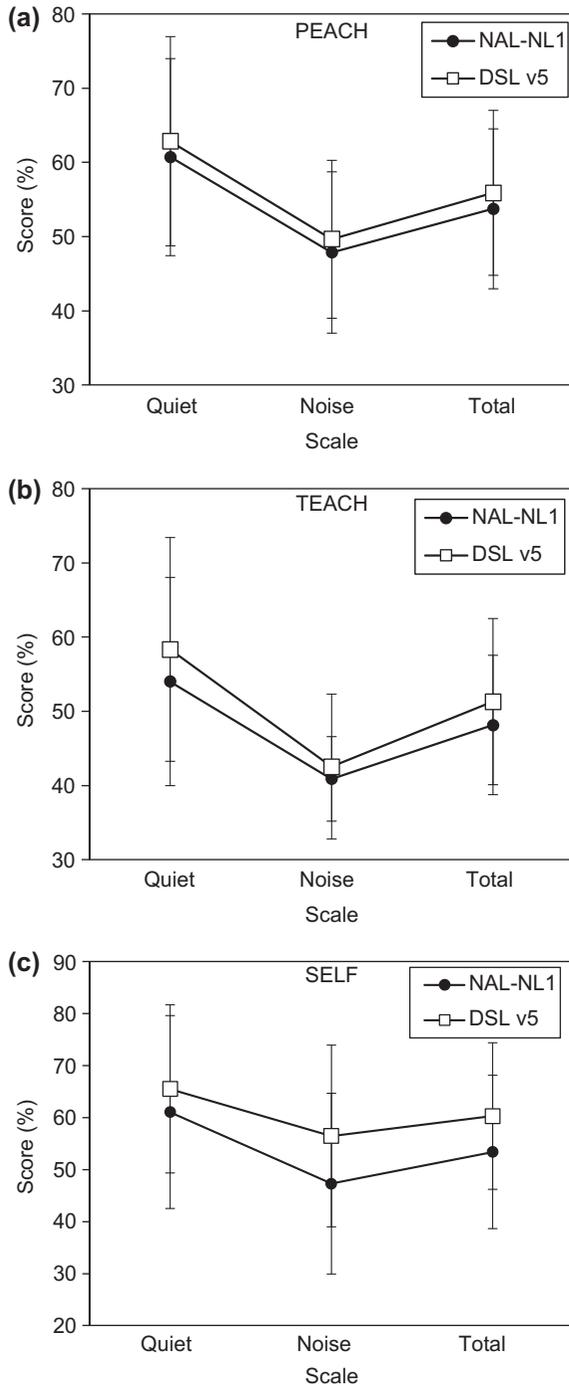
#### CHILDREN'S RATINGS AND PREFERENCE

Children's prescription ratings and preferences were assessed using a diary in trials 3 and 4. Results were obtained from 15 children. One child (the youngest in the group) was assisted by his mother with the task of changing program everyday and also in completing the diary.

Spearman's rho revealed a significant correlation between the children's ratings in trial 3 and trial 4, suggesting consistency of responses given by the children ( $r(15) = 0.678, p = 0.01$ ). Thus, the ratings were averaged across trials and the results are presented in

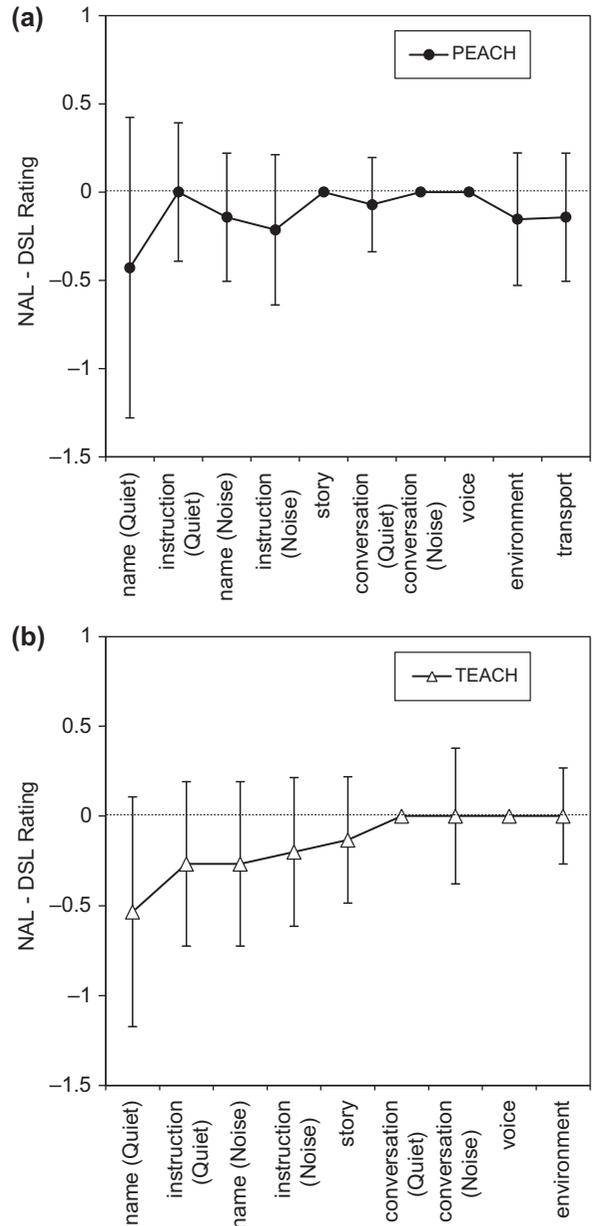


**Figure 1.** (a) Mean sentence reception threshold (SRT) in quiet by prescription and trial. NAL-NL1 in filled circles and DSL v5 in open squares. (b) Mean sentence reception threshold (SRT) in noise by prescription and trial. NAL-NL1 in filled circles and DSL v5 in open squares.



**Figure 2.** (a) Average PEACH scores by prescription, for the quiet, noise, and total subscales. NAL-NL1 in filled circles and DSL v5 in open squares. (b) Average TEACH scores by prescription, for the quiet, noise, and total subscales. NAL-NL1 in filled circles and DSL v5 in open squares. (c) Average SELF scores by prescription, for the quiet, noise, and total subscales. NAL-NL1 in filled circles and DSL v5 in open squares.

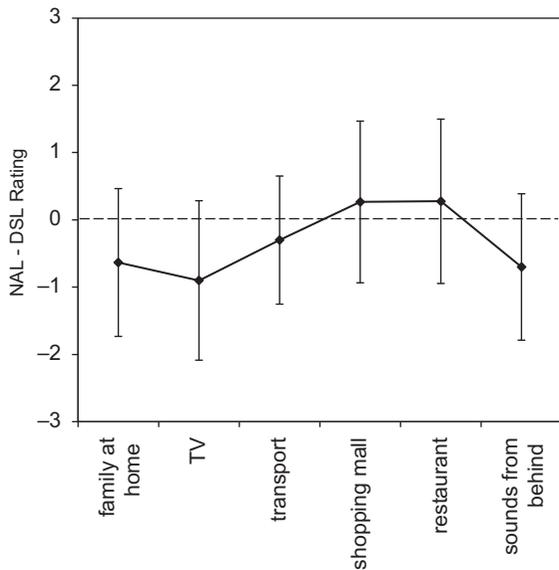
Figure 4. The positive values in Figure 4 denote a preference for NAL-NL1 and negative values indicate a preference for DSL v5. On average, the DSL v5 prescription was rated as slightly better than NAL-NL1 for listening to family at home, listening to television at home, listening in cars/buses, and listening to sounds from behind.



**Figure 3.** (a) Mean ratings provided by parents (PEACH) for different listening situations. Positive values indicate a preference for the NAL-NL1 prescription and negative values indicate a preference for the DSL v5 prescription. (b) Mean ratings provided by teachers (TEACH) for different listening situations. Positive values indicate a preference for the NAL-NL1 prescription and negative values indicate a preference for the DSL v5 prescription.

The NAL-NL1 prescription was rated to be slightly higher for listening in the shopping malls and in the restaurants.

At the end of trial 3, eight children preferred DSL v5, four preferred NAL-NL1, and three had no preference. All the three children who had no overall preference, stated they preferred DSL v5 for quiet situations and NAL-NL1 for noisy situations. In trial 4, one of the three children who expressed no overall preference before, indicated a preference for the DSL v5 prescription. The other children expressed the same preferences as before and two children had no overall preferences at the end of trial 4. For subsequent discussion,



**Figure 4.** Mean ratings provided by children for different listening situations. Positive values indicate a preference for the NAL-NL1 prescription, and negative values indicate a preference for the DSL v5 prescription.

the preference reported in trial 4 (final trial) will be taken as the children's final preference.

Spearman's rho analysis indicated that the children's preference of prescription were significantly correlated with their ratings for prescription ( $r(13) = -0.804$ ,  $p < 0.01$ ). The relationship between results from the laboratory test (paired-comparison intelligibility judgments) and the children's preferred prescription was also investigated. The Spearman's rho analysis revealed a significant correlation between the paired-comparison test results and the children's final preference of prescription ( $r(8) = 1.00$ ,  $p < 0.01$ ).

To investigate whether children's preferences were related to their hearing levels, the Spearman's test was carried out. The results indicated that the correlation was not significant ( $r(13) = -0.089$ ,  $p = 0.772$ ). We also examined whether children's preferences were

related to their previous hearing-aid experience. Coupler gain information of hearing aids used by children prior to enrolment in the study (personal hearing aids) was available for 10 out of the 17 children. Table 3 compares the 4FA gain preferred by the children when they used the experimental hearing aids to the NAL-NL1 targets, DSL v5 targets, as well as their personal hearing aids. On average, the preferred gain was 8 dB higher than the NAL-NL1 targets (SD = 5.5 dB; range = -1.7 to 13.8 dB), and 3.7 dB less than the DSL targets (SD = 3.9 dB; range = -10 to 0.5 dB). One child (child 8) preferred gain that is midway between the NAL-NL1 and the DSL v5 prescribed gains, two preferred gains as prescribed by the NAL-NL1 procedure. The remaining children preferred gains between 0 and -4 dB of the DSL v5 prescribed gain.

#### HEARING-AID USAGE AND LOUDNESS DISCOMFORT

Hearing-aid usage and loudness discomfort were analysed from the PEACH, TEACH, and SELF scales completed during trials 1 and 2. On average, the children used the hearing aids often, as reported by the parents, teachers, and the children themselves. Using hearing-aid usage as dependent variable and scale and prescription as independent variables, the general linear model repeated measures analysis showed no significant main effect of scale ( $p = 0.08$ ), prescription ( $p = 0.08$ ), and interaction between the two variables ( $p = 0.23$ ). For loudness discomfort, there was a significant main effect of prescription ( $F(1, 12) = 10.108$ ,  $p = 0.01$ ) and scale ( $F(2, 24) = 6.247$ ,  $p = 0.03$ ). Average across all scales, the loudness discomfort scores for the DSL v5 prescription (mean = 2.9; SD = 1.2) were significantly lower than for the NAL-NL1 prescription (mean = 3.6; SD = 0.7). This suggests children experienced loudness discomfort more frequently with DSL v5. On average, the children reported that they experienced loudness discomfort more frequently (mean SELF score for DSL v5 = 2.6; SD = 1.2) than was observed and reported by their parents (mean = 3.2; SD = 0.9), and teachers (mean = 3.5; SD = 0.8), for the DSL v5 prescription.

#### DATA LOGGING

Based on the information from trials 1 and 2, the children used hearing aids for nine hours per day for both prescriptions (mean = 9.3 hours per day for NAL-NL1 and 8.8 hours per day for DSL v5). Paired t-test revealed no significant difference between the amount

**Table 3.** Four frequency average (4FA) measured from the experimental hearing aids used in the study (preferred gain), as compared to the average gains prescribed by the NAL-NL1, DSL v5 procedures as well as the average gain measured from child's personal hearing aids, prior to the study.

Child	NAL prescribed gain	DSL prescribed gain	Personal hearing aid gain	Preferred gain	Preferred: NAL	Preferred: DSL	Preferred: personal
1	22.4	35.1	21.8	35.2	12.8	0.1	13.4
2	23.8	36.0	20.8	36.1	12.3	0.1	15.3
3	22.8	36.1	45.4	36.6	13.8	0.5	-8.8
4	37.6	51.9	32.9	47.4	9.8	-4.5	14.5
5	44.3	53.1	42.3	50.7	6.4	-2.4	8.4
6	39.1	52.6	52.8	51.3	12.2	-1.3	-1.5
7	56.0	64.3	38.3	54.3	-1.7	-10.0	16.0
8	39.1	55.8	49.3	47.1	8.0	-8.7	-2.2
9	40.9	50.9	42.9	48.0	7.1	-2.9	5.1
10	47.5	54.9	37.6	46.8	-0.7	-8.1	9.2
Mean	37.4	49.1	38.4	45.4	8.0	-3.7	6.9
SD	11.2	9.9	10.7	6.9	5.5	3.9	8.6
Range	22.4-56.0	35.1-64.3	20.8-52.8	35.2-54.3	-1.7-13.8	-10.0-0.5	-8.8-15.3

**Table 4.** Data logging showing the mean percentage of the NAL-NL1 and DSL v5 program being used for different default programs.

	NAL	SD	DSL	SD
Default NAL	62.0%	37.4	38%	37.4
Default DSL	23.7%	29.0	76.1%	29.0
Total	42.8%	38.3	57.0%	38.3

of hours used for the NAL-NL1 and DSL v5 prescription ( $p = 0.45$ ). Individual data showed that the two new hearing-aid users used hearing aids the least (average of four hours per day). For NAL-NL1, Spearman's rho showed that the logged hours were significantly correlated with results on hearing-aid use reported in PEACH, TEACH, and SELF. For DSL v5, logged hours were significantly correlated with PEACH and SELF but were not significantly correlated with TEACH.

Data logging information from trials 3 and 4 showed the percentage of time that each prescription was being used when either the NAL-NL1 or the DSL v5 was set as the default hearing-aid program. Table 4 shows the results when averaged across ears. On average, children used the default program more often than the alternative program, and they used the DSL v5 program more often than the NAL-NL1 program. The general linear model repeated measures analysis was used to analyse the data with data logging information as dependent variable and prescription, ear and default program as independent variables. The analysis showed no significant main effect of prescription ( $p = 0.17$ ), ears ( $p = 0.34$ ), and default program ( $p = 0.59$ ). However, there was a significant interaction between the prescription and the default program ( $F(1,12) = 16.869$ ,  $p < 0.01$ ). The mean values showed that when the DSL v5 prescription was set as the default program, the children tend to use the DSL v5 program more often. The same thing occurred when the NAL-NL1 prescription was set as the default program where the children tended to use the NAL-NL1 program more often but to a lesser degree compared to the frequency of using the DSLv5 program, when it was set as the default program.

The percentage of prescription use presented by the data logging feature was found to be significantly correlated with the children's overall preferred prescription ( $r(12) = 0.102$ ,  $p < 0.01$ ) suggesting that on average, the children used their preferred prescription more often than the alternative prescription.

## Discussion

### Speech recognition test

The consonant discrimination test presented in quiet and at medium level revealed no significant difference between prescriptions. This finding is consistent with the NAL/UWO study which implemented the test not only at medium level but also at soft and loud levels. Individual data showed the DSL v5 procedure prescribed higher overall gain than the NAL-NL1 procedure, for vast majority of the tested ears. Despite the provision of higher gains by the DSL v5 procedure than the NAL-NL1 procedure, the children's abilities to discriminate the consonants were similar between prescriptions. This could be explained in terms of hearing loss desensitization (Ching et al, 2001b) whereby the amount of speech information that can be extracted from an audible signal decreases with increase in hearing loss (Murray & Byrne, 1986; Ching et al, 1998; Hogan & Turner, 1998; Turner & Cummings, 1999; Vickers et al, 2001). It is also possible that the consonant test presented at medium level and in quiet,

was not sensitive enough to detect any differences of performance between the NAL-NL1 and DSL v5 prescriptions. Other studies have found significant difference in performance for hearing aids with different amplification characteristics, using consonant discrimination tests conducted at soft levels (Davies-Venn et al, 2009) and in noise (Hickson et al, 1995).

For the sentence tests presented in quiet, there was a significant difference in performance between prescriptions. The mean results indicated that the SRT required by the DSL v5 prescription to perceive 50% of the speech material correctly was 3.5 dB lower than what was required by the NAL-NL1 prescription. This implies that the children performed better with the DSL v5 prescription for sentences presented at soft levels and in quiet. The 4FA (0.5, 1, 2, and 4 kHz) gain prescribed by the DSL v5 procedure was 9 dB higher than the NAL-NL1 prescription for soft input level. The 4FA gain achieved in the children's hearing aids was 8 dB higher for the DSL v5 procedure in relative to the NAL-NL1 procedure. This gain difference does not correlate with the HINT test in quiet which showed the DSL v5 fitting was only 3.5 dB better than the NAL-NL1 fitting. There is a possibility that the speech performance does not depend only on the overall gain provided by the hearing aids but on other factors such as the frequency response slopes prescribed by the two procedures and whether or not the higher gain prescribed by the DSL v5 procedure for the higher frequency region actually helped to improve speech intelligibility.

For sentences presented in noise, the results were similar to the NAL/UWO study in that no significant differences were found between prescriptions.

The present study also found that the consonant scores and SRT of sentences measured in quiet and in noise improved from trial 1 to trial 4. This effect is consistent with the findings of the NAL/UWO study and is possibly associated with hearing aid acclimatization (Horwitz & Turner, 1997; Kuk et al, 2003; Scollie et al, 2010c).

### Functional performance

The children's real-life performance were assessed using questionnaire scales (PEACH, TEACH, and SELF) and comparison rating scales completed by the parents, teachers, and children. Across all scales, the mean scores for the DSL v5 prescription were significantly higher than those for the NAL-NL1 prescription. This finding is not consistent with the NAL/UWO study that showed no significant difference in prescriptions assessed using the PEACH and TEACH scales.

In this study, the children's self-report (SELF) on the performance of the two prescriptions did not correlate with the outcome provided by their parents (PEACH) and the teachers (TEACH). The parents' and teachers' reports were significantly correlated with each other. The discrepancies between the children's self-report and of their parents' reports have also been shown in previous literature (Kopun & Stelmachowicz, 1998; Huber, 2005; Warner-Czyz et al, 2009). The lack of consistency in reports provided by children and their parents suggests that it may be useful to combine child and parental report for counseling purposes (Kopun & Stelmachowicz, 1998). The comparison rating scales showed that while parents and teachers rated the DSL v5 prescription to be slightly better for listening in noise, children tended to rate the NAL-NL1 as better for listening in noise. The children's preferences were possibly related to listening comfort, which appeared to be significantly better for the NAL-NL1 prescription than for the DSL v5 prescription. These findings were consistent with the NAL/UWO study on Australian children

which indicated on average the children perceived the NAL-NL1 prescription to be better than the DSL v4.1 prescription in noisy places such as restaurants, playgrounds and shopping malls (Scollie et al, 2010e).

#### *Child's preference and individual comments*

The children's preferences for prescriptions were consistent across trials. By the end of trial period 4, nine children (60%) preferred the DSL v5 prescription, four children (27%) preferred the NAL-NL1 prescription, and two children (13%) preferred neither. The children who preferred the NAL-NL1 prescription included one new hearing-aid user, one child with severe sensorineural hearing loss, one child with mixed hearing loss and one child with profound hearing loss. The child with severe hearing loss preferred NAL-NL1 because it was not as noisy as the DSL v5 prescription. For the other two children, the child with mixed hearing loss preferred the NAL-NL1 prescription because it was clearer as compared to the DSL v5 prescription, while the child with profound hearing loss stated he liked the NAL-NL1 prescription because he could tell sounds were not equally loud and could hear the soft/distanced sounds better. For these two children, the NAL-NL1 procedure prescribed slightly higher low-frequency gain (0.25–1 kHz) than the DSL v5 procedure for all input levels.

The children's preferences in the present study were found to be highly correlated with their paired-comparison judgments of intelligibility assessed in the clinical setting. This finding is consistent with the NAL/UWO study which suggested the paired-comparison test can be a valid method for selecting the appropriate amplification characteristics (Ching et al, 2010d).

Half of the children commented that the DSL v5 prescription was noisy. Nonetheless, the children who indicated that DSL v5 was associated with loudness discomfort more often than NAL-NL1, indicated that they preferred the DSL v5 prescription because they could hear speech in quiet more clearly by end of trial 4. It is possible that the children in the study had experienced gain adaptation over the trial period. Nevertheless, hearing-aid loudness discomfort should be regarded as an important aspect that can affect hearing-aid outcome (Hickson et al, 2010). Parents and teachers commented that children responded better when called, less repetitions were required for them to follow instructions, and demonstrate greater awareness of environmental sounds (searching) when the DSL v5 prescription was used. Children preferred the NAL-NL1 for better listening comfort in noisy situations.

#### *Data logging*

The data logging showed that the children used their hearing aids for an average of about nine hours per day and the hours did not differ significantly between the prescriptions. The logged hours for both prescriptions were also found to be correlated with the duration of hearing-aid use as reported by the parents, teachers, and children in the questionnaires (except for DSL v5, logged hours did not correlate with the TEACH). This is consistent with other studies (Haggard et al, 1981; Humes et al, 1996) implying that both methods can be used reliably to measure the usage of hearing aids.

On average, the results showed that the DSL v5 prescription was used by children more often than the NAL-NL1 prescription during trials 3 and 4 (by 14.2%) and they also tended to use the default program more often than the second program. There was a significant interaction between prescription and default program

suggesting that children tend to use the default program more often, but the frequency of using the default program varied depending on which prescription was set as the default program. It was found when the DSL v5 prescription was set as the default program, children would use that program more frequently as compared to the use of the NAL-NL1 prescription when it was set as the default program. Individual data revealed about half of the children used their preferred program most of the time (up to 98% of usage) and used very little of the second program across trials. This indicates that the children did not fully utilize the different memory programs activated in their hearing aids. This is consistent with feedback gathered from some of the children stating they did not like having two different programs in their hearing aids. Only two children (with sloping mild to severe hearing loss) reported that the multiple memory function was beneficial to them. In contrast to findings in a previous study on children with mild to moderate hearing loss (Scollie et al, 2010e), this study finds that children with severe or profound hearing loss did not express a preference for access to multiple memories in their hearing aids. Further research is required to investigate the relative benefits of providing this hearing-aid feature to children with severe to profound hearing loss.

#### *Limitations*

It is known that different compression parameters such as the compression threshold, compression ratio, attack and release time can affect speech recognition ability and speech-quality judgment in patients fitted with non-linear hearing aids and that the performances of these parameters are dependent upon the signal presentation level, signal-to-noise ratio, and degree of hearing loss (Dillon et al, 1998; Davies-Venn et al, 2009). In the NAL/UWO study, the compression thresholds and maximum power outputs were assigned common values for both the NAL-NL1 and DSL v4.1 procedures (Ching et al, 2010b). As the present study did not control for variations in compression parameters, the extent to which differential variations in compression parameters between prescriptions and their influence on children's auditory performance remained to be investigated.

The present study is limited by the small sample size. Furthermore, the findings could be influenced by the type of hearing aids used and the sample characteristics (for example, there were more boys than girls). Finally, a single-blind study was used in the research and hence it is subjected to argument that the findings could be under the influence of bias from the tester.

#### **Summary and Conclusions**

The findings on the relative effectiveness of the NAL-NL1 and DSL v5 are summarized below:

1. The children performed significantly better with the DSL v5 prescription than the NAL-NL1 prescription for sentence perception in quiet. There were no significant differences between prescriptions for sentence perception in noise and for consonant discrimination in quiet.
2. The paired-comparison judgments of speech intelligibility tests showed seven children preferred the DSL v5 prescription while two children preferred the NAL-NL1 prescription, at a 5% significance level.
3. The PEACH, TEACH, and SELF scales showed that on average, the children's real-life performances were significantly better with the DSL v5 prescription than with the NAL-NL1 prescription.

4. On average, the parents and teachers rated the DSL v5 prescription as either the same or slightly better than the NAL-NL1 prescription for all listening situations. The children rated the NAL-NL1 prescription to be better for listening in restaurants and shopping malls, and the DSL v5 prescription to be better in other listening situations.
5. The data logging feature showed a significant interaction between prescription and default program, suggesting that DSL v5 when set as the default program, was used more frequently by the children than when NAL-NL1 was set as the default program. The results also showed that children did not utilize the multiple memory programs in hearing aids.
6. By the end of all trials, nine children preferred the DSL v5 prescription, four children preferred the NAL-NL1 prescription, and two children had no significant preferences.

In conclusion, the speech tests, paired-comparison judgments of speech intelligibility, and subjective measures in real life showed that children with moderately severe to profound hearing loss required gain and frequency responses which were closer to the DSL v5 prescription than the NAL-NL1 prescription, at least for quiet listening environments. Future research is required to find out the required or preferred hearing-aid gains of children with conductive or mixed hearing loss and children who have long-term auditory deprivation (new hearing-aid user), since our data showed children in these categories preferred the NAL-NL1 procedure more.

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