Comparison of three fitting rationales in adults in an artificial intelligence parallel processing hearing aid

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Introduction

Hearing rehabilitation using nonlinear hearing aid (HA) fitting formulae provides hearing-impaired individuals with the audibility, comfort, and speech intelligibility for a better life.

Objective

To compare three nonlinear HA fitting formulae in adults in a Channel Free artificial intelligence parallel processing HA.

Materials and methods

The study included 19 adults with bilateral moderate to severe sensorineural hearing loss, monaurally fitted with nonlinear HA. Comparisons were made on the basis of aided speech intelligibility in quiet and in noise, aided sound field thresholds, and functional performance in real life using APHAB, COSI, and GHABP questionnaires.

Results

The three formulae have significantly improved speech discrimination in adults, with no significant difference among the formulae for speech intelligibility in quiet or in noise, with no sex or HA experience differences. The three formulae have significantly improved functional performance in real-life speech communication, with the NAL-NL1-based formula showing the greatest degree of benefit and improvement in listening needs, followed by NAL-NL1 and then DSL [I/O]. However, amplification with the three formulae increased aversiveness to environmental sounds. Participants reported significant benefits using NAL and NAL-NL1-based formulae. Experienced HA users, using the NAL-NL1-based formula, showed significantly less difficulty in listening quality in large spaces and greater capacity to recognize speech within competitive noise and better tolerance to environmental sounds than nonexperienced users. The SPIN test correlated well with real-life speech communication.

Conclusion

The three fitting rationales have equally improved intelligibility, with variable degrees of improvement in real-life speech communication with preferences for NAL-NL1 and the manufacture-specific NAL-NL1-based formula.

Keywords:
APHAB, COSI, DSL, fitting rationale, GHABP, NAL-NL1, nonlinear hearing aid, speech discrimination

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Introduction

There are essential core features that help define modern amplification, each of which is worth considering to fulfill the needs and desires of the hearing-impaired patient. Unfortunately, no single feature in isolation meets the full range of patient needs associated with various degrees and configurations of hearing loss. These are multichannel, nonlinear amplification (MCNL), adaptation management, intelligent, fully automatic operation, intelligent use of directionality, and intelligibility-based noise reduction [1]. MCNL processing provides greater gain, and audibility, for softer speech inputs. Of course, greater audibility is possible with linear amplification; however, user intervention would be required. Therefore, MCNL compression provides automatic audibility for soft speech inputs. MCNL processing provides greater user acceptance in louder environments [2,3]. With gain for soft to medium input levels set to provide maximal audibility, the full-range compression effect reduces gain for louder sounds, thereby avoiding loudness and annoyance issues while providing a 'cleaner' sound. In the case of a severe loss with considerably reduced dynamic range, a high compression ratio will improve audibility and prevent loudness discomfort but might also distort important speech cues [4]. Essentially, all fitting rationales, whether independent (such as NAL-NL1 or DSL 5.0) or manufacturer specific, use a combination of speech audibility maximization along with loudness perception predictions to determine prescribed gain values across frequency and input level [5]. They provide access to a broad range of sounds in everyday listening environments. However, different rationales represent different solutions to this problem [6]. For example, DSL [I/O] [7] maximizes audibility across the entire bandwidth by restoring access to the full normal dynamic range. In contrast, NAL-NL1 [8] maximizes speech intelligibility across a large range of inputs while maintaining normal loudness perception and emphasizing mid and high frequencies – where the greatest portion of speech information falls. Under some circumstances, different philosophies will lead to different levels of the prescribed gain and compression [6].

Abbreviated Profile of Hearing Aid Benefit (APHAB) has undergone extensive psychometric testing and is in common use [9]. This scale explores the benefits of hearing aid (HA) use while communicating for three listening environments: (a) ease of communication (EC), (b) reverberation (RV), and (c) background noise (BN). The reliability of the APHAB has been shown to be good [9]. The APHAB has not been shown to be sensitive, however, when comparing different HA technologies [10,11]. The Client Oriented Scale of Improvement (COSI) [12] is an alternate HA self-assessment scale in which individual HA users determine the content of the scale. The data available do suggest good test–retest reliability and good validity [12]. It is possible that this test will also have good sensitivity but this has not been measured. Because the content of this scale is determined by individual HA users, it ensures that the content will consist of items that are of importance to each listener in his or her daily life. It is possible that this increased validity will result in increased sensitivity when the COSI is used to differentiate between different HA technologies or processing schemes. The Glasgow Hearing Aid Benefit Profile (GHABP) is a hearing handicap scale that is designed to be a measure of individual client concern and expectation accountability [13]. With this questionnaire, the patient identifies listening situations he/she considers to be difficult and rates the amount of difficulty, level of annoyance, the proportion of time the HA is worn during the situation, the amount of help provided by the HA, the level of difficulty in the situation with the HA, and the degree of satisfaction with the HA. The GHABP represents a client-focused rehabilitation protocol. The importance of this is that it sets up a paradigm in which the clients identify their own communication difficulties and then utilize the audiologist as a resource for solving these communication problems. This concept of patient empowerment has its theoretical basis in the work of educators and psychologists, who have worked primarily with socially disadvantaged populations [14].

Aim of the work

To compare three nonlinear HA fitting formula [National Acoustic Laboratories nonlinear version 1 (NAL-NL1), desired sensation level version 5 (DSL [I/O]), and a manufacture-specific NAL-NL1-based fitting formulae], in adults in a Channel Free artificial intelligence parallel processing HA.

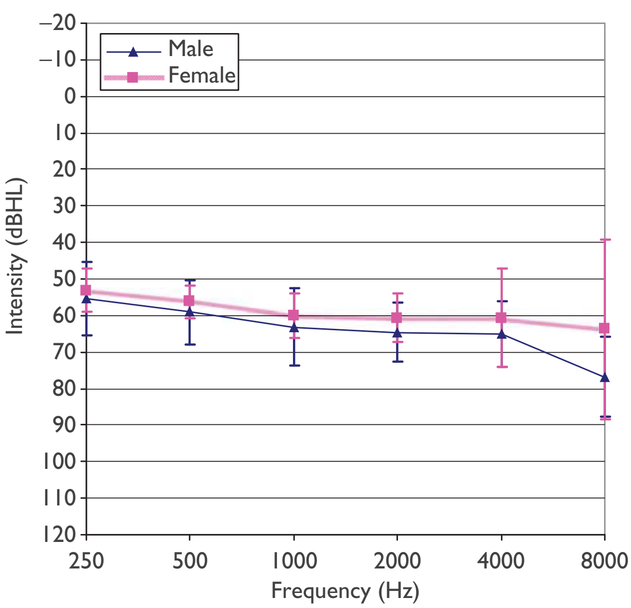
Materials and methods

The study included 19 hearing-impaired adult individuals with bilateral symmetrical sensorineural hearing loss (SNHL). Their mean age was 31.11 ± 12.04 years, ranging from 18 to 62 years of age and included eight women (42.1%) and 11 men (57.9%). Patients were recruited from Kasr Al-Aini Hospital, Cairo University. The study was carried out during the period from June 2009 to September 2011. All patients had bilateral moderate to severe SNHL, and included first users and experienced HA users. They were unilaterally fitted with the hearing aids (for financial reasons) using three fitting formulae. The exclusion criteria were as follows: chronic ear, conductive hearing loss, and retrocochlear hearing loss. Patients served as their own controls, where the three conditions were compared.

All patients included in the study were subjected to the following assessment: (1) assessment of full history excluding general medical diseases. Detailed assessments of patients' medical history were performed in relation to hearing loss including onset, course, duration, expected cause, and history of previous HA fitting. In addition, patients reported any history of operations, postoperative complaints, history of ototoxic drugs, noise exposure, trauma, and history of a similar condition in the family or positive consanguinity. (2) General and neurological examination excluding general medical diseases. (3) Full ENT examination, excluding otolaryngologic diseases. (4) Audiologic evaluation including: (a) Pure tone audiometry in the form of air conduction in the frequency range of 250–8000 Hz and bone conduction in the frequency range of 500–4000 Hz. This was performed in a sound-treated room: Amplisilence, using a two-channel clinical audiometer: Grason–Stadler (GSI) 61 meeting the American National Standards Institute (ANSI) [15]. (b) Loudness discomfort threshold level (LDL), which is the uncomfortable loudness level (ULL) using pure tones at frequencies of 500, 1000, 2000, and 4000 Hz. (c) Speech audiometry word discrimination scores (WDS) speech audiometry, including speech reception threshold (SRT) using Arabic spondaic words [16]. WDS using Arabic phonetically balanced (PB) words [17]. (d) Tympanometry (single-component, single-frequency tympanometry using an immittancemeter (Madsen Zodiac 901 middle ear analyzer; GN Otometrics A/S, Copenhagen, Denmark), with a probe tone of 226 Hz) and testing of the acoustic reflex threshold, for the ipsilateral and contralateral elicited reflexes using pure tones at frequencies 500, 1000, 2000, and 4000 Hz. (e) HA fitting using the Bernafon Inizia-3-system (Bern, Switzerland) in the right ear with three different fitting rationales: (i) the National Acoustic Laboratories nonlinear hearing aid fitting software (NAL-NL1): NAL-NL1 stands for National Acoustics Laboratories (of Australia), Nonlinear version 1 [18]. The NAL-NL1 formula does not attempt to restore normal loudness at each frequency. The underlying theory is to maximize intelligibility while maintaining the overall loudness of speech no louder than normal [8]. (ii) DSL [I/O]: DSL [I/O] is a nonlinear fitting rationale developed by Richard Seewald and his colleagues at the University of Western Ontario. DSL [I/O] was originally developed specifically for children but has also been validated in adults. DSL [I/O] [19] defines the sensation levels at which amplified speech is expected to be audible, comfortable, and intelligible across the relevant frequencies. These targets are paired with a maximum output target at each frequency to prevent discomfort. (iii) BERNAFIT NL, which is based on NAL-NL1, but is tailored specifically for Bernafon hearing instruments. It includes modifications to the targets derived from recent independent research findings. These included modifications for sex on the basis of the fact that women generally prefer less gain. Modifications for children because of the fact that they require more gain than adults. Modifications to the response to reduce the interaction between the amplified signal and the unamplified signal that passes through the vent of the hearing instrument. Modifications for Channel Free hearing instruments to optimize the amplification for this unique digital signal processing. HA fitting was performed using a desktop personal computer PC with an installed fitting module with the Bernafon manufacturer's hearing aid fitting software: OASIS version 12.0.1.35, on a NOAH 3 platform, an HIPRO USB unit: type 1072 (GN Otometrics A/S); a serial USB (Universal Serial Bus) port is used for communication between a PC. For all fitting rationales, the targets will be maintained below the measured or the calculated UCL of the client. The patient's audiogram and loudness discomfort threshold data were first entered into the fitting software, then the Inizia IN3CPX BTE HA (Bern, Switzerland) was selected, the HA was connected through a HIPRO box to the computer, in the Tuning screen in Oasis, and each HA user (whether child or adult) was fitted with one of the three fitting algorithms under study (NAL-NL1, DSL, and BERNAFIT). Each was selected at a time as the fitting rationale so that the HA was preset to the corresponding targets in the fitting software. The compression thresholds for the low-frequency, mid-frequency, and high-frequency bands were set as prescribed by the corresponding formula software. After setting the HA using a 'formula' fine tuning the fitting using a speech signal, and reconfirming audibility and patient satisfaction using subjective outcome measures, self-report questionnaires and sound field testing were used. The compression threshold was not maintained constant. The compression ratio was adjusted while patients listened to a continuous discourse in a sound-treated room. The compression characteristics were adjusted so that speech at 50 dB was rated as 'soft', speech at 65 dB was rated as 'comfortable', and speech at 85 dB was rated as 'loud but OK'. These compression characteristics were used for setting or changing the compression ratio in each fitting session in each formula used. The compression ratio affected all frequency bands, including low, mid, and high frequencies. The three different formulae were compared with assess the benefit of each condition for the HA user. Then verification of HA benefit and satisfaction was performed to confirm that the HAs had fulfilled the appropriate standards using three different self-report questionnaires that have been translated into Arabic: The APHAB questionnaire was filled by the HA users before fitting to assess unaided difficulty. The COSI and GHABP included questions related to unaided and aided ability. The three questionnaires were administered after using each fitting procedure for 1 month to assess the benefits. The scores of the questionnaires were examined and compared with assess changes in performance after fitting of each condition for the HA user. (a) COSI developed by the National Acoustic Laboratories (NAL) [12]. This has been translated into Arabic (with permission from Dr Harvey Dillon, PhD). The COSI is an open-ended scale in which the patient targets up to five listening situations for improvement with amplification. The patient is able to choose up to five listening situations from a list of 16. This subjective evaluation tool involves the identification of several patient-specific listening situations in which the patient is experiencing communication difficulty. The goal of the COSI is for the patient to target up to five specific listening situations and report the degree of benefit gained compared with that expected for the population in similar listening situations. The situations are rank ordered according to importance to the patient. (b) APHAB form A was used with the original Cox scoring [9]. APHAB has been translated into Arabic (with permission from Dr Robyn M. Cox, PhD) using guidelines for questionnaire translations from the HA research laboratory. The goal of the APHAB is to quantify the disability caused by hearing loss and the reduction of that disability achieved with HAs. The APHAB uses 24 items covering four subscales referring to speech recognition in daily environments: (a) ease of communication (EC) in environments without competitive sounds, (b) background noise (BN) evaluating the capacity to recognize speech within competitive noise, (c) reverberation (RV) referring to listening quality in large spaces, and (d) aversiveness of sounds (AV) referring to the reaction of users to environmental sounds, not the benefit itself. The first three scales evaluated speech recognition in three different situations of daily life and the last one quantified negative reactions to environmental sounds. The results of each subscale are given as percentages of difficulty with listening in that specific situation. The participants completed the APHAB under both aided and unaided conditions in the same administration by indicating what percentage of time they have experienced difficulty in each situation described in the inventory. A patient's score on each subscale is the mean rating of the six items making up the subscale. A global score is the mean of the scores for all the items in the EC, RV, and BN subscales. Benefit was calculated by subtracting the aided average from the unaided average. (c) GHABP [13]. We used the Arabic GHABP already translated by the institute of hearing research, UK. GHABP examines six dimensions of outcome including disability, handicap, HA use, benefit, satisfaction, and residual disability. The GHABP consists of four predetermined items. We excluded the other four patient-nominated items. Therefore, we used the GHABP as a closed-ended measure of outcome only, not an open-ended measure to facilitate matters for our patients and to allow a standardized comparison. The mean of the applicable data was taken, which yields scores. These values are then scaled to lie between 0 and 100 (rather than between 1 and 5) by subtracting 1 from each of them and then multiplying by 25. GHABP-derived benefit (computed from the difference between the two-state scales of initial disability and residual disability) [13].

Then, aided sound field testing was carried out after fitting including functional gain: aided sound field thresholds (ASFTs) for pure or warble tones at 0.5, 1, 2, and 4 kHz. Functional gain was obtained by subtracting the patients' aided sound field response from his/her unaided sound field response [20]. Aided sound field speech testing was carried out including aided SRT and aided speech discrimination using WDS (with and without visual cues). The aided discrimination was obtained at 65 dB HL in a sound field with the patient wearing his HA. Subtraction of the unaided score from the aided score was performed to obtain the improvement (benefit) in amplification. Aided speech in noise (SPIN) test: the participants' ability to understand speech in noise, in the form of WDS, was assessed using

Figure 1



The pure tone audiogram of the study group.

monosyllabic words in noise at different signal to noise ratios (SNRs): 0, + 5, and − 5, and at 1 presentation level (40 dB SL). Two loudspeakers were used and oriented at 45° azimuth to the forward-facing head. Patient positioning in the test environment was about a distance of 1 m far from the loudspeaker (s). This provided an idea of how the patient would hear in a noisier environment. Note that we did not use any objective verification methods for HAs (e.g. real ear measurements).

Statistical analysis

Analysis of data was carried out using SPSS 17 (Statistical Package for Scientific Studies Inc., Chicago, Illinois, USA) for Windows. Description of variables was presented as follows: description of quantitative variables was in the form of mean, SD, minimum, and maximum. Description of qualitative variables was in the form of *N* (%). Nonparametric tests were used for comparisons. A comparison between parametric quantitative variables was carried out among more than two groups using the Kruskal–Wallis test and to compare between two groups of variables, the Mann–Whitney test was used. Binary correlation was determined by Pearson's correlation. Results were expressed in the form of correlation coefficient (*R*). Significance was expressed in the form of *P*-values [significant (S) when $P \leq 0.05$; nonsignificant when $P > 0.05$).

Results

The study group included 11 (57.9%) men and eight (42.1%) women. All of them had bilateral moderate to severe SNHL. The study group was divided into 10 experienced HA users and nine nonexperienced HA users. Figure 1 shows the pure tone audiogram of the group. There was no statistically significant difference between the audiogram, the UCL, or the DR of men and women.

Table 1 shows the mean and SD of the ASFT at 500, 1000, 2000, and 4000 Hz in the cases with HA fitted to the three formulae BERNAFIT, NAL-NL1, and DSL. There was a statistically significant ($P < 0.05$) difference between BERNAFIT and NAL at 500 and 2000 Hz, and between BERNAFIT and DSL at 500, 1000, and 2000 Hz.

Table 1 Mean and SD of the ASFT in dB HL at 500, 1000, 2000, and 4000 Hz in the 3 hearing aid fitting formulae in adults

	BERNAFIT		NAL		DSL			
ASFT (Hz)	Mean	SD	Mean	SD	Mean	SD	χ^2 of Kruskal–Wallis test	*P*-value
500	30.00	3.73	35.00	5.27	36.84	4.15	18.136	0.000
1000	24.21	5.59	26.58	5.28	28.95	5.42	6.319	0.042
2000	21.58	5.79	25.79	6.29	26.58	6.47	6.689	0.035
4000	25.00	6.01	28.42	5.28	27.89	5.35	4.194	0.123

ASFT, aided sound field threshold.
ASFT at 500 Hz: BERNAFIT : NAL ($z = -3.004$; $P = 0.003$); BERNAFIT : DSL ($z = -4.144$; $P = 0.000$); NAL : DSL ($z = -1.120$; $P = 0.263$).
ASFT at 1000 Hz: BERNAFIT : NAL ($z = -1.332$; $P = 0.183 =$); BERNAFIT : DSL ($z = -2.420$; $P = 0.0155$); NAL : DSL ($z = -1.133$; $P = 0.183$).
ASFT at 2000 Hz: BERNAFIT : NAL ($z = -2.062$; $P = 0.039$); BERNAFIT : DSL ($z = -2.352$; $P = 0.019$); NAL : DSL ($z = -0.452$; $P = 0.651$).

Table 2 Mean and SD of the CR at moderate (65 dB SPL) and loud sounds (80 dB SPL), in the low-frequency, mid-frequency, and high-frequency bands, using the three hearing aid fitting formulae in adults

	BERNAFIT		NAL		DSL			
CR	Mean	SD	Mean	SD	Mean	SD	χ^2 of Kruskal–Wallis test	*P*-value
Medium input sounds								
Low frequency	1.33	0.48	1.59	0.52	1.66	0.38	15.536	0.000
Mid frequency	1.26	0.36	1.38	0.16	1.47	0.14	11.450	0.003
High frequency	1.23	0.2	1.35	0.13	1.35	0.13	9.123	0.010
Loud input sounds								
Low frequency	1.43	0.27	1.27	0.13	1.53	0.21	16.045	0.000
Mid frequency	2.27	0.6	1.97	0.47	1.94	0.34	3.937	0.140
High frequency	2.34	0.83	2.07	0.68	2.46	0.48	3.628	0.163

CR, compression ratio.
CR at medium input low frequency: BERNAFIT : NAL ($z=-2.726$; $P=0.006$); BERNAFIT : DSL ($z=-3.510$; $P=0.000$); NAL : DSL ($z=-1.948$; $P=0.051$).
CR at medium input mid frequency: BERNAFIT : NAL ($z=-1.951$; $P=0.051$); BERNAFIT : DSL ($z=-3.082$; $P=0.002$); NAL : DSL ($z=-2.087$; $P=0.037$).
CR at medium input high frequency: BERNAFIT : NAL ($z=-2.567$; $P=0.010$); BERNAFIT : DSL ($z=-2.633$; $P=0.008$); NAL : DSL ($z=-0.121$; $P=0.904$).
CR at loud input Low frequency: BERNAFIT : NAL ($z=-2.167$; $P=0.030$); BERNAFIT : DSL ($z=-1.589$; $P=0.112$;) NAL : DSL ($z=-4.103$; $P=0.000$).

Table 3 Mean and SD of the aided speech discrimination in quiet and in noise (SPIN) at signal to noise ratios +5, 0, and −5 in adults using the three different hearing aid fitting formulae

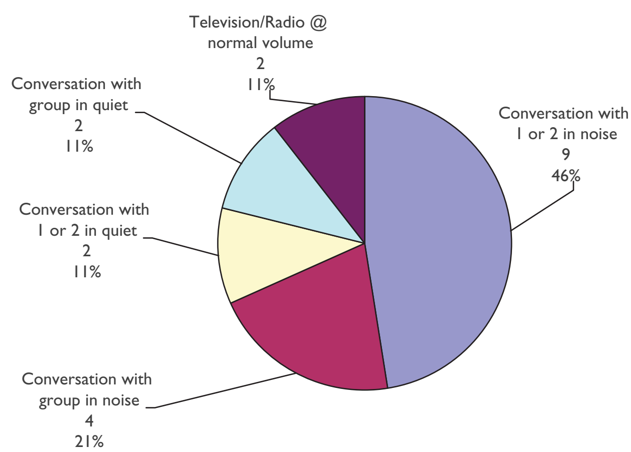
	BERNAFIT		NAL		DSL			
	Mean	SD	Mean	SD	Mean	SD	χ^2 of the Kruskal–Wallis Test	*P*-value
Aided speech discrimination in quiet	89.89	6.72	89.05	6.09	86.74	7.43	2.731	0.255
Improvement in speech discrimination in quiet	12.00	8.54	11.16	8.39	8.84	8.39	1.448	0.485
SPIN +5	90.91	6.22	89.09	6.47	89.09	5.39	2.582	0.275
SPIN 0	89.45	6.27	86.55	5.45	86.18	5.76	3.350	0.187
SPIN −5	86.55	6.76	85.45	6.99	85.45	5.45	1.563	0.458

Table 2 shows the mean and SD of the CR at moderate-level and high-level input sounds, in the low-frequency, mid-frequency, and high-frequency bands, using the three HA fitting formulae in adults. There was a statistically significant difference among the formulae with respect to the CR at medium input levels and at loud input levels in the low-frequency bands.

The unaided speech discrimination of the study group was 77.89 ± 11.34%, which differed significantly from the aided speech discrimination using each of the three HA fitting formulae: BERNAFIT ($z=-3.527$, $P=0.000$); NAL-NL1 ($z=-3.463$, $P=0.001$); and DSL ($z=-3.358$, $P=0.001$). There was no statistically significant difference among the three HA fitting formulae in the aided speech discrimination and aided speech discrimination in noise (SPIN) at SNRs +5, 0, and −5 (Table 3).

Using the COSI questionnaire, the first priority need of adults from the 16 different categories of COSI in adult listeners is shown in Fig. 2. χ^2-Tests did not show any statistically significant difference ($P>0.05$) between experienced and nonexperienced HA users with respect to the distribution of the COSI needs. Figure 3 and Table 4 show the final ability in improving the client priority needs with HAs fitted to each formula. Figure 4 shows the final ability in improving other needs with HA fitted to each of the three formulae.

Figure 2

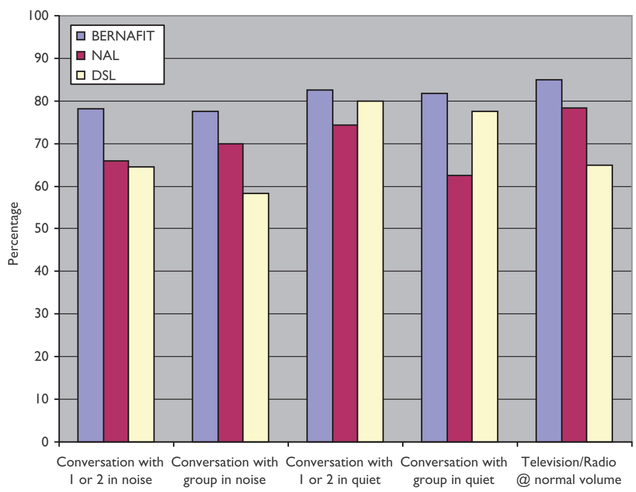


The priority needs in the COSI questionnaire. COSI, Client Oriented Scale of Improvement.

Tables 5 and 6 show the distribution of the degree in change in the five reported needs of the COSI questionnaire with the three fitting HA formulae in adults. There was a statistically significant difference among the three formulae with respect to the distribution of the degree of change in all needs.

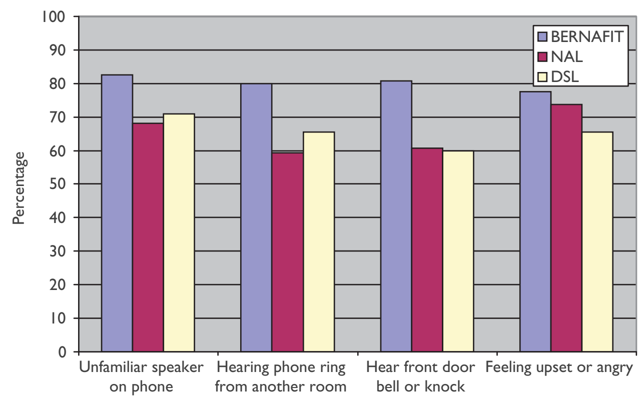
Figure 5 shows the global APHAB and APHAB subscale scores without the HA and with the HA fitted to each of

Figure 3



The final ability in improvement of the priority needs using the COSI questionnaire with the HA fitted to each formula. COSI, Client Oriented Scale of Improvement; HA, hearing aid.

Figure 4



The final ability in improving other needs with hearing aid fitted to each formula.

Table 4 The final ability in improving the client needs with hearing aids fitted to each formula

	BERNAFIT		NAL		DSL			
Category of COSI	Mean	SD	Mean	SD	Mean	SD	χ^2 of the Kruskal–Wallis test	*P*-value
Conversation with 1 or 2 individuals in noise	78.18	13.09	65.91	12.61	64.55	28.5	3.195	0.202
Conversation with group in noise	77.5	16.66	70	17.32	58.33	20.41	2.899	0.235
Conversation with 1 or 2 individuals in quiet	82.5	10.35	74.375	12.08	80	9.26	2.085	0.353
Conversation with a group in quiet	81.67	10.33	62.5	13.69	77.5	16.66	4.958	0.084
Television/radio at normal volume	85	10.95	78.33	8.16	65	28.11	2.290	0.318
Unfamiliar speaker on phone	82.5	10	68.13	15.9	70.94	16.45	7.477	0.024[a]
Hearing phone ring from another room	80	9.26	59.38	12.94	65.63	18.6	8.252	0.016[b]
Hear front door bell or knock	80.71	9.76	60.71	19.67	60	23.09	5.191	0.075
Feeling upset or angry	77.5	7.07	73.75	17.06	65.63	12.94	3.223	0.200

COSI, Client Oriented Scale of Improvement.
[a]Mann–Whitney test: BER : NAL ($z=-2.713$; $P=0.007$); BER : DSL ($z=-1.934$; $P=0.053$); NAL : DSL ($z=-0.496$; $P=0.620$).
[b]Mann–Whitney test: BER : NAL ($z=-2.612$; $P=0.009$); BER : DSL ($z=-2.096$; $P=0.039$); NAL : DSL ($z=-1.135$; $P=0.256$).

Table 5 Comparison of the degree of change in the top five common reported needs of the COSI questionnaire among the three fitting hearing aid formulae in the cases under study

	BERNAFIT	NAL	DSL	χ^2 of the Kruskal–Wallis test	*P*-value
Conversation with 1 or 2 individuals in noise [*n* (%)]					
Much better	8 (72.73)	3 (27.27)	1 (9.09)	9.300	0.157
Better	3 (27.27)	6 (54.55)	2 (18.18)		
Slightly better	0 (0.00)	2 (18.18)	7 (63.64)		
No difference	0 (0.00)	0 (0.00)	1 (9.09)		
Conversation with a group in noise [*n* (%)]					
Much better	4 (66.67)	2 (33.33)	2 (33.33)	19.530	0.003
Better	2 (33.33)	3 (50.00)	0 (0.00)		
Slightly better	0 (0.00)	1 (16.67)	3 (50.00)		
No difference	0 (0.00)	0 (0.00)	1 (16.67)		
Conversation with 1 or 2 individuals in quiet [*n* (%)]					
Much better	4 (50.00)	1 (12.50)	2 (25.00)	13.714	0.033
Better	4 (50.00)	4 (50.00)	0 (0.00)		
Slightly better	0 (0.00)	3 (37.50)	4 (50.00)		
No difference	0 (0.00)	0 (0.00)	2 (25.00)		
Conversation with a group in quiet [*n* (%)]					
Much better	2 (33.33)	1 (16.67)	1 (16.67)	11.100	0.025
Better	4 (66.67)	5 (83.33)	1 (16.67)		
Slightly better	0 (0.00)	0 (0.00)	4 (66.67)		
Television/radio [*n* (%)]					
Much better	4 (66.67)	1 (16.67)	1 (16.67)	6.667	0.353
Better	2 (33.33)	4 (66.67)	3 (50.00)		
Slightly better	0 (0.00)	1 (16.67)	1 (16.67)		
No difference	0 (0.00)	0 (0.00)	1 (16.67)		

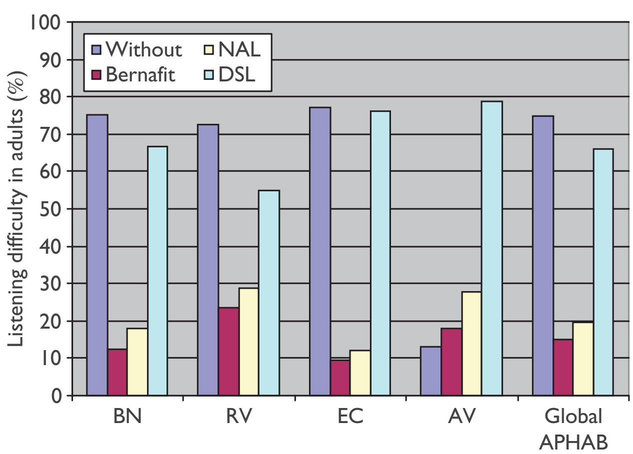
COSI, Client Oriented Scale of Improvement.

Table 6 Comparison of the degree of change in other reported needs of the COSI questionnaire among the 3 fitting hearing aid formulae in the cases under study

	BER	NAL	DSL	χ^2 of the Kruskal–Wallis test	*P*-value
Unfamiliar speaker on phone [*n* (%)]					
Much better	8 (50)	1 (6.25)	0 (0)	28.524	0.000
Better	8 (50.00)	8 (50.00)	5 (31.25)		
Slightly better	0 (0.00)	7 (43.75)	7 (43.75)		
No difference	0 (0.00)	0 (0.00)	4 (25.00)		
Hearing phone ring from another room [*n* (%)]					
Much better	3 (37.50)	3 (37.50)	2 (25.00)	8.917	0.178
Better	5 (62.50)	3 (37.50)	1 (12.50)		
Slightly better	0 (0.00)	2 (25.00)	4 (50.00)		
No difference	0 (0.00)	0 (0.00)	1 (12.50)		
Hear front door bell or knock [*n* (%)]					
Much better	2 (28.57)	2 (28.57)	0 (0.00)	13.800	0.032
Better	4 (57.14)	0 (0.00)	1 (14.29)		
Slightly better	1 (14.29)	5 (71.43)	4 (57.14)		
No difference	0 (0.00)	0 (0.00)	2 (28.57)		
Feeling upset or angry [*n* (%)]					
Much better	6 (75)	1 (12.5)	2 (25)	13.667	0.034
Better	2 (25.00)	4 (50.00)	1 (12.50)		
Slightly better	0 (0.00)	3 (37.50)	3 (37.50)		
No difference	0 (0.00)	0 (0.00)	2 (25.00)		

COSI, Client Oriented Scale of Improvement.

Figure 5



Global APHAB and APHAB subscale scores comparing adults without a hearing aid and with a hearing aid fitted with each of the three fitting formulae BERNAFIT, NAL-NL1, and DSL. AV, aversiveness; APHAB, Abbreviated Profile of Hearing Aid Benefit; BN, background noise; EC, ease of communication; RV, reverberation.

the three fitting formulae. There were statistically significant differences between the results without HA and each HA condition of the three fitting formulae in all APHAB subscale scores and the global APHAB score ($P<0.005$). Table 7 shows the listening difficulty shown in the aided global APHAB score and the APHAB subscales scores comparing HAs fitted with each of the three fitting formulae. There was a statistically significant difference ($P<0.05$) among them.

Figure 6 and Table 8 show HA benefits reflected in the aided global APHAB score and the APHAB subscale scores comparing HAs fitted with each of the three fitting formulae. There was a statistically significant difference ($P<0.05$) among them (Table 8).

Figure 7 and Table 9 show the GHABP scores among the three HA fitting formulae. There were statistically significant differences among the three HA fitting formulae with respect to the GHABP scores. Further analyses using the Mann–Whitney test showed that these differences existed between each two formulae (Table 9).

There was no statistically significant difference between experienced and nonexperienced HA users with respect to the mean ASFT, aided discrimination in quiet or in noise, using any of the three HA fitting formulae. There was no statistically significant difference between experienced and nonexperienced HA users with respect to the mean aided APHAB scores using any of the three HA fitting formulae. Experienced users showed statistically significantly better mean APHAB benefit scores at BN ($z=-2.449$, $P=0.014$), AV ($z=-2.002$, $P=0.045$) subscales and global improvement scores ($z=-2.449$, $P=0.014$) than the nonexperienced users. There was no statistically significant difference between experienced and nonexperienced users with respect to the distribution of COSI degrees of change or the total GHABP scores of the four predetermined conditions using any of the three fitting HA formulae. There was no statistically significant difference between men and women with respect to any of the measured parameters using any of the three fitting HA formulae.

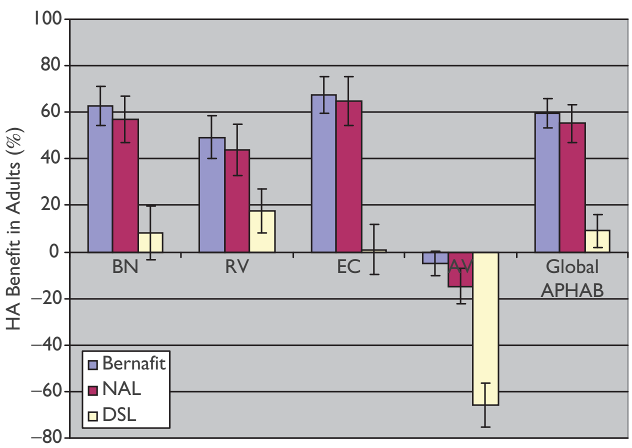
With respect to the correlation between questionnaire and speech assessment measures, Pearson's correlation coefficient (*R*) results showed a statistically significant direct correlation between APHAB benefit in the BN subscale and aided speech discrimination in noise (SPIN) at SNR: +5 ($r=0.274$, $P=0.039$), SNR: 0 ($r=0.275$, $P=0.039$), and aided speech discrimination in quiet ($r=0.287$, $P=0.030$). There was no correlation between the total GHABP postfitting scores with aided speech discrimination in noise (SPIN) at different SNR or aided speech discrimination in quiet and improvement in speech discrimination ($P>0.05$).

Table 7 Mean and SD of the APHAB subscales: BN, RV, EC, and AV, comparing cases with a hearing aid fitted with each of the three fitting formulae

	Listening difficulty							
	BERNAFIT		NAL		DSL			
	Mean	SD	Mean	SD	Mean	SD	χ^2 of the Kruskal–Wallis test	*P*-value
BN	12.35	5.41	18.02	7.63	66.71	8.21	23.109	0.000
RV	23.50	3.61	28.79	5.98	55.06	9.95	24.546	0.000
EC	9.53	3.79	12.17	5.86	76.00	9.03	19.714	0.000
AV	17.82	3.08	27.75	5.97	78.92	8.77	24.980	0.000
Global APHAB	15.13	3.35	19.66	5.65	65.92	7.56	23.200	0.000

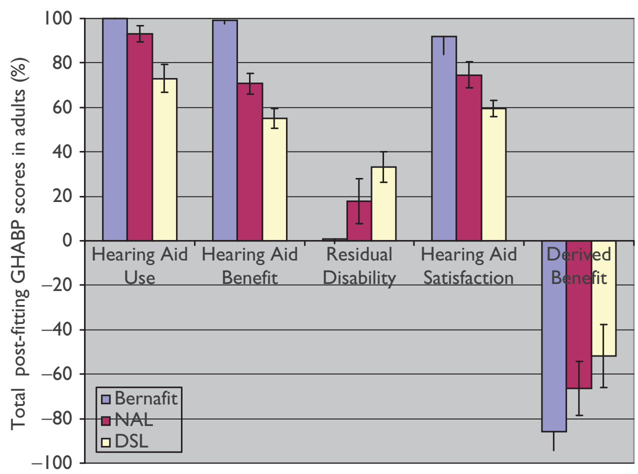
AV, aversiveness; APHAB, Abbreviated Profile of Hearing Aid Benefit; BN, background noise; EC, ease of communication; RV, reverberation.
Further analyses comparing each two formulae using the Mann–Whitney test showed that the difference resides between every two, except BERNAFIT and NAL in EC.
BN: BERNAFIT and NAL ($z=-2.222$; $P=0.026$); BERNAFIT and DSL ($z=-5.274$; $P=0.000$); NAL and DSL ($z=-5.274$; $P=0.000$).
RV: BERNAFIT and NAL ($z=-2.732$; $P=0.006$); BERNAFIT and DSL ($z=-5.275$; $P=0.000$); NAL and DSL ($z=-5.244$; $P=0.000$).
EC: BERNAFIT and NAL ($z=-1.510$; $P=0.131$); BERNAFIT and DSL ($z=-5.277$; $P=0.000$); NAL and DSL ($z=-5.274$; $P=0.000$).
AV: BERNAFIT and NAL ($z=-4.882$; $P=0.000$); BERNAFIT and DSL ($z=-5.274$; $P=.000$); NAL and DSL ($z=-5.275$; $P=0.000$).
Global: BERNAFIT and NAL ($z=-2.541$; $P=0.011$); BERNAFIT and DSL ($z=-5.270$; $P=0.000$); NAL and DSL ($z=-5.271$; $P=0.000$).

Figure 6



Benefit in the scores of the APHAB using the three different HA fitting formulae. AV, aversiveness; APHAB, Abbreviated Profile of Hearing Aid Benefit; BN, background noise; EC, ease of communication; HA, hearing aid; RV, reverberation.

Figure 7



Total GHABP scores of the four predetermined conditions using each of the three fitting hearing aid formulae in adults. GHABP, Glasgow Hearing Aid Benefit Profile.

Table 8 Benefit in the score of the APHAB in adults comparing the three different HA fitting formulae

	HA benefit							
	BERNAFIT		NAL		DSL			
	Mean	SD	Mean	SD	Mean	SD	χ^2 of Kruskal–Wallis test	*P*-value
BN	62.69	8.53	57.02	9.77	8.33	11.62	38.799	0.000
RV	49.19	9.27	43.9	10.82	17.63	9.29	36.112	0.000
EC	67.45	7.67	64.81	10.46	0.98	10.62	37.817	0.000
AV	−4.77	5.19	−14.68	7.52	−65.86	9.31	44.528	0.000
Global APHAB	59.78	6.28	55.25	8.15	8.98	6.99	38.815	0.000

AV, aversiveness; APHAB, Abbreviated Profile of Hearing Aid Benefit; BN, background noise; EC, ease of communication; HA, hearing aid; RV, reverberation.
There were statistically significant differences among the three HA fitting formulae with respect to the APHAB benefit (Table 6). Further analyses using the Mann–Whitney test comparing every two formulae showed that these differences reside between every two, except between BERNAFIT andand NAL in BN, RV, EC, and global score.
BN: BERNAFIT and NAL ($z=-1.796$; $P=0.072$); BERNAFIT and DSL ($z=-5.270$; $P=0.466$); NAL and DSL ($z=-5.270$; $P=0.000$).
RV: BERNAFIT and NAL ($z=-1.548$; $P=0.122$); BERNAFIT and DSL ($z=-5.183$; $P=0.000$); NAL and DSL ($z=-5.009$; $P=0.000$).
EC: BERNAFIT and NAL ($z=-1.008$; $P=0.314$); BERNAFIT and DSL ($z=-5.271$; $P=0.000$); NAL and DSL ($z=-5.271$; $P=0.000$).
AV: BERNAFIT and NAL ($z=-4.001$; $P=0.000$); BERNAFIT and DSL ($z=-5.271$; $P=0.000$); NAL and DSL ($z=-5.271$; $P=0.000$).
Global: BERNAFIT and NAL ($z=-1.810$; $P=0.070$); BERNAFIT and DSL ($z=-5.270$; $P=0.000$); NAL and DSL ($z=-5.270$; $P=0.000$).

Table 9 Total postfitting GHABP scores of cases in this study

	GHABP after fitting							
	BERNAFIT		NAL		DSL			
	Mean	SD	Mean	SD	Mean	SD	χ^2 of the Kruskal–Wallis test	*P*-value
Hearing aid use	100	0	93.09	3.54	73.03	6.27	50.628	0.000
Hearing aid benefit	99.34	1.97	70.72	4.68	54.93	4.46	51.177	0.000
Residual disability	0.66	1.97	17.76	10.05	33.22	6.93	44.809	0.000
Hearing aid satisfaction	91.78	8.08	74.67	5.7	59.54	3.82	46.189	0.000
Derived benefit	−85.86	8.55	−66.45	12.01	−51.97	14.14	35.662	0.000
	BERNAFIT : NAL		BERNAFIT : DSL		NAL : DSL			
	z	*P*	*z*	*P*	*z*	*P*		
Hearing aid use	−5.303	0.000	−5.671	0.000	−5.415	0.000		
Hearing aid benefit	−5.583	0.000	−5.583	0.000	−5.251	0.000		
Residual disability	−5.15	0.000	−5.552	0.000	−4.223	0.000		
Hearing aid satisfaction	−4.775	0.000	−5.376	0.000	−5.014	0.000		
Derived benefit	−4.233	0.000	−5.252	0.000	−3.088	0.002		

GHABP, Glasgow Hearing Aid Benefit Profile.

Discussion

The success of an HA prescription can be measured in terms of clinical efficacy or how closely the HA settings achieve a desired clinical result or test outcome [21]. Recent nonlinear WDRC prescriptive fitting algorithms include DSL [I/O]; DSL v5 Adult; DSL v5 Child [22]; NAL-NL1; and the newest NAL method NAL-NL2 [23,24]. The goal of a WDRC prescriptive algorithm is usually believed to be in terms of real-life benefits, including the ways in which this type of compression improves audibility across frequency, prevents loudness discomfort, improves sound intelligibility, improves sound comfort, preserves sound quality, and reduces the distortion of important speech cues [25].

The study group included 19 adults (mean age 31.11 ± 12.04 years), 11 men and eight women, with bilateral moderate to severe SNHL, who were monaurally fitted with BTE nonlinear HA. There were 10 experienced and nine nonexperienced (new) HA users. Patients served as their own controls, where the three fitting formulae were compared: NAL-NL1, DSL, and a manufacture-specific rationale: BERNAFIT. Comparisons were made on the basis of aided speech intelligibility in quiet and in noise, and ASFT at different frequencies and subjective performance and benefit in real life, and how any fitting rationale preferences were affected by sex or HA experience.

ASFT and functional gain CR at different input levels and at different frequency bands

As HAs become increasingly able to adapt to the acoustic environment, it is becoming increasingly possible to fit HAs that have no volume control. For these HAs, it is just as important to correctly prescribe the average gain as it is to prescribe the correct frequency response shape if additional appointments to adjust the HA are to be minimized or avoided [25]. The ASFT represents the softest sound that the wearer can hear inside the audiometric test booth when using an HA. For a WDRC HA without volume control, the aided threshold approximates the softest sound that the wearer hears in real-life listening situations [26]. This perceptual index reflects the ‘audibility of sounds’ to the HA user [27].

In the current study, among patients with moderate to severe SNHL, BERNAFIT provided the best ASFT across frequencies, followed by NAL and DSL, and there was a statistically significant difference in the ASFT between BERNAFIT and DSL at 500 and 2000 Hz and between BERNAFIT and NAL at 500, 1000, and 2000 Hz. Although NAL yielded better ASFT at 500, 1000, and 2000 Hz, but worse ASFT at 4000 Hz than DSL, this was not statistically significant.

Byrne *et al.* [28] found that for flat losses, NAL-NL1 prescribes less low-frequency gain than DSL [I/O]. For severe and sloping losses, NAL-NL1 prescribes less high-frequency gain than DSL [I/O]. The prescriptions are similar for moderate, gently sloping losses.

The NAL methods equalize, rather than normalize, loudness relationships across speech frequencies. NAL methods strive to normalize loudness only for the total speech spectrum as a whole. As other fitting methods attempt to normalize, rather than equalize, the loudness of adjacent speech frequencies, they prescribe relatively more low-frequency gain. NAL-NL1 again prescribes less low-frequency and high-frequency gain than DSL; prescribed mid-frequency gain is similar for the two fitting methods. The ‘missing’ NAL-NL1 target below 500Hz for a reverse audiogram; and the missing NAL-NL target for the high frequencies for a gently sloping audiogram; and for a precipitous high-frequency hearing loss, and for a steeply sloped high-frequency hearing loss, according to NAL-NL1, these frequencies will not contribute to ’effective audibility’ for this particular hearing loss. For flat audiograms with a 0 dB/octave slope, the differences between prescribed outputs by DSL versus NAL-NL1 are more evident at 5 kHz than they are at 4 kHz, with DSL requiring more low-frequency output than NAL-NL1. The differences in prescriptions were most pronounced only for soft input levels (50 dB SPL) and, furthermore, the differences also increased with increased degree of flat hearing loss. For flat and sloping hearing losses, NAL-NL1 proponents showed that DSL prescribes much more high-frequency gain [29].

In many fitting programs, the CR is determined by the relative gain for soft versus loud speech. In other manufacturers' programs, the compression ratio can be adjusted directly. However, it should be noted that fitting software varies [25].

In this study, which included adults with moderate to severe SNHL, the CR at which matching of the gain to the target was good was recorded. We found that BERNAFIT provided significantly lower CR (1.33 and 1.23) at medium input levels compared with DSL (1.59 and 1.35) and NAL (1.66 and 1.35) in the low-frequency and high-frequency bands, respectively. DSL provided significantly higher CR (1.47) in the mid-frequency band at medium input levels compared with BERNAFIT (1.26) and NAL (1.38). NAL provided significantly lower CR (1.27) in the low-frequency band at loud input levels compared with DSL (1.53) and BERNAFIT (1.43).

In comparison, for the severe hearing loss, NAL-NL1 [8], prescribed CRs were between 1.3 : 1 and 2.5 : 1 whereas for DSL version 5.0 [19], prescribed CRs were between 2.8 : 1 and 4.3 : 1. For listeners with mild-to-moderate hearing loss, NAL-NL1 [8], prescribed ratios were between 1.2 : 1 and 1.9 : 1 and for DSL version 5.0 [19], prescribed ratios were between 1.4 : 1 and 3.4 : 1.

Keidser and Dillon [24] studied the fitting results from several studies and showed that NAL-NL1, on average, overprescribes gain by about 3 dB at average input levels for adults with mild and moderate hearing loss. Keidser *et al.* [30] reported that NAL-NL2 prescribes relatively more gain across low and high frequencies and less gain across mid frequencies than NAL-NL1.

Dillon [23] reported that adults showed a unanimous preference for the NAL-NL1 response, driven strongly by DSL [I/O] prescription being judged as too loud. Theoretically, an increased gain is most likely to lead to improved intelligibility at low input levels; thus, the child and adult versions of NAL-NL2 will be most different at low input levels [23]. At these levels, there are no adverse safety implications from using a higher gain [23].

CRs for severe loss will likely need to be higher than for milder losses to fit speech within the listener's dynamic range. CRs might also need to be higher if loudness comfort is a priority. CRs will increase if either the gain for soft sounds is increased or the gain for loud sounds is decreased, whereas maintaining gain for other sound levels [25]. If intelligibility is a priority, the CR must be maintained at 2 : 1 or less for mild-to-moderate losses. Intelligibility is maintained below this point of a 2 : 1 ratio [31–35]. Complaints of muffled or unclear sound quality can also be addressed by lowering the CR [31,34,36,37]. Acoustically, this occurs because the amplitude contrast in speech has been reduced with the use of higher compression ratios. The CR should also be decreased if the patient complains that distant sounds are heard more easily than close sounds or that background sounds are too loud [25].

Speech discrimination in quiet and in noise

Patients had significantly improved speech discrimination using their HAs fitted to each of the three formulae compared with the unaided condition. BERNAFIT showed higher mean percentages of speech discrimination improvement than NAL-NL1, which in turn showed more improvement than DSL, but this was not statistically significant. Similarly, the three fitting rationales did not differ with respect to the aided speech discrimination score in quiet or in noise.

Johnson and Dillon [38] concluded that the DSL [I/O] and NAL-NL2 methods prescribe insertion gain in such a way that loudness is likely preferred by typical HA users while ensuring that speech intelligibility in quiet and noise remains comparable with that of the other prescriptive methods: (NAL-NL1, IHAFF, and FIG6).

Although speech intelligibility predictions favored the DSL [I/O] method, there was no statistically significant difference between DSL [I/O] and NAL-NL1 when comparing the actual speech recognition measurements obtained with both prescription methods. This speech recognition result obtained is certainly thought provoking as one would not expect that the two methods with highly different amplification strategies could achieve the same amplification goal, which is to provide optimum speech intelligibility [39].

Real-world effectiveness of performance in the HA fittings

This study has shown improved subjective satisfaction with amplification across a range of daily listening situations as reflected on APHAB, GHABP, and COSI. Using the COSI questionnaire, the five top priority needs of adults from the 16 different categories of COSI in adult listeners were as follows: conversation with one or two individuals in noise, conversation with a group in noise, conversation with one or two individuals in quiet, conversation with a group in quiet, and television/radio at normal volume.

In the recent study, BERNAFIT provided the highest final ability with the HA in improving the client needs determined by the COSI questionnaire, compared with NAL and DSL. NAL showed higher final ability than DSL in improving the conversation with one or two individuals or with a group in noise and in listening to television/radio at normal volume. However, DSL showed higher final ability than NAL in improving the conversation with one or two individuals or with a group in quiet, but this was not statistically significant ($P > 0.05$).

In the COSI normative study by Dillon *et al.* [40], the top five situations chosen by patients in which they hoped to hear better were (a) conversation with a group in noise; (b) conversation with a group in quiet; (c) conversation with one or two partners in noise; (d) listening to the television or radio; and (e) conversation with one or two partners in quiet. This was also in agreement with

Polonenko *et al.* [21], who obtained COSI ratings of real-world performance at the 90-day appointment.

Scollie *et al.* [19] studied patients with bilateral moderate to moderately severe SNHL including 24 children and 24 hearing instrument-experienced adult users and 24 new hearing instrument adult users. Prescriptive targets were calculated according to the DSL [I/O] algorithm. The COSI questionnaire was used to evaluate HA performance. The average degree of change was 4.1, corresponding to a rating of 'better'. Similarly, the mean final listening ability was 4.2, which falls between the rating of 'most of the time' and 'almost always'. This indicates that most of the hearing instrument users in that sample were able to function in high-priority listening situations at least half of the time. Scollie *et al.* [19], using DSL, reported that the largest mean COSI scores were in situations of listening in quiet, listening to the television or radio, and in conversation in a group with noise in the background.

The final ability in improving needs with HA fitted to each of the three formulae did not differ, except that BERNAFIT showed a statistically higher final ability in listening to an unfamiliar speaker on the phone compared with NAL, and BERNAFIT showed a statistically higher final ability in hearing a phone ring from another room compared with NAL and DSL.

Polonenko *et al.* [21], who studied the revised DSL prescriptive targets for adults, found positive outcomes for final hearing ability and benefit on the COSI for the HA users. This suggested that the fittings provided acceptable benefit and communication performance in the opinions of the participants. They found that COSI scores were high and acceptable for those situations in which the DSL-fitted memory would have been recommended for use. Specifically, the average benefit scores were 4.6, 4.3, and 4.2 for conversations in quiet, TV/radio listening, and hearing on the phone, respectively. The final ability scores in these same situations were also high, at 80% or better on average. This provided some evidence that the DSL v5 prescriptive target and individualized fitting method is effective when used to fit the base memory of a modern HA fitting [21].

In our study, the volume control in the HA used in the current study has been active, with a range of + 5 dB. The multienvironment program showed an adaptive noise reduction that was applied similarly in the three fitting rationales for a fair comparison.

BERNAFIT showed the least listening difficulty in different real-life listening situations using the APHAB questionnaire (global APHAB score and the APHAB subscales: BN, RV, EC, and AV), followed by the NAL, and finally the DSL showing the most difficultly.

Comparing the three formulae in terms of the degrees of benefit (listening improvements in different real-life situations) in the global APHAB score and APHAB subscales, the BERNAFIT yielded the greatest benefit, reflecting the greatest improvement in speech recognition in three different situations of daily life (ease of communication in environments without competitive sounds and the capacity to recognize speech within competitive noise and listening quality in large spaces). This was followed by NAL and DSL. Using BERNAFIT, the global benefit was 59.78%, which was comparable with that of NAL (55.25%); both were higher than using DSL, with which the global benefit was only 8.98%. There were statistically significant differences among the three HA fitting formulae in adults with respect to the APHAB benefit but not the speech intelligibility tests. These differences were between every two except between BERNAFIT and NAL in BN, RV, EC, and the global score, which indicates that adults benefited from NAL and BERNAFIT equally and to a huge extent than the DSL. BERNAFIT and NAL seem to have the same concept in amplification.

HAs fitted to any of the three formulae resulted in significant improvements in the speech communication subscales compared with the unaided condition. However, there was an increase in the aversiveness to environmental sounds after amplification using the HAs fitted to all three formulae, reflected by the deterioration of the aided AV subscale score compared with the unaided AV score. The aversiveness in the patients studied was mostly perceived using DSL, followed by NAL to a less extent and then BERNAFIT.

Amorim and Almeida [41] observed that the majority of patients with bilateral symmetric moderate to severe SNHL fitted with NAL-NL1 showed a significant increase in the benefit with HAs in the scales EC, RV, and BN of the APHAB in the initial period of HAs adaptation: after 4 weeks and 16/18 weeks of amplification, indicating less difficulty in different communication environments. They also observed that hearing difficulties after the HA fitting process were statistically smaller after 2 and 6 months with the same subscales: EC, RV, and BN [42]. However, analysis of the AV subscale showed an average increase, indicating a significant reduction in the benefit with HAs. After 4 weeks and 16/18 weeks of HA usage, the participants experienced an increase in sound aversiveness, which could be attributed to the increase in the audibility of acoustical signals after amplification [41,42].

However, Johnson *et al.* [43] reported that despite improvements in technology, HAs capable of WDRC processing have not resulted in perceived improvements in the magnitude of benefit for speech communication on the first three scales of the APHAB questionnaire (EC, RV, and BN). In contrast, there have been improvements in auditory discomfort with sound amplification, that is, overall, problems in understanding amplified speech did not decrease in frequency when HAs transitioned from linear to compression processing; however, the compression capabilities of current HAs (with a possible contribution from noise reduction algorithms) have resulted in less negative reactions to amplified environmental sounds [43]. Their results suggested that modern technology has ameliorated (to some extent) the common complaint that HAs cause many everyday sounds to become objectionably loud. They reported that although the results of this study suggest that the advantages of improved technology do not lie in the domains of improved subjective speech communication performance, the considerable improvement in the rate of successful adjustment to HAs between the 1995 and 2005 participant groups provides evidence that modern HA technology has led to progress in other outcome domains.

In the current study, in terms of the answers of the total GHABP questionnaire of each of the four predetermined situations, BERNAFIT showed the highest statistically significantly percentage of HA use, benefit, satisfaction, and derived benefit and the least residual disability, followed by NAL and DSL.

Correlation between subjective satisfaction with amplification (real-world effectiveness) reflected by different self-rating measures and aided speech intelligibility tests

In the present study, there was a statistically significant direct correlation between the HA benefit of the BN subscale with aided SPIN at all SNRs as well as with the aided speech discrimination in quiet. This indicates that the SPIN reflects real-life speech communication in the noise score reflected on the APHAB BN subscale.

Kuk *et al.* [27] have reported that the hearing in noise test scores obtained in the unaided and aided conditions with the omni-directional microphone may predict the extent of real-world difficulty without a HA.

Experienced versus nonexperienced HA users, functional performance in real life, and speech intelligibility tests using the three different HA fitting formulae

In the present study, experienced HA users showed a statistically significant greater capacity to recognize speech within competitive noise and better communication and tolerance to the environmental sounds, reflected by the better BN, AV subscale scores, and global score than the nonexperienced users. Experienced users showed a statistically significant lower CR than nonexperienced users at mid-frequency bands for medium-level sounds and statistically significantly higher CR than nonexperienced HA users at mid-frequency bands for loud sounds using DSL.

In a systematic evidence-based review by Convery *et al.* [44], of gain preference over time, there was only a slight (2 dB) difference in gain preferences between new and experienced HA users.

Keidser *et al.* [45] found that new HAs users preferred 2.7 dB less gain relative to the NAL-NL1 target than did experienced HAs users. They also found that the overall gain relative to the target was independent of the degree of hearing loss among experienced HA users. Keidser and Dillon [24] in a review of five separate studies involving 189 patients, compared the NAL-NL1 prescribed gain to the preferred gain for a 65 dB input speech signal. Although half (49%) of the patients preferred the NAL-NL1 prescribed gain (± 2 dB), 46% of the patients preferred less gain. They noted that preferred gain appears to be influenced by HA experience and sex.

Keidser *et al.* [46], in a study of 21 experienced HA users with a moderate severe to profound hearing loss, found that NAL-NL2 prescribes lower CRs ratios (or higher compression threshold) than prescribed by NAL-NL1 for patients with severe to profound hearing loss, which was preferred by patients. They reported that these listeners preferred lower CRs than would intuitively be prescribed or would be prescribed by many generic and proprietary fitting methods such as DSL [I/O], NAL-NL1, FIG6, or IHAFF, especially in the low frequencies and especially in patients with a severe or profound hearing loss. Consequently, for severe to profound hearing losses, the CR is constrained to be less than 3 : 1 in the high frequencies and less than 2 : 1 in the low frequencies.

Keidser *et al.* [47] reported that the clinical manifestation of auditory plasticity is sometimes associated with acclimatization to amplification; experienced HA wearers have been shown to prefer more gain than individuals receiving their first HAs. The difference between the two groups increases from 0 dB for mild hearing losses up to around 10 dB for severe hearing losses. On average, the overall preferred gain was 3 dB lower for new users and increases were noted at subsequent appointments. By the time of the final appointment, new users reported higher gain settings than they did before, but did not reach the preferred levels of experienced users. This suggests that the gain acclimatization process for some users may continue beyond the 13-month point. The degree of hearing loss had a significant effect, as patients with moderate hearing loss preferred 6 dB lower overall gain than those with mild hearing loss. Many authors have studied acclimatization to amplification in the preferred gain for new and experienced users [48–50]. Munro and Lutman [51] suggested that acclimatization may occur specifically in relation to high-level, high-frequency sounds.

Keidser *et al.* [52] found that new and experienced users preferred the high-frequency cut (HFC) program most often. Initially, about 60% of the new users preferred the HFC program, but by 13 months after fitting, the preferences of new and experienced users were very similar to approximately half of the patients still preferring the HFC program. Fewer than 10% of the users preferred the low-frequency cut program across the duration of the study. Initially, high-frequency gain in particular may need to be reduced relative to target settings. However, care should be taken to determine each individual's comfort with high-frequency sounds. They reported that because it appears that the acclimatization process may continue beyond a year, follow-up care after the initial trial period should be planned accordingly. It may be appropriate to schedule check-ups at 4, 8, and 12 months after fitting. In this way, the final target settings can be approached systematically for each individual [52]. However, Smeds *et al.* [53,54] have found no statistically significant difference in preferred gain deviations from NAL-NL1between new and experienced HA users.

Functional performance of men versus women in real life and speech intelligibility tests using the three different HA fitting formulae

In the current study, there was no sex difference, using any of the three different HA fitting formulae, with respect to the ASFT at any frequency, the CR, or the APHAB scores or the benefit in the global APHAB score and scores of the subscales, or with respect to the distribution of the degrees of change in the needs reported by the COSI questionnaire. Using the GHABP questionnaire, we found that women showed statistically significant more HA use than men with DSL.

Keidser and Dillon [24] have reported that NAL-NL2 prescribes relatively less gain (about 2 dB) for female HAs users irrespective of the degree of hearing loss and experience than male HAs users, which was preferred by female patients.

Conclusion

(1) The three formulae have significantly improved speech discrimination in adults, with no differences among them either in quiet or in noise.
(2) The SPIN test correlated well with real-life speech communication in noise reflected on the APHAB BN subscale score.
(3) On assessment with the APHAB questionnaire, the three formulae have significantly improved speech communication in real life, with BERNAFIT and NAL showing similar benefit that was significantly greater than DSL.
(4) However, aversiveness to environmental sounds was increased with the use of all three formulae, mostly by DSL.
(5) There were no differences among the three formulae in the final ability with amplification assessed by the COSI questionnaire in the priority-reported needs, although BERNAFIT and NAL yielded statistically significantly higher percentages of better and much better degrees of change compared with DSL.
(6) On assessment with the GHABP questionnaire, BERNAFIT showed the statistically significantly greatest percentage of HA use, benefit, satisfaction, and derived benefit and the least residual disability, followed by NAL and DSL.

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Conflicts of interest

The authors have the following perceived conflict of interest: Hearing aids included in this study were bought from the hearing aid dispenser with a financial donation that was offered by a benefactor who is unrelated to the dispensing company. A single hearing aid was given to each patient (monaural fitting) -due to the limited amount of money donated.

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