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RESEARCH ARTICLE

The comparison of gains prescribed for digital behind-the-ear hearing aids using the manufacturer-specific and conventional prescriptive formulas

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Abstract

Background and Aim: There are several prescriptive formulas for covering a variety of hearing loss, each of which applies relatively different amplifications at different frequencies. This study aims to compare the gains prescribed for digital behind-the-ear (BTE) hearing aids by the Desired Sensation Level Multi-Stage [Input/Output] (DSLm[I/O]), National Acoustic Laboratories-non linear2 (NAL-NL2) and manufacturer-specific formulas at different levels of input intensity.

Methods: The gain values in 12-channel BTE hearing aids prepared from four companies (Oticon, Phonak, ReSound and Siemens) were measured at three levels of input intensity (45, 65, and 85 dB SPL) and at a frequency range of 250−8000 Hz for two moderately severe flat and mild sloping to severe hearing losses by using the DSLm[I/O], NAL-NL2 and manufacturer-specific formulas in the Frye FP35 test box.

Results: There was no significant difference between the four selected hearing aids in terms of prescribed gain values using the prescriptive formulas ($p > 0.05$).

Conclusion: The DSLm[I/O] formula prescribes higher gain in the 12-channel BTE hearing aids from Oticon, Phonak and Siemens companies at all input intensities and frequencies for moderately severe flat and mild sloping to severe hearing losses compared to the NAL-NL2 formula and manufacturer-specific formulas (Voice Aligned Compression (VAC), Adaptive Phonak, Connexx Fit and audiogram+).

Keywords: National acoustic laboratories-non linear2; desired sensation level multi-stage [input/output]; gain; frequency; intensity levels

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Introduction

Until the early 1990s, hearing aids provided equal gains at different inputs with different intensity levels. The gain prescription methods are divided into two categories: threshold and loudness based methods. The prescribed gain is reduced by increasing the input intensity [1]. Gain prescription rules have always included a specific formula. When a prescription method is selected, the prescribed gain should also be calculated. These formulas are used by the

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hearing aid manufacturers in hearing aid applications. Most of these companies allow a clinical specialist to choose their own formulas [2]. The gain prescription formula provided by the National Acoustic Laboratories (NAL) was first introduced in 1976. The goal of this method is to unify the loudness perception in speech bands, leading to the highest level of speech perception [1,3,4].The desired sensation level (DSL) prescriptive formula aims to help simply receive the speech signal (target signal) at different frequencies [2,5]. If linear amplification and inappropriate nonlinear prescription formulas are used for a person with hearing loss, it can make worse the hearing loss due to amplification. This is very important in children [6]. In Jenstad's study on the comparison of NAL-non linear1 (NAL-NL1), NAL-nonlinear2 (NAL-NL2), desired sensation level (DSL) version 4 [Input/ Output] (DSLv4[I/O]) and the DSL Multi-stage [Input/Output] (DSLm[I/O]), the results showed that the NAL formula prescribed lower overall gain compared to the DSL formula [7]. A study reported that the DSLm[I/O] formula, compared to the NAL-NL2 formula, leads to temporary hearing threshold changes and eventually permanent hearing loss by increasing the hearing loss rate at moderate-to-high and high levels of input intensity [8]. In children, the DSLm[I/O] formula focuses more on the ability to hear high frequencies, while the NAL-NL2 formula emphasizes the clarity of speech. In adults, both of these formulas provide similar ability to hear high frequencies [9]. When hearing aids provide poor hearing ability for children, it can cause impaired communication and academic failure. The DSL[I/O] formula prescribes higher gain than the NAL formula. It also provides more amplification for severe-to-profound hearing loss [10]. The NAL-NL2 formula provides better speech clarity at the medium and high levels of input intensity compared to the DSLm[I/O] formula; that is, when we choose the NAL-NL2 formula by increasing the input intensity level, the patient's speech perception is improved [11]. In the phenomenon of reduced cochlear hearing desensitization which occurs due to a sharp drop in the gain at high frequencies, with the increase in amplification instead of improved speech comprehension and enhanced sound quality, speech perception and sound quality are deteriorated and the patient feels discomfort and annoyed; hence, by reducing the amplification rate at high frequencies, the person's speech perception and sound quality improve [12,13]. Experimental studies have shown that women prefer lower overall gain than men, and the new hearing aid users prefer lower gain compared to the experienced hearing aid users [1]. The NAL-NL2 formula provides higher output and gain at low and high frequencies compared to the NAL-NL1 formula, but prescribes lower gain at mid frequencies [1]. Early adjustment of hearing aids in children is usually based on the formulas such as NAL-NL2 and DSL[I/O]. The NAL-NL2 formula is based on hearing thresholds and prescribes gain based on the audiogram. The DSL[I/O] formula is based on the assessment of loudness levels; however, since the results of loudness assessment in children are not valid and stable, this method also uses hearing thresholds to prescribe gains [14]. Comparing the gain estimated by a group of prescriptive formulas in 237 hearing-impaired adults, the results of a study showed that in mild-to-moderate hearing loss, the gain prescribed by the DSLm[I/O] formula was higher compared to the NAL-NL2 formula at all frequencies, and the gains prescribed by these two methods at mid and high frequencies become almost equal with the increase of hearing loss [15]. Furthermore, hearing aids' gains for real life stimuli such as speech and music are considerably different from those for signals such as sound and noise. The difference depends on the number of factors such as hearing aid channels, compression ratio, and compression thresholds [16,17] as well as features like noise reduction or feedback cancellation. The aim of the current study was to determine the gain of hearing aids at different octave and half-octave frequencies (250−8000 Hz) and at three input intensity levels (low, mid and high) for the moderately severe flat and mild sloping to severe hearing loss, and to reduce the hearing loss by using three prescriptive formulas (NAL-NL2, DSLm[I/O], and manufacturer s'-specific formula).

Methods

First, two 12-channel behind-the-ear (BTE) hearing aids were prepared from the four companies (Oticon, Phonak, ReSound, and Siemens). The hearing aid fitting software included Oticon Genie2 2016 (For OPN3+ and NERA2models), Phonak Target v.6 (For BOLERO B90-PR and BOLERO B50-SP models), ReSound Smart Fit (For ENZO 3D5 and LINX 3D5 models), and Siemens Connexx 8.2(For INTUS 2M and INTUS 2SP models). To select the hearing aids' model from each company, three conditions were determined: availability, newness, and meeting the inclusion criteria. The hearing aids could cover moderately severe hearing loss. After selecting and preparing the hearing aids, each hearing aid was initially adjusted using the related software according to the DSLm[I/O] and NAL-NL2 formulas and based on the audiogram thresholds for moderately severe flat and mild sloping to severe hearing losses. After adjustment of each hearing aid, they were placed in the FP35 test box (Frye Electronics Inc., USA) where they were attached to the hearing aid coupler2. In order to accurately determine the frequency of gain, the gain value of the hearing aids using the speech stimulus for 45, 65 and 85 dB SPL inputs (which are the criteria for mild, medium and high level sounds) was set at 250 to 8000 Hz depending on the octave and half-octave frequencies (low frequencies: 250, 500, 750 Hz; mid frequencies: 1000, 2000 Hz; high frequencies: 3000, 4000, 6000, 8000 Hz). This operation was performed three more times consecutively and then the final result was recorded. Then, the hearing aids were adjusted using the specific formula provided by each manufacturer and analyzed in the test box and, finally, its results were compared with those of other two formulas. The way that the hearing aids were placed in the test box was similar to that of conventional BTE hearing aids. The selected hearing aids' microphone was in omnidirectional mode. In order to prevent unwanted changes, the volume control, program selection key, and all adaptive circuits such as feedback management and noise reduction systems in hearing aids were deactivated. Age, gender, and hearing aid use in all applications were set as 27 years, male, and inexperienced, respectively. Data analysis was performed in SPSS version 17 software, considering a significance level at $p < 0.05$. In this regard, after confirming the normality of data distribution by using Kolmogorov-Smirnov test, we used ANOVA and Tukey's post hoc test to examine the difference between the results.

Results

The gain values of different hearing aids obtained by the FP35 text box are presented in Tables 1 to 4, which shows the comparison results of gains prescribed by three formulas under the same conditions. The prescriptive formula provided by each manufacturer had lower gains than the other two conventional prescriptive formulas. The DSLm[I/O] formula in ReSound hearing aids reported lower gain than the NAL-NL2 and audiogram+ formula results for moderately severe flat and mild sloping to severe hearing losses. The results of ANOVA showed no significant statistical difference in gain between the four types of hearing aids regarding the hearing loss severity, conventional formulas, and the manufacturer-specific formulas (Voice Aligned Compression (VAC) for Oticon Company, Adaptive Phonak for Phonak Company, Connexx Fit for Siemens Company, and audiogram+ formula for ReSound Company) ($p > 0.05$). However, the difference in gain within the formulas mentioned was significant in terms of input intensity ($p < 0.05$).

In Oticon hearing aids according to the results of ANOVA presented in Table 1, the DSLm[I/O] prescriptive formula provided higher gain than the other two formulas (NAL-NL2 and the manufacturer-specific formula) at low and mid frequencies (250−2000 Hz) and at all three intensity levels (45, 65 and 85 dB SPL) for the moderately severe flat hearing loss. For the mild sloping to severe hearing loss, the DSLm[I/O] formula prescribed higher gain at all frequencies only at the intensity levels of 65 and 85 dB SPL.

In Phonak hearing aids, the DSLm[I/O] formula also provided higher gain than the other two formulas (NAL-NL2 and the manufacturer-specific formula) for the mild-to-severe flat hearing loss

Table 1. The average frequency gain of the Oticon 12-channel behind the ear hearing aids in desired sensation level multi-stage [input/output], national acoustic laboratories-non linear2 and voice aligned compression+ prescription formulas, hearing loss and the same intensity level in the frequencies range 250 to 8000 Hz

Hearing loss	Intensity level (dB SPL)	Prescription formulas	Frequency (Hz)								
			250	500	750	1000	2000	3000	4000	6000	8000
Moderately severe flat											
	45	**NAL-NL2 (SD)**	13.75 (2.47)	9.70 (13.15)	11.25 (13.78)	14.20 (12.44)	13.00 (13.31)	13.50 (10.60)	14.70 (7.07)	16.50 (10.60)	9.00 (2.82)
		DSLm[I/O] (SD)	19.40 (5.09)	18.50 (13.43)	13.90 (18.52)	17.70 (18.80)	14.70 (12.72)	13.50 (12.02)	17.30 (12.72)	14.50 (12.02)	4.50 (0.70)
		VAC+ (SD)	19.75 (6.01)	15.30 (19.79)	14.50 (19.09)	15.30 (15.13)	14.50 (13.43)	10.20 (13.85)	12.00 (7.07)	9.50 (4.94)	2.50 (2.12)
	65	**NAL-NL2 (SD)**	8.05 (2.89)	5.90 (7.21)	7.30 (8.06)	9.65 (6.15)	7.00 (2.82)	6.50 (3.53)	7.85 (0.70)	9.70 (4.24)	3.00 (2.82)
		DSLm[I/O] (SD)	16.45 (6.43)	14.70 (11.31)	11.75 (14.49)	13.85 (14.35)	13.30 (11.31)	13.00 (12.72)	12.70 (7.07)	13.50 (9.89)	3.00 (1.41)
		VAC+ (SD)	13.80 (3.11)	10.20 (13.85)	9.85 (12.94)	12.40 (10.74)	10.50 (9.19)	6.45 (7.48)	7.50 (2.12)	6.00 (1.41)	−1.50 (6.36)
	85	**NAL-NL2 (SD)**	1.65 (2.33)	0.15 (0.21)	0.40 (0.56)	1.95 (1.34)	0.00 (5.65)	0.00 (4.24)	1.30 (7.07)	3.00 (2.82)	−3.50 (9.19)
		DSLm[I/O] (SD)	7.50 (6.36)	8.30 (8.48)	8.45 (8.48)	9.40 (9.33)	9.00 (7.07)	8.50 (7.77)	7.30 (2.82)	5.40 (4.24)	−3.50 (6.36)
		VAC+ (SD)	6.70 (3.25)	7.10 (8.34)	6.35 (6.75)	7.50 (6.36)	4.25 (5.30)	6.45 (7.84)	3.50 (2.12)	2.50 (2.12)	−5.00 (9.89)
Mild sloping to severe											
	45	**NAL-NL2 (SD)**	8.35 (10.39)	3.00 (2.82)	5.35 (6.75)	9.80 (7.35)	13.50 (12.02)	16.00 (14.14)	16.30 (12.72)	16.50 (14.84)	7.50 (3.53)
		DSLm[I/O] (SD)	7.75 (8.13)	6.50 (4.94)	7.00 (7.07)	9.75 (8.83)	15.00 (9.98)	15.50 (12.02)	17.00 (11.31)	15.50 (14/48)	6.10 (2.82)
		VAC+ (SD)	9.95 (7.00)	6.50 (6.36)	7.50 (7.77)	11.65 (10.39)	14.30 (12.02)	14.45 (10.60)	16.50 (7.77)	13.30 (10.60)	7.00 (2.82)
	65	**NAL-NL2 (SD)**	6.70 (6.64)	0.50 (0.70)	2.30 (0.98)	5.60 (1.97)	7.50 (4.94)	9.70 (7.07)	10.00 (5.65)	10.50 (9.19)	2.00 (1.41)
		DSLm[I/O] (SD)	5.58 (5.44)	5.50 (4.94)	5.30 (6.36)	7.65 (6.15)	12.85 (8.48)	14.50 (12.02)	13.45 (9.19)	13.40 (13.43)	4.50 (2.12)
		VAC+ (SD)	6.70 (5.65)	3.50 (3.53)	3.25 (3.88)	7.05 (4.17)	10.50 (7.77)	10.70 (7.07)	12.00 (4.24)	11.55 (9.19)	2.30 (2.82)
	85	**NAL-NL2 (SD)**	2.10 (1.55)	0.00 (1.41)	-0.15 (2.61)	0.90 (2.68)	1.70 (2.83)	3.30 (0.70)	2.50 (0.70)	4.00 (1.41)	−4.30 (8.48)
		DSLm[I/O] (SD)	2.95 (0.07)	4.50 (4.94)	3.75 (4.59)	4.80 (4.52)	8.50 (4.94)	9.00 (7.07)	8.30 (4.24)	9.50 (10.60)	−3.50 (6.36)
		VAC+ (SD)	4.10 (2.96)	1.75 (1.76)	1.15 (1.20)	3.40 (0.84)	4.50 (2.12)	11.30 (7.07)	6.50 (2.12)	7.00 (5.65)	−2.50 (6.36)

NAL-NL2; national acoustic laboratories-non linear2, DSLm[I/O]; desired sensation level multi-stage [Input/Output], VAC+; voice aligned compression

Table 2. Average frequency gain of the Phonak 12-channel behind the ear hearing aids in desired sensation level multi-stage [input/output], national acoustic laboratories-non linear2 and Phonak adaptive prescription formulas, hearing loss and the same intensity level in the frequencies range 250 to 8000 Hz

Hearing loss	Intensity level (dB SPL)	Prescription formulas	Frequency (Hz)								
			250	500	750	1000	2000	3000	4000	6000	8000
Moderately severe flat											
	45	**NAL-NL2 (SD)**	12.00 (12.72)	22.70 (7.07)	29.50 (2.12)	32.50 (0.63)	34.00 (0.70)	33.30 (0.72)	33.30 (0.59)	33.00 (1.41)	25.50 (2.12)
		DSLm[I/O] (SD)	21.00 (7.07)	26.50 (0.70)	26.30 (0.63)	28.50 (0.67)	29.00 (0.69)	28.10 (0.59)	29.00 (1.41)	29.50 (2.12)	20.00 (4.24)
		Phonak adaptive (SD)	9.00 (11.31)	15.30 (7.07)	19.70 (1.41)	21.80 (0.69)	23.50 (0.74)	23.70 (0.67)	22.00 (1.41)	17.50 (0.72)	16.30 (0.70)
	65	**NAL-NL2 (SD)**	8.00 (11.31)	14.70 (7.07)	20.50 (2.12)	23.30 (0.70)	24.30 (0.67)	24.50 (0.68)	25.00 (1.41)	25.50 (2.12)	25.30 (2.12)
		DSLm[I/O] (SD)	17.00 (7.07)	23.85 (0.63)	24.30 (0.70)	24.70 (0.70)	25.35 (0.74)	25.45 (0.67)	26.25 (1.41)	26.55 (2.12)	19.45 (4.94)
		Phonak adaptive (SD)	6.30 (8.48)	10.00 (7.07)	15.35 (1.41)	16.75 (0.69)	18.25 (0.74)	18.50 (0.73)	17.00 (1.41)	14.45 (0.64)	15.50 (1.41)
	85	**NAL-NL2 (SD)**	3.30 (4.24)	4.50 (6.36)	9.50 (2.12)	12.30 (0.70)	14.50 (0.61)	15.30 (0.71)	16.00 (1.41)	16.50 (2.12)	21.00 (1.41)
		DSLm[I/O] (SD)	13.70 (7.07)	19.50 (0.70)	18.50 (0.67)	19.30 (0.69)	18.85 (0.74)	19.75 (0.80)	20.15 (1.41)	20.50 (2.12)	19.00 (4.24)
		Phonak adaptive (SD)	3.50 (4.94)	5.00 (7.07)	9.50 (2.12)	11.75 (0.67)	12.65 (0.68)	12.45 (0.72)	11.30 (1.41)	8.60 (0.68)	9.35 (1.41)
Mild sloping to severe											
	45	**NAL-NL2 (SD)**	1.00 (1.41)	3.50 (6.36)	11.45 (3.53)	19.55 (0.70)	29.75 (0.74)	33.50 (0.70)	34.45 (1.41)	33.75 (0.69)	31.50 (0.72)
		DSLm[I/O] (SD)	−0.50 (0.70)	5.50 (0.70)	9.45 (0.68)	14.75 (0.72)	25.65 (0.74)	29.85 (0.72)	32.00 (1.41)	33.95 (1.41)	29.49 (0.69)
		Phonak adaptive (SD)	1.00 (1.41)	4.20 (7.07)	10.50 (3.53)	15.45 (0.70)	21.25 (0.68)	24.45 (0.69)	24.10 (2.82)	22.50 (2.12)	20.40 (0.71)
	65	**NAL-NL2 (SD)**	−1.00 (1.41)	1.30 (2.82)	6.50 (3.53)	13.45 (0.70)	23.35 (0.72)	26.75 (0.68)	27.50 (2.12)	29.47 (2.12)	31.48 (0.67)
		DSLm[I/O] (SD)	−0.50 (0.70)	5.30 (0.72)	8.45 (0.67)	12.60 (0.66)	22.55 (0.72)	28.47 (0.71)	34.00 (5.65)	32.50 (2.12)	29.49 (0.69)
		Phonak adaptive (SD)	0.50 (0.70)	2.45 (4.94)	6.85 (2.82)	11.43 (0.71)	17.45 (0.69)	19.50 (0.70)	19.25 (10.41)	19.40 (2.12)	20.75 (0.72)
	85	**NAL-NL2 (SD)**	−2.00 (2.82)	−0.70 (0.70)	1.30 (2.12)	6.50 (0.70)	13.75 (0.71)	16.60 (0.67)	17.55 (2.12)	20.25 (1.41)	25.65 (0.64)
		DSLm[I/O] (SD)	−0.50 (0.70)	5.30 (0.71)	7.45 (0.68)	9.65 (0.69)	13.50 (3.53)	20.48 (0.72)	22.35 (1.41)	25.00 (2.82)	25.45 (0.72)
		Phonak adaptive (SD)	0.00 (0.00)	1.45 (3.53)	3.45 (3.53)	7.48 (0.70)	11.50 (0.68)	13.75 (0.67)	13.00 (1.41)	13.50 (2.12)	15.80 (0.72)

NAL-NL2; national acoustic laboratories-non linear2, DSLm[I/O]; desired sensation level multi-stage [input/output]

Table 3. Average frequency gain of the Resound 12-channel behind the ear hearing aids in desired sensation level multi-stage [input/output], national acoustic laboratories-non linear2 and audiogram+ prescription formulas, hearing loss and the same intensity level in the frequencies range 250 to 8000 Hz

Hearing loss	Intensity level (dB SPL)	Prescription formulas	Frequency (Hz)								
			250	500	750	1000	2000	3000	4000	6000	8000
Moderately severe flat											
	45	**NAL-NL2 (SD)**	21.60 (12.58)	19.15 (1.76)	27.55 (0.91)	23.60 (0.42)	23.80 (6.08)	28.60 (1.69)	14.50 (2.12)	5.00 (1.41)	44.30 (0.70)
		DSLm[I/O] (SD)	28.90 (0.42)	12.85 (0.91)	26.60 (0.84)	22.35 (0.49)	18.90 (1.27)	26.40 (1.97)	13.90 (1.97)	8.30 (3.25)	7.00 (2.82)
		Audiogram+ (SD)	30.80 (0.70)	20.75 (1.48)	27.65 (0.63)	24.55 (0.49)	20.85 (3.18)	27.35 (3.60)	14.05 (3.04)	6.95 (2.61)	6.00 (1.41)
	65	**NAL-NL2 (SD)**	26.20 (1.27)	15.90 (1.55)	21.10 (2.26)	15.45 (2.89)	11.70 (1.83)	19.00 (1.13)	5.30 (0.70)	2.60 (0.56)	2.50 (0.70)
		DSLm[I/O] (SD)	23.30 (0.56)	12.85 (0.91)	17.35 (0.49)	11.80 (0.28)	9.70 (0.98)	17.70 (1.69)	4.70 (2.12)	3.80 (1.69)	5.50 (2.12)
		Audiogram+ (SD)	24.85 (0.91)	14.70 (1.27)	18.70 (0.70)	13.70 (0.42)	12.30 (1.41)	18.60 (3.39)	5.40 (2.96)	5.75 (1.44)	3.70 (1.41)
	85	**NAL-NL2 (SD)**	9.75 (1.34)	9.70 (2.82)	13.10 (3.81)	6.25 (4.87)	3.50 (3.25)	11.75 (2.47)	3.35 (0.70)	1.45 (0.69)	1.55 (0.72)
		DSLm[I/O] (SD)	8.85 (0.42)	5.85 (1.06)	8.25 (0.63)	0.85 (0.21)	4.50 (4.49)	9.40 (1.83)	4.30 (1.43)	2.70 (1.41)	4.45 (1.41)
		Audiogram+ (SD)	9.05 (0.21)	7.85 (1.48)	9.70 (0.70)	2.85 (0.49)	2.35 (2.05)	10.55 (3.18)	3.70 (2.82)	4.50 (0.72)	3.30 (1.41)
Mild sloping to severe											
	45	**NAL-NL2 (SD)**	32.60 (0.14)	21.25 (0.63)	28.65 (0.21)	24.50 (0.42)	19.70 (1.69)	28.30 (1.83)	14.75 (1.76)	6.90 (4.38)	6.50 (3.53)
		DSLm[I/O] (SD)	32.65 (0.21)	17.10 (0.14)	28.50 (0.28)	24.35 (0.07)	20.70 (1.83)	28.10 (2.68)	14.50 (2.12)	6.80 (4.52)	6.00 (2.82)
		Audiogram+ (SD)	31.70 (0.70)	19.75 (0.49)	24.60 (3.95)	23.85 (1.20)	17.45 (0.77)	24.80 (0.42)	11.30 (0.42)	5.75 (4.87)	8.70 (4.24)
	65	**NAL-NL2 (SD)**	27.05 (0.63)	17.10 (0.14)	21.95 (0.63)	16.60 (0.14)	13.55 (1.62)	22.30 (1.13)	7.90 (1.69)	3.60 (0.84)	5.00 (4.24)
		DSLm[I/O] (SD)	26.90 (0.70)	17.10 (0.14)	21.80 (0.42)	16.50 (0.28)	13.90 (1.41)	21.70 (1.83)	7.75 (1.76)	3.65 (0.91)	2.30 (0.70)
		Audiogram+ (SD)	26.35 (0.20)	15.95 (0.21)	21.35 (0.49)	16.25 (0.77)	11.85 (0.77)	18.60 (0.28)	4.85 (0.35)	3.25 (0.35)	2.70 (1.41)
	85	**NAL-NL2 (SD)**	9.70 (0.84)	11.75 (0.21)	15.05 (0.63)	8.85 (0.21)	6.30 (1.41)	15.25 (1.20)	1.60 (1.69)	2.50 (0.69)	1.50 (0.70)
		DSLm[I/O] (SD)	9.55 (0.63)	11.95 (0.21)	14.85 (0.49)	8.10 (0.70)	6.50 (1.55)	15.35 (1.20)	1.75 (1.76)	1.45 (0.72)	0.30 (0.70)
		Audiogram+ (SD)	9.90 (0.14)	10.75 (0.07)	14.50 (0.42)	8.10 (0.84)	4.45 (0.49)	12.35 (0.07)	3.45 (0.72)	1.30 (0.69)	0.40 (0.72)

NAL-NL2; national acoustic laboratories-non linear2, DSLm[I/O]; desired sensation level multi-stage [input/output]

Table 4. Average frequency gain of the Siemens 12-channel behind the ear hearing aids in desired sensation level multi-stage [input/output], national acoustic laboratories-non linear2 and Connexx fit prescription formulas, hearing loss and the same intensity level in the frequencies range 250 to 8000 Hz

Hearing loss	Intensity level (dB SPL)	Prescription formulas	Frequency (Hz)								
			250	500	750	1000	2000	3000	4000	6000	8000
Moderately severe flat											
	45	**NAL-NL2 (SD)**	20.50 (3.53)	23.45 (4.94)	25.40 (6.36)	27.50 (6.36)	27.25 (8.48)	26.70 (5.65)	26.30 (11.31)	33.48 (6.36)	34.00 (7.07)
		DSLm[I/O] (SD)	29.30 (0.70)	29.45 (0.68)	29.50 (0.67)	30.35 (0.70)	29.75 (0.72)	30.45 (0.71)	29.60 (0.69)	34.40 (0.72)	39.65 (0.67)
		Connex Fit (SD)	11.00 (1.41)	22.50 (3.53)	24.85 (5.65)	31.45 (3.53)	30.50 (3.53)	28.40 (2.12)	25.00 (4.24)	23.25 (4.24)	12.50 (3.53)
	65	**NAL-NL2 (SD)**	14.35 (5.65)	14.85 (7.07)	19.45 (2.12)	20.25 (2.82)	21.30 (3.53)	21.00 (2.82)	24.47 (6.36)	24.85 (7.07)	28.00 (8.48)
		DSLm[I/O] (SD)	27.35 (0.67)	27.45 (0.70)	28.45 (0.72)	29.75 (0.70)	29.55 (0.67)	30.25 (0.69)	29.50 (0.72)	33.85 (0.68)	37.70 (0.73)
		Connex Fit (SD)	9.00 (1.41)	15.50 (4.94)	19.45 (2.12)	24.85 (7.07)	24.35 (4.94)	22.55 (3.53)	19.00 (1.41)	21.70 (2.82)	12.30 (3.53)
	85	**NAL-NL2 (SD)**	4.00 (5.65)	3.85 (5.65)	6.25 (4.24)	9.45 (3.53)	13.00 (5.65)	11.75 (4.24)	14.30 (5.65)	15.40 (6.36)	18.45 (9.19)
		DSLm[I/O] (SD)	19.50 (0.70)	19.75 (0.69)	20.35 (0.72)	22.45 (0.70)	22.30 (2.12)	24.00 (1.41)	22.85 (1.41)	27.25 (0.67)	30.45 (0.68)
		Connex Fit (SD)	7.00 (1.41)	9.30 (1.41)	14.50 (4.94)	18.45 (2.12)	17.85 (2.82)	12.50 (3.53)	14.35 (3.53)	19.75 (2.82)	12.45 (3.53)
Mild sloping to severe											
	45	**NAL-NL2 (SD)**	4.50 (3.53)	5.00 (2.82)	11.30 (1.41)	19.45 (0.70)	28.75 (1.41)	31.85 (2.82)	34.00 (2.82)	33.50 (2.12)	32.00 (2.82)
		DSLm[I/O] (SD)	2.30 (3.53)	5.50 (0.70)	10.70 (1.41)	15.00 (4.24)	29.75 (0.70)	31.85 (0.72)	33.45 (0.69)	41.50 (0.68)	46.00 (5.65)
		Connex Fit (SD)	2.50 (3.53)	5.00 (2.82)	10.75 (1.41)	19.45 (2.12)	24.30 (4.94)	23.00 (4.24)	19.35 (2.12)	18.40 (2.12)	7.50 (3.53)
	65	**NAL-NL2 (SD)**	−1.00 (1.41)	2.50 (3.53)	5.30 (4.24)	10.75 (1.41)	21.45 (2.12)	26.30 (2.82)	28.55 (2.12)	28.45 (2.12)	29.35 (0.70)
		DSLm[I/O] (SD)	2.50 (3.53)	9.30 (0.70)	9.75 (0.68)	13.00 (2.82)	28.45 (0.71)	31.50 (0.69)	33.75 (0.72)	41.35 (0.67)	43.45 (2.12)
		Connex Fit (SD)	2.30 (3.53)	2.50 (3.53)	9.00 (1.41)	14.45 (4.94)	22.70 (4.24)	22.00 (4.24)	18.35 (2.12)	18.45 (2.12)	7.50 (3.53)
	85	**NAL-NL2 (SD)**	2.50 (3.53)	2.30 (3.53)	3.00 (4.24)	5.30 (4.24)	11.75 (2.82)	15.45 (0.70)	19.50 (0.68)	20.45 (0.71)	21.00 (1.41)
		DSLm[I/O] (SD)	2.50 (3.53)	9.75 (0.70)	8.45 (0.70)	11.00 (1.41)	21.35 (2.12)	27.50 (0.72)	29.45 (0.68)	33.50 (2.12)	39.45 (0.73)
		Connex Fit (SD)	2.50 (3.53)	1.70 (2.82)	3.30 (4.24)	8.50 (0.70)	16.00 (5.65)	14.50 (4.94)	18.35 (2.12)	18.45 (2.12)	7.50 (3.53)

NAL-NL2; national acoustic laboratories-non linear2, DSLm[I/O]; desired sensation level multi-stage [input/output]

at low frequency (250−750 Hz) and at all three intensity levels. It cannot be said that the DSLm[I/O] formula is superior to the NAL-NL2 formula at all intensity levels and frequencies; however, the Adaptive Phonak formula by Phonak company considered lower gains than the two standard prescriptive formulas at two intensity levels (45 and 65 dB SPL) and within the overall frequency range (250−8000 Hz). For the mild sloping to severe hearing loss, the DSLm[I/O] formula generally provided higher gain than the other two formulas at all frequencies only at the intensity levels of 65 and 85 dB SPL (Table 2).

In ReSound hearing aids, audiogram+ formula prescribed higher gain than the DSLm[I/O] and NAL-NL2 formulas at all intensity levels and at low and high frequencies for the moderately severe flat hearing loss. For the mild sloping to severe hearing loss, the NAL-NL2 formula showed higher gain than the DSLm[I/O] and audiogram+ formula at all intensity levels and at low and high frequencies (Table 3).

In Siemens hearing aids, the DSLm[I/O] formula provided higher gain than the other two formulas (NAL-NL2 and the manufacturer-specific formula) for the moderately severe flat hearing loss at low and high frequencies and at all intensity levels. For the mild sloping to severe hearing loss, the DSLm[I/O] formula prescribed higher gain than the other two formulas at all intensity levels but only at high frequency (3000−8000 Hz) (Table 4).

Discussion

The purpose of this study was to compare the gain in digital BTE hearing aids prescribed by the manufacturer and by the DSLm[I/O] and NAL-NL2 formulas. For this purpose, speech stimulus at intensity levels of 45, 65 and 85 dB SPL for moderately severe flat and mild sloping to severe hearing losses was performed. Each formula yielded different gains at low, mid, and high frequencies. When fitting a hearing aid, it is important to choose the prescribed formula carefully so that the hearing aids become suitable to the patients and do not worsen the hearing loss due to amplification. Statistical analysis showed no significant differences between the prescriptive formulas of hearing aids used by the manufacturer ($p > 0.05$), but the difference in gain within the manufacturer-specific formulas was significant based on the input intensity ($p < 0.05$). We found out the manufacturer-specific formulas provided more gain than the two NAL-NL2 and DSLm[I/O] formulas under same conditions; Oticon Company’s formula for the mild sloping to severe hearing loss at low and mid frequencies (250−2000 Hz) and only at the intensity level of 45 dB SPL; ReSound Company’s formula for the moderately severe flat hearing loss at low and high frequencies and at all three intensity levels (45, 65 and 85 dB SPL); Siemens Company’s formula for the moderately severe flat hearing loss at mid frequency and only at the intensity level of 45 dB SPL, and Phonak Company’s formula for the moderately severe flat hearing loss at low input intensity (65 dB SPL) and low frequency.

For the moderately severe flat hearing loss, the DSLm[I/O] formula applied higher gain than the NAL-NL2 formula in Siemens and Oticon hearing aids with the same level of input intensity and at low and high frequencies, and in Resound hearing aids at an input intensity of 65 dB SPL and at high frequency, which is similar to the results of Jenstad [7]. For the severe hearing loss, the DSLm[I/O] formula prescribed higher gain than the NAL-NL2 formula in the Oticon, Phonak, and Siemens hearing aids at an input intensity level of 65 dB SPL and at high frequency which is consistent with the results of Jenstad [7]. According to our results, the prescriptive formulas at different frequency ranges reported different prescribed gains. Choosing an appropriate prescriptive formula for the hearing aids in children is very important. In children where the exact hearing threshold level is not available, it is recommended to use the manufacturers' own prescriptive formula. Our results can help the audiologists choose the right prescriptive formula for hearing aids. This study was only applied on 12-channel BTE hearing aids from the Oticon, Phonak, ReSound and Siemens companies. The models from other companies may report different results.

Conclusion

The Desired Sensation Level Multi-Stage Input/ Output [DSLm[I/O] formula prescribes higher gain than the National Acoustic Laboratories-non linear2 (NAL-NL2) formula in Oticon, Phonak and Siemens hearing aids, but not in ReSound hearing aids. In these models, the manufacturers' own prescriptive formulas provides lower gain than the NAL-NL2 and DSLm[I/O] formulas. There is no significant difference in gain between the manufacturer-specific formulas, but the difference within them was significant. Audiologists should be careful in choosing the prescriptive formulas for hearing aids. In cases where the patient's exact hearing threshold is not available, the prescriptive formulas should be chosen with caution because presenting a higher gain may worsen the hearing loss due to amplification.

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Conflict of interest

There are no conflicts of interest.

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