

Original Article

Amplification Strategies to Reduce Tinnitus: A Paired Comparison Method

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Cite this article as: Narayan Shetty H, Basavaraj V. Amplification strategies to reduce tinnitus: A paired comparison method. *J Int Adv Otol*. 2022;18(1):8-13.**BACKGROUND:** The study investigates the best amplification strategy that provides tinnitus relief in a quiet environment, for individuals with sensorineural hearing loss with bothersome tinnitus.**METHODS:** The repeated measures research design was utilized. Twenty participants (age range 25 years to 65 years; mean: 48.28 years) with bilateral symmetrical sloping sensorineural hearing loss with bothersome unilateral tinnitus were recruited. They were sub-grouped into low- and high-pitched tinnitus groups. A preference score was obtained for each of the strategies in hearing aid fitting, using the paired comparison method. The 4 strategies used were the desired sensation level (input/output) and the National Acoustic Laboratories' nonlinear fitting method (version 1), at each of the low (30 dB SPL) and high (50 dB SPL) compression thresholds. Besides, the severity of tinnitus was assessed using the tinnitus severity index before and after 1 month of using the hearing aid in the best-selected strategy.**RESULTS:** A repeated-measure ANOVA revealed no significant effect of the group on the preference score but was significant for strategies on relief from tinnitus. The desired sensation level (input/output) at a low compression threshold was the best strategy for alleviating tinnitus. Thirty-five percent of the study participants preferred the desired sensation level (input/output) strategy at low and high compression threshold, respectively. The remaining 25% preferred the National Acoustic Laboratories' nonlinear hearing aid (version 1) at low compression threshold, and 5% selected the same device at high compression threshold. Furthermore, a significant association was observed in the severity of tinnitus before and after the hearing aid fitting set at the preferred program.**CONCLUSION:** The desired sensation level (input/output) method at the low compression threshold is the best program to alleviate bothersome tinnitus.**KEYWORDS:** Hearing aid, hearing loss, prescriptive formula, tinnitus

INTRODUCTION

Tinnitus is a perception of sound in the brain without any external stimulus.¹ Tinnitus is majorly associated with either unilateral or bilateral hearing loss.² Most patients describe tinnitus as ringing (38%), buzzing (11%), the sound of crickets (9%), and humming (5%).³ Older adults often complain of a ringing sensation, more than other age groups. Assessments of tinnitus pitch and loudness are the preliminary measures necessary to initiate any rehabilitation program. Tinnitus is more common in individuals with hearing loss. Thirunavukkarasu and Geetha⁴ reported that 97.5% of the individuals having tinnitus had hearing loss. Among 97.5% of tinnitus patients, a total of 23.7% had moderate to moderately severe degrees of hearing loss.

The use of a hearing aid is one of the management options available to improve audibility and also suppress tinnitus. Tinnitus is masked by the device amplifying ambient noise (low-intensity environmental sounds to audible levels), and low-level circuitry noise is amplified to an audible level. It reduces tinnitus audibility and improves the quality of life by reducing the secondary effects of tinnitus, such as anxiety, stress, and depression.⁵ Surr et al⁶ reported that approximately 50% of tinnitus patients achieved some relief from a hearing aid. Yet another study by Surr et al⁷ found an average of 10% improvement in tinnitus handicap over 4-6 weeks following hearing aid fitting. The likelihood of reducing tinnitus depends on the careful selection of hearing aid characteristics to reduce tinnitus audibility. Some of the options in the hearing aid should be changed for tinnitus management, which include the

open-fit hearing aid,⁸ low compression thresholds (CT),² deactivation of the noise reduction circuit, omnidirectional microphone,⁹ and finally, prescribing the gain using the desired sensation level (input/output) (DSL (i/o)).¹⁰

Any environmental sound can easily enter the ear canal when fitted with an open-fit hearing aid, thereby reducing tinnitus.¹¹ However, blocking the ear canal with molds can produce an occlusion effect, thereby enhancing the internal physiological noise, while at the same time, increasing the tinnitus sound. Thus, a hearing aid fitted with a dome is more effective in suppressing tinnitus compared to an ear mold. The digital hearing aid is comprised of a compression circuit. The compression circuit activates when the input sound exceeds the set level in the hearing aid. The CT is the level at which the compression circuit of the hearing aid activates, and thereby the resultant amplified output is changed. The gain provided by the hearing aid is relatively higher when the input sound falls below the CT, rather than above it. Wise² conducted a study on the effect of changing the CT in the hearing aid on tinnitus audibility. The results revealed that the low CT effectively reduced the audibility of tinnitus as the low-level circuitry noise is amplified to an audible level. Thus, in wide dynamic-range compression, the knee-point should be set at around 20-30 dB sound pressure level (SPL) to suppress the tinnitus effectively.

Other options in hearing aids, such as changing the microphone sensitivity and activating the noise reduction circuits, were used to understand speech against background noise. However, these options were disabled in another program set in the hearing aid for those individuals having hearing loss with bothersome tinnitus. Ricketts and Mueller⁸ demonstrated maximum relief from tinnitus when the noise reduction algorithm was deactivated and the microphone sensitivity set to omnidirectional. This is because the microphone captures signals from all directions. Besides, deactivated digital noise reduction (DNR) in the hearing aid does not change the gain in each of the bands based on temporal rate and depth of noise. Thus, the DNR algorithm should be turned off, and the microphone should be sensitive in all directions to suppress tinnitus effectively.

Further, prescriptive procedures for hearing aid amplification, such as the National Acoustic Laboratories' nonlinear hearing aid (version 1) (NAL-NL1)¹² and the DSL (i/o)¹³ have been used to provide the appropriate amount of amplification based on the hearing threshold of individuals to improve speech perception scores. To be specific, the NAL-NL 1 and the DSL (i/o) are the prescriptive formulas that generate the target gain as a function of frequency to which the gain of the hearing instrument is matched. Wise² investigated the effect of the prescriptive formula on tinnitus suppression. It was reported that 80% of individuals with tinnitus experienced less audible tinnitus when the hearing aid was programmed according to the DSL (i/o) version 4.0 than the NAL-NL1 prescriptive formula. The reason could be that the DSL (i/o) gives more gain at low frequency.¹³ Moreover, ambient noise frequency concentrates in the low-frequency region. Thus, amplified ambient noise might have suppressed the tinnitus when the hearing aid was set in DSL (i/o).

From the literature, it is clear that varying the setting in the hearing aid suppresses tinnitus. The experimental studies have proved that in most subjects, tinnitus audibility is reduced after fitting the hearing aid with the recommended setting. This is because a hearing aid

amplifies speech during conversation and effectively masks the tinnitus. However, individuals fitted with a hearing aid and having tinnitus suffer more in a quiet environment than during conversation. Most of the hearing-aid users self-reported that tinnitus is still perceived in quiet environments.

Thus, in the present study, the tinnitus handicap inventory (THI) was administered to assess the severity, based on which 2 groups were formed. The hearing aid was programmed in 4 different strategies to investigate tinnitus relief, especially in quiet conditions. The behavioral paired-comparison method was utilized to determine the best hearing aid strategy that suitably provides relief from tinnitus in a quiet condition. The association in the severity of tinnitus before and after the patient was fitted with the hearing aid was determined in the preferred setting. It is hypothesized that those strategic settings in the hearing aid which amplify the ambient noise maximally may receive relief from tinnitus. The study aimed to investigate the best amplification strategy that provides tinnitus relief in a quiet environment.

METHODS

A repeated-measures research design was utilized to investigate the best program that can provide relief from tinnitus in a quiet environment.

Participants

A total of 20 participants diagnosed to have had bilateral moderate to moderately severe symmetrical sloping sensorineural hearing loss, ranging in age from 25 years to 65 years (48.28 years), were involved in the study. Those individuals whose hearing sensitivity ranged from 40 dB HL to 60 dB HL in 250 Hz to 2 kHz (in octave) and 65 dB HL to 80 dB HL in >2 kHz to 8 kHz (in octave) were recruited in the study (Figure 1). All the study participants had unilateral tinnitus and complained of bothersome tinnitus in a quiet environment. Each participant had normal middle ear status, as indicated by the type A tympanogram. The participants chosen were naive hearing aids users. None of the participants had experience with the hearing aid and had no other neurological, psychological, or cognitive problems. The study participants were divided into low-pitched (N=8) and high-pitched (N=12) tinnitus groups, depending on whether

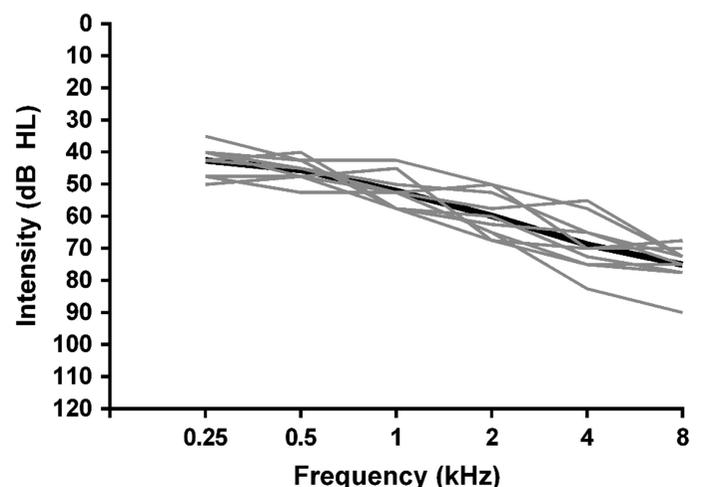


Figure 1. Audiogram of the ear having tinnitus from the participants of the study.

Table 1. Participants' Detail on Demographic Data and Tinnitus Evaluation

SI	PTA (HL)	Age (in years)	Tinnitus Ear	Pitch (Hz)	Loudness (HL)	Groups	Preferred Setting in Hearing Aid	THI Before Hearing Aid	THI After Hearing Aid
1	60	58	R	6000	72	High	DSL (i/o) 30	Moderate	Slight
2	58.75	60	L	3000	60	Low	DSL (i/o) 30	Catastrophic	Moderate
3	57.5	56	R	2000	65	Low	NAL-NL 1 (30)	Moderate	Slight
4	48.75	45	L	750	50	Low	NAL-NL 1 (50)	Moderate	Moderate
5	53.75	33	R	2000	68	Low	DSL (i/o) 50	Severe	Mild
6	48.75	58	R	4000	60	High	DSL (i/o) 50	Severe	Mild
7	56.25	52	R	5000	58	High	NAL-NL 1 (30)	Catastrophic	Catastrophic
8	57.5	53	L	6000	64	High	NAL-NL 1 (30)	Severe	Moderate
9	63.75	58	L	8000	74	High	DSL (i/o) 50	Moderate	Slight
10	53.75	72	R	3000	60	Low	DSL (i/o) 50	Severe	Slight
11	60	33	L	5500	70	High	DSL (i/o) 30	Catastrophic	Moderate
12	62.5	35	L	3000	65	Low	DSL (i/o) 30	Severe	Mild
13	58.75	45	L	1500	60	Low	DSL (i/o) 30	Severe	Mild
14	58.75	48	R	8000	65	High	DSL (i/o) 30	Moderate	Slight
15	40	58	R	6000	50	High	DSL (i/o) 50	Severe	Slight
16	62.5	60	R	5000	70	High	NAL-NL 1 (30)	Catastrophic	Moderate
17	57.5	56	R	4500	65	High	NAL-NL 1 (30)	Severe	Mild
18	62.5	45	L	750	70	Low	DSL (i/o) 50	Catastrophic	Moderate
19	51.25	33	L	5000	60	High	DSL (i/o) 50	Severe	Mild
20	57.5	58	R	5000	65	High	DSL (i/o) 30	Catastrophic	Moderate

their tinnitus was below or above 4000 Hz. The level of 4000 Hz was used as the demarcating frequency in which a standard conventional hearing aid amplification provides a flat response (till 4000 Hz).¹⁴ The details of demographic details and tinnitus evaluation of each participant are represented in Table 1. The study was approved by the ethical research committee's of JSS institute of Speech and Hearing (JSSISH/ AUD/012). Informed consent was received from each participant and the procedure was explained before collecting the data.

Tinnitus pitch and loudness were assessed using the adaptive method.¹⁵ The ear having no tinnitus was used for matching tinnitus pitch and loudness. Loudness was matched before pitch matching was done. The initial intensity level, set at 5 dB SL, was varied step-wise by 1 dB until the loudness was matched. Loudness matching was performed at octave frequencies from 125 Hz to 8000 Hz. To match the pitch, a pair of loudness-matched tones were presented sequentially. Each participant was instructed to report the tone that was closer to their tinnitus. This procedure was continued for consecutive octave frequencies until the participant matched the pitch. The matching of pitch and loudness was performed twice and averaged.

Hearing Aid Programming and Verification of Gain from Different Processing Strategies

A personal laptop loaded with WinCHAP (version 3) (Frye Electronics, Inc., Beaverton, OR) was connected to the FONIX 7000 hearing-aid analyzer (Frye Electronics, Inc., Beaverton, OR). This software controls the operation of the hearing-aid analyzer. The participant was seated at a 12-inch distance from the loudspeaker of the hearing aid analyzer. The loudspeaker was positioned at 45° azimuth in reference to the test ear having tinnitus. The probe tip was detached from the

probe unit of FONIX 7000 to mark 5 mm past the end of the dome of the RIC hearing aid (Sorino X-Mini P). The probe microphone was inserted into the ear canal until the probe tube marking was visible at the tragal notch. Leveling was performed after the insertion of the probe tube into the ear canal. A digital speech at 65 dB SPL was delivered. The output SPL in the ear canal was measured at different frequencies (250 Hz to 8 kHz in octave), and the resultant curve, the real ear unaided response (REUR), was obtained.

A hardware Hi-PRO (GN Otometrics North America, Schaumburg, Ill, USA) connected to the same personal laptop loaded with hearing-aid specific software to program the Sorino X Mini RIC (HANSATON, Germany) hearing aid. A prescriptive formula NAL- NL1 at the low CT (30 dB SPL) was selected. Further, the noise reduction circuit was switched off, and the directional microphone was disabled. The hearing aid was programmed for the participant's hearing loss. The programmed hearing aid was fitted into the participant's ear without changing the probe tip position at the ear canal. Real ear aided responses (REAR) were measured for the digital speech presented at 65 dB SPL.

The hearing aid analyzer automatically calculates the real ear insertion response (REIR) by taking the difference between REAR and REUR at each frequency (250 Hz to 8 kHz in octave). It was ensured that the gain of hearing aid at each frequency was almost matched with the prescriptive target. A similar procedure was carried out by changing only the CT from 30 dB SPL to 50 dB SPL (P2). The entire procedure was performed by programming the hearing aid using the DSL (i/o) (version 5) prescriptive formula at the CTs of 30 dB SPL (P3) and 50 dB SPL (P4), respectively.

Rating the Amplification-Processing Strategy on Suppression of Tinnitus Using the Paired Comparison Method

A paired comparison method was used to judge the best hearing aid program which gives tinnitus relief. A total of 6 comparisons (P1, P2, P3, and P4) were made. Each participant was instructed to select the best program between the 2 while listening to the ambient noise presented at 30 dB SPL through the loudspeaker. Each pair was presented 3 times in a random order, resulting in a total of 18 paired comparisons (6 comparisons \times 3 times). Each participant was asked to select the best program of the pair which provided tinnitus relief. A preference score of 1 mark was awarded for the best program for each pair. The winner in preference-based tinnitus relief would be the program that secured the highest marks out of a maximum of 18 marks. A similar procedure was carried out in each comparison. The presentation order of the hearing aid programs in each trial was counterbalanced across participants.

The Tinnitus Handicap Inventory

A standardized Kannada version of the Tinnitus Handicap Inventory (THI)¹⁶ was administered to each of the study participants. The THI comprised 25 questions. Each question was rated on a 3-point rating scale, with "yes" as 4, "sometimes" as 2, and "no" as zero. The maximum score that can be obtained from this test battery is 100. The scoring pattern is 2-16, slight; 18-36, mild; 38-56, moderate; 58-76, severe; and 78-100, catastrophic. The THI was administered before the hearing aid fitting and after 1 month of wearing the hearing aid in the winning program.

RESULTS

The best hearing aid program that alleviated the bothersome tinnitus in a quiet environment between the 2 groups (low and high pitch) was investigated in the present study. A repeated-measure ANOVA (programs) with the between-subject factor as a group (low- and high-pitched tinnitus) revealed a significant main effect of the preference of program in hearing aid on tinnitus relief ($F(3, 54) = 22.50$, $P = .000$). However, the interaction effect, as preference program \times group, and the main effect as the group failed to reach significance. Thus, the best-preferred program among the 4 strategies was investigated by the participants of the study.

The higher preference score for tinnitus relief was noted in DSL (i/o) 30 dB SPL, followed by DSL (i/o) 50 dB SPL, then NAL-NL1 30 dB SPL and NAL-NL 1 50 dB SPL. A paired samples *t*-test was administered with an alpha correction value ($0.05/6 = 0.08$) to examine the best program among the 4 offered that relief from tinnitus. Except for the comparisons between DSL 30 vs. 50 and NAL-NL 1 30 vs. 50, the other comparisons showed significant differences in preference score of tinnitus relief ($P < .08$) (Figure 2).

The winner in preference-based tinnitus relief (in percentage) for each participant was calculated. Out of 20, there were 7 participants who preferred DSL (i/o) 30 dB and DSL (i/o) 50 dB, respectively, which accounts for 35% each. In addition, 5 participants preferred NAL-NL1 30 dB (25%), and 1 participant preferred NAL-NL1 50 dB (5%).

To investigate the association in the severity of tinnitus reflected in the THI, the association between the results before and after the

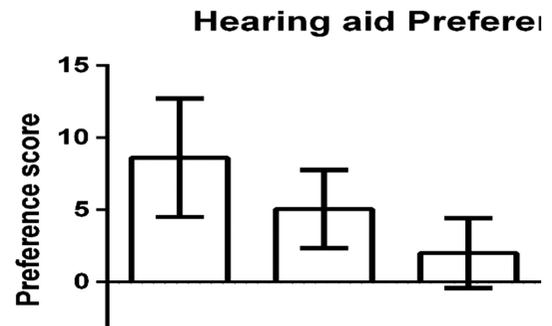


Figure 2. Hearing aid preference score of different programs for tinnitus relief.

hearing aid fitting set at the preferred program was measured using a chi-square test. The results revealed a significant association in the severity of tinnitus before and after the hearing aid fitting set at the preferred program [$X^2(1, 6) = 21.90$, $P = .001$]. It indicates that if the severity is less before fitting the hearing aid, then the severity of tinnitus reduces significantly when the hearing aid is set at the preferred program (Table 2).

DISCUSSION

It is observed that the preference score on tinnitus perception was higher when the hearing aid was set at DSL (i/o) than at NAL-NL 1. The possible reason could be that for the soft level of ambient noise, the gain provided by the DSL (i/o) is relatively higher than that with NAL-NL 1. Although both DSL (i/o) and NAL-NL 1 prescribe similar gain in the mid frequencies, the DSL (i/o) prescribes more low-frequency gain than the NAL-NL 1 formula. Therefore, the lower frequencies are perceived as being louder than higher frequencies. In addition, the DSL (i/o) also prescribes more gain above 4000 Hz. However, the NAL-NL 1 provides a lower prescribed gain in regions of severe hearing loss, which has reduced audibility of environmental sound.

The CT caused no significant difference in tinnitus perception between the low and high set levels. This is true for each of the fitting formulae. However, the preference score was high when the CT was set at 30 dB SPL than at 50 dB SPL. A low-compression knee-point enables the amplification of low-intensity environmental sounds to audible levels. There is a trade-off between the compression knee-point and gain assignment. If the compression knee-point is set at a low level (30 dB SPL), then gain increases, and vice versa, such that the ambient noise is heard relatively louder than the CT set at the higher knee-point (50 dB SPL). By having a low-compression knee-point, greater amplification is provided to low-intensity ambient sounds audible to hearing-impaired individuals having tinnitus. This allows low-intensity environmental sounds to interfere with the detection of tinnitus.

Furthermore, the multichannel non-linear hearing aid utilized in the study splits the input into its component frequencies so that the effective input in each channel is lower than the overall input level. The spectral level of noise at lower frequencies is high, and it activates the compression circuit, often set at 30 dB SPL. The CT set at 50 dB SPL is relatively high in a multichannel non-linear hearing aid, to activate the compression for the ambient noise condition.

Table 2. Cross-Tabulation Between the THI Scores Before and After Hearing-Aid Fitting

		THI—After Hearing Aid Fitting				Total	
		Slight	Mild	Moderate	Catastrophic		
THI—Before Hearing aid Fitting	Moderate	Count	5	-	1	-	6
		%	83.3%	0.0%	16.7%	0.0%	
	Severe	Count	2	5	1	-	8
		%	25.0%	62.5%	12.5%	0.0%	
	Catastrophic	Count	-	-	5	1	6
		%	0.0%	0.0%	83.3%	16.7%	

In the preferred hearing aid setting, there was a significant association in severity at the baseline and after 1 month of using the hearing aid in the winning program. If the severity of the tinnitus perception was low at the baseline, then a significant reduction was observed, and vice versa, after using the hearing aid for 1 month. The amplified speech in the daytime and ambient noise in quiet conditions might have masked the tinnitus sound, and thereby attention toward the tinnitus and its associated problem reduced significantly, which was reflected in the THI. From Table 1, it is observed that there is no relation between severity at the baseline and preference of program in hearing aid. It means that the participants in each group preferred either of the programs. However, considering the frequency of preference, the DSL (i/o) was chosen the maximum number of times. The CT, set at either 30 dB SPL or 50 dB SPL, shares the same frequency of choice as the best strategy to get relief from tinnitus. The CT set at 30 dB SPL enhances the ambient noise relatively more than at 50 dB SPL, as iterated. Thus, it is recommended to start with DSL (i/o) and a CT set at 30 dB SPL to get relief from tinnitus perception.

Caution must be taken in fitting the hearing aid to amplify ambient noise for tinnitus relief. A greater proportion of hearing aid users might achieve tinnitus masking if the emphasis is placed on amplifying ambient sounds.¹⁷ However, this also must be balanced against the potential reduction in hearing satisfaction. A few options in the hearing aid to amplify the ambient noise should be activated if the subject complains of bothersome tinnitus. The options in the hearing aid selected are: omnidirectional on, wide bandwidth, DSL i/o v5 prescriptive formula, and low knee-point. These options shall be carefully handled to amplify the ambient noise, as excessive annoyance may cause rejection of the hearing aid. The best practice is to set it as a separate program to give maximum relief from tinnitus, especially in quiet conditions.

Limitation of the Study

The use of DSL (i/o) at a low CT is considered the best amplification strategy as it amplifies an ambient noise significantly and suppresses the tinnitus. However, speech intelligibility is not studied when the hearing aid is set using different amplification strategies, particularly in ambient noise. It is speculated that speech intelligibility may be compromised when the hearing aid gain is prescribed by DSL (i/o) and CT is set at a low level, but this needs empirical evidence. Thus, it is advised to set it as a separate program in the hearing aid, especially for those hearing-impaired patients who complain that the tinnitus is bothersome.

CONCLUSION

Ideally, the best practice is to prescribe the gain using the DSL (i/o) and CT set at the low level in the hearing aid as a separate program to

obtain tinnitus relief, especially in the quiet condition. It amplifies an ambient noise significantly and suppresses the tinnitus.

Ethics Committee Approval: Ethical committee approval was received from the Ethics Committee of JSS institute of Speech and Hearing (JSSISH/AUD/012).

Informed Consent: Informed consent was obtained from the patients who participated in this study.

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