Effect of Prescriptive Formulae on the Perception of Music in Hearing aid Users

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Abstract

The main objective of the study was to investigate the effect of prescriptive formulae on music perception by comparing the perceptual rating of the quality of music heard in the unaided condition with the aided condition. The hearing aid was programmed using NAL NL1, DSL (i/o) and FIG6 formulae. Twenty subjects in the age range of 18 to 64 years having mild to moderate sensorineural hearing loss participated in the study. The participants were fitted with a digital hearing aid in which NAL NL1, DSL (i/o), and FIG6 formulae were used for prescribing the first fit program. The participants rated the quality of music on a five point rating scale in the unaided and aided conditions with hearing aid programmed using NAL NL1, DSL (i/o), FIG6 Participants ranked the unaided and three aided conditions based on the order of preference of each condition for listening to music. The Fast Fourier Transforms (FFTs) were obtained for unamplified music as well as music amplified through NAL NL1, DSL (i/o) and FIG6.The results showed that the aided conditions were rated to be better than unaided condition in the perceptual rating of quality of vocal and violin music. For vocal as well as violin, subjects preferred the hearing aid with DSL (i/o) and FIG6 formulae over NAL NL1 formulae. FIG 6 was ranked as the best, DSL (i/o) as second, NAL NL1 and unaided as third as the condition preferred for listening to music.

Key words: *NAL NL1, DSL i/o, Fig 6, music perception.*

Although studies on music perception in persons with hearing impairment shows that sensorineural hearing loss impairs the perception of musical elements (deLaat & Plomp, 1985; Santurette & Dau, 2007), the processing of music in hearing aid is not much investigated. According to Chasin (2003), a hearing aid ideal for music perception can be programmed to have good speech intelligibity but the vice versa is not true because speech and music differs from each other in terms of many factors, such as the long-term spectrum, differing overall intensities, crest factors, and the perceptual requirements. Considering these differences, Chasin (2004) defined a set of optimal electro acoustic parameters for enjoying music which included, high peak input limiting level, single channel system or multi channel system with similar compression ratios and knee points for all channels, RMS detector compression scheme, a disabled feedback reduction system and a disabled noise reduction circuit. One such factor is the prescriptive fitting procedure used for prescribing the gain and frequency response of the hearing aid.

Prescriptive fitting formulae which are commonly used are based on two principles, One, loudness normalization and two, speech intelligibility maximization (Smeds & Leijon, 2001). Loudness normalization aims at amplifying the sounds in such a way that they sound as close as possible to how the normal listener perceive the loudness of the same sound. The aim of speech intelligibility maximization is to maximize the speech intelligibility for every input level without exceeding the overall loudness above the overall normal loudness for speech. This is achieved by presenting all the speech bands at equal loudness. Hence, it is also known as loudness equalization (Kaidser & Grant, 2003). Keidser and Grant (2003) found that NAL-NL1 being a fitting procedure based on loudness equalization, prescribe lesser low frequency gain than fitting procedures based on loudness normalization such as DSL (i/o) and FIG 6. This is to reduce upward spread of masking. This would improve speech intelligibility. But according to various studies done by Franks (1982) , Punch (1978), and Chasin (2003), in music perception in persons with normal hearing and hearing impairment, low frequency information contribute significantly to the quality of music. The prescriptive fitting procedure which prescribes lesser gain at low frequencies improves speech intelligibility by reducing the upward spread of masking. However, this low frequency information is important for music perception. Thus we cannot say that those procedures would improve music perception also.This led to the need for the present study.

The main objectives of the study were to investigate the effect of prescriptive formulae on music perception by comparing the perceptual rating of the quality of music heard in the unaided condition with the aided condition where in the hearing aid was programmed using NAL NL1, DSL (i/o) and FIG6 formulae, to study the subjective preference of the quality of music processed through hearing aids programmed using different prescriptive formulae for listening to music and to compare and analyze the

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Fast Fourier Transform of unamplified music with the music processed through hearing aid programmed as per different prescriptive formulae.

Method

The main aim of the study was to study the effect of hearing aid prescriptive formulae on music perception in hearing aid users. To study the same, the following method was employed.

Participants: Twenty subjects (twelve males and eight females) participated in the study. The age of the subjects ranged from 18 to 64 years. The mean age was 42.2 years. Subjects had moderate to moderately severe sensorineural hearing loss in the better ear. Pure tone average of the subjects in the better ear ranged from 41 dB HL to 70 dB HL (The mean pure tone average was 52.36 dB HL) Subjects with history or indications of middle ear pathology, otological or neurological problem were excluded from the study.

Instrumentation: A calibrated two channel clinical audiometer Madsen OB922 was used for the testing. TDH-39 headphones housed in Mx-41/AR ear cushions were used for obtaining air conduction thresholds, for speech audiometry and for delivering the test stimulus. Radio ear B 71 bone vibrator was used for obtaining the bone conduction thresholds. A calibrated immittance meter, GSI-TYMPSTAR was used to assess the middle ear functioning of the subjects. A commercially available two channel digital signal processing behind the ear hearing aid was used in the study. Custom made ear moulds were used to couple the hearing aids to the subject's ear. A personal computer installed with NOAH (3.0 version) software connected with Hi-pro was used to program the hearing aids. A laptop was used to play the test stimulus. Half inch pressure microphone (4192) was used to collect the acoustic energy generated inside the anechoic chamber and to give it to the 'Pulse' analyzer for further analysis. 'B & K Pulse' Analyzer (B & K 3560B) was used to obtain the Fast Fourier transform of the unamplified and amplified music. A 2 CC Coupler was used for coupling the hearing aid with half inch pressure microphone for objective analysis of input and of the hearing aid. Testing was done in a sound treated double room. The ambient noise levels were within permissible limits as recommended by ANSI (S3.1.1991).

Music stimuli: Two different music stimuli were used in this study. They were Carnatic -vocal and Carnatic-instrumental (violin). The stimulus of ninety seconds was used for the testing.

Case history: A detail case history was taken in order to see if the subjects met the inclusion criteria set for the study.

Pure tone audiometry: Pure tone audiometry was done for octave frequencies from 250 Hz to 8kHz for air conduction stimuli and from 250 Hz to 4kHz for bone conduction stimuli. The testing was done using a calibrated double channel audiometer. Air conduction stimuli were presented through a calibrated head phone and bone conduction stimuli was presented through a calibrated bone vibrator. The testing was done using modified Hughson – Westlake procedure (Carhart & Jerger, 1959).

Speech audiometry: Speech recognition threshold (SRT) and Speech Identification Scores (SIS) were established using the Olsen and Tillman Method (1973) (as sited in Gelfand, 1997).

Uncomfortable loudness level: The speech stimulus was presented through head phones at a comfortable loudness level and the intensity of the stimuli was increased gradually. The subjects were asked to indicate when the experience of loudness becomes uncomfortable. The level at which the subject report the loudness of the speech to be uncomfortably loud was taken as the subject's uncomfortable loudness level (UCL).

Immittance audiometry: Tympanometry was done to rule out the presence of middle ear pathology. The probe frequency was 226 Hz and the level of probe tone was 85 dB SPL. Reflexometry was done at 500 Hz, 1 kHz , 2 kHz and 4 kHz with ipsilateral as well as contralateral mode of stimulation.

Programming of the hearing aid: The hearing aid was programmed for the better ear by applying the first fit program with NAL NL1, FIG 6 and DSL (i/o) formula for gain prescription. DSL (i/o) gives the option to enter the patient's real ear to coupler difference (RECD) or loudness discomfort levels (LDL).Since this was not mandatory, it was not done in the present study. The same hearing aid was used for all the subjects participating in the study, in order to isolate the effects of the prescriptive formulae without confronting it with other differences in design and circuitry of the hearing aid.

Familiarization of the rating scale: Subjects were given a training period of ten minutes where in they were given an opportunity to listen to a sample of Carnatic music other than which is used in the study using a hearing aid. They were instructed to rate the quality of music on the five point rating scale used in the study which is as follows: 1- very bad, 2-bad, 3-good, 4-very good and 5-excellent. This was done to familiarize the subjects with the rating scale.

Presentation of the music: The laptop which was used to play the music was connected to the audiometer. The music stimuli was presented through a speaker which was placed at 45 degree azimuth and at one meter distance from the subject's aided ear. The presentation level of the music was adjusted at the subject's most comfortable loudness level for music which was the level at which the subject reported the music to be loud enough to listen to it without causing any discomfort.

Subjective analysis of the music samples: Sound quality judgments were obtained using a five point perceptual rating scale. Five parameters that are relevant to music were rated by the subjects. The subjects were asked to rate the music samples on the perceptual parameters of clarity, rhythm, melody, naturalness and overall impression after they were briefed about these parameters. Each parameter was rated separately on the five point rating scale. The scale for rating on the parameters was as follows: 1-very bad, 2-bad, 3-good, 4-very good and 5-excellent.The subjective analysis and perceptual rating of the quality of music samples were obtained under four conditions with Carnatic vocal music sample and a Carnatic violin sample.

Establishing the subjective preference: After listening and rating the vocal and violin music, the subjects were asked to rate each condition in terms of their preference in listening to music.

Measurement of spectra of the music samples: The aim of objective evaluation was to analyze and compare the spectrum of the input music stimulus as well as the music processed by the hearing aid using different prescriptive formulae. A 'B&K Pulse' Analyzer, a hearing aid, HA1 2cc coupler, half inch pressure microphone and preamplifier were used for the measurement. The music stimuli were fed into the 'Pulse' analyzer system. The stimulus was delivered through the channel of the 'Pulse' analyzer which was connected to the speaker inside the anechoic chamber. In the analysis of unamplified music, the output from the speaker in the anechoic chamber was picked up by the half inch pressure microphone and it was given back to the 'Pulse' analyzer system. In the analysis of the music processed through the hearing aid, the hearing aid was placed at the designated place in the anechoic chamber. The transducer of the hearing aid was coupled to a 2cc coupler. The acoustic of the hearing aid was picked up by the half inch pressure microphone attached to the 2cc coupler and fed back to the 'Pulse' analyzer system for analysis. The 'Pulse' analyzer system captured the spectrum of the stimulus that it received from the anechoic chamber.

Results

Perceptual rating of the vocal music for the five perceptual parameters in the four listening conditions*:* Perceptual rating was obtained for the quality of vocal music for the five perceptual parameters namely clarity, melody, rhythm, naturalness and overall impression under the four listening conditions namely unaided, aided using NAL NL1, DSL (i/o) and FIG6 prescriptive formulae. Mean and standard deviation of the perceptual rating of the vocal music for the four listening conditions are shown in Table 1. It can be seen that for all the parameters, in the unaided and aided condition with NAL NL1 formula, a rating of 'good' (rating 3) was obtained where as in the aided condition with DSL (i/o) and FIG6 formulae, a rating of 'very good' (rating 4) was obtained for all the parameters except for the naturalness in the DSL (i/o) condition.

Perceptual rating of the violin music for the five perceptual parameters for the four listening conditions: Perceptual rating was obtained for the quality of violin music for the five perceptual parameters namely clarity, melody, rhythm, naturalness and overall impression under four listening conditions namely unaided, aided with NAL NL1, DSL (i/o) and FIG6 prescriptive formulae. Mean and standard deviation of the perceptual rating of the violin music for the four listening conditions are shown in Table 2. It can be seen in table 4 that the ratings obtained for violin music was also similar to that obtained for vocal music except that NAL NL1 condition was rated as 'very good' (rating of 4) for the overall impression.

Table 1. Mean and standard deviation (with in brackets) of perceptual rating of the vocal music for the five perceptual parameters in the four different conditions

Perceptual Parameters	Unaided	Aided with the prescriptive formulae		
		NAL NL1	DSL (i/o)	FIG 6
Clarity	3.05 (.759)	3.35(.812)	4.05 (.510)	4.05(.759)
Melody	3.35(.587)	3.60(.820)	4.10(.552)	4.00(.648)
Rhythm	3.75(.786)	3.95(.604)	4.35(.587)	4.20(.695)
Naturalness	3.75(.786)	3.80(.833)	3.95(.510)	4.15(.745)
Overall	3.60(.502)	3.95(.686)	4.30(.470)	4.10(.640)

Table 2. Mean and standard deviation (within brackets) of perceptual rating of the violin music for five perceptual parameters in the four different conditions

Perceptual Parameters	Unaided	Aided with the prescriptive formulae		
		NAL NL1	DSL (i/o)	FIG 6
Clarity	3.30(1.031)	3.65(.812)	4.20(.695)	4.05(.887)
Melody	3.65(.988)	3.90(.640)	4.15(.812)	4.00(.794)
Rhythm	3.75(.910)	3.90(.640)	4.25(.716)	4.35(.670)
Naturalness	3.70(.923)	3.95(.887)	4.35(.587)	4.25(.716)
Overall	3.60(.820)	4.20(.615)	4.30(.864)	4.30(.732)

Table 3. Friedman's test results: Comparison of perceptual ratings of vocal music with violin music under each condition and for each parameter

Perceptual parameter	Unaided	Aided with the prescriptive formulae		
		NAL NL1	DSL(i/o)	FIG 6
Clarity	0.166	0.058	0.257	1.0
Melody	0.058	0.083	0.739	1.0
Rhythm	1.0	0.739	0.414	1.13
Naturalness	0.705	0.317	0.005 *	0.480
Overall	1.0	0.059	1.0	0.102

(* significant difference; $p< 0.05$)

quality of violin music for the five perceptual parameters namely clarity, melody, rhythm, naturalness and overall impression under four listening conditions namely unaided, aided with NAL NL1, DSL (i/o) and FIG6 prescriptive formulae. Mean and standard deviation of the perceptual rating of the violin music for the four listening conditions are shown in Table 2. It can be seen in table 4 that the ratings obtained for violin music was also similar to that obtained for vocal music except that NAL NL1 condition was rated as 'very good' (rating of 4) for the overall impression.

Comparison between vocal and violin music for the perceptual rating: Friedman's test was done to compare the rating obtained for vocal and violin music. For each of the four listening condition, the rating obtained for vocal music was compared with that of violin music. Table 3 shows the results of Friedman's test for each condition and for each parameter.

From Table 3 it can be seen that the perceptual rating obtained for Vocal and Violin music were not significantly different from each other in the unaided condition and in the aided conditions with NAL NL1, DSL (i/o) and FIG 6 prescriptive formulae for any of the perceptual parameters except that in the DSL (i/o) where the rating obtained for naturalness for the vocal music differed significantly from that of violin. The violin music was rated to be better than vocal music.

Comparison of the unaided and aided conditions with NAL NL1, DSL (i/o) and FIG6 prescriptive formulae for the perceptual rating of vocal music: The ratings for the perceptual parameters of clarity, melody, rhythm, naturalness and overall impression of vocal music under the unaided and aided conditions with NAL NL1, DSL (i/o), and FIG6 prescriptive formulae were compared.

Table 4. Mean ranks for Unaided and aided conditions with NAL NL1, DSL (i/o) and Fig6 prescriptive formulae based on the perceptual rating for the vocal music. Higher ranks indicate better quality

Perceptual parameter	Unaided	Aided with the prescriptive formulae		
		NAL NL1	DSL (i/o)	FIG 6
Clarity	1.62	2.10	3.20	3.08
Melody	1.72	2.25	3.10	2.92
Rhythm	1.90	2.28	3.08	2.75
Naturalness	2.22	2.35	2.58	2.85
Overall impression	1.75	2.42	3.10	2.72

Table 4 shows the mean ranks for unaided and aided conditions with NAL NL1, DSL (i/o) and FIG6 prescriptive formulae based on the perceptual rating for the vocal music. Higher ranks indicate better quality.

From Table 4, it can be seen that for all the parameters, unaided condition was given the lowest rank compared to the aided conditions. In the aided condition, NAL NL1 was given lower ranks compared to DSL (i/o) and FIG6 prescriptive formulae. DSL (i/o) was ranked higher than FIG6 in clarity, melody, rhythm and overall impression and FIG 6 was ranked higher than DSL (i/o) in naturalness.

Friedman's test was done to compare the four conditions. The Table 5 shows the results of Friedman's test comparing the perceptual ratings obtained for quality of vocal music under the four conditions.

Table 5. Friedman test results for the comparison of perceptual rating obtained for quality of vocal music under the four conditions

Perceptual parameter	F value
Clarity	* 0.00
Melody	* 0.00
Rhythm	* 0.002
Naturalness	0.187
Overall impression	* 0.00

* significant difference, p<0.05

From Table 5, it can be seen that there was a significant difference between unaided and aided conditions with NAL NL1, DSL (i/o) and FIG 6 prescriptive formulae in the perceptual rating of clarity, melody, rhythm and overall impression. There was no significant difference between the four conditions for the perceptual rating of naturalness for vocal music. In all the three aided conditions, the quality of naturalness was rated as 'bad' (rating of 2) as shown in Table 4. For the perceptual parameters at which perceptual rating showed significant difference between unaided and aided conditions with NAL NL1, DSL (i/o) and FIG6 prescriptive formulae, Wilcoxon signed rank test was done. Table 6 shows the results of Wicoxon signed rank test for pair wise comparison for the perceptual rating of clarity, melody, rhythm and overall impression of vocal music.

Table 6 shows that the aided condition with NAL NL1 prescriptive formula was significantly better than unaided condition for perceptual rating of overall impression only. The rating as 'very bad' (rating 1) changed to 'bad' (rating 2). But for the rating of clarity, melody and rhythm there was no significant difference between unaided and aided condition with NAL NL1 prescriptive formula. The parameters were rated either as 'bad' or 'very bad' for both the conditions (Ratings are shown in Table 4). Further, the aided conditions with DSL (i/o) and Fig 6 prescriptive formulae were significantly better than unaided condition for the perceptual rating of clarity, melody, rhythm and overall impression of vocal music. The ratings changed from 'very bad' (rating 1) to 'good' (rating 3). Rating obtained for aided conditions with DSL (i/o) and FIG 6 prescriptive formulae for any of the perceptual parameters. Both these conditions improved the perceptual ratings from 'very bad' (rating 1) to 'good' (rating 3).

Table 6. Wicoxon signed rank test results for pair wise comparison between unaided and aided conditions with NAL NL1, DSL (i/o) and FIG6 prescriptive formulae for the perceptual rating of clarity, melody, rhythm and overall impression of vocal music

Pairs compared	Perceptual parameters			
	Cl	Mel	Rhy	Over
Unaid	0.1	0.1	0.15	0.02
Unaid	0.0	0.0	0.00	0.00
Unaid	0.0	0.0	0.02	0.00
NAL	0.0	0.0	0.01	0.03
NAL	0.0	0.0	0.13	0.31
DSL	1.0	0.3	0.31	0.20

* significant difference, p<0.05

Table 6 also shows that in the in the aided conditions, DSL (i/o) was rated significantly better than NAL NL1 for the perceptual rating of clarity, melody, rhythm and overall impression. Aided condition with FIG6 was significantly better than NAL NL1 for the perceptual rating of clarity and melody. However there was no significant difference between the perceptual parameters. Both these conditions improved the perceptual ratings from 'very bad' (rating 1) to 'good' (rating 3).

Comparison between the unaided and aided conditions with NAL NL1, DSL (i/o) and FIG6 prescriptive formulae for the perceptual rating of violin music: The perceptual rating of clarity, melody, rhythm, naturalness and overall impression of violin music under the unaided, and aided conditions with NAL NL1, DSL (i/o), and FIG6 were compared. Friedman's test was done to compare the four conditions.

Table 7 shows the mean ranks for unaided and aided conditions with NAL NL1, DSL (i/o) and Fig6 prescriptive formulae based on the perceptual rating of violin music. Higher ranks indicate better quality.

From Table 7, it can be seen that for all the parameters, unaided condition was given the lowest rank compared to the aided condition. In the aided condition, NAL NL1 was given lower ranks compared to DSL (i/o) and FIG6 prescriptive formulae. DSL (i/o) was ranked higher than FIG6 for clarity, melody, and naturalness and FIG 6 was ranked higher than DSL (i/o) for rhythm and overall impression. Friedman's test was done to compare the four conditions. The Table 8 shows the results of Friedman's test comparing the perceptual ratings obtained for quality of violin music under the four conditions.

Table 7. Mean ranks for Unaided and aided condition with NAL NL1, DSL (i/o) and FIG6 prescriptive formulae based on the perceptual rating of violin music. Higher ranks indicate better quality

Perceptual parameter	Unaided	Aided with the prescriptive formulae		
		NAL NL1	DSL (i/o)	FIG 6
Clarity	1.72	2.28	3.08	2.92
Melody	2.10	2.40	2.90	2.60
Rhythm	1.92	2.18	2.85	3.05
Naturalness	1.80	2.30	3.00	2.90
Overall impression	1.62	2.70	2.82	2.85

Table 8. Friedman test results in the comparison of perceptual rating obtained for quality of violin music under the four conditions

Perceptual parameter	f value
Clarity	* 0.00
Melody	0.083
Rhythm	* 0.00
Naturalness	* 0.00
Overall impression	* 0.00

From the Table 8 it can be seen that there is significant difference between unaided and aided conditions with NAL NL1, DSL (i/o) and FIG6 prescriptive formulae for the perceptual rating of clarity, rhythm, naturalness and overall impression of the violin music. However, there was no significant difference in the perceptual rating obtained for the melody for violin music. In all the conditions, the melody was rated as 'bad' (rating of 2) as shown in Table 7.For the perceptual parameters at which the ratings showed significant difference between unaided and aided conditions. With NAL NL1, DSL (i/o) and FIG6 prescriptive formulae, Wilcoxon signed rank test was done for pair wise comparison. Table 9 shows the results of Wicoxon signed rank test for pair wise comparison between unaided and aided conditions with NAL NL1, DSL (i/o) and FIG6 prescriptive formulae for the perceptual rating of clarity, rhythm, naturalness and overall impression for violin music.

Table 9 shows that the aided condition with NAL NL1 prescriptive formula was significantly better than unaided condition for perceptual rating of clarity, naturalness and overall impression of violin music. But for the rating of rhythm there was no significant difference between unaided and aided condition with NAL NL1 prescriptive formula. The aided conditions with DSL (i/o) and FIG 6 prescriptive formulae were significantly better than unaided condition for the perceptual rating of clarity, rhythm, naturalness and overall impression of violin music. In the aided condition, DSL (i/o) and FIG6 were rated significantly better than NAL NL1 for the perceptual rating of clarity, rhythm and naturalness. However for the perceptual rating of overall impression, there was no significant difference between aided conditions with FIG 6, DSL (i/o) and NAL NL1 prescriptive formulae. Further there was no significant difference between the perceptual rating obtained for aided conditions with DSL (i/o) and FIG 6 prescriptive formulae for any of the perceptual parameters.

Perceptual ratings compared with subjective preference: Based on the perceptual rating given by subjects, the percentage of subjects who rated 1(very bad), 2(bad), 3(good), 4(very good), and 5(excellent) respectively for each condition/ parameter was calculated. The percentage of subjects who rated a parameter/condition as four (very good) and five (excellent) was calculated for each parameter in each condition and is shown in Table 10.

The condition which had the highest percentage was ranked as one for each parameter. Further, the conditions with the decreasing order of percentages for the same parameter were given ranks of two, three and four. The ranks obtained in this way for vocal music and for violin music for each parameter was compared with subjective preference (ranking 1 to 4) of conditions .According to the ranking it was found that none of the subjects preferred the unaided and NAL NL1 condition, even though one subject reported that there was no difference between all the four conditions. Thus, the conditions available for ranking of subjective preference were only DSL (i/o) and FIG6. DSL (i/o) was ranked two and FIG6 was ranked one in the subjective preference. In vocal music DSL (i/o) was ranked one on the parameters of clarity, melody, rhythm and overall impression and was ranked two on naturalness. FIG 6 was ranked two on clarity, rhythm and overall impression and was ranked one for melody and naturalness. It may be noted that for melody there was a tie between DSL (i/o) and FIG6. In violin music, DSL (i/o) was

Table 9. Wicoxon signed rank test results for pair wise comparison between unaided and aided conditions with NAL NL1, DSL (i/o) and FIG6 prescriptive formulae for the perceptual rating of clarity, melody, rhythm and overall impression of violin music

Pairs	Perceptual parameters			
	Clarity	Rhythm	Naturalness	Overall impression
Unaided vs. NAL	0.035 *	0.317	0.025*	0.001*
Unaided vs. DSL	0.002*	0.018*	0.003*	0.005*
Unaided vs. FIG	0.001*	0.003*	0.002*	0.001*
NAL NL1 vs.	0.005*	0.008*	0.003*	0.414
NAL NL1 vs.	0.046*	0.003*	0.034*	0.414
DSL (i/o) vs. FIG	0.405	0.157	0.414	1.0

* significant difference: $p<0.05$

Table 10. Percentage of subjects who rated a parameter/condition as four (very good) and five (excellent)

Stimuli	Vocal					Violin				
Parameter/condition	C	M	R	N	O	C	M	R	N	O
Unaided	3	4	6	6	60	3	6	6	6	5
NAL NL1	4	6	8	7	75	5	7	7	7	9
DSL (i/o)	9	9	9	8	10	8	8	8	9	8
FIG 6	8	9	8	9	85	8	8	9	9	8

Key: C- clarity, M- melody, R- rhythm, N- naturalness, O- overall impression

Table 11. Ranking of the two preferred conditions, i.e. DSL (i/o) and FIG6, based on the perceptual rating of vocal and violin music for each parameter plotted against the ranks based on the subjective preference

			Ranks based on perceptual rating																			
			Clarity				Melody				Rhythm				Naturalness				Overall impression			
			a		b		a		b		a		b		a		b		a		b	
			1	2	1																	
Subjective preference	DSL(i/o)	1																				
		2	*		*																	
	FIG6	1		*	*																	
		2																				

Key : a- vocal music, b- violin music, 1- rank one, 2- rank two.

ranked one on clarity, melody and naturalness and it was ranked two on rhythm and overall impression. On the other hand FIG6 was ranked one on clarity, rhythm and naturalness. Even here, it may be noted that both DSL (i/o) and FIG 6 obtained the same ranking on clarity and naturalness. Further, Fig 6 was ranked two on melody and overall impression.

Table 11 shows ranking of the two preferred conditions, i.e. DSL (i/o) and FIG6, based on the perceptual rating of vocal and violin music for each parameter plotted against the ranks based on the subjective preference. In table 12, the lightly shaded areas indicate the ideal situation where there will be one to one agreement between the ranks obtained on perceptual rating and subjective preference. The conditions/parameters at which there was one to one agreement between the ranks obtained based on perceptual rating and subjective preference in the present study are showed in areas shaded dark. Table 12 shows that the agreement between the two types of ranking was done on five parameters for two types of samples in each condition i.e. DSL (i/o) and FIG6. Thus, there were twenty slots (lightly shaded slots) available to show the perfect agreement between the ranking where in ten slots each depicts perfect agreement for rank one and rank two. FIG 6 which was ranked first in subjective preference obtained perfect agreement of first rank in five out of ten slots (50%) where as DSL (i/o) which was ranked second in subjective preference obtained perfect agreement of rank one in none of the slots and obtained perfect agreement of rank two only in three out of ten slots. These results show that the perceptual parameters were well considered by the subjects in making their subjective preferences. The result also shows FIG6 as the preferred formula for listening to music.

Objective analysis: Fast Fourier Transform of the unamplified music and the music amplified by a hearing aid programmed with NAL NL1, DSL (i/o) and FIG6 prescriptive formulae were obtained for vocal and violin music. The level in dB SPL corresponding to each frequency starting form 1 kHz to 8 kHz was obtained. Pearson's test of correlation was used to find out the correlation between the Fast Fourier Transforms of the unamplified music and amplified music with NAL NL1, DSL (i/o) and FIG6 prescriptive formulae.

Correlation between the FFT obtained for unamplified vocal music and vocal music amplified by a hearing aid programmed with NAL NL1, DSL (i/o) and FIG6 programming: Pearson's correlation test was done to find out the correlation between the FFT obtained under the four test conditions. Table 12 shows the results of Pearson's correlation test for the FFT obtained for vocal music. The FFT obtained for the unamplified music was compared with that of the amplified music with NAL NL1, DSL (i/o) and FIG6 prescriptive formulae. The FFT obtained for the amplified music with NAL NL1, DSL (i/o) and FIG 6 prescriptive formulae were also compared across each other.

From the Table 12 it can be seen that the correlation between the unamplified vocal music and the amplified music with NAL NL1, DSL (i/o) and FIG6 formulae was not more than 0.586 which is not an indication of good correlation. This shows that the vocal music was modified by the hearing aid irrespective of the prescriptive formulae used for programming. The FFT obtained for amplified music with DSL (i/o) and FIG 6 showed more differences from the FFT of unamplified music as compared to the FFT obtained for amplified music with NAL NL1. The correlation between the prescriptive formulae shows that there was good correlation between the FFT obtained for the amplified music with NAL NL1, DSL (i/o) and FIG6 prescriptive formulae. Highest correlation was found between DSL (i/o) and FIG6 prescriptive formulae.

The Figure 2 shows the results of objective analysis showing the FFT of unamplified vocal music and that amplified through a hearing aid programmed using NAL NL1, DSL (i/o) and FIG6 prescriptive formulae. As can be seen from the Figure I, the amplified music is different from unamplified music irrespective of the prescriptive formulae used for programming the hearing aid. The differences were seen in the frequency range of 500 Hz to 4k Hz only. At the frequencies above and below this range, there is no difference seen between the unamplified music and the music amplified by the hearing aid irrespective of the prescriptive formulae used for programming. DSL (i/o) provided the highest amount amplification followed by FIG 6 and NAL NL1 respectively except at 500 Hz, 1kHz and 1.5 kHz where the FIG6 provided more amplification than DSL (i/o).

Table 12. The results of Pearson's correlation test for FFT obtained for the vocal music

Test Condition	√
Unamplified music & NAL	0.586
Unamplified music & DSL	0.379
Unamplified music & FIG6	0.458
NAL NL1 & DSL (i/o)	0.852
NAL NL1 & FIG6	0.843
DSL(i/o) & FIG6	0.883

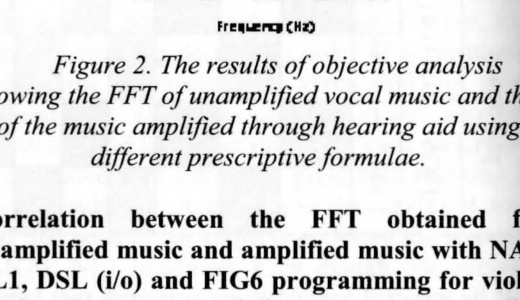

Figure 2. The results of objective analysis showing the FFT of unamplified vocal music and that of the music amplified through hearing aid using different prescriptive formulae.

Correlation between the FFT obtained for unamplified music and amplified music with NAL NL1, DSL (i/o) and FIG6 programming for violin music: Pearson's correlation test was done to find out the correlation between the FFT obtained under the four test conditions. Table 13 shows the results of Pearson's correlation test for the FFT obtained for violin music. The FFT obtained for the unamplified music was compared with that of the amplified music with NAL NL1, DSL (i/o) and FIG6 prescriptive formulae. The FFT obtained for the amplified music with NAL NL1, DSL (i/o) and FIG 6 were also compared across each other.

Table 13. The results of Pearson's correlation test for the FFT obtained for violin music

Test Condition	√
Unamplified music	0.649
Unamplified music	0.353
Unamplified music	0.559
NAL NL1 & DSL	0.666
NAL NL1 & FIG6	0.741
DSL (i/o) & FIG6	0.717

From the table 13 it can be seen that the correlation between the unamplified violin music and the amplified music with NAL NL1 prescriptive formulae was 0.649 which is a fairly good correlation. The correlation between the unamplified violin music and amplified music with DSL (i/o) and FIG6 prescriptive formulae were 0.353 and 0.559 which were not an indication of good correlation. This shows that the violin music was modified by the hearing aid irrespective of the prescriptive formulae used for programming. The amplified music with DSL (i/o) showed more differences than FIG 6 and NAL NL1. The correlation between the prescriptive formulae shows that there was fairly good correlation between the FFT obtained for the amplified music with NAL NL1, DSL (i/o) and FIG6 prescriptive formulae. Highest correlation was found between the FFT obtained for the amplified music with NAL NL1 and FIG6 prescriptive formulae.

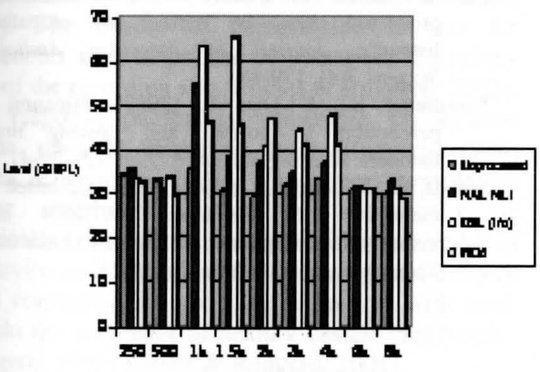

Figure 2. The results of objective analysis showing the FFT of unamplified violin music and music amplified by hearing aid programmed with different prescriptive formulae.

Figure 2 shows the results of objective analysis showing the FFT of unamplified violin music and that of the music amplified through hearing aid programmed using NAL NL1, DSL (i/o) and FIG6 prescriptive formulae. As can be seen in Figure 2, the hearing aid provided amplification to the music in the frequency range of 1 kHz to 4 kHz. At the frequencies above and below this range, there is no difference seen between the FFT obtained for the unamplified music and the music amplified by the hearing aid irrespective of the prescriptive formulae used for programming. DSL (i/o) provides the highest amount amplification followed by FIG 6 and NAL NL1 respectively except at 2 kHz where the FIG6 gives more amplification than DSL (i/o).

The results of subjective analysis showed that for vocal and violin music the aided listening conditions were rated as better than the unaided listening condition. Among the three aided conditions, conditions with DSL (i/o) and FIG6 were found to be significantly better than NAL NL1 prescriptive formulae. The subjective preference was greater for FIG6 followed by DSL (i/o), NAL NL1 and unaided respectively. The results of objective analysis showed that the FFT of unamplified condition was poorly correlated with amplified conditions for vocal and violin music.

Research on hearing aid design mainly focuses on improving speech intelligibility since hearing loss adversely affects speech perception. However, music perception through hearing aid is also an important concern when the person having hearing loss is a musicians or someone who likes to listen to music. In these cases, the design of hearing aid should take into account the hearing aid characteristics that are ideal for music.

The present study investigated the effect of prescriptive fitting formulae on music perception in hearing aid users. Overall, the subjective ratings of quality of vocal and violin music showed that for music perception, aided listening condition was better than unaided condition. In the aided condition, DSL (i/o) and FIG6 prescriptive formulae were rated to be better than NAL NL1.This finding was observed for the rating of clarity, melody, rhythm and naturalness of vocal music and clarity, rhythm and naturalness of violin music. Out of twenty subjects who were participated in the study, thirteen subjects reported that they preferred the hearing aid programmed with FIG6 formulae for listening to music, nine subjects preferred DSL (i/o) formulae and one subject reported equal preference for unaided, NAL NL1, DSL (i/o) and FIG 6 conditions. Considering the importance of low frequency information for music perception, the present study attributes the better rating and subjective preference for DSL (i/o) and FIG6 over NAL NL1 to the prescription of more low frequency gain by FIG6 and DSL (i/o) compared to NAL NL1.The objective analysis showed that the FFT obtained for unamplified music was not correlated well with the FFT obtained for hearing aid processed music which indicated that the unamplified music does become different when it passes through hearing aid.

Conclusions

Listening in the aided condition was better than unaided condition. Hence, it can be said that hearing aids improves music perception in persons with hearing impairment. There is an effect of prescriptive formulae on music perception through hearing aids. According to the present study, DSL (i/o) and FIG6 are better than NAL NL1 for music perception.Irrespective of the prescriptive formula used for programming the hearing aid, music is modified when passing through hearing aids.

The study has implications on designing of hearing aid characteristics for optimizing music perception. The study points out that music and speech are differently processed by hearing aids. Those hearing aid characteristics that result in improvement in speech perception may not result in an improvement in music perception. So, if the hearing aid user wants to listen to music in addition to speech, additional modifications has to be made in the hearing aid in terms of an alternate programme for better music perception. The provision to switch over from the programme suitable for speech to programme suitable for music should be made user friendly. Such developments will assist in improving the quality of life of hearing aid users.

Limitations and future directions

The present study was carried out with the help of perceptual measures of quality of music. Perceptual rating is a highly subjective tool for assessing the quality of music and it is highly variable within and across subjects. Perceptual rating depends upon various subjective factors apart from the perceived musical quality such as knowledge, experience and exposure to music, the physical and psychological state during the evaluation, motivation and memory. Since these factors were not controlled in the present study, the generalization of the results is guarded.

The present study compared three formulae namely NAL NL1, DSL (i/o) and FIG6 all of which were threshold based procedures for hearing aid fitting. Future research may be directed towards comparing music perception between threshold based formulae and loudness based formulae.

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