Acta Scientific Otolaryngology

Volume 3 Issue 5 May 2021

Research Article

Quality of Music Amplified by Hearing Aids

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Received: April 08, 2021

Published: April 20, 2021

Abstract

Hearing aids are known to produce deleterious effect on music perception. This study explored how music perception through hearing aids can be improved. The recorded samples were rated subjectively by three groups of adult listeners. Group 1 consisted of 15 non-musicians, Group 2 included 15 professional singers and Group 3 comprised of 10 instrumentalists. The digital hearing aids were programmed for a flat 50 dB HL hearing loss. In this experiment, four-channelled (HA A) and fifteen- channelled (HA B) hearing aids were used. The knee-points of the hearing aids were set at default setting and at the highest possible setting. The noise reduction system and feedback management system were either turned off or on. A total of seven music samples processed through hearing aids were recorded along with the original sample using the same set up. The subjects rated all these music samples on a five-point perceptual rating scale that was relevant to music. Furthermore, the music samples were evaluated objectively by using the PRAAT software. In every parameter of perceptual analysis, it was observed that the highest rating was given to the original music sample followed by the music sample recorded through HA B with knee-point high, signal processing off and HA A with knee-point high, with signal processing off, respectively. The objective analysis results were similar to subjective analysis. This study demonstrated that a multi-channel hearing aid with knee-point set high and signal processing turned off provided the best representation of original music sample which is in agreement with a previous study.

Keywords: Hearing Aid; Music; Spectral Analysis; Hearing Loss; Music Perception

Introduction

Music is an important and enjoyable aspect of life for people of different age groups. Perception is the process of identifying and interpreting sensory information. When an individual who enjoys listening to music becomes hearing impaired, one may expect a significant deleterious effect on perception of music and the satisfaction derived from it. Hearing aid technology, from its inception, is primarily designed to optimise speech perception. The optimisation of speech perception by hearing aids has been achieved both by the use of appropriate signal processing technology and by the use of prescriptive formula to determine the gain provided by the hearing aid [1]. However, these preferred selection of gain and signal processing strategies for speech may not be appropriate for perception of music [2]. Hearing-impaired listeners perform poorly compared to normally hearing listeners on perceptual tasks related to music perception such as pitch discrimination, melodic intonation and identifying instruments. This happens due to threshold elevation, reduced frequency selectivity, loudness recruitment and anomalies in pitch perception [3-6].

Aim of the Study

The aim of the study was to compare the processing of music by using a four- channelled and a fifteen-channelled hearing aid, wherein all other parameters of signal processing of the hearing aid are kept constant. Moreover, the study aimed to compare the music processed in a four-channelled hearing aid and a fifteen-channelled hearing aid by changing signal processing parameters, such as, noise reduction system and feedback management system of hearing aids. It was expected that a four-channelled hearing aid with knee-point set high and signal processing turned off to give the best representation of the original music sample.

Methods

Participants

Three groups of adult listeners participated in this study; Non-musicians (Group 1); Musicians (Group 2), and the Musician-instrumentalists (Group 3). Overall, 15 non- musicians' adults (M = 20.75; Range: 18 - 25 years), 15 professional singers (M = 39.90; Range: 24 - 59 years) and 10 musician-instrumentalist practicing "Odishi" style of instruments (M = 48.10; Range: 36 - 52 years) were recruited. All these subjects had hearing sensitivity within normal limit with no significant history of either external or middle ear infection, or malformation of the ear.

Materials

Hearing aids

Two digital Behind-The-Ear (BTE) hearing aids, one having four channels (Hearing aid A) and another having fifteen channels (Hearing aid B), were used in this study. These two hearing aids were selected because they used the same signal processing strategy, microphone technology and noise reduction system [23]. Both the hearing aids used expanded dynamic range compression (EDRC), soft-level noise reduction and high-definition noise locator. The music program of the Hearing aid B was turned off. Hearing aid of this particular company was chosen as it employed a slow rate of compression. Moore (2012) in an experiment found out that the compression speed of the hearing aid had an effect at higher input levels (around 80 dB) and preference was given to slower compression speeds [7]. These hearing aids also had an option of switching off the noise cancellation system and feedback management system.

Music sample

A music sample of Carnatic music played instrumentally was selected in this study. The music sample had the lead music played by the violin and the other instrument played was the mrudhangam (an Indian version of drums played with hands). A 90 second duration of sample was selected for the study.

Music sample recordings

A personal computer, installed with the software for programming the particular brand of hearing aids and connected with the appropriate link was used to program the hearing aids. The original music sample was played from a compact disk player connected to a dual-channel audiometer (Maico MA 42) on a loudspeaker (LD systems, 200-Wattpower). The loud speaker was kept at a distance of one metre from KEMAR manikin (IEC 60959) and the sounds were recorded on a laptop using the PRAAT software through a power module 12 AK interface [8]. This was carried out so that the original music sample was recorded in exactly the same condition as the music processed through hearing aids. The samples were later transferred to an audio compact disc. In the same set up, the KEMAR manikin was fitted with different hearing aids in different setting and music sample processed by hearing aids were recorded. All these recordings were carried out in a sound- treated chamber.

Procedure

The hearing aids were programmed for a hypothetical flat sensory neural hearing loss with air conduction threshold being 50 dB HL across all frequencies using prescriptive formula provided by the particular hearing aid company. The knee-point varied across different frequencies and it was set to maximum level at each frequency. The music samples were recorded with noise cancellation and feedback management system off.

Different music samples were recorded in different settings (Table 1). We had a hypothesis that the four-channelled hearing aid will provide a better representation of the music sample. Hence, Hearing aid A recordings were obtained with either or both noise reduction turned off and on, while for Hearing aid B recordings, both these signal processing algorithms were either switched on or off simultaneously. A total of seven music samples processed through the hearing aids were recorded along with the original sample using the same set up.

Music sample	Setting of hearing aid
Sample 1	Original music sample without being processed by hearing aid
Sample 2	Hearing aid B with knee-point high, noise cancellation and feedback management off
Sample 3	Hearing aid A with knee-point high, noise cancellation and feedback management off
Sample 4	Hearing aid B with knee-point high, noise cancellation and feedback management on
Sample 5	Hearing aid A with knee-point high, noise cancellation and feedback management on
Sample 6	Hearing aid A with Knee-point at default, noise cancellation and feedback management off
Sample 7	Hearing aid A with knee-point high noise cancellation on and feedback management off
Sample 8	Hearing aid A with knee-point high noise cancellation off and feedback management on

Table 1: Different music samples recorded with different settings of the hearing aids.

Subjective analysis of the music sample

A five-point perceptual rating scale was used for sound quality judgement. This is a modification of the work of Gabrielsion., *et al.* (1979) that has been used extensively in the hearing aid industry [10,11]. The subjects were asked to rate the music samples on the parameter of loudness, fullness, crispiness, naturalness and overall fidelity. Specifically, the subjects were asked to rate from 1 (poorest) to 5 (best) on the 5-point rating scale. All the subjects in the three groups listened to the samples in a quiet room. Each subject listened to the eight different music samples. The participants on arrival in the clinic were explained about the study and a written consent for participation in the testing was obtained from them. The listeners were given a written instruction in English. The instructions were further clarified by the experimenter before the subjects rated the music sample. The music samples were played to the listeners from a laptop by using the PRAAT software through the head phones (Fontopia MDR-EX51LP Consumer Headphones from Zebronix Company). Statistical analyses were carried out using Statistical Package for the Social Sciences (SPSS, Version 20). The non-parametric test was used in the statistical analysis. The perceptual data, measured by the five perceptual parameters, was used to see the pairwise difference between the groups, wherein the comparisons were made taking two groups at a time by using the Mann-Whitney *U* test. The Wilcoxon signed rank test was used to compare the original music samples with other music samples.

The software version that we used allowed us for analysing samples of 10 seconds epoch window. In total three 10-second duration of music samples were selected for spectral analysis by using the PRAAT software. For the precise comparison, samples of music were taken from the original music sample and the hearing aid processed music samples at the exact time interval, i.e. at the interval from 14 to 24 seconds, 48 to 58 seconds and 74 to 84 seconds.

Results

Subjective analysis

For the subjective analysis, the 45 participants listened to the samples and rated them by using the 5-point rating scale. In the loudness parameter, the highest rating was given to music sample 1 followed by samples 2 and 3. For fullness parameter, the highest rating was given to music sample 1. The second highest rating was given to music sample 2 by all the three groups of participants. For clearness parameter, the highest mean value rating was given to music sample 1 followed by music sample 2. The mean clearness rating of the rest of the music samples were not significantly different. In naturalness parameter, the highest rating was given to music sample 1, followed by samples 2 and 3, respectively. The mean of the rest of the music sample had a very little difference. For overall fidelity parameter, the highest mean value rating was given to music sample 1 followed by music sample 2.

The Mann-Whitney *U* test was used to observe the pairwise differences between the different groups of participants. It was revealed that the singers and instrumentalist did not differ in their rating of any of the samples and, hence, they were grouped together for further analysis. The original music sample was compared with the music sample recorded in the different setting of hearing aids using the Wilcoxon signed rank test. In this test, the non-musicians (Group 1) were taken separately, and the singers (Group 2) and instrumentalists (Group 3) were grouped to form the musicians group.

		Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
Loudness	Group 3	4.90 (0.31)	3.90 (0.73)	2.0 (1.49)	2.70 (1.33)	1.60 (0.84)	1.70 (1.05)	1.80 (1.31)	1.70 (0.82)
	Group 2	3.67 (0`81)	3.53 (1.68)	2.0 (1.06)	2.93 (1.03)	1.86 (0.83)	1.46 (0.74)	1.67 (0.81)	1.73 (0.88)
	Group 1	4.53 (0.74)	4.20 (0.56)	2.86 (0.74)	2.80 (0.94)	2.20 (0.77)	2.00 (0.84)	2.60 (0.82)	2.40 (0.59)
Fullness	Group 3	4.50 (0.97)	3..70 (1.05)	1.70 (1.05)	2.30 (0.94)	1.50 (0.70)	1.80 (1.22)	1.50 (0.70)	1.70 (0.94)
	Group 2	3.60 (1.39)	3.33 (1.54)	2.20 (1.32)	2.40 (1.12)	1.60 (0.73)	2.00 (1.16)	1.60 (0.91)	1.93 (1.16)
	Group 1	3.93 (1.16)	3.60 (0.81)	2.73 (0.79)	2.53 (0.99)	2.53 (0.83)	2.20 (0.77)	2.66 (0.89)	2.26 (0.59)
Clearness	Group 3	4.50 (1.26)	3.60 (0.84)	1.70 (1.33)	2.40 (0.69)	1.90 (0.87)	2.20 (1.13)	1.60 (0.96)	1.90 (0.99)
	Group 2	3.46 (1.18)	3.26 (1.48)	1.67 (1.11)	2.13 (1.06)	1.86 (0.91)	1.80 (0.77)	1.53 (0.91)	1.53 (0.91)
	Group 1	4.33 (0.97)	4.06 (0.88)	3.00 (0.84)	2.46 (0.91)	2.53 (0.74)	2.33 (0.81)	3.20 (0.67)	2.86 (0.83)
Naturalness	Group 3	4.60 (1.26)	3.50 (0.97)	1.50 (0.97)	2.20 (0.78)	1.80 (0.91)	2.20 (1.31)	1.40 (0.69)	1.80 (0.78)
	Group 2	4.06 (0.79)	3.06 (1.43)	2.33 (1.34)	2.06 (1.09)	2.26 (1.38)	2.26 (1.38)	1.80 (1.14)	1.86 (1.24)
	Group 1	4.20 (1.01)	3.80 (1.01)	2.93 (0.88)	2.13 (0.99)	2.66 (0.89)	2.33 (0.72)	3.00 (1.00)	2.86 (1.12)
Overall Fidelity	Group 3	4.50 (1.26)	3.50 (0.84)	1.40 (0.96)	2.30 (0.82)	1.40 (1.10)	1.90 (0.99)	1.40 (0.69)	1.90 (0.96)
	Group 2	3.80 (1.20)	3.06 (1.38)	1.93 (1.27)	2.13 (0.91)	1.80 (0.86)	1.93 (1.09)	1.80 (1.14)	1.86 (1.27)
	Group 1	4.50 (1.26)	3.50 (0.84)	1.40 (0.96)	2.30 (0.82)	1.40 (1.10)	1.90 (0.99)	1.40 (0.69)	1.90 (0.96)

Table 2: Mean and standard deviation (S.D) values of the five parameters in the perceptual rating scale of all the recorded music samples by three groups of participants.

The Wilcoxon signed rank test revealed that the non-musicians and musicians group rated loudness of the music sample 2 to be similar to the original music. The other music samples recorded through hearing aids were rated as significantly different from the original music by both the groups of listeners (Non-musicians and Musicians).

In fullness parameter, both the groups rated fullness of the music samples in different conditions to be significantly different from the original music (P = 0.005), but rating of the music sample 2 was not significantly different from the original sample.

For the parameter of clearness, both the groups (Non-musicians and Musicians) rated the music samples in different condition to be significantly different from the original music. They rated the music sample 2 to be not significantly different from the original music sample (P = 0.05).

The Non-musicians rated the music sample 2 as significantly not being different from the original music sample in the parameter of naturalness. However, the musicians group rated the music sample 2 to be significantly different from the original sample. All other samples were rated as significantly different from original music sample in the parameter of naturalness.

The Non-musicians rated the music sample 2 to be similar from the original music sample in the parameter of overall fidelity. However, the musicians group rated the music sample 2 to be significantly different from the original sample (P = 0.02) in this parameter. All other samples were rated as significantly different from sample 1 for overall fidelity parameter.

Overall, it was observed that the fifteen-channelled hearing aid with knee-point set high and signal processing algorithms turned off gave the best representation of the original music sample followed by the four-channelled hearing aid with similar signal processing settings. In addition to the subjective analysis, the music samples were also subjected to spectral analysis.

Spectral analysis

The result of the objective measure was similar to that of the subjective measures. In the version of the PRAAT software used, a sample of maximum 10 seconds could be analysed, hence, the sampling for each music sample was done at intervals from 12 to

Sample No	Loudness		Fullness		Clearness		Naturalness		Overall Fidelity	
	Non-Musician	Musician	Non-Musician	Musician	Non-Musician	Musician	Non-Musician	Musician	Non-Musician	Musician
2	1.68	1.27	0.91	1.18	1.01	1.44	1.10	2.78**	1.27	2.14*
3	3.48**	3.94**	2.44**	3.70**	2.59*	3.88**	2.50*	3.98**	2.97**	3.93**
4	3.22**	3.38**	2.96**	3.61**	3.17**	3.75**	3.20**	4.19**	2.96**	4.03**
5	3.50**	4.32**	2.84**	4.23**	3.14**	3.79**	2.86*	3.85**	3.02**	3.95**
6	3.47**	4.32**	3.19**	3.58**	3.34**	3.74**	3.30**	4.00**	3.10**	3.95**
7	3.50**	4.15**	2.95**	4.17**	2.98**	4.05**	2.36*	4.12**	2.82**	3.94**
8	3.46**	4.24**	3.10**	3.64**	2.71**	3.94**	2.23*	4.01**	3.10**	3.84**

Table 3: Difference between the original sample and the other samples by non-musicians and musicians.

*: Significant difference at 0.05 level.

**: Significant difference at 0.01 level.

22 seconds, 48 to 58 seconds and 74 to 84 seconds. The energy concentration at each of octave and mid-octave frequency was measured and was plotted as graphs as shown in figure 1. From the figures it was evident that the music sample 2 gave the best representation of the music sample. The music sample 3 (Hearing aid A with knee-point high, noise cancellation system and feedback management system turned off) and music sample 4 (Hearing aid B with knee-point high, noise cancellation system and feedback management system turned on) gave the second and third best representation of the original music sample, respectively. It was noticed that activation of the noise cancellation system or the feedback management system in the hearing aids led to degradation of the sample in terms of reduction of energy level in the low frequencies and increase of energy in mid- and high frequencies.

Figure 1.1: Hearing aid output at different frequencies for different samples, in 12 to 22 second interval.

Figure 1.2: Hearing aid output at different frequencies for different samples, in 48 to 58 seconds interval.

From this graph it was evident that the outputs from the hearing aids were lower than the original in the low frequency. Nonetheless, from the mid frequency, around 1 kHz to 4 kHz, the hearing aid amplified the music. The activation of the noise cancellation system and feedback management system (Samples 4, 5 and 8) led to a reduction of energy at the frequency about 2 kHz, which is evident as a dip in the energy output. The output through Hearing aid B gave the best representation of the original music.

Figure 1.3: Hearing aid output at different frequencies for different samples, in 74 to 84 seconds interval.

Discussion

This study involved both the perceptual and spectral analysis of music samples processed by hearing aids in different varieties of settings. The quality of music can be determined by a perceptual analysis and the poor ratings given to a music sample can be explained by the objective analysis of the music sample. Hence, the study evaluated the music samples processed by hearing aids, both subjectively and objectively.

Subjective evaluation of music sample

Both the hearing aid chosen in this experiment employed a slow rate of compression as slow rate of compression provided better representation of music [9]. A much poor rating was given to the music sample processed by hearing aid compared to original music sample by all the three groups of participants. This is in agreement with previous studies [2,10-15]. Frequency in harmonicity introduced by modern digital hearing aids is the primary reason for perception of poorer quality of music processed by hearing aids. In this study, it was expected that the four-channelled hearing aid would give a better representation of music. However, the fifteen-channelled hearing aid having noise cancellation system and feedback management system off (Sample 2) always gave a better rating on all the five perceptual rating scale in comparison to other samples. The knee-point was recommended to set between 65 dB and 75 dB for better perception of music through the hearing aid [11]. The knee-point of Hearing aid A was set at the highest possible level for different frequencies, but no significant difference was found between the ratings given to the music in the condition wherein the knee-point was at default setting (Sample 6) and wherein the knee-point was raised (Sample 3) with the feedback management and noise cancellation system turned off for Hearing aid A.

The activation of noise cancellation system in Hearing aid A with knee-point high (Sample 7) led to a poorer rating compared to the rating given to Hearing aid A with knee-point high and noise cancellation system and feedback management system turned off (Sample 3) by all the three groups of participants which is in agreement with the previous studies [2,13,16-18].

The activation of the feedback management system in Hearing aid A with the knee-point high (sample 8) also leads to poorer rating on all the perceptual parameters as compared to the condition when both the feedback management system and the noise cancellation system was turned off (Sample 3). However, the instrumentalist group rated the music sample higher in the condition of activated feedback management system in parameters of clearness, naturalness and overall fidelity. The rest of the subjects rated the same sample to be poorer than the sample from the fifteen-channelled hearing aid with signal processing algorithm turned off. Nevertheless, the difference was not statistically significant.

Spectral analysis

The output from hearing aid gave a poor representation of the original music sample in the lower frequencies. Furthermore, in the mid frequency, from 1 kHz to 4 kHz, the hearing aid amplified the music. Hearing aid outputs did not represent the original music sample well, especially, in the lower frequencies. The lack of perception of music quality, in terms of loudness and naturalness, has been also objectively verified previously. Moreover, the findings of this study are similar to this previous study [14].

A single- or double-channelled hearing aid was conceptualised to be ideal for music perception [16]. Subsequent studies reported a multi-channel hearing aid made to function as a single channel hearing by setting the same parameters in all the channels was better for music perception [10,13]. Contrary to the expectation, the fifteen-channelled hearing aid performed better than the four-channelled hearing aid in representing the original music sample in this study.

In this study, Hearing aid A with knee-point set higher, noise cancellation and feedback management system turned off (Sample 3) always gave higher energy output compared to hearing aid with default knee-point setting, noise cancellation and feedback management turned off (Sample 6). The activation of noise cancellation system in both the hearing aids (samples 4, 5 and 7) led to decrease in energy in the lower frequency. The activation of the feedback management system in both the hearing aids (samples 4, 5 and 8) led to a suppression of energy at around the frequency of 2 kHz which is evident as a dip in the energy output. The diminished quality of perception of music with activation of noise reduction system and feedback management system is in agreement with previous study [14].

Summary of the subjective and spectral analysis

All the music samples recorded through the hearing aid were given a poorer rating in the subjective rating by all the listeners. In the previous studies, it was shown that the hearing aid users always preferred a lower cut-off frequency in judgement of the quality of music [19,20,23]. The information in the low frequencies contributes significantly to the quality judgement of music [16]. The output of the hearing aid was always poorer than the original music sample in the low frequencies region and the hearing aids were able to amplify the music after a frequency of around 1 KHz. In a previous study, music processed through the hearing aids showed a poor representation of waveform in the low- frequency regions [11].

Increase in the number of channels in hearing aid leads to different gain and compression setting in different frequency bands and leads to disturbance of the low-frequency fundamentals and the high-frequency harmonics. The graphs obtained for the outputs of the hearing aid in different condition also showed that setting the knee-point higher gave a better representation of the music in the lower frequencies. When the knee-point was set at the default setting for speech, the output of Hearing aid B was much lower in intensity in the low- frequency region (Sample 6). On raising the knee-point, the output obtained from the Hearing aid A was better compared to the default setting.

From the spectral analysis, it was observed that the activation of the noise cancellation system lead to suppression of energy in the low-frequency region. The hearing aids used these days filter out speech and noise in the low frequencies because for time invariant noise, the energy concentration is mostly in low frequencies that masks the speech. Therefore, filtering out both speech and noise over this frequency range will either have little or no effect on intelligibility, but will reduce the loudness and annoyance of the noise, i.e., overall sound quality will be improved [21]. In this study, it was noted that whenever the feedback management system was activated, it led to a dip at the frequency region of around 2 kHz. Most hearing aids use a notch filter to counter the acoustic feedback, where the notch is tuned to remove a narrow band of frequency around the offending frequency [22]. Suppression of energy in a particular frequency will have a deleterious effect on music perception as the gain should be equal and balanced over the frequency region for the optimal perception of music.

Conclusion

The findings of the study revealed that a multi-channel hearing aid with knee-point set at maximum level and signal processing turned off will be ideal for music perception. Future research can be carried out on hypothetical high-frequency hearing loss and also can explore the adverse effect of hearing loss on music perception using the same paradigm for study.

Acknowledgement

The authors are thankful to Widex India Pvt. Ltd. for providing access to Kemar Mankin. The authors are also grateful to Secretary, International Institute of Rehabilitation Sciences and Research (IIRS & R) for permitting us to conduct the study.

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