Music Processed by Hearing Aids

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Abstract

The processing of music by hearing aids is a challenge which the hearing aid industry is facing today. The present study is an attempt to study the hearing aid processed music while changing different parameters of the hearing aid. Thus through a controlled study design the parameters in a hearing aid appropriate for good music perception were evaluated. The evaluations were done using the spectral measurement and subjective perception of the music samples processed by hearing aids programmed with different parameters.

The recorded music samples were subjected to perceptual analysis of five parameters on a five-point rating scale and objective analysis was done using spectral slice in Praat software. The results of objective and subjective analysis implied the following settings of the parameters in the digital hearing aid to be more appropriate for the music sample studied. All these conclusions are made with reference to the music samples, hearing aids and settings that were used in the study. A fifteen channeled hearing aid was better for music perception than a six channeled hearing aid. Further, the knee-point for ideal music perception should be set as high as possible till it is not uncomfortable for the subject, feedback management and the noise cancellation system should be turned off.

Key words: spectral measurement, music perception, compression knee-point, Noise cancellation, feedback management

Introduction

Music is an important and enjoyable part of life for people of all ages. It has been found to release tension, raise spirits and promote a feeling a well-being. There are just a few people who do not enjoy listening to music but there are many people who regard music as one of their chief pleasures. Music is an important ingredient of every culture throughout the world as a form of entertainment and as a form of an art.

Following the perception of speech the appreciation of music is the next commonly expressed requirement by the users of cochlear implants (Stainsby, McDermott, McKay & Clark 1997). This may well be said for the individuals who use hearing aids also. When the individuals who enjoy listening to music acquire hearing impairment one might expect a significant effect on music perception and the pleasure derived from music. Although there may be some restoration of hearing through the use of hearing aids, it is questionable whether most hearing aids process

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music in such a way as to enable the user to hear and enjoy music to the same degree as prior to acquiring hearing loss.

The reason that individuals with hearing impairment fail to perceive or appreciate the sound quality of music is because the hearing loss has differential effects on frequency selectivity, temporal resolution, loudness perception/intensity discrimination and suprathreshold performance. These contribute to the difficulty of the individuals with hearing impairment to perceive or appreciate music (Chasin, 1996).

There is a dearth of research in the field of music and hearing impairment. This is also because the musicians and the scientists often use different terminologies in describing the characteristic of a tone. For example, a researcher may say 440 Hz tone and a western musician may denote it by ‘A’. The musicians are particularly interested in the tones below ‘C’, i.e. 262 Hz. But most audiologists would ignore the sound energy below 250 Hz because of the poor signal-to-noise ratio and because of hearing assessment problems. But for musicians this low frequency information can significantly contribute to the quality judgment (Chasin, 2003).

Speech tends to be a well controlled spectrum with well established and predictable perceptual characteristics. In contrast music spectra are highly variable and the perceptual requirement can vary based upon the musicians, type of music and the type of instrument being played. There are five major differences between speech and music stimuli as reported by Chasin (2003 & 2006) and Chasin and Russo (2004). They are (i) the long-term average spectrum of music vs. speech (ii) differing overall intensities (iii) crest factors (iv) phonetic vs. phonemic perceptual requirements and (v) difference in loudness summation and loudness intensity.

Unlike the long-term average spectrum of speech, music is highly variable and a goal of a long-term average music spectrum is poorly conceived. The potential intensity range for speech is quite restricted, approximately 30 to 35 dB. But the dynamic range of music is of the order of 100 dB. A typical crest factor with speech is about 12 dB. Crest factors of 18 to 20 dB are not uncommon for many musical instruments. The perceptual need for speech is quite clear. But for music the perceptual need is quite varied and depends upon the instrument being played. The vocal cords function as half wave resonators whereas the musical instrument can be half wave resonator or quarter wave resonator depending upon the instrument which is played. These differences make it difficult for a hearing aid user to enjoy music with a hearing aid that is mainly designed for speech.

Historically the primary concern for the hearing aid design and fitting is the optimization for speech input (Chasin & Russo, 2004). Musicians with hearing loss have often complained about the poor sound quality while they are playing or listening to the music through their hearing aid (Chasin, 2003). Not only the technology for music input in hearing aids is in its infancy but the research and clinical knowledge of what the musicians and those who like to listen to music need to hear is also in the early stage of understanding (Chasin & Russo, 2004). Presently, the digital technology is replacing the analog technology used in the hearing aid industry. The digital technology has the advantage of employing various algorithms such as adaptive noise-reduction systems, adaptive directionality, adaptive feedback suppression and highly flexible control of numerous amplification characteristics including complex forms of compression. Digital technology is also enabling the processing of sounds in different channels having different compression settings. Chasin (2003, 2006) recommended a set of parameters being ideal for the perception of music through the hearing aids. Thus, through a controlled study design the parameters in a hearing aid ideal for music perception need to be evaluated.

The present study is an attempt to evaluate the hearing aid processed music while changing different parameters of the hearing aid. Thus, the objectives were as follows:

1. To compare the processing of music by using a six-channeled and a fifteen-channeled hearing aid where all the other parameters of signal processing of the hearing aid are kept the same.
2. To compare the music processed in a six-channeled hearing aid with
    a. the compression knee-point being set high than that optimized for speech for a particular hearing loss
    b. by enabling and disabling the noise reduction system
    c. by enabling and disabling the feedback management system

Method

The efficacy of the hearing aids was evaluated using the subjective perception and objective spectral analysis of the music samples processed by the hearing aids.

Participants

Three groups of participants participated in this study, namely, Group I (Non-musicians group), Group II (Musicians-Singers group) and Group III (Musicians-Instrumentalists Group). They had hearing sensitivity within normal limits with no significant history of external or middle ear infection or malformation of the ear.

Group I (Non-musicians group):15 participants with no formal education in music were considered. The age of the participants ranged from 18 to 25 years (mean age of 20.75 years). It was ensured that all the participants selected in the study enjoyed listening to music.

Group II (Musicians-Singers group): 15 participants with at least 10 years of experience in professional singing were selected. The age range of the participants was from 24 years to 59 years (the mean age of 39.90 years). The average experience with professional singing in this group was 24.8 years (range being 10 to 39 years). In order to have homogeneity in the group care was taken to see that all the participants were practicing the Carnatic style of singing.

Group III (Musicians-Instrumentalists Group): 10 participants were selected in this group. All the participants were practicing ‘Odissi’ style of playing the instrument. Three of the instrumentalists played sitar, two of them played the flute, three played the sarod and the other two played the veena. The age range of the participants was between 36 and 52 years (mean age being 48.10 years). The average experience in professional music for this group was 27.2 years (range being 24 to 32 years).

Instruments used

Hearing Aids: Two commercially available digital Behind-The-Ear (BTE) hearing aids were used in the study. The first hearing aid (Hearing aid A) was a six-channeled hearing aid and the second hearing aid (Hearing aid B) was a fifteen-channeled hearing aid. These two hearing aids were selected because, apart from the number of channels, the signal processing strategy, the microphone technology and the noise canceller were technically similar. Both the hearing aids used wide dynamic range compression (WDRC), dynamic noise canceller (dNC), feedback management system and an omni directional microphone technology. Both these hearing aids had an option of switching off the noise cancellation system and the feedback management system.

Computers and Hi-Pro: A personal computer installed with NOAH (3.0 version) software and connected with Hi-Pro were used to program hearing aids. Two laptops operating on Windows XP and Praat software were also used in this study for recording the music sample. Frontech speakers, 340 Watt PMPO were connected to the laptop that played the music. The volume was set at a comfortable loudness level. The music samples were recorded on another laptop using the Praat software. These samples were later transferred to an audio compact disc. The sampling rate used in all the recording of the study was 32 kHz. The music samples were played to the listeners from a laptop through the head phones (Fontopia MDR-EX51LP Consumer Headphones) using the Praat software.

Coupler: A 2 cc coupler (HA-2) was used for coupling the hearing aid to the microphone while recording.

Microphone: An omni directional microphone was connected to the laptop computer. This microphone was in turn attached to the coupler using ‘fun tak’ to record the output from the hearing aid on the laptop using the Praat software.

Music Sample: A music sample recorded on an audio compact disc was used. Carnatic music which was being played instrumentally was selected. The music sample had the lead music played by violin and the other instrument being played was the mrudhagam. The music sample was chosen from the music album titled ‘lagudi’ and the music was based on raaga ‘Mohana Kalayani’. 90 second duration of the sample was selected for the purpose of evaluation.

Room Setting: A sound treated air conditioned room was selected for recording the music sample from the hearing aids. The ambient noise levels inside the room were within permissible limits.

Procedure: For the purpose of the study, the study was divided into 4 stages:
Stage 1: Recording of the hearing aid processed music samples
Stage 2: Programming of the hearing aid

Stage 3: Subjective analysis of the music samples
Stage 4: Measurement of spectra of the music samples

Stage 1: Recording of the Hearing Aid Processed Music

For the comparison of the effect of channels on processing of music, two digital hearing aids were taken; one comprising of 6 channels (Hearing aid A) and the other comprising of 15 channels (Hearing aid B). The knee-point of both the hearing aids was at 54 dB when programmed for the speech in quiet (default program). The knee-point was raised by 18 dB to make it 72 dB. The music samples were recorded with noise cancellation and feedback management systems off. Apart from the difference in number of channels the other signal processing parameters in the hearing aids were similar.

A sample was recorded from the fifteen channeled hearing aid (Hearing aid B) with knee-point set at 18 dB higher than the default knee-point setting for the speech as recommended by the first fit of the programming software. This time both the noise cancellation system and the feedback management system were turned on.

For recording the other music samples a 6-channeled digital hearing aid (Hearing aid A) was selected. Music sample was played to the programmed hearing aids. The hearing aid processed music was recorded. During recording of different samples the hearing aid A was taken and the hearing aid processed music was recorded in each of the following conditions: knee-point set at 72 dB with both the noise cancellation system and feedback management systems switched off initially. Then, a music sample was recorded with the high knee-point (i.e., 72 dB) with the noise cancellation system on and the feedback management system off. Later another music sample was recorded with the knee-point being high (i.e. 72 dB) with the feedback management system on and the noise cancellation system off. Finally, a music sample was recorded with the noise cancellation system and feedback management system being switched on with the knee-point being high (i.e., 72 dB).

On the whole there were eight music samples; two from the fifteen channeled hearing aid, five from the six channeled hearing aid and the original music sample recorded through the coupler. They are given in the following Table 1.

Thus, the recording of the music sample without and with the hearing aid was done. These eight recorded music samples were later used for the subjective ratings and the spectral analysis. The music sample was played using Praat software from a laptop through the speakers. The hearing aid was placed at equivalent distance of 5 cm from either of the speakers and at 90^0 Azimuths, as shown in the figure. A foam sheet was placed below the hearing aid so that it did not pick-up any noise due to vibration of the table. It was taken care that the microphone of the hearing aid was at the level of centre of the speakers. The digital hearing aid was connected to a HA-2 (2 cc) coupler which in turn was connected to the recording microphone. The recording microphone was connected to the lap top computer for recording the music sample using the Praat software. All the recordings in Praat software were made using 16 bit mono recording.

Thus, the music processed by the hearing aid in each of the seven different programmed settings of the hearing aids was recorded.

Table 1: The eight music samples recorded with different settings of the hearing aids

Music samples	Conditions of recording
Sample 1	Original music sample recorded through 2 cc coupler
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

In order to make all the music samples equivalent, the original music sample was also played in the same condition and recorded through the coupler to make the unprocessed music sample equivalent to the music sample processed through the hearing aids. The music samples were not normalized. The samples were then transferred to an audio compact disc.

Stage 2: Programming of the Hearing Aid

The hearing aids were programmed for a hypothetical flat sensorineural hearing loss with air conduction threshold being 50 dB HL at all the audiometric frequencies. A flat hearing loss was used so that the compression characteristic, when tested, remained same across all the frequencies. The digital hearing aid was connected through a Hi-Pro to the personal computer (PC) with software for programming. After the hearing thresholds were fed into the software (NOAH 3.0) the digital hearing aids were programmed based on the NAL-NL1 prescriptive procedure in the hearing aid programming software. An acclimatization level of 2 was used while programming.

Stage 3: Subjective analysis of the music samples

Measures of quality judgment of the music samples were obtained using five, five-point perceptual rating scales that was relevant to music. This is a modification of the work of Gabrielsion and Sjogren (1979) that has been used extensively in the hearing aid industry (Chasin & Russo, 2004). The participants were asked to rate the music samples on the perceptual parameters of loudness, fullness, crispiness, naturalness and overall fidelity. Participants were given the following definitions of the five perceptual parameters (Chasin & Russo, 2004).

Loudness was defined as the music that is sufficiently loud in contrast to faint, ranging from 5 to 1 on the rating scale. Fullness was defined as the music being full in contrast to thin, ranging from 5 to 1 on the rating scale. Clearness was defined as the music being clear and distinct in contrast to being blurred or diffused, ranging from 5 to 1 on the rating scale. Naturalness being defined as the music seems to be as if there is no hearing aid and the music sounds as “I remember it”, ranging from 5 to 1 on the rating scale. Overall fidelity being defined as that the dynamics and range of the music is not constrained or narrowed, ranging from 5 to 1 on the rating scale.

Specifically, the participants were asked to rate from 1 (poorest) to 5 (best) on the following perceptual scales: loudness, fullness, crispiness, naturalness and overall fidelity. Thus, a perfect perceptual reproduction score was 25 considering all the five parameters on the scale. The scales for rating on the five parameters were as follows:

1. For loudness: 1 (faint)……………….5 (sufficiently loud)
2. For fullness: 1 (thin)………………5 (full)
3. For clearness: 1 (blurred)………………5 (distinct and clear)
4. For naturalness: 1 (unnatural)……………...5 (natural)
5. For overall Fidelity: 1 (restricted)………………5 (wide and not constrained)

The music samples were played from a computer using the Praat software through the head phones (Fontopia MDR-EX51LP Consumer Headphones). The participants were instructed to listen to the samples at their comfortable loudness level.

All the participants in the three groups were made to listen to the music samples in similar conditions. A relatively quiet room away from traffic noise and other noises was selected. Each subject was made to listen to the eight different music samples mentioned above.

Instruction: The participants were given an identical set of instruction in a written format, in English, so that the instruction for all the participants remained essentially the same. Four participants in Group III asked for instruction written in Oriya, hence a translation of the instruction were done which was verified by two graduate students in Oriya for the correctness of the meaning. The instructions were further clarified by the experimenter before the participants rated the music sample, if required. It was made certain that the participants were absolutely clear with the terminology and completely certain about the rating scale before they rated the music samples.

Stage4 - Measurement of spectra of the music samples

The selected music sample, from the recorded music samples, as processed by the hearing aid were subjected to spectrum analysis using the Praat software. For the precise comparison equivalently paired music slices were taken from the eight music samples. In each of the samples recorded the samples for analysis were taken at the interval of 14 to 24 seconds, 48 to 58 seconds and 74 to 84 seconds. Three ten-second duration of the music samples were selected for analysis with Praat software as the Praat software could analyze the music sample of less than 10 second duration. Spectral analysis of three ten-second duration of the music samples was obtained in the Hammin window. The energy concentration at octave and mid-octave frequencies (from 200 to 8000 Hz) was measured and tabulated.

Results

The main objective of the study was to compare the processing of music through different hearing aid settings, subjectively using a rating scale and objectively using the spectral analysis.

Subjective Analysis

For the subjective analysis the samples were first presented to 40 listeners to be rated on a rating scale. There were a total of eight music samples. Details of these samples are provided in Table 1. The original music sample and seven hearing aid processed music samples were rated on a five-point rating scale. These ratings were tabulated. The statistical analysis was carried out with the help of the Statistical Package for the Social Sciences (SPSS, Version 10). The non-parametric test was used in the statistical analysis. The data, in terms of the five parameters, were analyzed for the comparison of the three groups of participants using Kruskal-Wallis test (Non-parametric equivalent of one-way ANOVA). Mann-Whitney U test was used to see the pair-wise difference between the groups, where the comparisons were made taking two groups at a time. Later, the original music sample was compared with all the other music samples using the Wilcoxon Signed Rank test. These analyses were repeated for all the five parameters.

The Kruskal-Wallis and Mann-Whitney U Test was applied to all the parameters in the rating scale. It revealed that the there was a significant difference ($p<0.05$) between the ratings given by the non-musicians and singers, and the non-musicians and instrumentalists. But the rating given by the singers and the instrumentalist group was not significantly different ($p>0.05$). Wilcoxon signed rank test revealed that the non-musicians rated the music sample recorded from the fifteen channeled hearing aid with the noise reduction system and feedback management system (sample 2) to be similar to the original music sample ($p>.05$). It was interesting to note that the instrumentalist and the singers group rated the sample 2 to be similar to the original music sample in three parameters of perceptual rating but rated it to be different in two parameters, namely, naturalness and overall fidelity.

Spectral Analysis

The result of analysis of the objective measures was similar to subjective measures.

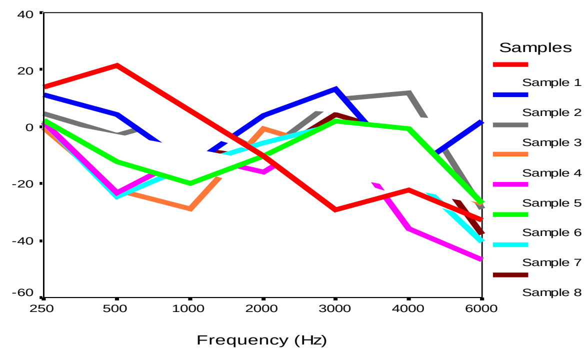

Fig. 1: Hearing aid output at different fqs for different samples, in 48 to 58 seconds interval
Note: All the values in the graph are referenced to 2.10^{-5} dyne/cm^2

Since on the Praat software a sample of maximum 10 seconds could be analysed, the sampling for each music sample was done at intervals of 12 to 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. All the three figures showed similar pattern and Figure 1 represents the sample in the interval 48 to 58 seconds.The descriptions of the music sample are given in Table 1. From the figures it is evident that the music sample 2 (Hearing aid B with knee-point set high, noise cancellation system and the feedback management system turned off) gave the best representation of the original music sample. The music sample 3 (Hearing aid A with knee-point high, noise cancellation and feedback management off) and music sample 4 (Hearing aid B with knee-point high, noise cancellation and feedback management on) gave the second and third best representation of the original music sample respectively. From the graph, it was evident 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 level in mid- and high-frequencies.

From the figure, it was evident that the outputs from the hearing aids were lower than the original in the lower frequency. But from the mid-frequency, around 1 KHz to 4 KHz, the hearing aid amplified the music. The activation of the feedback system and noise cancellation system (Sample 4, 5 & 8) led to a reduction of energy at the frequency about 2 KHz which is evident as a dip in the energy output. It is quite evident from the graph that the output through hearing aid B gave a better representation of the original music.

Discussion

The perception of music is dependent on various factors such as the relationship of the harmonics in the lower frequency fundamentals and the higher frequency harmonics, the concentration of energy in the lower frequency, the temporal resolution of the music in the ear in order to be judged as good in quality. Hence the objective spectral evaluation of the output alone will not provide a clear picture of the quality of music processed by a hearing aid. The finding from the objective study should be complimented by a subjective study. A perceptual rating inherently has many factors which are dependent on the subject. The experimenter has limited or no control over the subject-dependent factors such as motivation, understanding and bias of the participants. Hence the study evaluated the music samples processed by hearing aids both subjectively and objectively.

Integration of the Subjective and Spectral Analysis

All the eight music samples recorded through the hearing aid were given a poorer rating subjectively by all the listeners. In the studies done earlier hearing aid users have always preferred a lower cut-off frequency in judgment of the quality of music (Punch, 1978; Frank & Hall, 1985). Chasin (2003) noted that the information in the low frequencies contributed significantly to the quality judgment of music. The figures depicting the hearing aid output at different frequencies for different samples revealed that neither the hearing aid A nor the hearing aid B represented the original music well in the lower frequency region. The output of the hearing aid was always poorer than the original music sample in the lower frequency region and the hearing aids were able to amplify the music after a frequency of around 1 KHz. Mishra and Abraham (2007) have also noted that overall music processed through the hearing aids showed a poor representation of waveform in the low frequencies. It can be noted that the sample in which the hearing aids provided a good representation of the music in the lower frequency are rated higher by the listeners. The figures depicting the original music showed a concentration of energy in the lower frequency region and the energy falling precipitously after a frequency of 500 Hz. All the subjective/perceptual ratings indicated a much higher rating for the original music sample which had relatively higher energy in the low frequency region.

Further, it was seen in this study that the hearing aid B having 15 channels represented the original music better on perceptual rating with the knee-point being set higher. The observation of the figures which represented the output from the hearing aid also depicted that the output from the Hearing aid B having the knee-point raised to 72 dB (Sample 2) gave better representation of the original music sample (Sample 1) than Hearing aid A with similar settings. Hearing aid A with the knee-point raised to 72 dB (Sample 3) followed the output from the Hearing aid B. In the perceptual rating too the ratings given to the hearing aid B, with the knee-point high and the noise cancellation and feedback management off, was not significantly different from the original music.

The rationale for having a single channel or double channel hearing aid is to have equal compression ratio across the entire frequency range remains equal so that the ratio of the energy in the low frequency and the high frequency remains essentially the same. According to Chasin, and Russo (2004) if there is an imbalance in the amplification in the low frequencies and the high frequencies the timbre will be affected.

Chasin (2003) noted that for wood wind instruments and quieter music or for clients with precipitous sloping audiometric configuration, a multi-channel hearing aid may be acceptable, since for the wood wind instruments the perceptual reliance is on the information in the lower frequencies. But the music sample selected in the present study was not produced by any wood wind instrument and the lead instrument was violin.

Chasin and Russo (2004) had noted that some musical instruments like piano and violin are more speech-like. Such instruments are half wave resonator with evenly spaced harmonics. Since the lead instrument in the music sample in the present study was violin this may be a reason why a fifteen channel hearing aid performed better than a six channeled hearing aid. It has been noted in various studies that multi-channel hearing aids improve speech perception (Mispagel & Valente, 2006).

The increase in the number of channels leads to different gain and compression setting in different frequency bands and there is disturbance between the low frequency fundamentals and the high frequency harmonics. In the analysis of the subjective results of the Group I (consisting of individuals not having any experience in professional music) there was no significant difference between the original music and the out put from the hearing aid B with knee-point raised by 18 dB. However, participants in Group II and Group III (consisting of professional singers and instrumentalists) rated the music sample 2 to be similar to that given to the original music sample, except in two parameters in the perceptual rating, namely, the naturalness and overall fidelity. The differences in naturalness and reduced overall fidelity may be attributed to the disruption of ratio or balance of the low frequency fundamental and the high frequency harmonic structure. Such a difference was not perceived by the Group I who indulged in listening to music just to seek pleasure. The variation may also be too subtle to be picked up an untrained listener. This draws attention to the fact that special care should be taken while prescribing hearing aids to the trained musicians as the demand of the musicians is far greater than the non-musicians who just appreciate music.

Chasin (2006) had recommended that the knee-point of the hearing aid should be set around 65 to 75 dB and the compression ratio should be low (e.g. 1.5:1). In the present study the knee-point of the hearing aid was set at 72 dB. The knee-point while programming the hearing aid was 54 dB which was the knee-point setting for speech as suggested by first fit of the software. The subjective rating showed that the listeners had a preference for the hearing aid output where the knee-point that has been set to higher level for both the hearing aids (Sample 2 & 3). The graph obtained for the outputs of the hearing aid in different settings also showed that setting the knee-point higher gave a better representation of the music in the lower frequency region. When the knee-point was set at the default setting for speech, the output of the 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.

All the participants gave poorer rating to the music samples in which the noise cancellation system was activated (Sample 4, 5 & 7). In the graphs depicting the output from the hearing aid in different settings it was noted that whenever the noise cancellation system was activated it led to suppression of energy in the low frequency region. For time invariant noise, the noise cancellation system in the present day hearing aids assume that since most of the noise power is concentrated in the low frequencies, the speech is masked in this frequency region and filtering out both speech and noise over this frequency range will 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 (Levitt, 2001).

The long-term spectra of noise and speech reveal the difference between speech and noise in their concentration of energy. Hence, it can be assumed that the hearing aids used in this study were assuming the music sample to be a time invariant noise and hence there was a cancellation of energy in the low frequency region. As discussed previously the concentration of energy in the low frequency region is essential for the judgment of quality of music to be better. The findings of this study support that by Chasin (2003 & 2006), Chasin, and Russo (2004) and Mishra, Kunnathur and Rajalakshmi (2005). The previous studies have noted that there is high probability for the hearing aid to confuse music for noise and hence had recommended deactivation of the noise cancellation system.

The activation of the feedback management system led to low energy levels which in turn led to poorer rating by all the participants. In the figures it was noted that whenever the feedback management system was activated (Samples 4, 5 & 8), it led to a dip at the frequency region of around 2 KHz. In notch filtering of the feedback management system it is possible to invert a band pass filter and remove the part of the peak in frequency response. It generally removes a narrow part of the spectrum centered on the frequency of the filter. This type of filtering is used to counter the acoustic feedback where the notch is tuned to remove a narrow band of frequency around the offending frequency (Agnew, 1993). Most probably the activation of the feedback system led to employment of such a filter which nullified the gain at a frequency range centered around 2 KHz. Suppression of energy in a particular frequency will have a deleterious effect on music perception since the gain should be equal and balanced over the frequency region for the optimal perception of music.

The simultaneous activation of the noise cancellation system and the feedback management system led to greater deleterious effect on the perception of music both objectively and subjectively (Sample 4 & 5). It was worth noting that the hearing aid A had far more deleterious effect when both the noise cancellation system and the feedback management system were activated than hearing aid B by comparing outputs of sample 4 and sample 5 on the spectral analysis.

Mishra, Kunnathur and Rajalakshmi (2005) noted that directional system leads to significant loss of low frequency sound which may remove valuable information for music. Hence, they recommended an omni-directional hearing aid for better perception of music. Even though the hearing aids (Hearing aid A and Hearing aid B) in the present study had an omni-directional microphone, the output in the low frequency was reduced, may be because of the activation of the noise cancellation.

Conclusions

The hearing aid processed music samples were subjected to perceptual analysis of the five parameters on a five-point rating scale. An objective spectral analysis was also done using spectral slice in Praat software. The results of objective and subjective analysis implied the following settings of the parameters in the digital hearing aid to be better for music perception. All these conclusions are made with reference to the music samples, hearing aids, settings that were used in the study.

- A fifteen channeled hearing aid was better than a six channeled hearing aid for music perception
- The knee-point for ideal music perception should be set as high as possible till it is not uncomfortable for the subject
- The feedback management and the noise cancellation system should be turned off

In conclusion it can be said that music perception through the hearing aid can be optimized to a greater extent with appropriate changes in the parameters of the hearing aids. It was found from the results of the present study that a hearing aid with 15 channels (compared to 6 channels) disabling the noise cancellation and feedback management system would improve the perception of music appreciably. The experimenters quite agree with Chasin (2003) who noted that "a hearing aid ideal for music perception can be programmed to have good speech intelligibility but the vice-versa is not true".

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