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## Research Article

# Effective solutions for the hearing impaired subjects based on the comprehensive clinical trials

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**Abstract:** At present, endorsing suitable gains for different frequency bands of digital hearing aids is an uphill task for the audiologists to enhance hearing satisfaction among the hearing impaired subjects. Present work explored the data base appended by the audiologists in deciding the suitable gain values and produced successful gain recommendations for better deployment of the digital hearing aids. 328 subjects (103 females & 225 males) have partaken in the study, in that 218 subjects were identified as suffering with either sensorineural loss or with mixed hearing loss and rest of them had normal hearing. The hearing impaired subjects were fitted with apposite hearing aid by analyzing their hearing loss level in different frequencies, the fitting gain recommendations were prescribed based on the success rate of the previous recommendations. 185 subjects in the 218 subjects were content only with the altered gain values either by the expert system or by the audiologists. The alterations were made based on the factors like Pure Tone Average (PTA) value, minimum threshold of hearing at particular frequency, erroneously identified words etc. PTA value played a critical role in the enhancement of speech intelligibility. The system designed can be effectually utilized because of its high percentage of success rate, in giving hearing satisfaction. To get enhanced satisfaction level, mass screening has to be done at the earliest and apply the recommended gain suggestions by the proposed system.
**Keywords:** Hearing aid - Gain - Prescriptive procedure - Pure tine average - Frequency - Speech discrimination score.

## INTRODUCTION

The objective of the hearing aid is to intensify the perceived speech signals by varying the loudness level of the speech and also to provide an optimal sound so that the understanding of the speech signals amidst noise must be high in different environmental conditions [1–7]. To fulfill its function the electro acoustic characteristics of the hearing aid must be correctly adjusted on the basis of specific prescriptive procedure taking into account the type of hearing impairment of the subject [8, 9]. These prescription formulae were based on both threshold and supra-threshold of audiometric data in its specification and output requirements. More specifically, it calculates how much gain is to be provided to different frequencies and also it should be changed with different speech input levels [10-12]. The majority of the so far proposed prescriptive procedures have been based on the test results of the classical pure tone audiometry, not minding the exact relation to the type of hearing impairment of the subject. In addition, the systematization of the adjustment rules is to ensure the optimization of the hearing aid functioning, especially in terms of speech intelligibility. National Acoustics Laboratory (NAL) of Australia developed the nonlinear prescriptive procedures NAL-NL1 and NAL-NL2 for enhancing speech intelligibility [13 - 18]. In addition to the gain prescription, it also specifies the output limitation characteristics of the hearing aid. The gain-frequency response and the compression characteristics of the hearing aid may also be gradually adjusted to attain the manufacturer target [19 - 24]. The adaptation level is a practice that manufacturers build into the software in order to slowly proliferate the gain level in a patient's hearing aid. The idea is that a new subject with no prior hearing aid experience normally prefers lower gain and output and gradually adapt to higher levels of gain and output. As the subject fixes the hearing aid and uses it regularly for a couple of weeks or months and slowly starts to adapt to the hearing with amplification, the adaptation level is gradually increased. Some audiologists always fit the subjects with the highest adaptation level because the highest adaptation level means the closest to the target prescription of a given fitting rational. The audiologist may also choose to use a middle adaptation level as a tradeoff between a conservative and aggressive approach for prescribing gain and output [25-28]. The important significance of digital speech processing (DSP) technology in hearing aids is increased flexibility in programming capabilities, which allows the audiologists to be more precisely to fit a hearing aid to a prescriptive target. However, recent survey data indicates that few audiologists are verifying their hearing aid fittings in the initial visit [29]. This objective of the study was to make an attempt to formulate specific rules for the optimum adjustment of hearing aids based on the data base of successfully satisfied subjects. If the subject doesn't get satisfaction, the audiologist need to adjust the gain and frequency responses of the fitting based on the experience and then validate the fitting by patient's response. The data is successfully added to the database to enhance the satisfaction among the hearing aid users at the earliest.

## MATERIAL & METHODS

The type and level of hearing impairment were arrived on the basis of the subjects' examination with the pure tone audiometry and speech audiometry. The hearing impaired subjects considered for study were broadly classified into two groups according to the level of the hearing loss. The subjects suffer with mild and moderate hearing loss and the subjects suffer with severe and profound hearing loss. The prescriptive procedures DSL I/O (Desired Sensation Level Input /Output), NAL–NL1 (National Acoustical Laboratory — Non Linear 1), and NAL-NL2 were successfully used as first fit formula based on their success rate obtained with our previous test trials and comparative analysis. Hearing aids were selected and adjusted to the individual patients according to certain rules and taking into regard the type and scale of hearing impairment. After adjustment made with the hearing aid according to the rule, the patient was inquired to use it for couple of weeks under normal conditions. In the subsequent week, the effectiveness of the hearing aid adjustment was evaluated. The hearing aids used in the study were Siemens Intuis Life and Siemens Intuis SP DIR. Both of them have the following significant specifications as they are digital, fully automatic programmable BTE instrument and amplification control in 4 channels with AGC circuit inbuilt. The Intuis life hearing aid was preferred for the subjects suffering with mild, moderate and moderately severe loss. Whereas the Intuis SP DIR model was preferred for subjects suffering with severe and profound hearing loss. The audiometers of models ALPS 2100, Maico 33 were used for performing the pure tone audiometric test. The audiometer from Inventis was used for performing speech audiometric test. The hearing aid analyzer Fonix FP-35 was used to identify the gain values of hearing aids under study is shown in figure 1.


**Fig 1: Fonix FP-35 Hearing aid analyzer and its accessories**

It comes with the Integrated Probe Microphone for performing real-ear measurements (REM). It is used to present broadband signal consisting of 79 different frequencies presented simultaneously, updating up to five times a second. It has important additional accessories like HA-2 coupler and BTE adapter shown in figure 1, are very much useful for our study. The HA-2 coupler is used to mimic the real ear and BTE adapter is used to connect the HA-2 coupler in one side and hearing aid on another side through the tube and the experimental setup is shown in figure 2. The hearing aid analyzer is capable of displaying the real ear insertion gain values either as numerical data or as multi curve are shown in figure 3. In the period of study 328 subjects of which 225 males and 103 females were tested after getting the proper informed consent from them. Among the tested subjects 116 (23 females and 93 males) were suffering with sensorineural loss, 102 (34 females and 68 males) were suffering with mixed hearing loss and rest of 110 subjects (46 females and 64 males) had normal hearing. The classification of subjects with respect to age and hearing condition is shown in figure 4. The trend line drawn for abnormal subjects indicates that with the increase in age range, the number of abnormal subjects also increases. In short, age is an important factor in creating abnormal hearing condition.

**Fig-2: Experimental setup of BTE hearing aid attached to hearing aid analyzer**

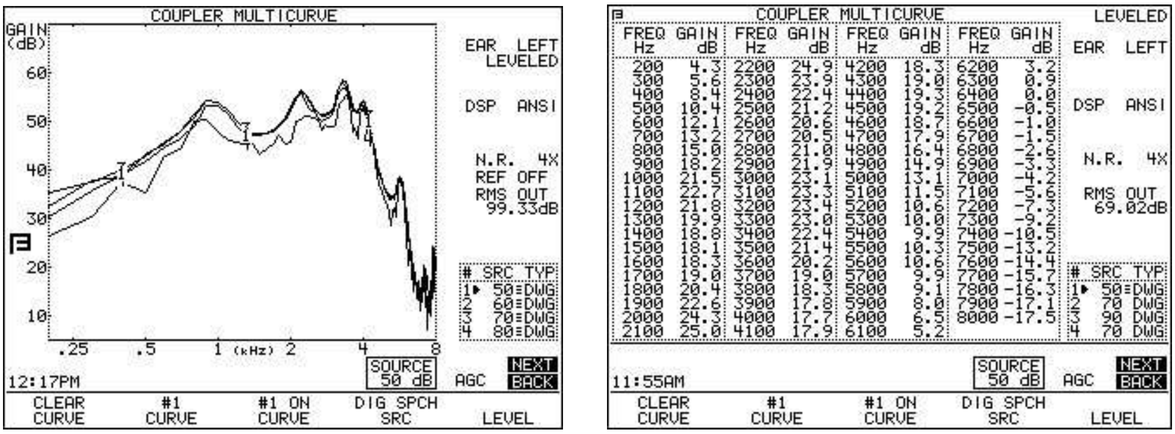
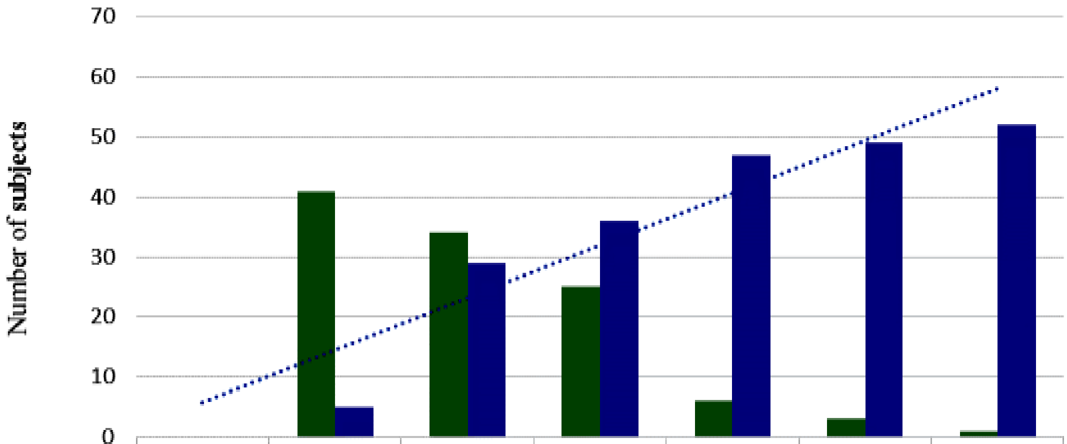



**Fig 3: Multi curve and numerical data of gain values of hearing aid under study**

Hearing aid trials were made with the 218 subjects found to be in abnormality condition i.e. having hearing loss. In the proposed system the following steps are to be performed sequentially to suggest suitable gain values for the digital hearing aid.

If the subject already performed pure tone and speech audiometric tests using conventional audiometer then they can go to step 5 directly for getting useful gain suggestions from the expert system.




| | 20 - 29 | 30 - 39 | 40 - 49 | 50 - 59 | 60 - 69 | 70 - 85 |
|---|---|---|---|---|---|---|
| Normal subjects | 41 | 34 | 25 | 6 | 3 | 1 |
| Abnormal subjects | 5 | 29 | 36 | 47 | 49 | 52 |

**Fig 4: Subjects' classification of the age and hearing condition**

**Step1:** Initially pure tone audiogram test for both the ears is to be done using the audiometer. The minimum threshold of hearing for the subject in the octave test frequencies 250Hz, 500Hz, 1000Hz, 2000Hz, 4000Hz, and 8000Hz were found out. Using the test results, the important parameter Pure Tone Average (PTA) is calculated by averaging the measured minimum threshold of hearing in the frequencies 500Hz, 1000Hz and 2000Hz.

**Step 2:** Next the speech audiometric tests have to be conducted. In that, first the Speech Reception Threshold (SRT) test has to be conducted by presenting spondee words with the dB value which lies within + or – 12dB to that of PTA value, so as to make the subject to identify at least 50% of words presented to them. Otherwise both the tests have to be repeated for assuring consensus with the test results.

**Step 3:** After that, Speech Discrimination Test (SDT) has to be performed for identifying unaided score. In that, Speech Discrimination Score (SDS) will be calculated by presenting the 50 standard Tamil and English phonetically balanced words recommended by Indian Speech Hearing Association (ISHA) stored in the system. The Tamil words have the frequency spectrum ranges between 0 Hz to 3561 Hz whereas for English it is 0 Hz to 5452 Hz. The words will be presented in free field environment with the decibel value 40dB higher than the SRT value.

**Step 4:** The calculated value of SDS i.e. ratio of correctly identified words to that of total presented words known as unaided score is stored.

**Step 5:** The subject now has to be tested with the hearing aid and the words were presented through standard headphones. In our study we used headphone has an impedance of 32 ohms and sensitivity of 96dB/V. The subject is to be tested for maximum satisfaction with the help of hearing aid using SDT test. Initially, the subject is tested with the first fit formula i.e. standard prescriptive procedure like NAL-NL1, NAL-NL2, and DSLI/O etc. The highest score obtained in a particular procedure to be noted as first fit score. The suggested gain values were stored in the expert system.

**Step 6:** If the subject doesn't gets Satisfaction, the expert system will suggest the gain values by virtue of its analysis with the earlier satisfied subject data. The subject will be tested for higher SDS value.

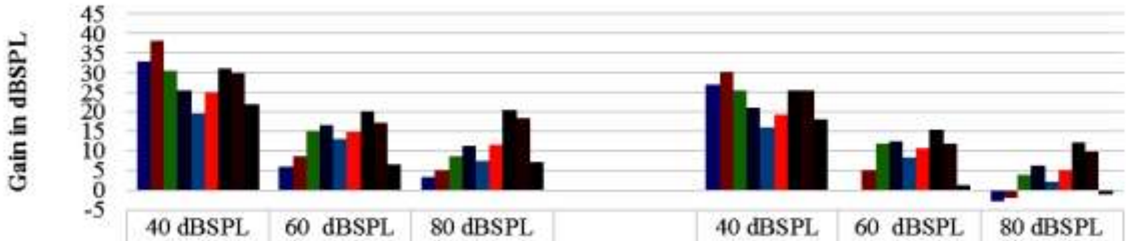
**Step 7:** If the subject still requires enhanced performance with the hearing aid fitting then the audiologist may attempt to do necessary alteration in the gain values in the affected frequency bands by interacting with the subject. After the satisfaction of the subject the gain values of different frequency bands are stored. This data will be used continually to redefine the expert system continually hence make this system adaptive.

## RESULTS

The subjects identified with abnormal hearing condition were undergone hearing aid trials with apposite hearing aids based on their hearing loss level during the period of study. The subjects were normally identified with NAL-NL1 or with NAL-NL2 as their first fit procedure. Even those subjects also got enhanced score with preferred settings. The following section explains the way in which the results and gain suggestions are related. The table depicts the results and gain suggestions of a male subject aged 63 suffers with bilateral moderately severe high frequency sloping mixed hearing loss made his hearing aid trials with the proposed system. The pure tone averages of the subject are 56.6 and 50 for right ear (RE) and left ear (LE) respectively. The unaided score calculated is 72 and with the first fit formula it is 74 and with the preference settings the score is 86 results in an enhancement of 12 in the SDS value, Which reasonably increased the speech intelligibility. The audiometric test results for air conduction (AC) and bone conduction (BC) for different frequencies of both the ears are shown in the table I. The comparison of gain suggestions for three different sound input levels (40dBSPL, 60dBSPL and 80dBSPL) are shown as chart in the figure 5.

**Table 1: Audiometric test results of a subject with bilateral moderately severe high frequency sloping mixed hearing loss**

| **Frequency in Hz** | **250** | **500** | **750** | **1000** | **1500** | **2000** | **3000** | **4000** | **6000** |
|---|---|---|---|---|---|---|---|---|---|
| REBC | 20 | 30 | | 30 | | 70 | | 80 | |
| LEBC | 20 | 30 | | 30 | | 70 | | 80 | |
| REAC | 30 | 40 | | 45 | | 85 | | 90 | 120 |
| LEAC | 30 | 40 | | 45 | | 80 | | 90 | 120 |




| | NAL-NL1 | | | Preferred | | |
|---|---|---|---|---|---|---|
| | 40 dBSPL | 60 dBSPL | 80 dBSPL | 40 dBSPL | 60 dBSPL | 80 dBSPL |
| 250Hz | 33 | 5.9 | 3.4 | 26.8 | -0.3 | -2.9 |
| 500Hz | 38.2 | 8.5 | 5 | 30.1 | 5.2 | -2.1 |
| 750Hz | 30.6 | 15 | 8.5 | 25.4 | 11.8 | 3.9 |
| 1000Hz | 25.4 | 16.5 | 11.3 | 20.9 | 12.4 | 6.3 |
| 1500Hz | 19.7 | 13.1 | 7.3 | 16.1 | 8.4 | 2.1 |
| 2000Hz | 24.9 | 14.8 | 11.7 | 19.2 | 10.6 | 5.1 |
| 3000Hz | 31 | 20.2 | 20.4 | 25.6 | 15.4 | 12.2 |
| 4000Hz | 29.8 | 17.2 | 18.3 | 25.6 | 11.8 | 9.8 |
| 6000Hz | 21.9 | 6.6 | 7.2 | 18 | 1.3 | -1.2 |

**Fig 5: Comparison graph of gain suggestions of a subject with bilateral moderately severe high frequency sloping mixed hearing loss**

The gain suggested by the preferred setting is comparatively lesser than the gain suggested by the NAL-NL1 procedure in all the frequency values of three different sound input levels. This solved the recruitment problem and used to attain a high SDS value and in turn improved the satisfaction level. A male subject aged 46 suffers with bilateral moderately severe mixed hearing loss was tested and made his hearing aid trials with the proposed system and whose audiometric test results and gain suggestions are shown in table II. The pure tone averages of the subject are 63.6 and 60 for right ear (RE) and left ear (LE) respectively. The subject attained a reasonable SDS value with the procedure NAL-NL2. But still the score was enhanced with the preferred settings. The unaided score calculated is 40 and with the first fit formula it is 70 where as for the preference settings a maximum score of 84 was attained. The comparison chart for the subject with the first fit formula NAL-NL2 and preferred gain recommendations are given in figure 6. The preferred setting suggested marginally higher gain in 500Hz and 750Hz for all input levels than the NAL-NL2 procedure. It also suggested higher gain in 1000Hz and 2000Hz for 40dBSPL input rest of the frequencies it recommended lesser gain than the NAL procedure to give a rise in the SDS value by 14. The comparison of SDS value for the most benefitted subjects is plotted between the unaided score, NAL score and SDS obtained with preferred settings as shown in figure 7. It gives how much incremental in SDS value is obtained with the subjects having different PTA value. The benefit however also depends on the unaided score because those having higher unaided score will get better improvement.

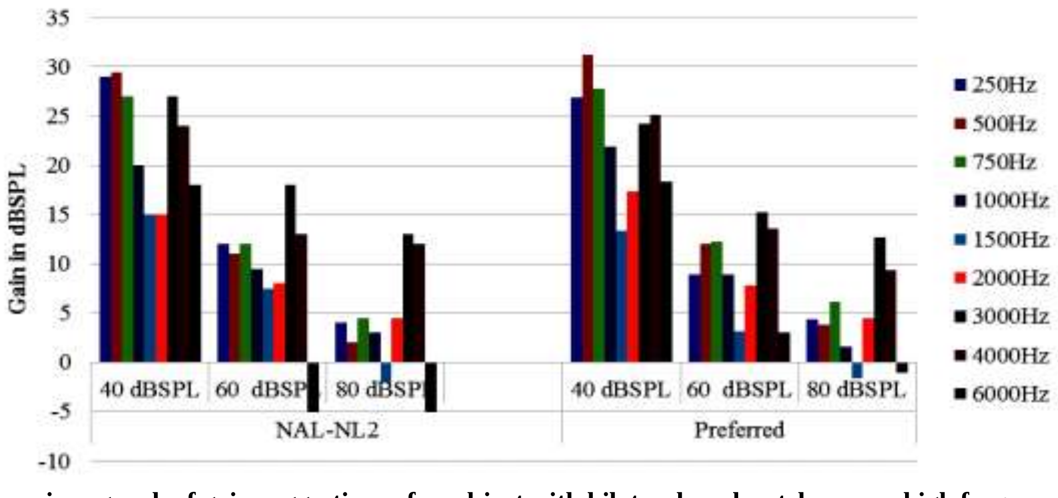



**Fig 6: Comparison graph of gain suggestions of a subject with bilateral moderately severe high frequency sloping mixed hearing loss**

**Table 2: Audiometric test results and gain suggestions of a subject with bilateral moderately severe mixed hearing loss**

| Frequency in Hz | | 250 | 500 | 750 | 1000 | 1500 | 2000 | 3000 | 4000 | 6000 |
|---|---|---|---|---|---|---|---|---|---|---|
| REBC | | 25 | 35 | | 45 | | 40 | | 55 | |
| LEBC | | 25 | 35 | | 45 | | 40 | | 55 | |
| REAC | | 70 | 60 | | 70 | | 65 | | 70 | 90 |
| LEAC | | 60 | 70 | | 60 | | 55 | | 75 | 70 |
| NAL | 40 dBSPL | 29.3 | 29.5 | 27.4 | 20.3 | 15.8 | 15.3 | 27.3 | 24.2 | 18.5 |
| | 60 dBSPL | 12 | 11 | 12 | 9.5 | 7.5 | 8 | 18 | 13 | -5 |
| | 80 dBSPL | 4 | 2 | 4.5 | 3 | -2 | 4.5 | 13 | 12 | -5 |
| | | | | | | | | | | |
| Pre | 40 dBSPL | 26.9 | 31.2 | 27.8 | 21.9 | 13.4 | 17.4 | 24.2 | 25.1 | 18.4 |
| | 60 dBSPL | 8.9 | 12 | 12.3 | 8.9 | 3.2 | 7.8 | 15.2 | 13.6 | 3 |
| | 80 dBSPL | 4.4 | 3.8 | 6.1 | 1.6 | -1.6 | 4.5 | 12.7 | 9.4 | -1.1 |

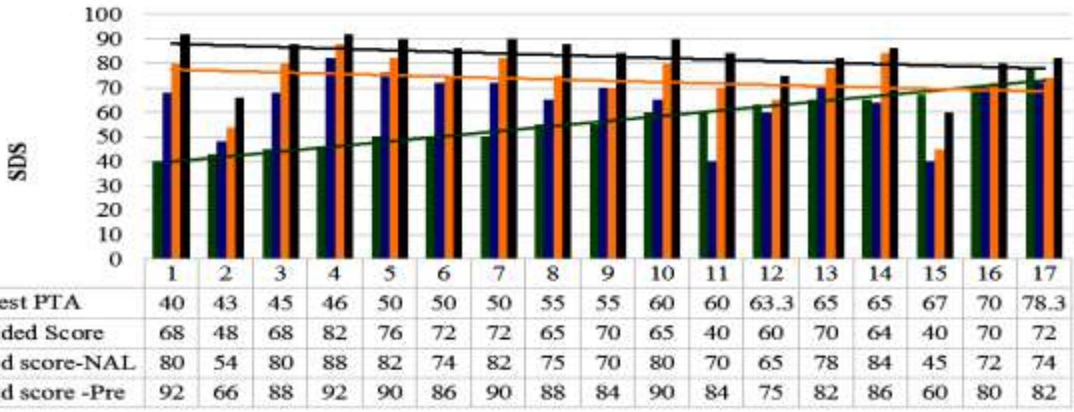



**Fig 7: Speech Discrimination Scores (SDS) of most benefitted subjects obtained with unaided, aided with first fit and aided with preferred settings**

## DISCUSSION

Endorsing the gain suggestions recommended by the proposed system was upheld by performing the comparison of gain suggestions and its success rate in giving satisfaction to the hearing aid users. The success rate of gain suggestions by the system was enhanced by strengthening the data base by performing better comparison and analysis of gain suggestion it made earlier in respect with the different factors frequency, pure tone average, sound level input to the hearing aid and the minimum threshold of hearing at particular frequency. The bar graph depicting the comparison of preferred gain suggestions at 500 Hz, 1000Hz and 2000Hz for subjects with different PTA values and the threshold of hearing are 60 dBHL, 70 dBHL, and 65 dBHL at 500Hz, 1000Hz and 2000Hz respectively shown in figure 8-10. In the figure 8, the gain suggestions for 500Hz for three different subjects having PTA value 63, 65, and 70 was compared for the input level of sound 40dBSPL, 60dBSPL, and 80dBSPL. If the PTA increases it is normally infers that the subject having comparatively higher hearing loss. So the proportionate gain suggestions were also increased for the different sound input levels. The gain for 500 Hz at 40dBSPL is 23 for the subject having PTA 63 and it is 30.5 and 43 for the subjects having PTA 65 and 70 respectively. Similar analysis can be made for other input levels also. The proportionate rise enables the subjects to hear the voice clearly and the incremental in the SDS score was consistently verified. The gain suggestions for 1000Hz for three different subjects having PTA value 63, 67, and 70 was compared for the input level of sound 40dBSPL, 60dBSPL, and 80dBSPL as shown in figure 9. As per the trend line for the subject with PTA value 67 the suggested gain for the input level 60 dBSPL and 80 dBSPL should be positive but the compression ratio selected for the subject is 2.2 hence negative gain was suggested which made the subject to got an increase in the SDS score by 10 over the first fit setting. The subject with the PTA value 63 got an increase of SDS score of 12. The gain suggestions for 2000Hz for three different subjects having PTA value 45, 60, and 67 was compared for the input level of sound 40dBSPL, 60dBSPL, and 80dBSPL as shown in figure 10. The subject with PTA 45 obtained a high SDS score 96 with the suggested gain values because of the advantage of having lower PTA value. The subject with the PTA 60 obtained an increase of 6 in the SDS. The case of the third subject with PTA 67 is already discussed in the previous section he get an increase of 10 in the SDS over the first fit settings. Similar type of comparisons were made for all the tested frequencies i.e. 250Hz,500Hz,1000Hz,2000Hz,4000Hz and 6000Hz for different values of threshold of hearing at the corresponding frequencies and PTA value.

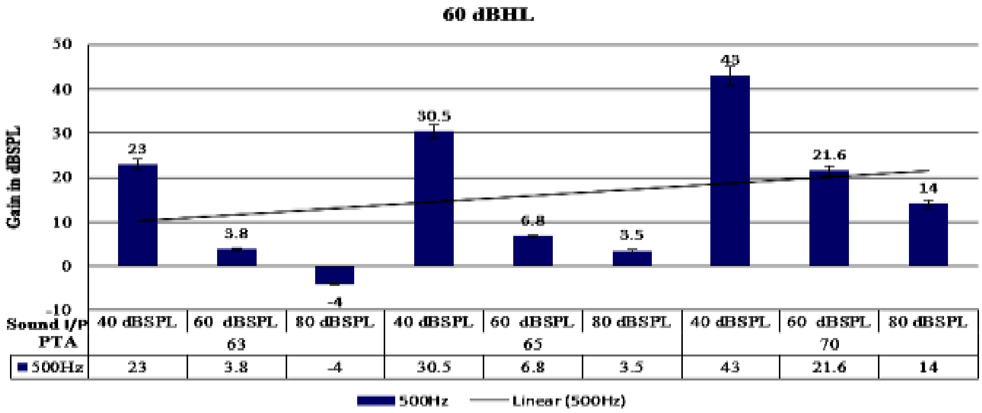



**Fig 8: Comparison of preferred gain suggestions at 500 Hz for subjects with different PTA values having 60 dBHL hearing loss at 500Hz**

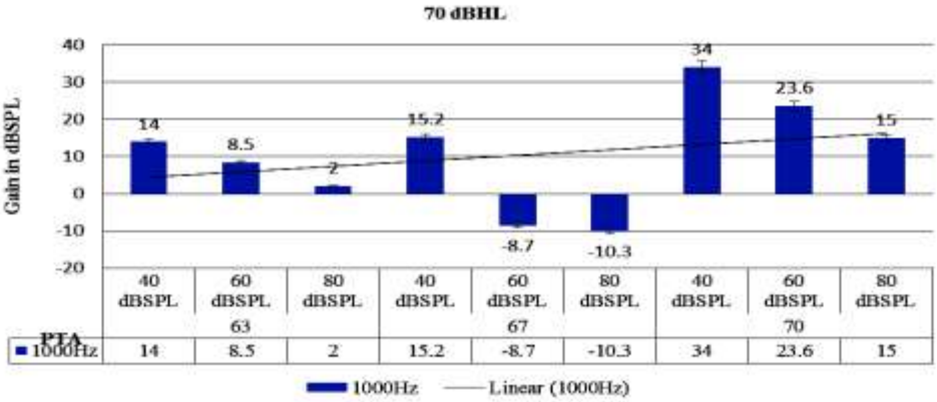



**Fig 9: Comparison of preferred gain suggestions at 1000 Hz for subjects with different PTA values having 70 dBHL hearing loss at 1000Hz**

As with the figure 7 it infers that, the considerable increase in the SDS value by more than 10 produced a reasonable enhancement in the speech intelligibility. Though the first fit score obtained a considerable rise over the unaided score still there is a scope of improvement with the preferred settings in turn on speech intelligibility. The trend line drawn for the PTA value, NAL score and preferred setting score indicates that the PTA value is an important factor in deciding the enhancement of SDS value. The subject with a lower PTA value is able to attain a satisfaction level easily when compared to the subjects with a higher PTA value.

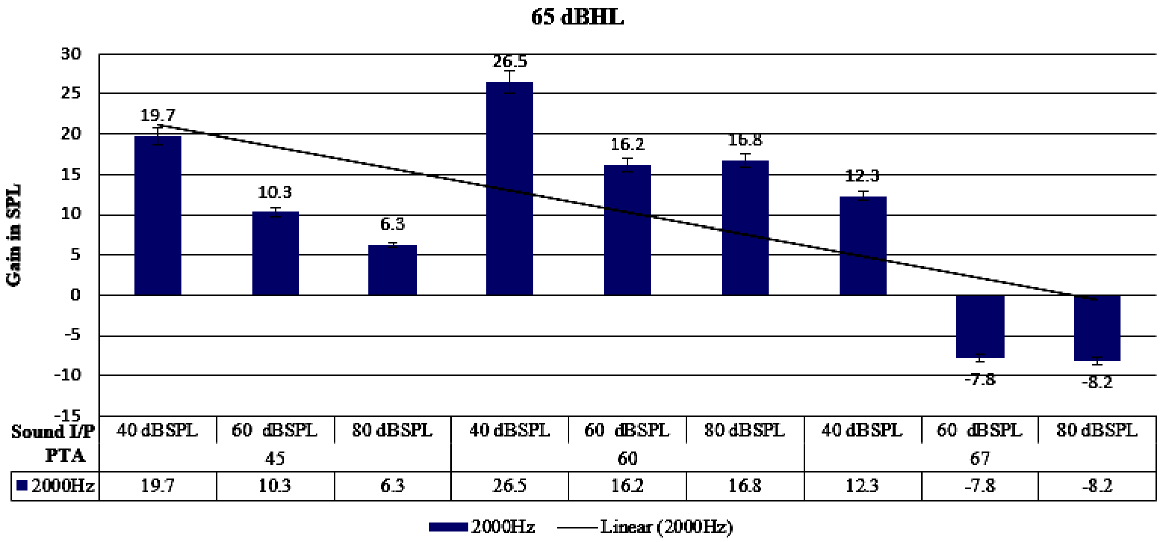



**Fig 10: Comparison of preferred gain suggestions at 2000 Hz for subjects with different PTA values having 65 dBHL hearing loss at 2000Hz**

## CONCLUSION

A system was successfully designed and developed for the benefit of the hearing impaired people to get utmost satisfaction with the performance of the digital hearing aid. The developed system in the present work was validated for its performance based on the outcome of the hearing impaired patients visiting the Government general hospital, Chennai. The system is capable for performing pure tone audiometric and speech audiometric test with the hearing impaired subjects and recommends suitable gain values for the digital hearing aid. The success rate of the system is arrived based on the SDS value obtained after the changes made in the gain settings as proposed by the expert system. The subjects having lower PTA value obtained maximum satisfaction with the hearing aid performance and arrived with higher SDS value. Hence the system can be effectively used to carry out audiometric tests early and used to propose better hearing aid gain suggestions so that a considerable enhancement in the speech intelligibility can be achieved.

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