CHAPTER - 6 SUMMARY AND CONCLUSIONS

The purpose of the study was to investigate the representation of spectral and temporal parameters of consonant-vowel syllables at the ear canal in unaided and aided conditions, using probe tube microphone measurement. In addition, the purpose was also to know the subsequent representation of the aided speech syllables at the brainstem and cortical levels of the auditory pathway. Further, the encoding of signals at different levels of auditory pathway in individuals with hearing impairment was compared with the individuals having normal hearing. Comparison was also made between the encoding of speech syllables at each of these levels of the auditory pathway in good and poor hearing aid performers.

The study was conducted in three phases. In Phase 1, audiological evaluation was carried out for selection and categorization of participants into clinical and normal hearing groups. Each clinical and normal hearing group consisted of four sub-groups based on age. Further, each participant in the clinical group was classified as either good or poor hearing aid performers based on the acceptable noise level (ANL) measure.

In Phase 2, the test hearing aid was fitted and optimized to each test ear of the participant in the clinical group. The output of the hearing aid for the CV syllables was recorded at the ear canal using probe microphone measurements, in the unaided and aided conditions. This recorded output of speech syllables were analyzed, using Adobe Audition 3.0, to obtain the spectral parameters such as $F_0$, and the frequencies of first two
formants $F_1$ and $F_2$. The first two formant frequencies $F_1$ and $F_2$ were analyzed at the onset and offset of the transition to each stimulus in unaided and aided conditions to determine spectral processing by the hearing aid. Further, the EDI was computed for each stimulus in order to know the extent of temporal alteration in the speech sound brought about by the hearing aid.

In Phase 3, the transient response followed by FFR at the brainstem level; and LLR and ACC at the cortical level were recorded from clinical and normal hearing groups in unaided condition. In addition, these potentials were recorded in aided condition from clinical group alone. At the brainstem level, the slope of $V-A$ was calculated from the transient response. The ‘Autocorrelation tool’ of MATLAB was utilized on FFR to obtain $F_0$ for each stimulus; and Fast Fourier Transform technique was utilized on the waveform of FFR for each stimulus, to obtain energies at $F_0$ and $F_1$. At the cortical level, the slope of $N1-P2$ of LLR, and latency and amplitude of ACC components were analyzed.

The findings of the present study have been discussed in the light of findings reported in literature on neurophysiological research in hearing. The findings of the study are with reference to the stimuli used for the purpose. In each clinical sub-group, the output of hearing aid at the ear canal was recorded and analyzed for spectral and temporal parameters. The hearing aid preserved the spectral parameters quite well. However, there is minimal alteration in temporal parameter. This could be due to the decreased
modulation depth due to compression in different channels of the hearing aid and varied gain across the frequency.

Further, to know the extent of changes provided from amplification device in clinical group, the responses were compared with normal hearing group at brainstem and cortical levels of the auditory pathway. The results at brainstem level revealed that the slope of V-A was steeper in normal hearing group than in clinical group. The $F_0$ of FFR encoded for each stimulus was well represented in both groups. In addition, the $F_0$ energy and $F_1$ energy reduced in clinical group than the normal hearing group, a significant difference was not noted. It inferred that after amplification the available acoustic cues are encoded precisely at the brainstem level.

At the cortical level, in the combined clinical sub-groups of ‘ABC’ the amplified responses of slope of N1-P2, latency and amplitude of ACC were almost same as that of normal hearing sub-group of ‘ABC’. However, the amplified response of ACC in clinical sub-group ‘D’ revealed prolonged latency and reduced amplitude than unaided response obtained from normal hearing sub-group ‘D’. These responses in clinical group reflect the asynchronous firing, interaction of hearing aid output and the transduction process in peripheral ear pathology and also the blurring of CV boundaries after amplification. It infer that in older adults, though the hearing aid was prescribed to overcome the problem in audibility, temporal distortion of input signal from hearing aid was present due to different compression parameters in two channels. Another source of distortion could be temporal asynchronous firing introduced by peripheral pathology in the older auditory
system. The envelope altered by amplification system and temporal asynchrony in peripheral pathology has complex interplay on perception. These effects modify the signals and are relayed as concomitant changes in the central auditory system, which in turn might have perceptual consequences.

Further, the responses at each level of the auditory system (brainstem and cortical) were compared between good and poor hearing aid performers. The responses at each level were relatively well represented in good hearing aid performers than in poor hearing aid performers. It can be inferred from these findings that there is relatively stronger afferent and efferent auditory pathways in good hearing aid performers i.e., in GHP, the central afferent mechanism are stronger such that neurons fire more robustly than in PHP. Additionally, the efferent mechanism is stronger, thus fine tuning the auditory input through inhibiting the fibres, which do not correspond to either $F_0$ or formant frequencies of the stimulus.

The present study provides an approach to measure the representation of amplified speech at different levels of the auditory pathway. Collecting data from this approach throws light on representation of speech at different levels of the auditory pathway. Further, it gives a direction for the audiologists and technologists to improve on the parameters in a hearing aid that might improve the performance. The obtained information will be utilized in counselling the clients regarding the encoding of speech at different levels and the limitation / ability of the available technology to solve the issue.
IMPLICATIONS OF THE STUDY

The implications of the present study include:

1. The study presents an evidence to use objective approaches to validate the hearing aid output at different levels of the auditory pathway.

2. To know the extent of modification induced by hearing aid, the acoustic content of the incoming signal serves as the template for output of the hearing aid. Utilization of the real ear measurement for analyzing the hearing aid output in the ear canal will help in knowing the representation of spectral and temporal properties of speech in the ear canal of the participant.

3. Studying the encoding of amplified speech in the impaired auditory pathway assists in guiding the hearing aid manufacturers to come up with the advanced technology. It also solves some of the practical problems faced by the audiologists regarding amplification parameters in providing the maximum usable information.

4. Findings of the present study help the audiologist in counselling a hearing aid user regarding the extent of benefit derived even with the best hearing aid prescribed.
FUTURE DIRECTIONS

From the findings in the present study it is imperative to conduct further research. These include -

1. Acceptable noise level (ANL) is one of the behavioural measures that can be used to predict the hearing aid usage. However, ANL considers the acceptance of noise as one of the prime factor for deciding hearing aid usage. ANL is a good behavioural tool for the acceptance of hearing aid, there are other factors which include psychological attitude towards willingness to wear hearing aid and cognitive status of participants, which might also influence its acceptance. Thus, these factors also need to be given consideration along with ANL to predict performance with the hearing aid. It helps the clinician to know the confronting variables that might contribute in rejection of the hearing aid and consequently taking appropriate measures or steps to utilize the available technology as well as counselling to solve the problem faced by individuals with the hearing impairment.

2. The current study gives information only on detection response at various levels of auditory pathway. This is because the conventional method was adopted in recording the FFR, LLR and ACC, as the stimulus was presented repeatedly. With the use of the stimulus in odd-ball paradigm, in addition to the detection process, the clinician can study the discrimination (mismatch negativity) and identification (P 300) processes of audition in individuals with hearing impairment.
3. The processing of hearing aid by the impaired auditory system was measured using electrophysiological approach in quiet condition. However, in noisy situation, the individuals with hearing impairment experience difficulty in understanding speech. Thus, there is a need to know how the individuals with sensorineural hearing impairment perform in the noise, as it obscures the temporal and spectral content of message, though the hearing aid alleviates the problem of audibility but introduce minimal temporal alteration.

4. Immediately after a listener is fitted with hearing aid, objective tests help to study the representation of amplified speech along the auditory pathway. However, the effect of experience in hearing aid usage (part time & full time hearing aid users) on the representation of amplified speech at different levels of auditory pathway needs to be investigated on a long-term basis.