CHAPTER - 1 INTRODUCTION

The hearing aids amplify the syllables. They have been successful at restoring hearing abilities for people with hearing impairment to some extent. However, even with some of the most advanced technologies, patients still have a degree of difficulty understanding speech. This is because, in addition to providing amplification, the hearing aids modify the inherent spectral and temporal aspects of speech signals (Eggermont, 1995).

Stelmachowicz, Kopun, Mace, Lewis, and Nittrouer (1995) have reported that the high frequency roll-off of the hearing aid response limits the high frequency consonant cues relative to the unprocessed signals. The low frequency roll-off essentially removes the first formant of certain vowels. According to Stelmachowicz, Mace, Kopun, and Carney (1993), a hearing aid can also blur the boundary between the aperiodic noise of consonants and the periodic onset of voiced vowels, making these transitions less distinct.

In older adults, Tremblay, Piskosz, and Souza (2002) have reported impaired temporal coding, due to the reduction of simultaneous discharge of neurons. This asynchronous firing in the auditory system of older adults have significant problem in encoding subtle acoustic cues. Coughlin, Kewley-port, and Humes (1998) investigated the relationship between identification and discrimination of vowels in older adults. They reported inability to extract temporal cues and indirectly suggested difficult to process vowel-format discrimination. In a similar line of investigation on temporal processing in older adults, Price and Simon (1984) have noticed deficits in discrimination of voice
onset time. This leads to difficulty in understanding speech, though this has no relationship with elevated thresholds (Willott, 1996). Thus, acoustic cues from impaired physiology at peripheral system relay the altered input to central auditory system through the auditory pathway (Chisolm, Willott, & Lister, 2003).

Altogether, the amplified speech signal alters the neural response patterns in the central auditory system by factors such as damaged mechanism in the peripheral auditory system, aging, complex interaction of aging and hearing loss, and alteration of inherent cues after processing by a hearing aid. Considering these and many more variables, audiologists are aware of the range of performance variability among individuals using hearing aids. Kochkin (2010) reported that performance variability could be because of factors anywhere from the microphone of the hearing aid till the processing of the signals in the brain. Much research is being undertaken focusing on hearing aid technology and the way the device might be modified to ensure better use. In spite of similar degree, type of hearing loss, and audiogram configuration, two individuals may not benefit from a hearing aid to a same extent. The reason for difference in improvement in speech understanding with similar hearing device by two individuals with a similar type, degree, and configuration of hearing loss is still unclear. Thus, it would be interesting to note how the processing of syllables at different levels of auditory system in a hearing aid user differs from that of a person with normal hearing.

Yund and Buckles (1995) reported wide variation in the degree of benefit that a person receives from a hearing aid. According to Kochkin (2010), 62.3% are dissatisfied
with hearing aids of which 25.3% reject their hearing aid because of background noise. Though there are various techniques to determine the extent of satisfaction with hearing aid viz., speech in noise test (SPIN), hearing in noise test (HINT), and connected speech test (CST), there is no strong relationship between the score obtained on speech intelligibility in noise of a person and his/her real world benefit/satisfaction with hearing aids.

Nabelek, Tucker, and Letowski (1991) developed a test procedure to determine the acceptable noise level (ANL) while listening to speech, as some individuals are unwilling to wear the hearing aid due to an inability to withstand the background noise. The ANL is calculated by subtracting the background noise level (BNL) from the most comfortable level (MCL). The ANL measure predicted the successful hearing aid use with 85% accuracy. However, the ANLs are not affected by age, hearing sensitivity (Branstrom, Lantz, Nielsen, & Olsen, 2011), content of speech signal, speaker (Plyler, Alworth, Rossini, & Mapes, 2011), speech presentation levels (Freyaldenhoven, Plyler, Thelin, & Hedrick, 2007) and different types of background noise (Nabelek, Tucker, & Letowski, 1991). The ANL ranges from 2 to 27 dB (Nabelek, Freyaldenhoven, Tampas, Burchfield, & Muenchen, 2006). In yet another study by Plyler, Alworth, Rossini, and Mapes (2011) reported ANL range -3.5 to 27 dB on an average. Harkrider and Smith (2005) suggested that the acceptance of background noise is related to individual variation in the afferent and/or efferent function of central auditory system. Thus, it is interesting to investigate, how the neural representation of amplified speech in good hearing aid users differed from poor hearing aid users.
Thus, in the present study, these were the research questions formulated for investigation. The questions included how are the acoustic features of speech syllables represented at the ear canal after being processed by a hearing aid. If the hearing aid preserved the spectral and temporal content of speech, then to what extent is the representation of amplified speech similar to the representation of speech in individuals with normal hearing at each level of the auditory pathway. If there is a significant effect on physiological response at each level of the auditory system, then how are the speech syllables encoded in good and poor hearing aid performers? These are the research questions being formulated for investigation in the present study.

In search of answers for these research questions, changes in signals in the output of the hearing aid should be recorded in the ear canal. Further, the representation of acoustic cues available at the brainstem and cortical levels also needs to be investigated using electrophysiological measurements. These provide information about the effect of amplification and hearing loss along the auditory pathway. It also improves our understanding regarding the representation of amplified speech at the different levels of auditory pathway. This information will in turn help the clinician to account the extent of success with auditory rehabilitation.

Need for the study

Despite improvements in technology and with well selected and appropriately fitted hearing aids, audiologists are not fully aware of the possible performance variability posed by the hearing aids, aging and hearing loss. Hence, there is a need to
study the representation of amplified speech along the impaired auditory pathway. This allows the audiologist to acknowledge the confronting variables. It might help in developing strategies in hearing aids to rectify some of these problems.

**Need for the measurement of the output of the hearing aid in the ear canal.**

The acoustic cues of the incoming signal serve as the template using which the output of the hearing aid is compared to know the extent of modifications induced by the hearing aid. The probe tube microphone (PTM) recordings are often used to measure the amplified signals at the ear canal because of their clinical efficiency in studying the output of the signals recorded close to the tympanic membrane and it gets done quickly. Bray and Nilsson (2002) reported that recording of the PTM reflects the acoustic effects of pinna, ear canal and the electroacoustic performance of the hearing aid.

The probe microphone measurements have limitation especially with the signals to verify the hearing aid gain using a pure tone sweep, a composite signal or a broadband noise as input to the hearing aid. The static signals that are generally used as input for the measurement cannot adequately describe the effect of some features of a hearing aid such as compression. The pure tone sweeps have constant level over longer duration than the brief speech component, which varies in intensity at each frequency band rapidly across time (Keidser & Dillon, 2003).

The human ears are exposed to speech signals in day-to-day life. Thus, utilizing speech signal as input for measurement facilitates in knowing the way in which the hearing aid represents the spectral and temporal properties of speech in the ear canal of
the participant during PTM measurement. In order to obtain the information about spectral and temporal parameters of the speech stimulus in the ear canal, the output from the PTM is recorded on to a computer with Praat software installed in it. Later, the recorded output is analyzed for spectral and temporal aspects of speech signal. Hence, there is a need to study the hearing aid output at the ear canal.

In some individuals, the critical cues appeared to be available at the output of the hearing aid. However, the errors exhibited by some participants can not be resolved by acoustic analysis of hearing aid output alone. Thus, it is for this reason that the study concerning the representation of acoustic cues at the brainstem and cortical levels become imperative (Stapells, 2000; Hall, 1992).

Need for studying the representation of acoustic cues available at the brainstem level. Auditory brainstem response (ABR) is most commonly used in the assessment of auditory sensitivity in infants, children and adults who cannot participate in behavioral hearing evaluation (Hood, 1998) or in evaluating the status up to the brainstem level. Several types of stimulus and recording methods have been proposed to provide frequency specific information such as tone bursts, filtered clicks, tone bursts and clicks mixed with various types of noise and high pass masking of clicks (Hood, 1998). While normal click- and tone burst- ABRs are an indication of the integrity of the cochlea and the ascending auditory pathway up to the level of the brain stem, they do not provide further information about the encoding of more temporally complex signals such as speech.
On the other hand, the brainstem response to speech has proven to be a mechanism for understanding the neural bases of normal attention-independent auditory function (Johnson, Nicol, & Kraus, 2005) and in assessing the integrity of the neural transmission of acoustic stimuli (Russo, Nicol, Masacchia, & Kraus, 2004). Recording brainstem response to sound has long been established as a valid and reliable means to assess the integrity of the neural transmission of acoustic stimuli.

Speech syllables have also been used in humans to study the response characteristics of the frequency following response (FFR) (Galbraith, 1994). FFR is a phase-locked response that ‘follows’ the waveform of the stimulating sound up to a frequency of 1000 Hz (Hoormann, 1992). The brainstem neural synchrony is well tuned to temporal and spectral characteristic of speech syllables (Banai, Nicol, Zecker, & Kraus, 2005) and imprecise encoding of speech syllables at the neural level contributes to communication problem (Kraus & Nicol, 2005). Johnson, Nicol, Zecker, Bradlow, Skoe, and Kraus (2008) have studied the brainstem response to voiced consonant vowel (CV) stop syllables /ba/, /ɖa/, and /ga/. Spectro-temporal information distinguishes these voiced consonant-vowel syllables. This information is contained within the burst and the first few milliseconds of the formant transition to the vowel. The spectro-temporal variations among stimuli were represented by the timing of the neural response. Hence, FFR to speech provides an objective way in which the sound structure of speech syllables is encoded at the brainstem level. Further, literature has documented that aging (Clinard, Tremblay, & Krishnan, 2010; Hemanth & Manjula, 2012; Anderson, Parbery-clerk, White-Schwoch, & Kraus, 2012) and hearing loss (Musser, 2010; Prabhash & Sandeep,
alter the input before it reaches brain. The findings from studies on biological aging and hearing loss recognized the changes in the brain processing (latencies) and strength (amplitudes). There is a dearth in literature on the effect of biological aging and hearing loss in spectral processing at the brainstem level. Additionally, the way in which the amplified speech is represented at the brainstem level after fitting an individual with a hearing aid is not clear. If the brainstem neuron follows the time varying cues of amplified speech, the extent to which the representation of amplified speech at brainstem level lessens the problems posed by hearing loss needs to be evaluated by comparing the encoding of amplified speech in individuals with hearing impairment with that of speech encoded in individuals with normal hearing. This needs to be studied in different age groups. In addition, the way in which the representation of amplified speech differed in good and poor hearing aid performers needs to be evaluated. Thus, there is a need to know the way in which these variables affect the representation of available acoustic speech cues at the level of auditory brainstem.

**Need for studying the representation of acoustic cues available at the cortical level.** Cortical auditory evoked potentials (CAEP) such as the N1–P2 complex are frequently used to assess the neural detection of sound. The N1–P2 complex is thought to represent the synchronous neural activity of structure in thalamic-cortical segment of the central auditory system. Many investigators have used brief stimuli such as clicks (Ponton, et al. 2000), tones (Pantev, Ross, Fujioka, Trainor, Schulte, & Schulz, 2003) and synthetic speech stimuli (Sharma, Dorman, & Spahr, 2002) to evoke this response. Although synthetic speech syllables allow the investigator to control stimulus
dimensions, these stimuli are not representative of everyday speech. Hence, naturally produced speech syllables which vary with time and are highly complex are more useful as they evoke a complex neural response pattern (Polen, 1984). Tremblay, Billings, and Rohila, (2004) utilized naturally produced CV syllables having plosives and shorter pre-transition duration to record the neural activity at the cortical level. The conventional N1-P2 complex of LLR was elicited for these stimuli. Thus, LLR at cortical level can be recorded using naturally produced speech syllables.

Goodin, Squires, Henderson, and Starr (1978), and Pfefferbaum, Ford, Roth, and Kopell (1980) studied neural representation of speech at the cortical level in individuals with biologic aging. The results revealed prolonged latency and reduced amplitude as a factor of aging. They speculated reason for this as decrease in rate of neural transmission, excitatory and inhibitory neurotransmitter, and conduction velocity. Tremblay, Piskosz, and Souza (2002) investigated the combined effect of aging and age-related hearing loss. They concluded that elderly individuals with hearing impairment have pronounced effect in encoding of speech. In yet another study Oates, Kurtzberg, and Stapells (2002) recorded LLR and P 300 in individuals with different degrees of sensorineural hearing loss. They reported that cognition was affected more than solely due to audibility. Further, LLR was studied after fitting individuals having sensorineural hearing loss with a hearing aid. The brain processing and response strength was better in the aided than in unaided condition. Collectively, the findings suggest that CAEPs are a sensitive tool to obtain information on aging, hearing loss and amplification.
Naturally spoken speech syllables contain rapid temporal and spectral changes. The speech evoked cortical response elicits N1-P2 obligatory response for voiced and unvoiced consonant vowel (CV) stop syllables (Tremblay, Friesen, Martin, & Wright, 2003). In these types of CV syllables, multiple response patterns temporally overlap, obscuring the presence of the rapid changes in the ongoing stimulus. Ostroff, Martin, and Boothroyd (1998) compared the cortical response to the syllable /si/ with the cortical responses to the sibilant /s/ and to the vowel /i/. They ascertained that the response to /si/ was a combination of the CAEPs to the onsets of the two constituent phonemes /s/ and /i/. These overlapping CAEPs within a single response for a stimulus have been termed the acoustic change complex (ACC) (Martin & Boothroyd, 1999).

Acoustic change complex (ACC) is one such potential that reflects the complex changes contained in the stimulus. These potentials are sensitive to time-varying cues such as changes in spectrum, amplitude, and periodicity (Ostroff, Martin, & Boothroyd, 1998), change from a harmonic tonal complex to a noise band with the same spectral envelope (Martin & Boothroyd, 1999) and formant frequency changes in an ongoing vowel (Martin & Boothroyd, 2000). Therefore, ACC response to speech provides objective information about the way in which the sound structure of speech syllables is encoded at the cortical level. However, there is a dearth of literature on how the speech encodes at cortical level in good and poor hearing aid performers.

From the literature, it is revealed that both hearing loss and amplification can alter the temporal and spectral contents of speech signal (Martin, Tremblay, & Korczak,
For a given signal, the input to the hearing aid is known. After amplification, the extent to which the hearing aid preserves temporal envelope and spectral cues was analysed in their study. The Envelope Difference Index (EDI) was utilized in order to study the difference in temporal envelope in the unaided and aided conditions. The spectrogram was used to measure the fundamental frequency and the first two formant frequencies (at onset and offset of transition) in unaided and aided conditions. In addition, spectra were also noted to know the intensity as a function of octave frequency. It will be interesting to find out how the spectral and temporal aspects of the speech sound are relayed at the brainstem and cortical levels influenced by aging, hearing loss and amplification. At brainstem level, the response was captured using FFR; and at cortical level the response obtained using LLR and ACC.

Aim of the study

The main aim of the study was to investigate the representation of amplified speech syllables along the ear canal, brainstem and cortical levels of the auditory pathway in individuals with sensorineural hearing loss.

Objectives of the study

The following objectives were formulated

1. At the ear canal level, to measure the spectral and temporal parameters of speech syllables in unaided and aided conditions.
2. At the brainstem level, to compare the representation of speech syllables between clinical group and group having normal hearing.
   a. To compare between the aided slope of V-A from clinical group and unaided slope of V-A from group having normal hearing.
   b. To compare FFR in terms of aided $F_0$, $F_0$ energy and $F_1$ energy in clinical group with unaided $F_0$, $F_0$ energy and $F_1$ energy in group having normal hearing.

3. At the cortical level, to compare the representation of speech syllables between clinical group and group having normal hearing.
   a. To compare the LLR in terms of aided slope of N1-P2 in clinical group with unaided slope of N1-P2 in group having normal hearing.
   b. To compare latency of ACC components in aided condition from clinical group with unaided condition from group having normal hearing.
   c. To compare amplitude of ACC components in aided condition from clinical group with unaided amplitude from group having normal hearing.

   a. To compare the brainstem responses between good and poor hearing aid performers.
      i. To compare slope of V-A between good hearing aid performers and poor hearing aid performers.
      ii. To compare FFR in terms of $F_0$ of FFR, $F_0$ energy and $F_1$ energy between good hearing aid performers and poor hearing aid performers.
b. To compare the cortical responses between good and poor hearing aid performers.

i. To compare LLR in terms of slope of N1-P2 between good hearing aid performers and poor hearing aid performers.

ii. To compare latency of ACC components between good hearing aid performers and poor hearing aid performers.

iii. To compare amplitude of ACC components between good hearing aid performers and poor hearing aid performers.

Statement of the problem

The input to auditory system is altered by the impaired physiological mechanism and then the altered input is relayed to the central auditory pathway. One of the rehabilitative tools to overcome the hearing problem is the use of hearing aid. Only some individuals with hearing problem benefit from a hearing aid, while others reject the hearing aids. Kochkin (2010) speculated the reason for rejection of hearing aid. He said that factors affecting the hearing aid use can be located anywhere from the hearing aid microphone till the integrity of neurons along the auditory pathway. From literature, it is also well documented that majority of individuals reject hearing aid due to background noise (Kochkin, 2010). Hence, it is necessary to classify the users of hearing aids into either good or poor hearing aid performers using a measure that can predict the hearing aid use.
The willingness to listen in noise may be more indicative of hearing aid use than understanding speech (Nabelek, Freyaldenhoven, Tampas, Burchfield, & Muenchen, 2006). The acceptable noise levels (ANL) is a measure that can be used at the time of audiological evaluation rather than speculate the reason for rejection through the measurement of outcome, i.e., after a period of use of the hearing aid. The ANL test can be administered prior to the hearing aid evaluation to predict the hearing aid use, as there was a good correlation between ANL scores and satisfaction and/or improvement with hearing aid in an individual. Nabelek, Freyaldenhoven, Tampas, Burchfield, and Muenchen (2006) have reported that the ANL differentiates good (<7 dB) from poor (>13 dB) hearing aid users.

Further, to know the extent of alteration from hearing aid, it is important to have an account on representation of the acoustic content of the incoming signal along the auditory pathway. As noted earlier the hearing aid alters some acoustic cues in terms of temporal and spectral parameters. Thus, the output of hearing aid has to be recorded in the ear canal to see the alteration in the signal after being processed by the hearing aid. Even when the speech cues are preserved after amplification, some listeners fail to recognize speech. Thus, the ability to measure electrical activity in the auditory system in response to sound provides information about the representation of the signal along the central auditory system.

The present study intends to provide direct evidence of electrophysiological changes along the auditory pathway in individuals with acquired sensorineural hearing
loss associated with aging, hearing loss and amplification. The finding from this study helps an audiologist to understand the extent of improvement provided by the hearing aid; and also the variability involved among good and poor hearing aid performers based on the integrity of the peripheral and central auditory system. Further, the findings on electrophysiological measurements throw light on the encoding of available acoustic cues by the auditory system of the listener.

**Hypotheses**

The null hypotheses were framed for each main objectives of the study. They were

1. At ear canal level, there is no difference in the spectral and temporal parameters of speech syllables between unaided and aided conditions.

2. At brainstem level, there is no difference in the representation of speech syllables between aided responses obtained from clinical group and unaided responses obtained from group having normal hearing.

3. At cortical level, there is no difference in the representation of speech syllables between aided responses obtained from clinical group and unaided responses obtained from group having normal hearing.

4. There is no difference in the brainstem responses between good and poor hearing aid performers and

5. There is no difference in the cortical responses between good and poor hearing aid performers.