CHAPTER 2
LITERATURE SURVEY

In this chapter, the literature survey in respect of the causes and solutions for hearing loss, the development of computerized audiometers for early detection of hearing loss and the evolution of prescriptive procedures for hearing aid gain predictions are presented.

The hearing level and speech intelligibility of an individual is affected by many factors in the environment. Continuous exposure to noise is the most important cause for the deterioration of hearing levels due to the destruction of hair cells in the inner ear (Malcovati 2001, Chung et al 2005). Because the outer and middle ear transmits sound frequencies around 4 kHz very efficiently, hair cells that carry the sound frequencies near 4 kHz are particularly vulnerable to noise damage. Most of us are always exposed to different forms of noise in our day to day life. The non-invasive solution of wearing hearing aid is preferred by many of the hearing impaired subjects. It has been proved that identifying the hearing loss at an early stage will give better satisfaction to the hearing aid users, and by taking effective measures, further deterioration can also be avoided. Age is the next important cause for hearing difficulties, because the body functions and sensory organs deteriorate as we grow older. In general, the deterioration in the hearing capability starts as early as the age of 20 (Agarwal 2008, Lut & Guy 2007). Human hearing is also affected by hereditary phenomena. Around one third of the hearing problems present are due to hereditary factors. In some cases, medicines,
alcohol and smoke can also harm hearing and are therefore defined as ototoxic (Malcovati 2001). Conductive hearing loss reduces the effective intensity of the air conducted signal reaching the cochlea, but it does not affect the bone conducted signal that passes directly to the inner ear by-passing the middle ear. Sensorineural hearing loss is caused by abnormalities in the cochlea and auditory pathway. Hearing impairment will affect linguistic skills, social, emotional development and academic performance (Ching et al 1998). Congenital hearing loss in the newborn population is high. The prevalence of newborn and infant hearing loss has been estimated at 1–2 per 1000 infants (Joint committee on infant hearing 2007). As a result of early identification of all infants with hearing impairment prognosis improves (Alessandro et al 2007, Kae Kitagawa et al 2009). Mixed hearing loss is caused by progressive down fall in the value of the minimum hearing threshold at all frequencies for air and bone conduction signals. Mixed hearing loss is a serious issue among the hearing impaired patients. The hearing impaired subjects delay in wearing hearing aids, because they are unaware of their deterioration in hearing and they are used to live with this minor problem (Sindhusake et al 2001). To overcome these issues, it is obligatory to screen persons for identifying loss of hearing at the earliest (Fausti et al 1999). The value of the threshold measured in dB with the audiometer is calibrated in dB HL with the standard data found out with the healthy young adult (American National standards Institute 1997).

In general practice, audiometers are used to perform audiological tests to measure the hearing loss level. Though the conventional audiometers manufactured today are well suited for testing the hearing loss, they are specific and are highly technical in nature (American National Standard Institute 2004a, American National Standard Institute 2004b). They also have
the drawback of requiring an expert for conducting the tests, and the audiometer and audiologist may not be available in every health centre. But due to the increase in the hearing impairment percentage and to prevent hearing loss, it is necessary to perform audiometric tests in houses, in primary health centers, and in workplaces where the workers are exposed to high noise levels. The present work assumes significance because of the availability of computer everywhere, and also it has the provision to store and retrieve an audiometric test database whenever required. Since the computer is used to perform the audiometric tests, it is also possible to perform the tests by using the internet network. The main objective of the audiological investigations using a computerized system is to conduct an efficient assessment of the hearing sensitivity of individuals in less time (Gelfand 1997, Hong & Csaszar 2005, Czyzewski et al 2002, Skarzynski et al 2002).

The advantage of the computer based audiometer is to save the patient information as well as the audiograms plotted at the end of the pure tone test for a particular patient (Bendaouia et al 2008). The first computer based audiometer was introduced in the year 1995. The facility to develop custom user tests reduces the process time and hence, more number of patients can be tested in lesser time, when compared to the conventional audiometer. The software permits the user to develop custom tests using any number of testing parameters (Margolis et al 2010). After installing the tests, it takes only a short time to start the audiological test with the new patient and load the desired user test.

Similar to the setting up of user tests, many numbers of interface options allow each clinician to create a routine testing process (Mikolai & Mroz 2010). In the year 2003, Tympany Inc. introduced an automated pure tone and speech audiometer, in which pure tone audiometry is performed by an automated Hughson-Westlake procedure. Speech recognition thresholds
and word recognition scores are obtained by performing a set of picture identifying tasks (Robert 2003). The new age of play audiometry: prospective validation testing of an iPad-based play audiometer assumed significance in the development of a computer based audiometer (Yeung et al 2013). The use of air conduction test results to identify the Air Bone Gap (ABG) and the use of automated testing procedures were emphasized (Convery et al 2014). The system solves the problems in conducting audiometric tests easily by helping the people to use it on their own (Lotfi et al 2006). The important features of these screening examinations are sensitivity and accuracy. This is achieved by providing effective software modules, designed and developed in the present work and subsequently installing them in a computer environment. The development of self fitting hearing aids which is used to identify the hearing threshold and the factors affecting the reliability and validity of the automated procedure are also considered (Convery et al 2015 and Keidser & Convery 2016).

Another important consideration in audiology is the hearing aid selection, and the interaction of the hearing impaired person for satisfaction. Once the audiological data of the subjects are obtained, the clinician must be cautious in suggesting a appropriate hearing aid for the type of hearing loss and fixing the gain suggestions of a suitable prescriptive fitting procedure with the hearing aid circuit (Schwartz et al 1988). The digital hearing aid of modern days uses different frequency bands in the audible range of sound. Most prescriptive procedures require only pure tone test results for the REIG calculations. REIG is the additional gain required for the hearing aid usage and to get a clear perception of sound by the hearing impaired patients. Most of the hearing aid users are comfortable with the lesser gain than what is actually prescribed for them.
Gerling (1992) states that, prescribing the same gain for all individuals, simply because they have the same hearing thresholds will result in inaccuracies of too little as well as too much gain. Also, some programmable systems require special equipment and specific measurement protocols, as part of their fitting process. It is reasonable to assess the inter octave frequencies, especially 1500 and 3000 Hz, because some prescriptive formulae not only calculate the gain and output at these inter octave frequencies, but also the hearing impairment could change somewhat over a full octave. In addition, there should be strong clinical contraindications to a binaural fitting before clients are directed to the monaural use of hearing aids (Silman et al 1984, Gelfand 1995). The integrated real ear measurement improves the accuracy of fitting initially, and subsequently, when the hearing aid is fine tuned to achieve better speech intelligibility by the patient (Yanz et al 2008; Yanz et al 2007). A useful and significant study conducted by Best et al (2015), in an examination in cafeteria in respect of SRT measurement is also considered. An article titled ‘Development and preliminary evaluation of a new test of ongoing speech comprehension’ is helpful to understand the significance of custom based audiological investigations (Best et al 2015).

Prescriptive procedures are the standard formulae developed continuously by the researchers, for suggesting hearing aid gain values to enhance the satisfaction with the hearing aid performance. The challenge for the audiologists is to choose the right prescriptive procedure and modify the gain values of the hearing aid suitably to enhance the satisfaction level of the subjects. This section explains the evolution of the different prescriptive procedures. Initially, Watson & Knudsen (1940) suggested a way to prescribe parameters for hearing aids, based on audiometric measurements. The objectives of prescriptive approaches are to provide an appropriate gain to
achieve normal hearing and to provide gain based upon the discomfort level (MeCandless 1988).

The objectives of prescriptive approaches (Mecandless 1988) are:

- to provide appropriate gain values to achieve normal hearing
- to present to the ear, an average speech spectrum of a comfortable level
- to provide the maximum dynamic range of sound
- to provide signals to restore an equal loudness function
- to provide aided speech signals at MCL in the speech frequencies
- to provide gain based on the size and shape of the dynamic range
- to provide gain based upon the discomfort level

Particular formulae may or may not accurately reflect the exact relationships between the audiological measured parameters and the amplification characteristics. It is essential that all the subjects have to undergo a comprehensive audiological evaluation, which includes pure tone and speech audiometric tests. Further, the measurements of speech at its Most Comfortable Level (MCL) and speech at its Uncomfortable Level (UCL) are also needed. Most prescriptive procedures require only pure tone test results for the REIG calculations. Some programmable systems require special equipment and specific measurement protocols as part of their fitting process. The specific requirements of the prescriptive formula generation and detailed discussion can be found in Humes & Hailing (1994) and MeCandless (1994).
In the initial periods of digital hearing aid trials, prescriptive hearing aid selection was done only with linear hearing instruments.

Hawkins’s approaches to the specification of gain and frequency response can be categorized in several ways. Researchers decide systematically to develop specific formulae to achieve the targeted goal with the hearing aid (Hawkins 1992). Usually, these formulae support a particular approach to the hearing aid fitting question. Cornelisse et al (1995) reported that the prescription as a frequency-specific gain function that can be recommended for each individual with hearing impairment on the basis of audiometric data.

The prescriptive procedures used for gain suggestions are categorized into two types:

1. Procedures that make use of threshold audiometric data.
2. Procedures that incorporate suprathreshold audiometric data in deriving electro acoustic prescriptions for listeners with hearing impairment.

Byrne (1993) states that the gain and frequency response requirements can be equally predicted from the threshold or suprathreshold measures. Particular formulae may or may not accurately reflect the specific relationships between the audiological measure and the amplification parameters. A detailed discussion on the advantages and limitations of the various popular and obscure prescriptive fitting approaches can be obtained from various sources (Cornelisse et al 1995, Humes et al 1994, McCandless 1994, Byrne 1993).

The prescriptive technique is an organized, systematic approach used in hearing aid fitting, to maximize the user benefit within a short period
of time. A detailed discussion on the advantages and limitations of the various popular prescriptive fitting approaches can be obtained from various sources. The development of Behind-The-Ear, In-The-Ear digital hearing aids, and the probe microphone, made prescriptive fitting techniques essential. With the audiometric test results, the clinician has to carefully select the appropriate prescriptive fitting technique for the specific type of hearing loss. The analysis and discussion should focus upon the two most often used approaches for linear instruments: National Acoustic Laboratory (NAL-R), Desired Sensation Level (DSL) and Prescription of Gain and Output (POGO). Further, the more recent prescriptive methods specifically designed for nonlinear hearing aids. The important among them are the Independent Hearing Aid Fitting Forum (IHAFF) (Cox et al 1994), and FIG6 procedure (Killion 1995). The following discussion focuses on the two most often used approaches for linear instruments, and the more recent prescriptive methods specifically designed for nonlinear hearing aids, including

- National Acoustic Laboratory - Revised
- Prescription of Gain and Output II
- Desired Sensation Level
- Independent Hearing Aid Fitting Forum
- FIG6 procedure

The NAL and POGO procedures are being used since 1976 and 1983. The revised versions NAL-R (1986) and POGO II (1988) created greater accuracy and utility, producing great satisfaction among the prescriptive procedure users. The National Acoustics Laboratory, Australia, developed the NAL formula for hearing aid models with linear circuits. The prescriptive method called NAL-R is the best and most extensively tested and
validated prescriptive method for linear amplification because of its successful recommendations (Byrne et al 1991).

The increased use of conventional and programmable nonlinear hearing aid circuits require new prescriptive methodologies to consider nonlinearity in hearing aids. They further assist clinicians in their ability to fit these products easily and accurately. Since the most popular methods were developed from research with linear instruments, nonlinear circuits that adjust themselves according to the input signal are not well reflected in these linear approaches (Cox 1995). The primary goals of the IHAFF protocol are to provide amplification, so that soft speech is perceived as soft, and conversational level speech is perceived as comfortable and loud speech, and involves the use of warble tones presented to the client at a minimum of two frequencies, typically 500 Hz and 3000 Hz. The Visualization of the Input/output Locator Algorithm (VIOLA) is the decision making unit of the IHAFF procedure: - it calculates the relationship between the overall speech input levels for soft, average, and loud speech at the hearing aid microphone, and the users' loudness judgments for warble tones (Van Vliet 1995). The FIG6 Procedure is a loudness-based fitting formula, designed to accommodate the different types of hearing losses (Fabry 2003). Modern digital hearing aids are designed to change their gain-frequency response depending upon the different sound input levels. The FIG6 procedure is utilized to calculate the gain-frequency response for low level 45 dB SPL, moderate level 65 dB SPL, and high level 95 dB SPL sounds (Keidser 2007).

The development of conventional and programmable nonlinear hearing aid circuits has led to a focus on prescriptive methodologies to accommodate nonlinearity, and assist clinicians in their ability to fit these products easily and accurately (Hojan-Jezierska & Olejnik 2010).
Specifically, approaches that are the result of this research includes

- DSL I/O procedure (Cornelisse 1995)
- NAL-NL1 procedure (Dillon 1999)
- NAL-NL2 procedure (Dillon et al 2010)

The DSL I/O procedure is evolved from the DSL and it is the first procedure used for children (Hawkins 1992). The objective is to achieve the desired sensation level of the amplified signal for multiple level inputs. The DSL I/O procedure can also be used as an effective method of achieving Loudness Equalization. The NAL-NL1 is a threshold-based procedure that prescribes the gain-frequency responses for different sound input levels, or the compression ratios of different frequencies, in wide dynamic range compression hearing aids. The aim of the NAL-NL1 is to maximize speech intelligibility for any input level of speech above the compression threshold, while keeping the overall loudness of speech at or below normal overall loudness, and not more than what a normal hearing person would perceive the same sound. The gain-frequency response varies with the sound input level; hence, it is applied to nonlinear hearing aids. It also adopts the principle of normalizing loudness, but it is applied to overall loudness, and does not consider the loudness at each frequency (Dillon 1999). The evaluation of the NAL-NL1 procedure inferred, that the prescribed overall gain was slightly too high for adults especially in the higher input levels, and slightly too low for lower input levels for children (Dillon et al 2010, Dillon & Keidser 2011).

The NAL-NL2 is the second generation prescriptive procedure from the National Acoustic Laboratories (NAL), to suggest the gain values for WDRC instruments. The NAL-NL2 procedure also aims at making a speech intelligible similar to that of NAL-NL1, and the overall loudness comfortable. These factors are most important for hearing aid users, and less information
was provided about the gain adjustments rules to optimize the parameters that affect prescription such as localization, tonal quality, detection of environmental sounds, and naturalness (Dillon et al 2010, Keidser 2007). The adaptive optimization technique used in the NAL-NL2 procedure consists of one loop as the intelligibility model to find the gain-frequency response that maximizes speech intelligibility. Another loop used a loudness model to calculate the loudness, which matched the loudness perception by the hearing-impaired subject to that of a normal hearing subject (Moore & Glasberg 2004). Further adjustments have been made to the theoretical component of NAL-NL2 with the empirical data collected with the hearing aid fitting trials using NAL-NL1 settings. Keidser et al (2011) explained the concept and development principles of the NAL-NL2 procedure. Keidser et al (2012) suggested the empirical adjustments to be incorporated in the NAL-NL2 procedure which is to be useful in redefining the NAL-NL2 procedure. Ching et al (2013) made a useful comparison between NAL-NL1 and DSL I/O prescriptive procedures. The study relating to the comparison of NAL-NL1 and DSL v5 in hearing aids fitted to children with severe or profound hearing loss and its impact on predicted loudness and speech intelligibility is a useful analysis considered in our work (Ching et al 2015).