Comparison of Word Recognition Scores using Different Settings of Telecoil in a Digital Hearing Aid

Register Number: 05AUD006
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A dissertation submitted in part fulfillment for the degree of
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DEDICATED

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CERTIFICATE

This is to certify that this dissertation entitled "*Comparison of speech recognition scores using different settings of telecoil in a digital hearing aid*" is a bonafide work in part fulfillment for the degree of Master of Science (Audiology) of the student with Registration No.: 05AUD006. This has been carried out under the guidance of a faculty of this institute and has not been submitted earlier to any other university for the award of any diploma or degree.

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DECLARATION

This is to certify that this master's dissertation entitled *"Comparison of speech recognition scores using different settings of telecoil in a digital hearing aid"* is the result of my own study and has not been submitted earlier to any other university for that award of any degree or diploma.

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Chapter I

Introduction

Communication plays an important role in everybody's life and the individuals with hearing impairment are no exception to it. People exchange their ideas, views and emotions through communicating with one another. Even individuals with hearing impairment need to communicate their needs and desires in the environment they live in. However, individuals with hearing impairment face a number of problems in communication due to their sensory impairment. To add on to their problem in their day- to-day communication due to their sensory impairment, various factors such as background noise, reverberant environment, difficulty listening from a distance, multi talker babble (two or more than two speakers), etc. pose as a hindrance for the individuals with hearing impairment. Another such problem arises while using telephone as a means of communication.

Telephone has become an integral and essential part of today's modern lifestyle. It is almost impossible to do without it. It is considered to be one of the fastest means of communication and hence it is desired by all. But the individuals with hearing impairment are not successful enough to make an effective use of this instrument because of either the limitations of the hearing aid they are using or the telephone they use (Rodriguez, Holmes, DiSarno & Kaplan, 1993). Hearing aid users have often expressed their dissatisfaction while using telephone (Kochkin, 2002). Thus, hearing aid users find it difficult to communicate over telephone. But with the advent of the telecoil within the hearing aid, this problem has been ameliorated to a large extent.

A feature available on many hearing aids to help during telephonic conversation is called the "telecoil". It is also referred to as a "t-coil". It is nothing more than a thin coil of wire wound around a core that will induce an electric current in the coil when it is in the presence of a changing magnetic field. The coil converts magnetic energy to electrical energy, in much the same way that a microphone converts sound waves to electrical energy. Generally, the strength of the inductive pick-up is determined by the number of turns of the copper wire which is wound around the metal rod. Larger rods permit more turns and more powerful telephone coils (Ross, 2005). Newer "T" coils include an integrated amplifier, which makes it feasible to reduce the physical size of the "T" coil and still operate effectively. Still, the smaller the hearing aid, the less room there is for a telecoil, and thus in tiny aids telecoils are either weaker or excluded entirely.

When a hearing aid is switched to "T" position, the telecoil is said to detect only an electromagnetic field. The strength of the electrical current "induced" in the telecoil by the electromagnetic field is directly proportional to both the energy in the magnetic field and the relative positions of the induction coil in the hearing aid to the magnetic field (in a telephone or wire loop). This latter consideration is particularly important because in some positions, little or no electrical current will be created in the induction coil. The magnetic field will simply "pass through" the coil without producing much, if any, electrical current. This is the reason why experienced hearing aid users always experiment with the positioning with unfamiliar telephones to find the "hot spot" where the strongest signal is heard (Ross, 2006).

The potential usefulness of telecoil extends beyond their purpose, which is, detecting the serendipitous electromagnetic field surrounding the earpiece of early telephones (and current "hearing aid compatible" telephones). Telecoils can be used in any setting that provides an induction loop assistive listening system. In such a system, a loop of wire around a room (or under a carpet) produces an electromagnetic field instead of or in conjunction with, amplified sound from a loudspeaker (McArdle, 2005). Telecoils can also pick up the electromagnetic signals emanating from neck loops that are placed around the neck. These are plugged into the earphone jack of FM and infra-red receivers and used with small and large area assistive listening systems. The telecoil permits hearing aid users to "inductively" couple these devices to their personal hearing aids.

A telecoil, can therefore, be an alternate or supplemental input device for a hearing aid. Normally, a hearing aid "listens" with its microphone, and then amplifies what it "hears". But with a telecoil used as the input source instead of (or in addition to) the microphone, the hearing aid can "hear" a magnetic signal which represents sound.

A telecoil in a hearing aid enables a hearing aid user to listen to conversation on the telephone, without acoustic feedback, by taking advantage of the electromagnetic induction associated with the signal coming from the telephone. Although audiologists carefully adjust the acoustic characteristics of hearing aids in the microphone mode in an attempt to improve speech understanding, very little attention has been given in adjusting the output characteristics of telecoils and evaluating how well individuals with hearing loss understand speech over the telephone when using telecoils (Takahashi, 2005). As audiologists we must attempt to improve both telephonic and face-to-face speech communication in individuals with hearing impairment. To achieve this we need to study the properties of the telecoil within the hearing aid. This knowledge will help us in modifying the telecoil gain settings. Electroacoustic evaluation of the output from the telecoil is important if a user of the hearing aid is advised to use the hearing aid in telecoil mode.

Fikret-Pasa and Garstecki (1993) used probe tube microphone measures to examine the frequency response of various telephone amplifiers in an ear simulator. They found that the frequency response of the telephone amplifiers varied dramatically in terms of spectrum and input/output functions. Mueller and Bryant (1991) described a method using probe tube microphone measurements to evaluate the telecoil response of the hearing aid in the ear canal using either an area induction loop installed in a room or a neck loop or silhouette receiver, but they were not sure whether the electromagnetic signal emanating from a telephone may or may not be similar to that from a loop or silhouette receiver.

Many newer hearing aids now allow programmable adjustments of the level and frequency response of the telecoil. Some manufacturers offer a telecoil that enables the hearing aid user to access the telecoil without having to manually switch to the telecoil mode that is, the "touch less" telecoil. The magnet within the telephone receiver serves to switch the hearing aid to telecoil mode automatically (Marshall, 2002). The "touch less" telecoil is an amplified telephone coil that uses an automatic switch in place of the conventional hand-operated switch.

It is often problematic to set the telecoil response as there are many factors that influence real world speech communication over the telephone, such as, the characteristics of the listener's as well as the talker's telephone, variability in transmission line characteristics, variability in the position of the telephone handset relative to the telecoil, and interference from other electromagnetic sources (Takahashi, 2005). Despite these challenges, in clinical situation, it may be valuable to program a hearing aid's telecoil response based on the performance. Programming the telecoil seems to require the same target that is used for acoustic response which may not be appropriate for telephone use because of factors such as the frequencies transmitted through a telephone line and electromagnetic field strength around the telephone (Davidson & Noe, 1994). The target is for acoustic input through microphone mode. Input through telecoil differs and hence target should be different. Hence the performance in telecoil mode is lesser than for microphone mode. At present, provisions are there in the hearing aid analyzer system for measurement with "teleboard" as well as "telewand" to evaluate the electroacoustic performance of the hearing aid in the "T" mode and it is also important to know how the electroacoustic characteristics for telecoil vary depending on the type of input source that is, "teleboard" or "telewand".

Need for the study:

Listeners with hearing impairment almost always perform poorly while using telephone as compared to face-to-face conversation. Tannahill (1983) reported poorer word recognition when the hearing aid coupled with telecoil signals compared with acoustic signals. He also recommended that when deciding on a hearing aid, audiologists should make sure that there is sufficient reserve gain in the hearing aid so that the volume can be turned up for use on the telephone. Until recently, there was no way to program the telecoil response independently from the acoustic response of a hearing aid. Hearing aid users had to switch their hearing aids manually to the telecoil mode and often needed to increase the volume setting on their hearing aids to receive adequate signal.

Although there is a capability to programme the overall gain and frequency response of the telecoil on some hearing aids, there is no standardized method of setting these parameters. Yanz and Preves (2003) reported that inductive coupling is better in the high frequencies than in the low frequencies. For this reason, the low frequency response of the hearing aid is often boosted relative to the high frequency response to compensate for poor coupling in the low frequency (Compton, 1994). In 2007, Chowdhury, Manjula and Abraham found similar findings to that of Yanz and Preves (2003) study. That is, they reported inductive coupling to be greater in the high frequencies than in the low frequencies. Takahashi (2005) studied the effect of different telecoil settings on the word recognition scores. The settings used were default setting obtained by simply switching to the telecoil mode without making any modifications and the modified telecoil settings obtained by changing the telecoil settings in an attempt to match the acoustic frequency response target. He found that word recognition scores were better with modified telecoil settings compared with the default settings (i.e., 72% vs. 52%).

The present study aimed

1. to evaluate the optimal settings of the telecoil by comparing the performance in terms of default and modified telecoil settings.

2. to find out with which of the input methods of measuring the electroacoustic performance of the telecoil of a hearing aid, that is, "teleboard" or "telewand", the speech performance related better.

Chapter II

Review of literature

A hearing aid telecoil enables a hearing aid user to listen over the telephone without any acoustic feedback by taking advantage of the electro magnetic field (Skinner, 1988). This phenomenon is known as inductive coupling and was first reported in 1947 by Sam Lybarger. Inductive coupling refers to the phenomenon whereby an electrical current is induced in a coil of wire as a time varying magnetic field passes through the coil (Ross, 2005). Lybarger discovered that telephone receivers produced a stray magnetic leakage flux signal proportional to the signal received by the telephone handset.

For the purpose of the study, the literature reviewed is being discussed under the following headings:

1. Advantages of inductive coupling
2. Telecoil standards
3. Issues and problem

1. Advantages of Inductive Coupling

Lybarger (1947) substituted a coil of wire wound around a metal core for the microphone used in typical hearing aids. The induced electrical field was amplified through the hearing aid and converted to acoustic energy just as a microphone signal is. Advantages of using induction coil input mode rather than microphone mode include reduced acoustic feedback problems and elimination of ambient noise surrounding the hearing aid wearer. Feedback occurs only during acoustic coupling. Sound from the output of the hearing aid reflects off the telephone handset, where it is picked up by the microphone of the hearing aid and re-amplified, creating a feedback loop and causing an audible whistle. The output of a hearing aid with feedback is characterized by an increase in amplitude of up to 25 dB in the 2000 Hz region (Kozma-Spytek, 2003). This feedback loop response will depend on the hearing aid type and is generally more pronounced for in-the-ear than behind-the-ear hearing aids (Hellgren, Limner & Arlinger, 1999).

Welsby (1993) found that when feedback occurs, the hearing aid user may remove the hearing aid, re-position the phone, or reduce the volume control of the hearing aid. If the individual removes the hearing aid, the volume of the speech reaching the ear may be inadequate even if the volume control of the phone is maximized. Re-positioning the phone can have a number of detrimental effects on telephone communication. First, it may cause discomfort to the hearing aid user in maintaining an unnatural telephone handset position. Second, it may cause an acoustic leak that can reduce the level of frequencies below 1000 Hz. Finally, if there is external background noise, the level of noise reaching the ear may be greater than it would be if a seal were maintained, because the noise can now enter the hearing aid microphone directly, as well as through the side-tone.

Again the telephone system itself presents limits on the signal received, the most notable being the band-limiting nature of telephone transmissions. The transmitting bandwidth of the telephone is approximately 3000 Hz, transmitting frequencies between 300 and 3300 Hz, with a relatively flat spectrum.

2. Telecoil Standards

In hearing aids, the T-coil is a substitute for the microphone and provides the input signal to the hearing aid when using telephone. There are two types of T-coils (passive and amplified or active). The basic strength of each depends on its size and the number of turns of wire in the coil. Passive telecoils consist of many turns of ultra fine copper wire on a suitable core. An active T-coil combines a conventional T-coil and a pre-amplifier. Some manufacturers offer a telecoil that enables the hearing aid user to access the telecoil without having to manually switch to the telecoil mode, called the "touch less" telecoil. The magnet within the telephone receiver serves to switch the hearing aid to telecoil mode automatically (Marshall, 2002). The "touch less" telecoil is an amplified telephone coil that uses an automatic switch in place of the conventional hand-operated switch. While the conventional telecoil works well for people who can handle a small toggle switch, it presents a challenge to patients with compromised manual dexterity (Palmer, 2001). For some, the switching creates a minor but annoying delay in answering the phone.

Two magnetic phenomena are essential for the operation of the "touch less" telecoil. All telecoils rely on an inductive (or varying electromagnetic) field of sufficient strength radiating, or 'leaking', from the telephone receiver. The "touch less" telecoil relies additionally on the permanent magnet that is part of every dynamic transducer, such as those in most telephones. The stationary magnetic field in the telephone receiver provides the stimulus to flip the internal automatic switch in the hearing aid from microphone input to telecoil input. As the performance specifications of telephones are not all the same, some dynamic receivers may not have a stationary magnetic field sufficiently powerful to trigger the "touch less" telecoil switch. In such cases, a small disk-shaped magnet can be attached to the telephone receiver to ensure reliable switching performance (Marshall, 2002).

Even though T-coils were an integral component of hearing aids for many years, standards for quality control and evaluation came into existence only in 1976. At that time, with the adoption of the ANSI S3.22 standards for evaluating the electroacoustic performance of hearing aids, T-coil performance became part of the ANSI testing procedure. Remarkably, T-coils were not even mentioned in the Hearing Industry Association (HIA) standards that preceded the 1976 ANSI standards. The inclusion of T-coil measurements in the 1976 standard was an advancement, but only a small one because the standard only required that the hearing aid, set on T-coil, be tested at 1 kHz with an electromagnetic field strength of 10 mA/m. The examiner would then manipulate the orientation of the hearing aid in the magnetic field until a maximum sound pressure level (SPL) reading was obtained in the coupler. This procedure only provided a gross estimate of the strength of the T-coil in different physical positions at one frequency.

It was not until 20 years later (1996) that the new ANSI standards included more detailed testing of T-coils. In these standards, a stronger magnetic field is used and three frequencies are tested i.e., 1000 Hz, 1600 Hz, and 2500 Hz. The characteristics of the test coil are specified and termed a telephone magnetic field simulator (TMFS). A TMFS generates a 31.6 mA/m magnetic field, meant to simulate the strength of an average hearing aid compatible (HAC) telephone. The standard requires that the average sound pressure level output generated at the three frequencies via the magnetic field input to be compared with the output obtained with an acoustic input of 60 dBSPL at the reference test gain (RTG) volume control setting. These two measured outputs should be the same. That is, the output with the magnetic field input should be equal to the output obtained with acoustic input. If the output measured with the T-coil input is less than that occurring in the acoustic condition, then the implication is that the strength of the T-coil should be boosted (Teder, 2003). This comparison between the average sound pressure level output generated via the magnetic field input and the output obtained with an acoustic input of 60 dBSPL at the reference test gain (RTG) volume control setting is called the simulated telephone sensitivity (STS).

Table 2.1: Comparison of 1976/87 and 1996 ANSI S3.22 Telephone Measurements.

	ANSI S3.22-1976/87	ANSI S3.22-1996
Field strength	10mA/m	31.6 mA/m
Frequency	1000Hz	1000, 1600, 2500 Hz
Measuring coil size	Not specified (Teleboard)	Simulated telephone (TMFS)
Hearing aid location	Move around for maximum reading	Simulated telephone use

It is as necessary to know the frequency response of the T-coil as it is to know the frequency response of the microphone. If a specific frequency response is thought most desirable for a hearing aid user, then the same target should be the goal whether a person listens through a microphone or a T-coil. Similarly, the Nordic Standard, as applied to telecoils, requires that an inductive input signal of 31.6 mA/m shall give the same output signal level as an acoustical input signal (using the 'M' position) of 57 to 67 dBSPL in the frequency range from 1000 to 4000 Hz and of 55 to 67 dBSPL in the range from 500 up to 1000 Hz. This requirement applies for both T and MT positions and for any setting of the tone controls of the hearing aid. Certain models of hearing aid allow for programming the telecoil that is similar to the acoustic program in terms of perceived volume and sound quality (Murphy, Bray, Nilsson & McDowell, 2000). These investigators discussed the benefits of adopting a microphone-to-telecoil transfer function. This transfer function establishes similar output levels between the two transducers at a given input level, thus ensuring that the microphone and telecoil are equivalent in loudness and sound quality. It has been seen that when both the telecoil and the microphone modes of a hearing aid are programmed exactly according to the target gain curve generated by a prescriptive formula, the output from the microphone is always more compared to the telecoil mode, more so in the low frequencies.

Hearing aid users have often expressed their dissatisfaction with their ability to hear on the phone (Kochkin, 2002). Although audiologists carefully adjust the electro acoustic characteristics of a hearing aid in the microphone mode in an attempt to improve face-to-face speech understanding, very little attention has been given to the output characteristics of telecoil and how well individuals with hearing loss understand speech over the telephone when using telecoil mode (Takahashi, 2005).

3. Issues and Problems

Although listening via inductive pick-up is often effective, problems can occur if interfering magnetic sources such as digital cellular phones, power lines, transformers, fluorescent lights, and computer peripherals are nearby (Levitt, 2001). Hearing aid wearers report that these interfering magnetic sources result in a continuous hum or buzzing sound from their hearing aids. If the conversation is close to a source of inductive noise, such as the ballast of a fluorescent light or a computer monitor, the noise is likely to degrade the desired signal. With a pre-amplifier included with the induction coil, the higher sensitivity induction coil is even more susceptible to amplifying undesired noise signals. Some of these interfering signals are not easy to remove by simple high-pass low-pass filters because their energy spectrum is relatively broadband, extending through at least part of the pass-band of the hearing aid. For example, the spectrum of a radiated signal from computer monitors.

Interference produced by power lines, fluorescent lights, computer monitors, copiers and fax machines is caused primarily by magnetic fields (H fields). Electric fields (E fields), such as those generated by digital cellular telephones, produced another type of high-frequency interference in hearing aids. To retain use of the telecoil to pick-up inductive energy from a telephone or loop, any solution for blocking magnetic field interference must not attenuate the desired magnetic field.

Another issue that comes into consideration while using hearing aid with telephone is the hearing aid compatibility (Smith, 1971). The 1988 law states that a telephone is hearing aid compatible (HAC) if it "provides internal means for effective use with hearing aids that are designed to be compatible with telephones which meet established technical standards for hearing aid compatibility" established by Electronic Industries Association (EIA) Standard RS-504. It had three major aims-

Telephones must be capable of working together with hearing aids effectively.

- The means by which telephones are compatible with hearing aids must be internal to the telephone and not accomplished through any type of external add-on device or accessory.
- Compatibility must be established using technical standards.

One challenge in achieving compatibility between hearing aids and telephones is that the two devices are regulated differently. The primary means of achieving compatibility between hearing aids and telephones, in future, may soon change to take the advantage of the recent technological advances in wireless communication. This can be achieved by use of a short-range wireless communication protocol called "Bluetooth" that permits little, if any, interference from other wireless communication.

The sound heard when listening through a T-coil is often quite different from that heard through a microphone. This is an observation that goes back many years but has rarely been examined objectively. Generally, when a T-coil is provided, audiologists give the user the opportunity to try it out with a telephone in the clinic. If the user's reactions are positive, then the response of the T-coil is considered acceptable. However, as mentioned above, it cannot be assumed that the responses obtained with microphone and T-coil is similar. In fact, as reported by Rodriguez, Meyers and Holmes (1991), typically they are not. This is unfortunate because it is usually possible to match microphone and T-coil responses pretty closely. One way to achieve a close match is to use an active (amplified) T-coil. There is a typical drop-off in the low and high frequency characteristics of passive T-coils; however, with the addition of an amplifier, the microphone response of the hearing aid can be duplicated.

A major factor influencing responses through inductive coupling is the physical orientation of the T-coil relative to the electromagnetic field. Compton (1994) discusses the relationship between telecoil sensitivity and orientation, and Revit (1996) from the perspective of an audiologist and hearing aid wearer, cites positioning and orientation as one of the essential instructions to new telecoil users. During telephone use, the best signal will be induced when the T-coil is perpendicular to the telephone. For listening through a loop system (either a floor or a neck loop), on the other hand, the best reception occurs when the coil is horizontally aligned relative to the loop system. For obtaining the best signal, the magnetic field must cut across the maximum number of turns of the wire in the coil. It is unfortunate that the optimum orientation for telephone use differs from the optimum orientation for a loop system. This situation is further complicated by the fact that audiologists generally do not know the orientation of the T-coil within the hearing aid.

The specific position of T-coils in the ear-level hearing aids depends on the space available within the case or shell. Thus, the consumer must experiment to determine the orientation of the telephone handset at which the signal is loudest. While, theoretically, the maximum magnetic field strength is greatest directly in front of the telephone receiver (the axial position), this does not appear to be the case with all telephones. Differences between telephones are almost always very noticeable. According to Yanz and Preves (2003), to deal with the orientation issue, multiaxis or omni directional T-coils that are insensitive to specific physical positioning within a hearing aid are required. Yanz and Preves (2003) also reported that inductive coupling is better in the high frequencies than in the low frequencies. This phenomenon creates rising frequency response in the hearing aid when the input is inductive (Madaffari & Stanley, 1996). For this reason the low frequency response of the hearing aid is often boosted relative to the high frequency response to compensate for poor coupling in the low frequency (Compton, 1994).

The goal while programming for optimal telecoil setting should be to achieve almost equal output from the telecoil mode and microphone mode, for 31.6 mA/m electromagnetic field and 60 dB SPL acoustic input respectively for frequencies from 500 to 4,000 Hz. Yanz and Preves (2003) reported that a bandwidth extending too far in high frequencies may introduce a high pitch hiss in the telecoil mode. Since input frequency information from the telephone line will be restricted to 4 kHz, telecoil gain optimization needs to be up to 4 kHz only. Also Dillon, in 2001, reported that it is advisable to reduce the gain in low frequencies as frequencies below 500 Hz may carry unwanted electromagnetic interference.

Preves (1996) has shown common inductive noise sources to have a wide bandwidth. The frequency response of a typical telephone is about 300 to 3400 Hz, narrower than a typical hearing aid acoustic response. A hearing aid telecoil bandwidth wider than that of the desired signal source may simply invite noise into the frequency range unused by the telephone signal. Achieving an optimal frequency response in telecoil mode may necessitate a compromise between the goals of broad bandwidth and minimal interference. Tannahill (1983) reported poorer word recognition with telecoil signals compared with acoustic signal. The frequency response of the telecoil signal was narrower than the acoustic telephone response and had lower output when a standard telephone receiver was used. Tannahill recommended that when deciding on a hearing aid, the audiologists should make sure that there is sufficient reserve gain in the hearing aid so that the volume can be turned up for use on the telephone.

In 2007, Chowdhury, Manjula and Abraham found similar findings to that of Yanz and Preves (2003) study. That is, inductive coupling to be greater in the high frequencies than in the low frequencies. The result of their study was justified based on the Faraday's law of electromagnetic induction. Faraday found that the electromagnetic force produced around a closed path is proportional to the rate of change of magnetic flux through any surface bounded by that path. Faraday's law of electromagnetic induction states that,

$$= -N \frac{d\text{Ø}B}{d\,t,},$$

here = is the induced emf in volts,

N = number of turns of the coil,

and ØB = magnetic flux in Webers through a single loop.

As the frequency reduces, the rate of change of flux, d0B/dt decreases. Therefore, the induced voltage also reduces. As we move higher in frequency, d0B/dt increases. This will lead to higher induced voltage. This is consistent with the results which show that the coupling becomes better as we go towards high frequencies. To compensate for poor inductive coupling at low frequency, a modified strategy was adopted for programming the telecoil for optimal inductive coupling which equalized output from microphone and telecoil modes at certain input levels. The output with telewand was considered during programming for optimal inductive coupling as the magnetic field of a telewand simulates that of a telephone.

In early hearing aids, telecoil sensitivity was much weaker than the microphone sensitivity. This problem was caused primarily because the induction coil, being just a long coil of wire, wound around a core, had no built-in preamplifier. Also, not all telephone handsets had receivers that radiated a sufficient amount of stray magnetic flux. For many hearing aid wearers, even at full-on gain control setting in telephone mode, amplification was not sufficient. At times the combination of a weak hearing aid in telephone mode and a poor quality telephone due to insufficient magnetic leakage made effective telephone communication difficult. Fikret-Pasa and Garstecki (1993) used probe microphone measures to examine the frequency response of various telephone amplifiers in an ear simulator. They found that the frequency response of the telephone amplifiers varied dramatically in terms of spectrum and input-output functions. Their study did not use hearing aids but rather separate telephone amplifiers or amplified telephones.

Mueller and Bryant (1992) described a method using probe microphone measurements to evaluate the telecoil response of the hearing aid in the ear canal. They suggested using either an area loop induction installed in a room or a neck loop or silhouette receiver. As the investigators noted, however, for the method to have face validity, the strength of the magnetic field produced by the induction loop, neck loop, or silhouette receiver would need to be similar to that produced by the device used by the hearing aid user. The electromagnetic signal emanating from a telephone may or may not be similar to that from a loop, or silhouette receiver.

Plyler, Burchfield and Thelin (1998) compared word recognition using acoustic versus electromagnetic coupling and found no significant difference between the two types of coupling. Subjects were allowed to adjust the volume on their hearing aid in each coupling condition. Ideally, hearing aid users should be able to pick up a telephone and not have to adjust the volume on their hearing aid to be able to understand speech over the telephone.

Not many studies were done in the past to see the effective use of telephone by the hearing aid users. Audiologist's main concern was always focused on the face-to-face conversation in the acoustic mode. Hence, the telecoil was hardly given importance in the past. Besides, most of the studies were done without a programmable telecoil within the hearing aid. The telephones used also had limitation such as most of them were not hearing aid compatible (HAC). But with the advancement in the telephone industry, these problems have been overcome. Also there had been similar improvement in the telecoil of a hearing aid. Today, we have programmable telecoil to match the gain in the telecoil mode to that of the acoustic mode in each frequency. Even the hardware system in the telephone has improved and the speaker quality too has a high fidelity. Although there were few studies done in the recent past with programmable telecoil that says there was an improvement in the understanding of speech over the telephone when the telecoil was programmed to match the target gain in the acoustic mode.

Hence, there is a requirement of new controlled studies in this regard. So, the present study was done with a view to investigate the benefit of programming the telecoil for an effective use of telephone by the individuals with hearing impairment.

Chapter HI

Method

The study intended to evaluate the optimal settings in terms of default and modified telecoil settings, needed for best performance over telephone. It also aimed to find out the relationship of speech performance with the electroacoustic performance of the telecoil of a hearing aid, that is, with "teleboard" or "telewand". To accomplish the above mentioned aims, the following method was adopted.

Subjects

15 participants took part in the study. The participants were adults ranging from 15 to 55 years of age, with a mean age of 34.13 years. They had an acquired sensorineural hearing loss ranging from moderate to moderately-severe degree in the test ear. All the participants were native speakers of Kannada. The tests were carried out with the informed consent from the participants to undergo the tests.

Instrumentation

1. A calibrated diagnostic sound field audiometer (Madsen OB922) was used for estimation of pure tone thresholds, unaided and aided performance.
2. A CD player connected to a calibrated sound field audiometer for playing the speech material in the unaided and aided testing condition.
3. A calibrated GSI-Tympstar middle ear analyzer was used for confirming normal functioning of the middle ear.

4. A digital behind-the-ear hearing aid with programmable telecoil, with a fitting range to suit the degree of hearing loss of the participants. Appropriate sized ear tips to fit the test ears of the participants were used.
5. A calibrated hearing aid analyzer, Fonix 7000 (version 1.4) system, to measure the root mean square (RMS) output value of the hearing aid in the microphone mode, and for evaluating the electroacoustic performance using both teleboard and telewand option.
6. Hipro and a personal computer with a soft ware to program the digital hearing aid.
7. Two landline telephones, one for sending and one for receiving the speech material.

Speech Material Used

Four different lists of Phonemically Balanced Kannada words, developed by Yathiraj and Vijaylakshmi (2005) with 25 words each, were presented through the CD player. One of the lists was presented through the audiometer to evaluate the word recognition scores in the unaided and aided (hearing aid in microphone mode) free field condition. The other three word lists were presented through the telephone- in unaided and in two aided conditions (hearing aid with its telecoil programmed in the default and modified settings). None of the word lists were repeated or made familiar to the participants. The recorded word lists were presented at a moderate level approximating the normal conversational level through the CD player via the telephone. The telephone receiving the speech material was held by the participant in such a way that it provided the best signal. This was achieved by asking the participant to adjust the placement of the telephone during an informal talk over the telephone prior to beginning with the test material. The word lists are given in Appendix A.

Instructions

The participants were instructed to repeat the words they heard during the testing in free-field condition, in microphone mode, and over telephone in telecoil mode.

Test environment

The test was conducted in a sound treated double room with ambient noise levels within permissible limits (re: ANSI S3.1 1991, cited in Wilber, 1994) for testing in microphone mode. A quiet environment, free of electromagnetic disturbances especially those caused by fluorescent lights and a power line, was used for testing in the telecoil mode.

Procedure:

Puretone thresholds were obtained using modified Hughson-Westlake procedure (Carhart & Jerger, 1959), across octave frequencies from 250 to 8000 Hz for air conduction and 250 to 4000 Hz for bone conduction. Tympanometry and reflexometry were done to rule out any middle ear pathology.

The testing procedure consisted of the following five stages:

I. Pre - selection and programming of the hearing aid in microphone mode.

II. Measurement of the output of the hearing aid in microphone or acoustic mode and measurement of the speech recognition scores.

III. Programming the telecoil of the digital behind-the-ear hearing aid- in default and modified settings.

IV. Measurement of the electroacoustic performance, in default and modified settings, with teleboard and telewand.

V. Measurement of the speech recognition scores (SRS) over the telephone, with hearing aid telecoil programmed in default and modified settings.

Stage I: Preselection and Programming of the Hearing Aid in the Microphone Mode

Commercially available digital behind-the-ear hearing aid was selected with the fitting range to suit the hearing loss of the participants. The digital hearing aid was connected through a Hipro to the Personal Computer (PC) that had the software for programming. After the hearing thresholds were fed into the software (NOAH 3.0 and Connex 5), the digital hearing aid was programmed based on the NAL- NL1 prescriptive procedure. An acclimatization level of 2 was used while programming. The volume control switch of the hearing aid was de-activated. The gain at different frequencies was set as per the hearing loss of each participant by fine tuning the microphone mode. Different program settings such as listening in quiet for program 1 and telecoil mode for program 2 were activated. This was done for each participant.

Stage II: Measurement of the Output of the Hearing Aid in Microphone or Acoustic Mode and Measurement of the Speech Recognition Scores

The hearing aid analyzer was first leveled before measuring the output value of the hearing aid in the microphone mode. Leveling was done with the reference microphone inside kept at the reference location in the sound chamber, for an input source of 60 dBSPL at all frequencies. The test hearing aid was then connected to the 2-cc coupler with the help of an adapter. The test microphone was connected to the other side of the coupler. The hearing aid microphone was located inside the sound chamber at the reference location. To start the test the following protocol was selected from the menu.

- Pure tone was selected in the set-up menu under general settings.
- Under pure tone settings, normal sweep type was selected.
- Noise reduction was kept at 4X.
- Reference microphone was kept off.
- The root mean square (RMS) source level was then adjusted to 60 dBSPL at all frequencies from 200 to 8000 Hz by adjusting the amplitude knob.
- Then the measurement was started. The output RMS was recorded and tabulated for each hearing aid program settings.

The participant was seated comfortably in the sound treated audiological test room with appropriate placement of the speakers, that is, one meter from the participant at 45° Azimuth. The Speech Recognition Scores (SRS) for Kannada PB word lists (Yathiraj & Vijaylakshmi, 2005) for each participant was noted down in the unaided sound field and aided sound field conditions.

In the unaided condition, the SRS was obtained. For this, one of the four PB word lists (Yathiraj & Vijaylakshmi, 2005) was presented through the CD player connected to the audiometer. The presentation level was 40 dBHL in sound field condition through the speaker. The speaker on the side of the test ear was used for presenting the speech material. The participant was instructed to repeat the words presented. The number of words repeated correctly was scored. Each word repeated correctly was given a score of one; the maximum score being 25, as the list consisted of 25 words.

In the aided condition, a similar procedure was used, except that the participant was wearing the hearing aid in microphone setting. Thus, speech recognition scores in the two test conditions, that is, in the unaided and in the aided (in M-mode) sound field were obtained for each participant.

Stage III: Programming the Telecoil of the Digital Behind-The-Ear Hearing Aid in Default and Modified Settings

The hearing aid was programmed in two settings for the telecoil program:

As suggested by the programming software when the audiogram of a particular configuration was plotted using prescriptive formula given by NAL-NLl. This was referred to as the 'default' program of the telecoil.

With modified settings based on the NAL-NLl and on the basis of the feedback given by the participant, that is the 'modified' program of the telecoil. The gain with respect to different frequencies was increased in the 'modified' program such that the gain in the T-mode almost matched with that of the target gain curve. That is, the gain in the telecoil mode was matched as close as possible to that of the target gain in the acoustic mode.

For each participant, electroacoustic performance and speech recognition scores were measured in the 'default' and 'modified' telecoil settings.

Stage IV: Measurement of electroacoustic performance in default and modified settings, with teleboard and telewand

Electroacoustic measurement with the two program settings (i.e., default and modified) was carried out. Teleboard and telewand were used as the input for creating the magnetic field while carrying out electroacoustic measurements. The Fonix 7000 hearing aid analyzer was used for the purpose.

a) Testing the electroacoustic performance of the hearing aid with the teleboard:

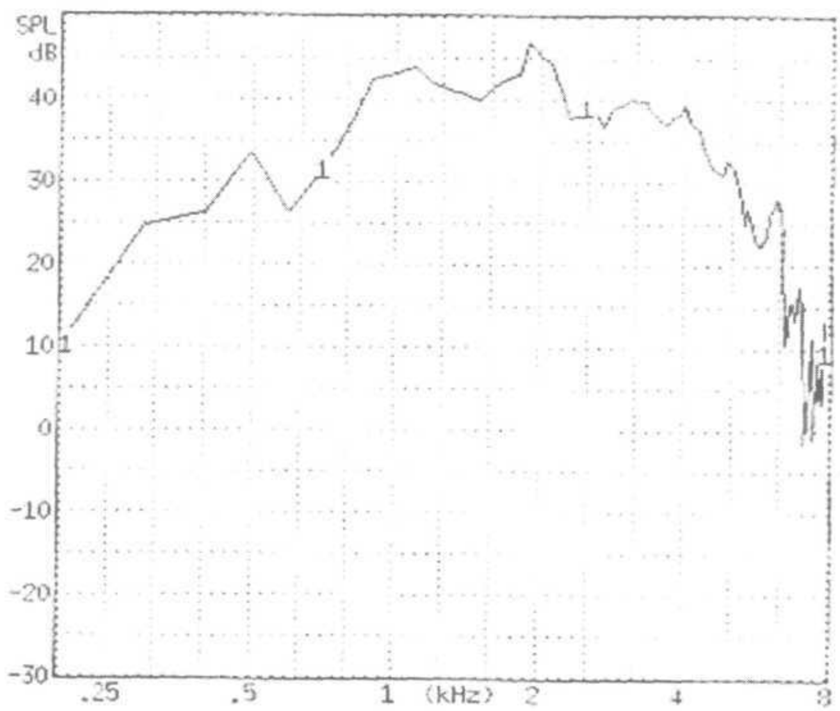
The Fonix 7000 sound chamber has a telecoil board that can be used to measure the hearing aid performance with telecoil setting.

1. The hearing aid was set for testing in the usual way by connecting it to the appropriate coupler (HA-2) which in turn was connected to the measurement microphone of the hearing aid analyzer.
2. The transducer was set to telecoil under the source settings.
3. The source type was set to composite. The composite signal is a continuous broadband signal containing 79 different frequencies presented simultaneously. This signal is usually "Speech Weighted", which means that the lower frequencies have a higher emphasis than the higher frequencies.

4. The strength of the magnetic field was set to 31.6mA/m.

5. The hearing aid was then positioned for maximum output. For BTE hearing aids, this usually occurred when the body of the aid was in a vertical position.

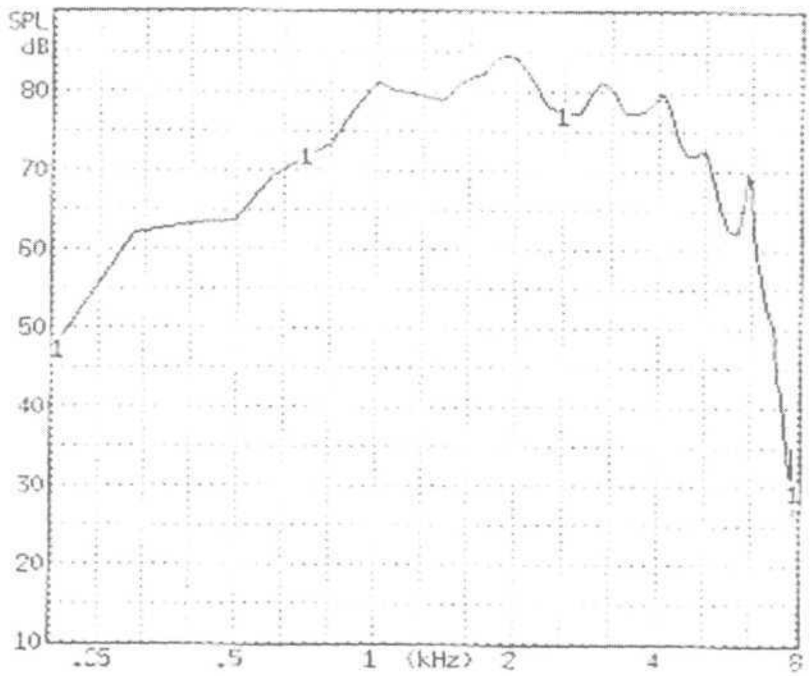
6. Measurement of the output of the hearing aid was made. The system displayed a graph with output versus frequency and the RMS output for the teleboard magnetic field input.



RMS Output: 57.6 dBSPL Source 31.6 mA/m

Fig. 3.1: RMS output (dBSPL) of hearing aid in telecoil default mode using teleboard.

The Figure 3.1 shows the RMS output value of the hearing aid in the telecoil default mode using teleboard as input magnetic field. From the figure it can be noted that the RMS output value in the telecoil default mode is 57.6 dBSPL when the source was kept at 31.6 mA/m. The output in the low frequencies is quite low compared to that in the high frequencies because of poor inductive coupling in the lower frequencies.



RMS Output: 95.9 dBSPL Source 31.6 mA/M

Fig. 3.2: RMS output (dBSPL) of hearing aid in telecoil modified mode using teleboard.

The Figure 3.1 shows the RMS output value of the hearing aid in the telecoil modified mode using teleboard as input magnetic field. From the figure it can be noted that the RMS output value in the telecoil modified mode is 95.5 dBSPL when the source was kept at 31.6 mA/m. As the gain was increased in the telecoil modified mode to match the target gain curve in the microphone mode, it led to an overall increase in the RMS output value. With increase in the gain in the low frequencies there was a better inductive coupling in the lower frequencies. This is evident from the response curve in the figure 3.2. Although frequencies above 3 kHz also get emphasized, it is not useful as the bandwidth of the telephone is limited to around 3300 Hz.

b) Testing the Electroacoustic Performance of the Hearing Aid with the Telewand

The telewand is a device that is supposed to provide a more realistic test of the telecoil features of a hearing aid than the teleboard because it more closely simulates the magnetic field strength produced by a telephone receiver. The telewand was connected to hearing aid analyzer instead of the teleboard to serve as input to the hearing aid.

1. First the hearing aid is set for testing in the usual way by connecting it to the appropriate coupler and inserting the measurement microphone.
2. The transducer was set to telecoil under the source settings.
3. The source type was set to composite.
4. The strength of the magnetic field was set to 31.6mA/m.
5. The hearing aid was held in one hand and the telewand in the other hand. The telewand was positioned parallel to the hearing aid as the receiver of a telephone is positioned in actual use. That is, the telewand was held a few millimeters in front of the hearing aid i.e., positioned parallel to the body of a BTE aid.
6. The hearing aid was positioned, with the telewand held against it, for maximum output. For BTE hearing aids, this usually occurred when the body of the behind-the-ear aid was in a vertical position.
7. The measurement of the output of the hearing aid, with telewand used as input, was done. The system displayed a graph with frequency versus output, and the RMS output for the telewand magnetic field as input.

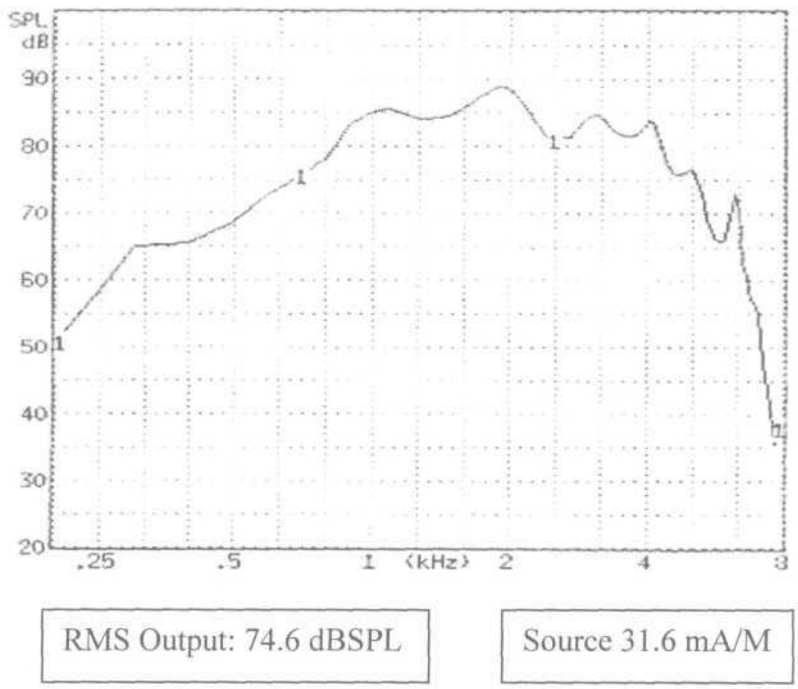


Fig. 3.3: RMS output of hearing aid in telecoil default mode using telewand.

The Figure 3.3 shows the RMS output value of the hearing aid in the telecoil default mode using telewand as input magnetic field. From the figure it can be noted that the RMS output value in the telecoil default mode is 74.6 dBSPL when the source was kept at 31.6 mA/tn. Since a telewand closely simulates the magnetic field strength produced by a telephone receiver, it provides a better way of measuring the RMS output of the telecoil. It is evident from the response curve that the RMS output from the telewand is more than the RMS output from the teleboard in the telecoil default mode.

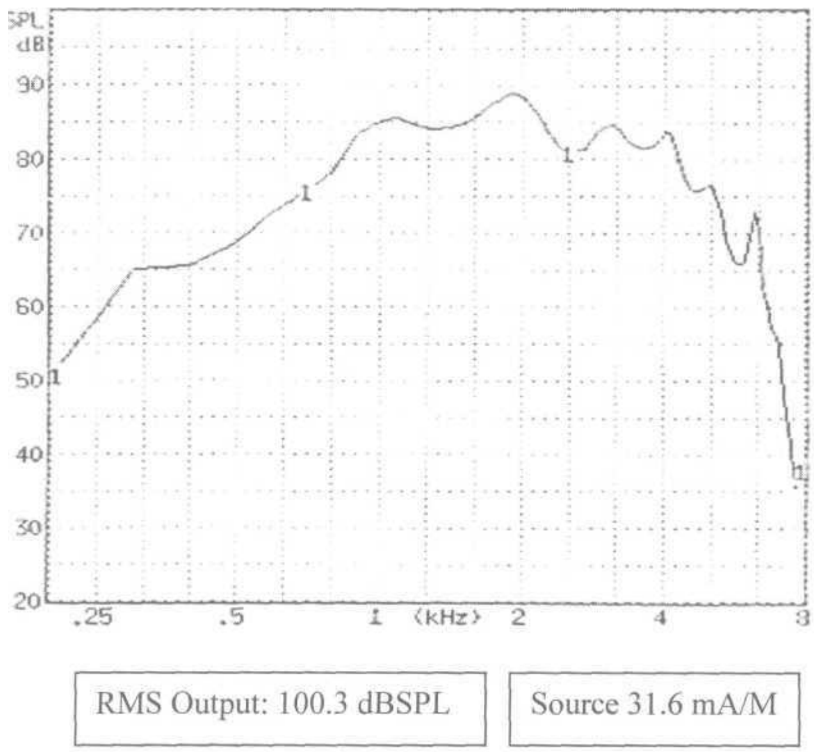


Fig. 3.4: RMS output of hearing aid in telecoil modified mode using telewand.

The Figure 3.4 shows the RMS output value of the hearing aid in the telecoil modified mode using telewand as input magnetic field. From the figure it can be noted that the RMS output value in the telecoil modified mode is 100.3 dBSPL when the source was kept at 31.6 mA/m. As the gain was increased in the telecoil modified mode to match the target gain curve in the microphone mode, the output RMS also increased accordingly. Better inductive coupling was achieved as the gain in the low frequencies was increased. The RMS output value with the telewand was more than the RMS output value of the teleboard.

Stage V: Measurement of the Speech Recognition Scores (SRS) over the Telephone, with Hearing Aid Telecoil Programmed to Default and Modified Settings

The performance of the participants, in terms of SRS, over the telephone was evaluated in the following two conditions:

1. Aided, over telephone. The telecoil of the hearing aid programmed to 'default' setting.
2. Aided, over telephone. The telecoil of the hearing aid programmed to 'modified' setting.

In the first condition, the speech recognition score was obtained with the hearing aid in the telecoil mode, set at default program. One of the PB word lists (Yathiraj & Vijaylakshmi, 2005) was presented to the participant over the telephone. The volume of the CD player was maintained at a moderate level, i.e., at normal conversational level. The speech material was played through the CD player. This was picked up by the telephone placed closed near the speaker of the CD player. The speech material was routed through the sending telephone to the receiver telephone which was used by the participant. The participant was asked to hold the receiver of the telephone behind the ear very near to the hearing aid. The participant was allowed to make adjustments regarding the positioning of the telephone handset to obtain the best signal. This was achieved during an informal talk over the telephone prior to beginning of the test. The participant was asked to repeat the words heard over the telephone. The number of words repeated correctly was scored. Each word repeated correctly was given a score of one; the maximum score being 25, as the list consisted of 25 words.

Chapter IV

Results and Discussions

The present study was conducted keeping in mind the following aims:

1. To evaluate the optimal settings of the telecoil by comparing the performance in terms of default and modified telecoil settings.

2. To find out with which of the input methods of measuring the electroacoustic performance of the telecoil of a hearing aid, that is, "teleboard" or "telewand", the speech performance related better.

To investigate the aims of the present study, statistical analysis using SPSS (Statistical Package for Social Sciences) software (version 10.0) was carried out for the data obtained. The following statistical analyses were carried out:

1. Comparison of performance between moderate and moderately-severe groups was done using Mann Whitney U-Test.

2. Comparison between different conditions i.e., unaided SRS, SRS with hearing aid in microphone mode, SRS with hearing aid in telecoil default mode and SRS with hearing aid in telecoil modified mode was done using One-way repeated measures ANOVA and Bonferroni's multiple comparison test.

3. Comparison of the RMS output of the hearing aid, programmed in different modes and settings, was carried out using paired t-test.

4. Test of significance of correlation coefficient was performed between RMS output and speech recognition scores (SRS).

1. Comparison between Moderate and Moderately-Severe Groups

The following table (Table 4.1) shows the mean and standard deviation values of SRS and RMS (dBSPL) output for the participants in moderate and moderately-severe groups.

Table 4.1: Mean and Standard deviation values of SRS (max. score 25) and RMS output (dBSPL).

		Mean		Standard deviation	
		Group			
		Moderate (N=7)	Mod.-Severe (N=8)	Moderate (N=7)	Mod.-Severe (N=8)
SRS	1. in unaided condition	10.71	8.75	2.14	1.49
	2. with HA in microphone mode	23.71	22.38	1.25	2.26
	3. with HA in T-coil default	18.14	15.88	3.13	2.53
	4. with HA in T-coil modified	22.00	20.63	2.45	2.62
RMS output	1. HA in microphone mode	92.76	104.03	5.57	4.18
	2. HA in T-coil default mode with teleboard	65.66	68.38	6.92	7.03
	3. HA in T-coil modified with teleboard	79.27	85.25	5.47	6.10
	4. HA in T-coil default mode with telewand	77.66	78.88	5.06	5.82
	5. HA in T-coil modified with telewand	92.13	98.88	5.03	4.79

Table 4.1 depicts the mean and standard deviation (SD) values of SRS and RMS output (in dBSPL). From the table, it can be noted that the mean SRS was higher for the subjects with moderate hearing loss than for subjects with moderately-severe hearing loss, in both the unaided and aided conditions. The fact that more the degree of hearing impairment leads to more difficulty in perception of speech is well documented.

Although both the moderate and moderately-severe categories may not be greatly varying in their threshold of hearing, there may exist considerable differences in their perception of speech. This was evaluated by performing the Mann Whitney U-Test.

The mean values of RMS output were higher for the hearing aids programmed for moderately-severe hearing loss than that programmed for moderate hearing loss. This is because, for the moderately-severe hearing loss category, the target gain required was more than that needed for the moderate hearing loss category. Since the target gain for the moderately-severe category was more, it leads to the greater RMS output value for the programming done for the moderately-severe group.

The Mann Whitney U-Test (Non-parametric equivalent of independent t-test) was performed to analyze the significance of difference between moderate and moderately- severe groups, in SRS and RMS output. The test revealed no significant difference, even at 0.05 level of significance, between the mean values of SRS and RMS output, in moderate and moderately-severe groups. Hence, for the further analysis, the scores of the subjects with moderate and moderately-severe degree of hearing loss were combined to form one single group.

2. Comparison between SRS in Different Conditions, i.e., Unaided SRS, SRS with Hearing Aid in Microphone Mode, SRS with Hearing Aid in Telecoil Default Mode and SRS with Hearing Aid in Telecoil Modified Mode.

The Table 4.2 shows that the mean SRS values in the unaided condition was the lowest, and those in the aided conditions were higher. Among the aided mean SRS values, the SRS was highest in microphone mode and least when the telecoil was programmed to "default" mode.

Table 4.2: Mean and Standard deviation values of SRS (max score=25) when scores from moderate and moderately-severe groups were combined (N=15) in different conditions:

	Mean	Standard deviation
Unaided SRS in free field	9.67	2.02
SRS with HA in microphone mode	23.00	1.93
SRS with HA in telecoil default mode	16.93	2.96
SRS with HA in telecoil modified mode	21.27	2.55

One-way repeated measures analysis of variance (ANOVA) was administered to check the significance of difference between unaided condition, hearing aid in the microphone mode, hearing aid in the telecoil default mode and hearing aid in the telecoil modified mode. A significant difference was found, with $F(3, 42) = 325.87$, $p < 0.01$. Bonferroni's multiple comparison test was carried out to see the pair-wise differences. It revealed that all the conditions, i.e., unaided SRS, SRS with HA in microphone mode, SRS with HA in telecoil default mode and SRS with HA in telecoil modified mode were compared individually with each other and all the conditions were significantly different from one another at 0.01 level of significance.

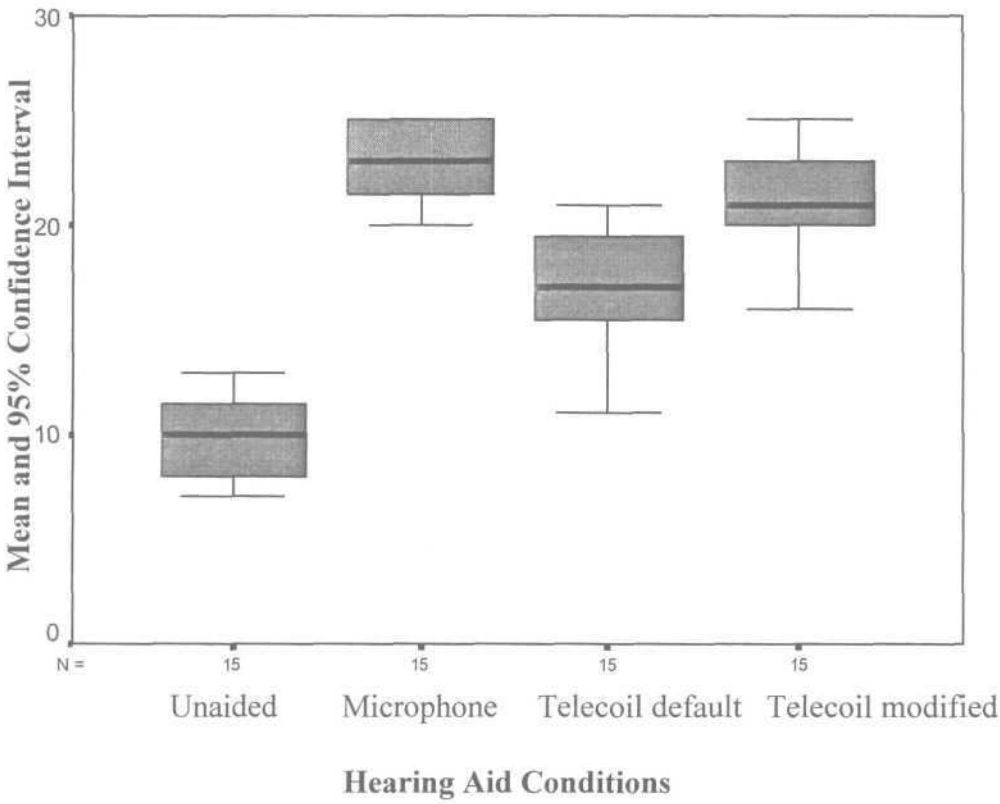


Fig. 4.1: Mean with Confidence Interval of 95% SRS values in unaided and aided (microphone, telecoil default and telecoil modified) conditions.

The Figure 4.1 shows that among the aided conditions, the microphone mode had the highest mean SRS values followed by the telecoil modified mode and then the telecoil default mode. The unaided condition had the lowest mean SRS value.

The reason for poorer SRS with the hearing aid in telecoil default mode is that when the telecoil is in the default mode there is a poor inductive coupling, especially in the low frequencies. Yanz and Preves (2003) also reported that inductive coupling is better in the high frequencies than in the low frequencies. This phenomenon creates a rising frequency response in the hearing aid when the input is inductive (Madafari & Stanley, 1996). For this reason, the low frequency response of the hearing aid is often boosted relative to the high frequency response to compensate for poor coupling in the low frequency (Compton, 1994). So, when the telecoil gain is matched to that of the microphone or acoustic mode by increasing the low frequencies, it gives a better coupling in the low frequencies. Thus, there is an improvement in the speech recognition scores in the telecoil modified condition.

Chowdhury, Manjula and Abraham (2007) found similar results to that of Yanz and Preves (2003). They found that the inductive coupling was poorer in the low frequencies and hence, gain should be increased in the low frequencies for better inductive coupling and thus leading to better SRS. Although in the present study, the SRS in the telecoil modified mode were never better than the microphone mode, in most of the cases the scores in the telecoil modified mode almost equated to that in the microphone mode. This could be because the transmitting frequencies through the telephone is different and hence requires appropriate changes in the 'telecoil modified' program in order to equate the performance to that of the hearing aid microphone mode. Hence, it can be inferred that programming the telecoil can be useful for individuals with hearing impairment while using the telephone optimally.

Tannahill (1983) reported poorer word recognition with telecoil signals compared with acoustic signal. His results were in support of the present study that acoustic mode provides a better SRS than the telecoil signals. He also recommended that there should be enough reserve gain so that the volume of the hearing aid could be turned up for use on the telephone. However, if the volume is increased, there may be an over amplification of the high frequencies. Hence, programs to equate the telecoil response to that of the microphone response would be more useful.

Although the difference between the mean SRS in the microphone mode and the telecoil modified mode was not much, there was a significant difference between the two. This may be because of a greater standard deviation among the difference in the groups.

Table 4.3: Comparison of SRS within different pairs of SRS in aided condition using microphone and telecoil (default and modified) settings.

	SRS in	Correlation (r)	Paired difference in Mean SRS	t(14)
Pair 1	HA-Microphone Mode - HA-Telecoil Default	0.63**	6.07**	10.02
Pair 2	HA-Microphone Mode - HA-Telecoil Modified	0.77**	1.73**	4.13
Pair 3	HA-Telecoil Default - HA-Telecoil Modified	0.88**	-4.33**	-12.01

**p<0.01

From the above Table 4.3, the results of the paired t-test are depicted. The test revealed that although the pairs were highly correlated, there was a significant difference between each pair at 0.01 level of significance. It was observed that in pair 1 there was greater mean difference than in pair 2. That is, when the telecoil was in the default mode, the scores were poorer than that obtained in the microphone mode. This is revealed from the difference in mean SRS. But when the telecoil gain in the modified setting was increased and matched to the target gain curve of the microphone mode, the SRS improved. The mean difference of the SRS in the microphone and the telecoil modified condition reduced. Thus, from the above findings it can be concluded that the telecoil gain be manipulated in order to achieve better speech recognition scores while using telephone.

3. Comparison within Pairs of RMS Output of the Hearing Aid Programmed in Different Modes and Settings

The RMS output of the hearing aid programmed in microphone mode, telecoil default and telecoil modified modes were measured. Figure 4.2 shows that the mean RMS output in the telecoil modified mode was higher than in telecoil default mode. Further, telewand as input magnetic field yielded higher RMS output than the teleboard.

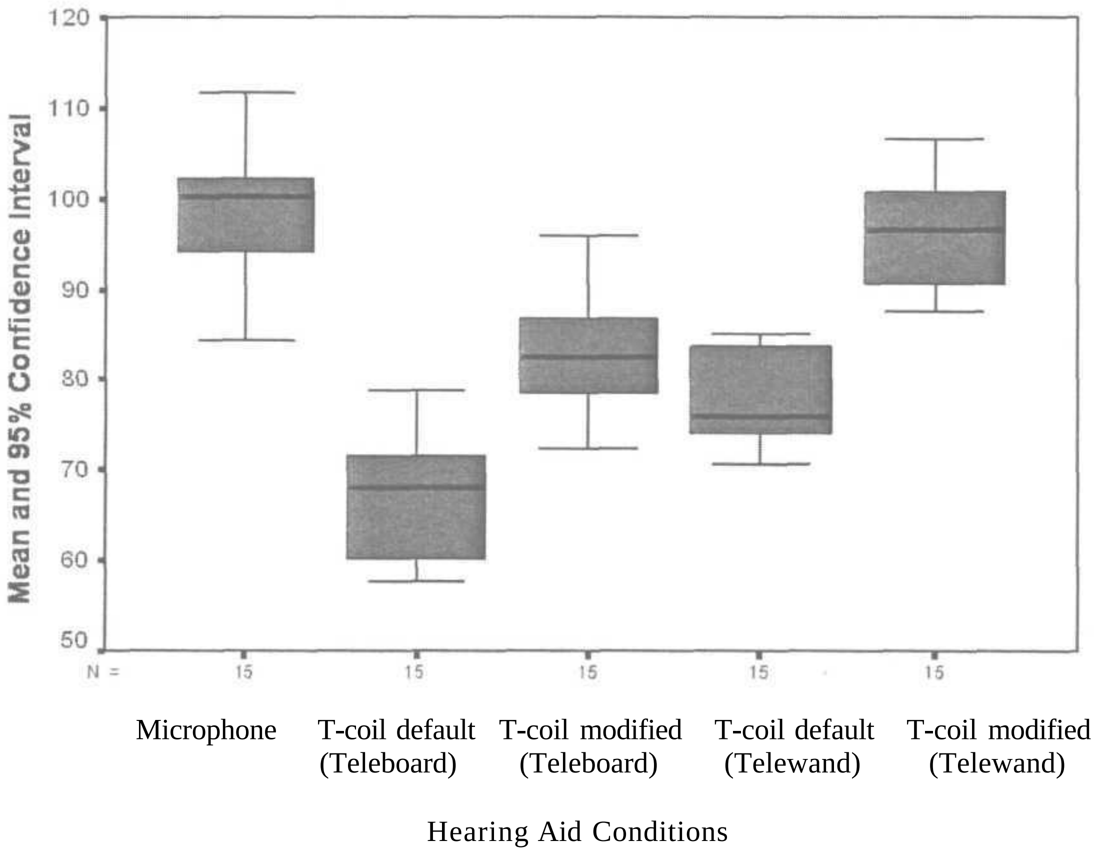


Fig. 4.2: Mean and Confidence Interval of 95% of RMS output (dBSPL) values in different conditions of hearing aid.

The Table 4.4 shows pairwise comparison of RMS output of the hearing aid using paired t-test.

Table 4.4: Comparison of selected pairs of RMS output of hearing aid in different conditions:

	Pairwise comparison	t(14)
RMS output of HA in	1. Microphone vs. Teleboard default mode	15.69**
	2. Microphone vs. Teleboard modified mode	8.19**
	3. Microphone vs. Telewand default mode	10.77**
	4. Microphone vs. Telewand modified mode	1.72
	5. Teleboard default vs. Teleboard modified mode	5.76**
	6. Telewand default vs. Telewand modified mode	8.08**
	7. Teleboard default vs. Telewand default mode	9.95**
	8. Teleboard modified vs. Telewand modified mode	10.93**

Significant at 0.01 level

The results of the paired t-test revealed that all pairs were significantly different at 0.01 level of significance, except for the Pair 4, that is, RMS output in microphone mode versus RMS output in telecoil modified mode, with telewand as the input source. That is, when the hearing aid program was modified in telecoil mode such that it matches the target curves in the microphone mode, the RMS output did not differ in the telewand measurement from the microphone mode. This is also be visualized in the

Figure 4.2. The difference in the mean SRS is also not much. This agrees with the mean SRS in the microphone mode and in the telecoil modified mode.

4. Test of Significance of Correlation Coefficient between RMS Output and SRS

The relationship between the RMS output in different hearing aid settings and the SRS in the respective hearing aid settings was measured using Pearson's correlation coefficient (r).

Table 4.5: Pearson's correlation coefficient (r) value between RMS output (dBSPL) and SRS in different hearing aid settings.

RMS Output of HA in	SRS with HA in	r
Microphone mode	Microphone mode	-0.30
Telecoil default (Teleboard)	Telecoil default	0.30
Telecoil default (Telewand)	Telecoil default	0.29
Telecoil modified (Teleboard)	Telecoil modified	-0.25
Telecoil modified (Telewand)	Telecoil modified	-0.12

It was found from the Table 4.5, that there was low correlation that was not significant, between the RMS output value and SRS in different hearing aid settings. That is, with increase in the RMS output of the hearing aid, there was no increase in the performance of the participants in their speech recognition scores at different settings of the hearing aid. Increasing the gain of the hearing aid led to increase in individual SRS and RMS output only. It can attributed from the fact that although the participants were not significantly different with respect to their degree of hearing loss, the mean SRS was higher for the subjects with moderate hearing loss than for subjects with moderately- severe hearing loss, in both the unaided and aided conditions. The variation, as revealed by standard deviation, was low. The mean values of RMS output were higher for the hearing aids programmed for moderately-severe hearing loss than that programmed for moderate hearing loss. The r value might have correlated better if the gain was considered instead of RMS output.

Further, there is a phenomenon called speech level distortion which states that not only audibility but also speech perception ability of the individuals with hearing impairment gets affected due to due high levels of presentations. In such conditions, just a 10 to 20 dBSL may yield a better speech recognition score, but further increase may lead to poor speech intelligibility. Hence, the findings may be attributed to this phenomenon.

Table 4.6: Pearson's correlation coefficient (r) value between RMS output of the hearing aid in telecoil default and modified mode using teleboard and telewand:

RMS Output in	RMS Output in	r
Telecoil default (Teleboard)	Telecoil default (Telewand)	0.77**
Telecoil modified (Teleboard)	Telecoil modified (Telewand)	0.71**

** Correlation is significant at 0.01 level

It was found from Table 4.6 that there was a highly significant correlation between the two pairs of RMS output using teleboard and telewand in the default and modified settings. That is, the increase in RMS output with teleboard was reflected in the increase in RMS output with telewand. However, the RMS output measured using telewand was always slightly higher than that measured with teleboard. The most appropriate reason for this increase in the RMS output using telewand is that, the telewand is a device that is supposed to provide a more realistic test of the telecoil features of a hearing aid than the built-in telecoil board in the sound chamber because it more closely simulates the magnetic field produced by a telephone receiver.

Thus from the results, it is inferred that the data from moderate and moderately-severe groups when tested in the different aided conditions using Mann Whitney U-Test, showed no significant difference between the groups. In view of the main aim of the study that was, whether it was telecoil default mode or the modified mode that gives the higher SRS, it was found that participants did significantly well in the telecoil modified mode compared to the telecoil default mode. This was evident from the mean and standard deviation values of SRS between these modes. Next, the comparison of RMS output of hearing aid in different modes was done using paired t-test and the test revealed that all the pairs were significantly different at 0.01 level of significance, except for one, that is, RMS output of microphone versus RMS output of the telecoil modified using telewand as input magnetic source.

To evaluate the second aim of the study, Pearson's correlation between the RMS output and the SRS in the different hearing aid settings was performed. It revealed that there was no correlation between the RMS output value and the SRS in any of the settings of the hearing aid.

Chapter V

Summary and Conclusion

Telephone has become an integral and essential part of today's modern lifestyle. But the individuals with hearing impairment are not successful enough to make an effective use of this instrument because of either the limitations of the hearing aid they are using or the telephone they use. Hence, hearing aid users often express their dissatisfaction while using telephone (Kochkin, 2002). But with the advent of the telecoil within the hearing aid, this problem has been ameliorated to a large extent. Many newer hearing aids now allow programmable adjustments of the level and frequency response of the telecoil.

Although audiologists carefully adjust the acoustic characteristics of hearing aids in the microphone mode in an attempt to improve speech understanding, very little attention has been given in adjusting the output characteristics of telecoils and evaluating how well individuals with hearing loss understand speech over the telephone when using telecoils (Takahashi, 2005). As audiologists, we must attempt to improve both telephonic and face-to-face speech communication in hearing aid users. To achieve this we need to study the properties of the telecoil within the hearing aid that optimize the performance. This knowledge will help us in modifying the telecoil gain settings.

In clinical situation, it may be valuable to program a hearing aid's telecoil response based on the performance. At present, provisions are there in the hearing aid analyzer system for measurement with "teleboard" as well as "telewand" to evaluate the electroacoustic performance of the hearing aid in the "T" mode and it is also important to know how the electroacoustic characteristics for telecoil vary depending on the type of input source, that is, "teleboard" or "telewand".

Thus keeping in mind the need of the individuals with hearing impairment, the present study aimed at:

1. evaluating the optimal settings, by comparing the performance in terms of default and modified telecoil settings.

2. finding out with which of the input methods of measuring the electroacoustic performance of the telecoil of a hearing aid, that is, "teleboard" or "telewand", the speech performance relates better.

The study was done on 15 adult participants with moderate to moderately-severe acquired sensori-neural hearing loss within age range from 15 to 55 years. All the participants were native speakers of Kannada. The following steps were used to collect data.

1. The SRS in unaided free-field condition was evaluated and the scores were recorded. The speech material used was Phonemically Balanced Kannada words, developed by Yathiraj and Vijaylakshmi (2005).
2. The digital behind-the-ear hearing aid, pre-selected to suit the degree of hearing loss of the participants, was programmed based on the NAL-NL1 prescriptive procedure.
3. The SRS was then found out for the particular settings of the hearing aid in aided free-field condition and on telephone with its default setting of the telecoil mode.

4. Then the hearing aid was again programmed for the modified settings of the telecoil i.e., to match the target gain curve in the microphone mode.
5. After the programming was done, the SRS was measured again over the telephone with the telecoil in modified mode and the responses were noted.
6. The output RMS of the hearing aid in microphone mode, telecoil default and telecoil modified was then recorded using hearing aid analyzer Fonix 7000. The RMS output in telecoil default mode and telecoil modified mode with teleboard and telewand as input magnetic source were measured.

These six steps were repeated on all the participants.

Statistical analysis using SPSS (Statistical Package for Social Sciences) software (version 10.0) was carried out for the data obtained. Mann Whitney U-test was performed between the moderate and moderately-severe groups to see if there was a significant difference between the groups in terms of SRS and RMS output. The test revealed that there was no significant difference, even at 0.05 level of significance, between the mean values of SRS and RMS output, in moderate and moderately severe groups. Hence, for the further analysis, the scores of the subjects were combined to form one single group. It was also noted that the mean SRS was higher for the subjects with moderate hearing loss than for subjects with moderately severe hearing loss, in both the unaided and aided conditions.

Then, comparison between SRS in different conditions, i.e., unaided SRS, SRS with hearing aid in microphone mode, SRS with hearing aid in telecoil default mode and SRS with hearing aid in telecoil modified mode was performed using one-way repeated measures ANOVA. A significant difference was found, with F (3 42) =

325.87, $p < 0.01$ among the different groups. Bonferroni's multiple comparison test revealed that all the conditions, i.e., when unaided SRS, SRS with hearing aid in microphone mode, SRS with hearing aid in telecoil default mode and SRS with hearing aid in telecoil modified mode, were compared individually with each other; all the conditions were significantly different from one another at 0.01 level of significance.

Paired mean difference of SRS within different pairs of aided condition using microphone and telecoil (default and modified) settings was carried out and the test revealed that although the pairs were highly correlated, there was a significant difference between each pair at 0.01 level of significance. It was observed that in pair 1 there was greater mean difference than the pair 2. That is, when the telecoil was in the default mode, the scores were poorer than that obtained in the microphone mode. But when the telecoil gain in the modified setting was increased and matched to the target gain curve of the microphone mode the SRS improved, and the mean difference in the SRS in the microphone and the telecoil modified condition reduced.

In the next stage the RMS output of the hearing aid programmed in microphone mode, telecoil default and telecoil modified modes were measured using paired t-test and the results of the paired t-test revealed that all pairs were significantly different at 0.01 level of significance, except for the RMS output of microphone versus telewand modified RMS output. That is, when the hearing aid program was modified in telecoil mode such that it matches the target curves in the microphone mode, the RMS output did not differ from the microphone mode, when telewand was used as the input.

In the last and final stage, test of significance of correlation coefficient between RMS output and SRS in the respective hearing aid settings was measured using

Pearson's correlation coefficient (r) and the test revealed that there was no correlation between the RMS output value and SRS in different hearing aid settings.

Thus, from the present study, it can be concluded that programming the telecoil to match the target gain curve in the microphone mode do help the individuals with hearing impairment to achieve better SRS than when the telecoil is kept in the default setting without increasing the gain. Statistical analysis has shown that there is a significant difference between the scores obtained in telecoil default and modified mode, with the SRS in the modified mode being higher. Therefore, it would be useful if the telecoil is programmed in a hearing aid. The poor inductive coupling in the low frequencies can be minimized by increasing the gain in the low frequencies as reported by Yanz and Preves (2003) and Chowdhury, Manjula and Abraham (2007).

Further, although there is a significant difference between the scores obtained in various conditions of the hearing aid, this does not correlate with the measurements of RMS output done using teleboard and telewand. Correlation could be seen only between the RMS output of teleboard and the RMS output of telewand, implying that the RMS output measured through teleboard or telewand are related.

Thus from the results, it is inferred that the data from moderate and moderately-severe groups when tested in the different aided conditions using Mann Whitney U-Test, showed no significant difference between the groups. In view of the main aim of the study that was, whether it was telecoil default mode or the modified mode that gives the higher SRS, it was found that participants did significantly well in the telecoil modified mode compared to the telecoil default mode. This was evident from the mean and standard deviation values of SRS between these modes. Next, the comparison of

RMS output of hearing aid in different modes was done using paired t-test and the test revealed that all the pairs were significantly different at 0.01 level of significance, except for one, that is, RMS output of microphone versus RMS output of the telecoil modified using telewand as input magnetic source.

To evaluate the second aim of the study, Pearson's correlation between the RMS output and the SRS in the different hearing aid settings was performed. It revealed that there was no correlation between the RMS output value and the SRS in any of the settings of the hearing aid.

Future Research Needs:

The present study was done taking a single hearing aid. Chowdhury, Manjula and Abraham (2007) reported that the inductive coupling of telecoil differs from hearing aid to hearing aid. So, future research should be carried out keeping in mind the different types of hearing aids. Again not much attention is paid to the telecoil settings while programming the hearing aid. This study provides information on the features to be programmed for using the telephone efficiently. Thus, this study may help to incorporate the programming of the telecoil as a routine clinical practice.

References

American National Standards Institute (1976). *Specification of Hearing Aid Characteristics.* ANSI S3.22-1976. In J. Katz, *Handbook of Clinical Audiology.* (pp. 73-96). Baltimore: Williams & Wilkins.

American National Standards Institute (1987). *Specification of Hearing Aid Characteristics.* ANSI S3.22-1987. In J. Katz, *Handbook of Clinical Audiology.* (pp. 73-96). Baltimore: Williams & Wilkins.

American National Standards Institute (1996). *Specification of Hearing Aid Characteristics.* ANSI S3.22-1996. In J. Katz, *Handbook of Clinical Audiology.* (pp. 73-96). Baltimore: Williams & Wilkins.

Carhart, R., & Jerger, J. (1959). Preferred method for clinical determination of pure tone thresholds. *Journal of Speech and Hearing Disorders, 24,* 330-345.

Compton, C. (1994). Providing effective telecoil performance with in-the-ear hearing instruments. *The Hearing Journal, 47,* 23-26.

Chowdhury, S., Manjula, P., & Abraham, K., (2007). Programming Modifications for Optimal Inductive Coupling in Hearing Aids. Presented in Indian Speech and Hearing Association, 39th Annual Conference, January 19-21, Kerala, Calicut.

Davidson, S.A., & Noe, CM. (1994). Digitally programmable telecoil responses: Potential advantages for assistive listening device fitting. *American Journal of Audiology, 3,* 59-64.

Dillon, H. (2001). Hearing aid systems. In: Dillon H, ed. *Hearing Aids.* New York: Thieme, 48-73.

EIA Standards RS-504 (1988). *Magnetic Field Intensity Criteria for Telephone Compatibility with Hearing Aids.* Washington, DC: Electronic Industry Association.

Fikret-Pasa, S., & Garstecki, D.C. (1993). Real-ear measures in evaluation of frequency response and volume control characteristics of telephone amplifiers. *Journal of American Academy of Audiology, 4,* 5-12.

Hellgren, J., Lunner, T., & Arlinger, S. (1999). Variations in the feedback of hearing aids, he *Journal of The Acoustical Society of America, 106, 2821-2833.*

Kochkin, S. (2002). Marke Trak VI: Consumers rate improvements sought in hearing instruments. *Hearing Review, 9,* 18-22.

Kozma-Spytek, M.A. (2003). Hearing Aid Compatible Telephones: History and Current Status. *Seminars in Hearing, 24,* 17-28.

Levitt, H. (2001). The nature of electromagnetic interference. *Journal of American Academy of Audiology, 12*, 322-326.

Lybarger, S. (1947). As cited in, Yanz JL, Preves D. (2002), Telecoils: principles, pitfalls, fixes, and the future. *Seminars in Hearing, 24,* 1:29-41.

Madaffari, P., & Stanley, K. (1996). Microphone, receiver, and telecoil option: past, present, future. In: Valente M, ed. *Hearing Aids: Standards, Options, and Limitations.* New York: Thieme, 140.

Marshall, B. (2002). Advances in technology offer promise of an expanding role for telecoils. *The Hearing Journal, 55*, 40-48.

McArdle, R. (2005). Use of FM Technology to Improve Telephone Communication: A Case Study. *Seminars in Hearing, 26,* 114-116.

Mueller, H.G., & Bryant, M.P. (1991) Some commonly over-looked uses of probe microphone measures. *Seminars in Hearing, 12,* 73-91.

Murphy, P.J., Bray, V.H., Nillson, M.J., & McDowell, C.T., (2000). Programming Algorithm for Optimal Telecoil Settings. Presented in *American Academy of Audiology 12th Annual Convention*, March 16-19, Chicago, Illinois.

Palmer, C.V. (2001). Ring, ring! Is anybody there? Telephone solutions for hearing aid users. *The Hearing Journal, 54,* 10-18.

Plyler, PN., Burchfield, S.B., & Thelin, JW. (1998). Telephone communication with in-the-ear hearing aids using acoustic and electromagnetic coupling. *Journal of American Academy of Audiology, 9,* 434-443.

Preves, D. (1996). Standardizing hearing aid measurement parameters and Electroacoustic performance tests. In: Valente, M. ed. Hearing Aids: Standards, Options and Limitations. New York: Thieme, 1-71.

Revit, L. (1996). Proper use of telecoils: it's as easy as 1, 2, 3. .. 4! Available at www.frye.com/library/application/larrv.html.

Rodriguez, G., Meyers, C, & Holmes, A. (1991). Hearing aid performance under acoustic electromagnetic coupling condition. *The Volta Review, 93,* 89-95.

Rodriguez, G., Holmes, A., DiSarno, N.J., & Kaplan, H. Preferred Hearing Aid Characteristics Under Acoustic And Telecoil Coupling Conditions. *American Journal of Audiology, 2,* 55-59.

Ross, M. (2005). Telecoils: Issues and Relevancy. *Seminars in Hearing, 26, 2,* 99-108.

Ross, M. (2006). Telecoils are about more than telephones. *The Hearing Journal, 59,* 24-28.

Skinner, M.W. (1988), *Hearing Aid Evaluation.* Englewood Cliffs. NJ: Prentice Hall, 222-223.

Smith, G. (1971).. Coupling hearing aids to the telephone. *The Volta Review 1,* 47-50.

Takahashi, G. (2005). Programming the Telecoil: A Case Study. *Seminars in Hearing,* 26,2:109-113.

Tannahill, J.C. (1983). Performance characteristics for hearing aid microphone versus telephone and telephone/telecoil reception modes. *Journal of Speech Hearing and Research, 26,* 195-201.

Teder, A.B. (2003). Quantifying Telecoil Performance: Understanding Historical and Current ANSI Standards. *Seminars in Hearing, 24,* 63-70.

Welsby, K. (1993). Problems of inductive coupling. Proceedings of the COST 219 *Seminar Telephones and Hearing Aids,* March 17.

Wilber, L.A. (1994). Calibration, pure tone, speech and noise signals. In J. Katz, *Handbook of Clinical Audiology.* (pp. 73-96). Baltimore: Williams & Wilkins.

Yanz, J.L., & Preves, D. (2003). Telecoils: principles, pitfalls, fixes and the future. *Seminars in Hearing, 24,* 29-41.

Yathiraj, A, & Vijaylakshmi, C.S. (2005). *Phonemically Balanced word list in Kannada.* Developed in Dept. of Audiology, AIISH.

Appendix

Phonemically Balanced Word List Developed by Yathiraj and Vijayalakshmi (2005).

rait̪a	tʃukki	huḷu	va:tʃu
anna	hagga	su:dzi	hoṭṭe
mola	bat̪t̪a	roṭṭi	döṇi
tʃa:ku	mantʃa	gu:be	vadzra
t̪uti	bekku	akka	va:ṇi
me:ke	lo:ṭa	e:ḷu	t̪ale
ha:vu	ba:la	vi:ṇe	kat̪t̪e
kat̪t̪u	dze:bu	mandi	me:dzu
bi:ga	manḍi	vaḍe	na:ji
o:d̪u	noṇa	go:li	ba:lu
baḷe	maḷe	ha:lu	ni:li
mu:ru	ṭi:vi	amma	gombe
ra:ṇi	d̪i:pa:	dzana	ka:ge
t̪apa:	rave	ravi	ad̪u
t̪a:ra:	moḷe	t̪ande	d̪ra:kṣi
brʌsu	railu	rakt̪a	bægu
hasu	ka:ru	sut̪t̪u	kaṣṭa
dzade	d̪ivja	ja:va	paisa
nalli	a:ru	tʃandra	mara
kivi	pu:ri	ja:ke	hu:vu
varṣa	had̪d̪u	ʃa:le	t̪innu
ja:ru	suṣma	aid̪u	iḍli
d̪a:na	t̪a:ji	nad̪i	ke:ḷu
ʃæmpu	d̪ana	uppu	sara
ili	ʃa:lu	kriṣna	pad̪a