MOBILE PHONES AND AIDED SPEECH PERCEPTION: IS THERE ANY INTERFERENCE?

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Manasagangothri, Mysore, 570006

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DEDICATION

In the memory of my beloved grandfather late Shri Nani Gopal Acharjee for his continuous support and innumerable Blessings. Ihis dissertation -wouldn't have been possible 'without the Coving support of him. I find myself over whelmed in offering him all my thanks in dedicating this dissertation to him. I offer him the tears that fill my eyes as I write this dedication.

CERTIFICATE

This is to certify that this Master's dissertation entitled **"MOBILE PHONES AND AIDED SPEECH PERCEPTION: IS THERE ANY INTERFERENCE?** " is the bonafide work done in fulfillment of the degree of Master's of Science (Audiology) of the student with register number **A0490013.** 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.

Mysore.
April, 2006

Prof. M. Jayaram
Director,
All India Institute of Speech
and Hearing, Manasagangothri,
Mysore - 570006

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Mysore
April, 2006

Mrs. Manjula, P.
Lecturer in Audiology
All India Institute of Speech and Hearing
Manasagangothri, Mysore - 570 006.

DECLARATION

This dissertation entitled **"MOBILE PHONES AND AIDED SPEECH PERCEPTION: IS THERE ANY INTERFERENCE?"** is the result of my own study under the guidance of Mrs. Manjula, P., Lecturer, Department of Audiology, All India Institute of Speech and Hearing, Mysore, and has not been submitted earlier at any university for any other Diploma or Degree.

Place : Mysore **Registration No. A0490013**

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

In recent times, telecommunication has become an important part in everybody's life including that of persons with hearing impairment. An important telecommunication device these days is the mobile phone, the use of which has achieved a level of inevitability in every ones lives. The use of mobile phones has been increasing at a stunning rate over the last decade.

The mobile phones use radio frequencies (RF) for transmission of signals. This RF causes interference in speech intelligibility when hearing aid users are themselves users of mobile phones or when they are in the vicinity of a mobile phone user. This interference depends on various factors such as the type of signal processing used in mobile phone (analogue & digital), type of signal processing in hearing aids (digital or analogue), the distance between mobile phone and base station, and the input mode to the hearing aid (microphone or telecoil).

The first mobile network that was introduced in early 1980s was an analogue wireless system. In this system the cell site would transmit on different frequencies, allowing many cell sites to be built near each other. Since it did not use temporal modulation of the radio frequency signal, the electromagnetic field that was produced did not generally introduce interference in the hearing aids. However, it had the disadvantage that each site did not have much capacity for carrying calls. It also had a poor security system that allowed people to share a phone serial code to use for making illegal calls, and conversation could be easily listened using a scanner.

Analogue wireless mobile phones have evolved into the more advanced digital wireless mobile phones that are being used in the present times. These systems were designed to allow frequencies to be re-used in a small geographic area, thereby increasing the available users density. Digital technology has many advantages over analogue technology for example, it allows for a large number of users, lower service fees, higher sound quality, reduced background noise and more secure conversation (Kozma-Spytek, 2001).

However, using a digital cell phone causes the emission of radio waves that is transmitted over a wireless network during mobile phone conversation. These radio waves, emitted by the mobile phones are referred to as radio frequency (RF) emission. The RF emission creates an electromagnetic (EM) field around the mobile phone's antenna and this EM field has a pulsating pattern. It is this pulsing energy that may potentially be picked up by the hearing aid microphone or telecoil circuitry and perceived by the hearing aid wearers as a "buzzing" sound. Since as early as 1989 due to the potential for the radio-frequency (RF) interference from the mobile phone these wireless telephones have been known to be incompatible with many hearing aids or cochlear implants. When held against a hearing aid of both analogue and digital type, digital cell phones sometimes produce a "buzzing" noise. In severe cases, it can even render the phone unusable (Kozma-Spytek, 2003).

To complicate the matters more, the digital technology for transmitting calls over a wireless network differs depending on the carrier services provider (Kozma-Spytek, 2003). The digital mobile phones use different technologies to achieve this, such as Time Division Multiple Access (TDMA), Global System for Mobile Communication (GSM) and Code Division Multiple Access (CDMA). Recent studies by Strange, Byrne, Joyner, Wood, Burwood and Symons (1995) carried out at National Acoustic Laboratories (NAL) indicate that most hearing aid users, who can successfully use a telephone on a landline connection or an analogue mobile phone, are also able to use CDMA digital mobile phone more competently when compared to GSM mobile phones. Even when interference was present in CDMA technology, it had a static like sound that did not affect the speech intelligibility to a large extent (Skopec, 1998).

The effect of RF interference on speech intelligibility also depends upon the type of hearing aids used. It is widely known that digital hearing aids are less affected by RF interference than analogue ones (Kuk & Nielsen, 1997; Schlegel, Ravindran, Raman & Grant, 2001; Kozma-Spytek, 2003). But since a large group of hearing aid users however, still use analogue hearing aids because of financial reasons, a few manufacturers have created designs that are effective in lowering the amount of interference in analogue hearing aids. None, however, are 100% effective in eliminating it. Kuk, and Nielsen (1997) have stated that behind-the-ears (BTEs) are usually more susceptible to interference than in-the-ears (ITEs) or in-the-canals

(ITCs), even when the all the instruments have the same level of immunity against interference. This may be due to the absorption of electromagnetic energy by the wearer's head which results in reduced interference in instruments that are worn inside the ear and therefore more shielded by the head than are BTE instruments. Further, the wires of BTEs are longer, creating the potential for more RF pick up. Custom ITEs also create difficulties because each has a different wiring. Some CIC aids, however, are relatively 'buzz-free'. The CIC instrument is the easiest to immunize because all its components are small and the wires are short.

Apart from the different types of hearing aids, the settings of hearing aids, i.e., microphone and telecoil positions, can also affect the speech intelligibility depending on the amount of RF interference. Kozma-Spytek (2003) suggested that telecoil users may experience another form of interference referred to as "base band, magnetic interference" which originates from the cell phones electronics (e.g. Backlighting, display, keypad, battery and circuit board) by virtue of the electromagnetic nature of transmission of sound signal. Since base band magnetic interference occurs along with RF interference, it potentially increasing the interference provided to the hearing aid user (Kozma-Spytek, 2003). The speech intelligibility reduces due to this interference problem also.

Other factors that affect speech intelligibility in hearing aids during mobile phone use as given by Schlegel, Ravindran, Raman and Grant (2001) are distance of the mobile phone to the base station, and proximity of the hearing aid user to the mobile phone.

- ❖ Distance of the mobile phone to the base station: As the distance between the mobile phone and base station increases, more power is required from the transmitter in the cellular phone and so more interference is experienced. This means that freedom from interference at one location does not guarantee freedom of interference from another location.

- ❖ Proximity of a hearing aid user to a digital mobile phone user may also affect the speech intelligibility and this is called the bystander effect. For bystander, the hearing aid users did not experience any annoyance unless the phone was within two feet of the hearing aid.

Various factors are therefore responsible for the better speech recognition ability and this study aims to measure the speech recognition through mobile phones using digital and analogue hearing aids.

Need of the Study

Many studies have been done with the GSM and CDMA wireless system and hearing aid interference. In most of these studies, the sound pressure level (SPL) and frequency spectrum of the interference were measured using a frequency analyzer while setting the volume control to a maximum gain in some of these studies. There is a dearth of studies on the effect of speech intelligibility when the hearing aid user is using a mobile phone using live voice. In addition to this, in the Indian context, where there is more number of analogue hearing aid users, interference with this hearing aid type should also be studied. This study is being conducted to investigate the effect of interference, if any, caused by GSM and CDMA wireless system when an individual with hearing impairment is using a hearing aid, either digital or analogue, in M or T setting.

Aims of the Study

The purpose of this research was to answer the following questions:-

1) Which mobile phone technology, GSM or CDMA, gives better speech intelligibility by reducing interference for a hearing aid user?

2) Which hearing aid technology, i.e., digital or analogue, is better for cell phone communication?

3) In which hearing aid setting, i.e., microphone or telecoil, is the mobile phone interference low?

REVIEW OF THE LITERATURE

Digital mobile phones are becoming more and more popular as a means of communication. However, people with hearing aids or cochlear implant may experience a loud interfering noise when using a digital mobile phone. This interference occurs because the telephone conversation is transmitted between the mobile phone - base station - mobile phone across the wireless network using the radio waves. These radio waves emitted by the mobile phones are referred to as radio-frequency (RF) emissions. When the digital mobile phone is in communication with the digital network, the RF emissions create an electromagnetic (EM) field around the phones antenna. This EM field has a pulsing pattern (Kuk & Nielsen, 1997). It is this pulsing energy that may potentially be picked up by the hearing aids microphone or telecoil circuitry and perceived by the hearing aid wearer as a buzzing sound (Kozma-Spytek, 2001).

Review of the literature relevant to the present study has been discussed under the following headings:

1) Interference of speech intelligibility

2) Factors affecting the interference

3) Remedies

1) Interference of Speech Intelligibility

There are two basic forms of interference:

a) User interference

b) Bystander interference

a) User interference is a more serious form of interference that occurs when a person using a hearing aid, places the wireless phone near the hearing aid to place or receive a call. Hearing aids are particularly more prone to pick up of EM interference from digital wireless telephones because of the close proximity of the phone antenna to the hearing aid amplifier.

b) Bystander interference is another form of interference that may occur when a digital wireless phone is used by someone else, close to a hearing aid user. Bystander interference can be reduced substantially by increasing the distance between the wireless telephone and the hearing aid. But in case of user interference, the hearing aid and telephone antenna are too close that near-field effect dominates. Under these conditions, small changes in the position of the telephone antenna relative to the hearing aid will produce a large change in the level of interference in a complex way. Since the EM field generated by a telephone antenna consists of both electrical and magnetic field, moving the wireless telephone handset relative to the hearing aid will thus change the strength of the EM interference. This will affect the speech recognition ability, but not always in the desired direction. This interference was found to be more when hearing aid was in the telecoil mode than in microphone mode (Kozma-Spytek, 2003). When the hearing aid is in magnetic coupling mode or the telecoil position, the hearing aid picks up the magnetic signal from the telephone antenna that is unfortunately is close relative to the RF-signal, thus increases the possibility of the RF interference.

In addition to that, the telecoil users may experience another form of interference referred to as "base band, magnetic interference" that originates from the mobile phone's electronics such as backlighting, display, keypad, battery and circuit board. Unfortunately, base band magnetic interference occurs in addition to the RF interference potentially increase the interference received by the hearing aid users and understanding of the speech becomes more difficult.

2) Factors Affecting the Interference

The amount of interference experienced by the hearing aid users depends on many factors and indirectly speech recognition ability also depends on these factors. They are:

a) Mobile Phone Technology

As the wireless technology became more and more popular, wireless service providers also are offering their customers more and more features. The first analogue mobile network came into existence in the early 1980s in United States. These analogue mobile phone systems allowed only one conversation per frequency that was very limited to the carriers in terms of how many customers they could serve and there were limited number of channels available for wireless phone. One of the most important advantage of this analogue mobile phone system was that, the electromagnetic field which was generated by this system did not generally introduce interference in the hearing aids because it does not use the temporal modulation of the radio frequency signals and hence the speech recognition ability was also better. In 1989, analogue technology has been challenged by the digital technology as digital allows them to offer more and more features as well as more and more customers per channel of frequency. The types of digital service that have evolved around the world vary from each other mostly in technical ways that affect the radio frequency emission produced by a particular digital mobile phone. The amount of interference as well as the speech intelligibility experienced by hearing aid users in turn depends on these degrees of RF emissions produced by the mobile phones. There are mainly four types of digital wireless system:

i. Global System for Mobile Communication (GSM)

ii. Code Division Multiple Accessory (CDMA)

iii. Time Division Multiple Accessory (TDMA)

iv. Enhanced Specialized Mobile Radio (ESMR)

Out of these systems, GSM and CDMA are most widely used throughout the world.

i. Global System for Mobile Communication (GSM)

This system keeps the idea of time slots on frequency channels. These time slots holds less data but allow for data rates starting at 300 bytes per second. One of the great benefit of a GSM phone is the addition of a SIM card or "subscriber identification module". It provides the personal configuration and information of that user. This includes telephone numbers, home systems and billing information. GSM system has a carrier frequency in the 900 MHz band and a 217 Hz repetition rate. It produces more interference than CDMA system because of the pulsed nature of the signal (Skopec, 1998)

ii. Code Division Multiple Access (CDMA)

Code Division Multiple Access system has a coded sequence across the entire frequency spectrum. Each conversation is modulated in the digital domain with a unique code that makes it distinguishable from other calls in the frequency spectrum. It is a spread-spectrum system. Interference may result due to the voice encoder/decoder (vocoder) as well as automatic adjustments in output power levels made to accommodate ranging distance to the nearest base station. This interference may reduce the speech intelligibility and produces annoyance.

iii. Time Division Multiple Access (TDMA)

Time division multiple access (TDMA) divides wireless conversation by frequency and time to increase the capacity of network. TDMA uses a single voice channel for multiple calls by taking each call, breaking it into timed electronics of a digital transmission to the tower and re-assembling the calls based on the time shots. The main source of interference in time division multiple access (TDMA) technologies, of which GSM is the subset, are considered to be the pulsed nature of the signal (the pulse repetition rate).

iv. Enhanced Specialized Mobile Radio Service (ESMR)

Enhanced specialized mobile radio (ESMR) is a wireless communication system in which numerous mobile portable transceivers are linked in a network of repeaters. Each repeater has a range of approximately 5 to 10 miles. Operating frequencies are in the ultra-high-frequency range, that is, between approximately 300 MHz and 3 GHz. Usually, the working band is 900 MHz. This system uses digital radio transmission. Spread-spectrum modes, such as frequency hopping are common in this system.

Several studies have investigated this electromagnetic interference with different mobile phone systems mainly the GSM, CDMA and TDMA systems as well as some other systems. Skopec (1998) used hearing aids and tested for the audible interference at various distances for five types of digital wireless telephones. The 70 dB SPL white noise was presented in order to bias the hearing aid as well as to approximate speech. Output of each hearing aid was measured.

The highest interference induced sound pressure level (SPL), 122.5 dB was measured from the hearing aid placed within 2 cm of a transmitting GSM phones whereas the interference is very less for CDMA system at the same distance. Interference were also measured in terms of frequency spectrum (i.e., frequency spectrum analysis of the buzzing noise were also done). The hearing aid output spectrum from GSM showed peak at 217 Hz modulation frequency, whereas, the CDMA phone showed no discrete peaks. When interference does occur, the buzzing sound makes understanding of speech more difficult. Hansen, and Paulsen (1996) found speech understanding more difficult due to the buzzing sound produced due to the interference when the GSM and Digital European Cordless Telecommunication (DETC) wireless phones are in close proximity to the hearing aids. Communication through all phones becomes more annoying and may render the phone completely unusable to the hearing aid wearer.

Since, in case of the GSM, the electromagnetic field present around the phone's antenna has a pulsing pattern (Kuk & Nielsen, 1997). It produces more interference compared to that of the CDMA because it is a spread spectrum system. Kozma (2001) reported that CDMA service causes less audible interference than the GSM technology which suggests that speech recognition will also be better for those using mobile phone having CDMA wireless system than with the GSM system. Qian, Loizou, and Dorman (2003) had studied the performance of GSM digital wireless system on individuals with hearing impairment to determine the speech recognition of telephone speech. The study showed that the GSM digital wireless telephones produces a low frequency (215-225 Hz) interference with harmonics spread well into the speech frequency range and the speech recognition through the telephone was found to be considerably lower due to the limited telephone band width as well as the interference that causes buzzing sound.

Joyner, Wood, Burwood, Allison, and Strange (1993) measured the interference to the hearing aids by the GSM system by using frequency analyzer as well as recorded speech material. The sound output of the hearing aid was measured in a 2 cc coupler with a B & K 2120 Frequency Analyzer set for wide band. The noise floor of each aid was measured with the microphone blocked to ambient noise. The hearing aid output was then measured under suitable range of field strengths. These outputs of each aid were recorded using tape recorded speech material to ascertain the suitable threshold for characterizing the effect of interference. Results showed that when the mobile phones were used in close proximity with the hearing aid, interference was seen more with the GSM systems. The above studies were supported by the European Hearing Instrument Manufacturers Association Global System for mobile communication (GSM) project by DELTA Acoustics and Vibration and Telecommunication Denmark (1995) and Research by European Telecommunication Standard Institute (1993). All these studies confirmed the existence of an annoying 'buzz' in some hearing aids exposed to digital GSM phones. Thus, it is possible that the presence of interference will affect the speech intelligibility when a person is wearing a hearing aid and using a mobile phone.

Schlegel, Ravindran, Raman, and Grant (2001) used three telephone technologies (a) 1900 MHz PCS (TDMA-217 Hz) (b) 800 MHz D-AMPS (DMA-50 Hz) and 800 MHz CDMA (IS-95) to evaluate the interaction between wireless phones and hearing aids on 68 subjects with hearing impairment. North Western University Auditory Test No. 6, standard audiotaped word list has been used to determine speech recognition score under the aided condition and exposed to the interference produced by the telephone technologies. User interference was evidenced by lower speech recognition scores for all three tested telephone technologies. Participants with BTE hearing aids noticed comparatively greater interference form 1900 MHz PCS system (GSM system) which shows that GSM system produces more interference compared to that of CDMA system.

Levitt, Kozma-Spytek, and Harkins (2005) used three types of digital wireless telephone, GSM with a modulation rate of 217 Hz, TDMA with a modulation rate of 50 Hz and CDMA with a spread-spectrum approach and variable modulation rate in order to find the signal - to - interference ratio (SIR). Real ear recordings of the speech with interference were made at each rating point of usability. Signal analysis of the recordings indicate that for 90% of the subjects, SIRs in the 28 to 32 dB range were needed to achieve a rating of highly usable mobile phone system. For CDMA, the estimated SIR is 28.6 dB while for GSM and TDMA corresponding SIRs are 31.7 dB and 31.9 dB respectively. CDMA thus shows a small advantage of approximately 3 dB over both GSM and TDMA which indicates that the speech intelligibility will also be better for the CDMA than GSM and TDMA. A comparison was done by Strange, Byrne, Burwood, Joyner, Symons and Wood, in 1995 that used GSM system to assess the interference with BTE hearing aids by measuring the interference in terms of equivalent input sound pressure level and by Burwood, (1999), that used CDMA digital wireless system to assess the interference with BTE hearing aids. Results revealed that CDMA provided a much more acceptable alternative with research indicating that majority of the hearing aid users experienced significantly less electromagnetic interference from CDMA phone than they do for GSM phones. Both the testing was conducted at National Acoustic Laboratories. Preves (2003) found that CDMA does not temporarily modulate the radio frequency signal significantly, making much better use of available RF transmission bandwidth. Some researchers have shown a 10 dB greater interference with TDMA than CDMA digital system. Six different hearing aids from three manufacturers were tested, including behind-the-ear (BTEs), in-the-ear (ITEs) and in-the-canal (ITCs). The same power amplifier and radiating antenna were used for both signal types. The author concluded that the CDMA signal could not be detected unless the distance was within 0.5 m, whereas the GSM signals could be detected at distance of 1 to over 2 meters from the hearing aid under test. So, it can be concluded that GSM produced more interference and poor speech recognition compare to CDMA (Preves, 2003).

b) Hearing Aid Technology and Types

Now-a-days most of the people around the world use digital hearing aids. But still in India, many people still use analogue hearing aids due to the financial reason. Digital hearing aids incorporate digital circuitry known as digital signal processing (DSP). This technology has been mainly incorporated in the ear-level hearing aids. This circuitry will inevitably be less susceptible to interference than analogue circuits. In the digital form, the signal will only be disturbed if the interference is strong enough to confuse the bit values. Due to the binary representation of the information, interfering signals must be in the same order of magnitude as the battery voltage to change the signal (i.e., from 1 to 0 or 0 to 1). In practical application, only the microphone and the input of the analogue to digital (A/D) converter, where the signals of a digital hearing aid are still analogue, can pick-up the interference.

In an analogue hearing aid, all the amplifying stages are susceptible to interference. They all process an analogue image to the signal, so any distortion or noise contribution will be present in the signal at the output. This opens more opportunities for noise to enter the hearing aid and so the interference will also be more in analogue hearing aids. Kuk, and Nielsen (1997) analyzed the output spectrum of the conventional BTE analogue hearing aid and fully digital hearing aid when a GSM phone was placed at the ear level. It has been found that there were dominant spikes with large amplitude at 217 Hz in case of analogue hearing aid and the amplitude was less in case of digital hearing aid which suggested that speech will be more intelligible with the digital hearing aid than with the analogue one. Study done by Kozma-Spytek, (2003) also supported the above findings.

In addition to that, behind-the-ear (BTEs) hearing aids produce larger amount of interference compare to in-the-ear (ITEs), in-the-canal (ITCs) and completely-in-the canal (CICs) hearing aids. This may be due to the absorption of electromagnetic energy by the wearer's head that results in reduced interference in instruments that are worn inside the ear and are therefore more shielded by the head than are BTEs instruments (Kuk & Nielsen, 1997). Another reason is that in BTEs, the wires are larger and the circuit components are large, creating the potential for more radio frequency pick up which causes more interference (Killion, 2001). Schlegel, Ravindran, Raman, and Grant (2001) evaluated 68 subjects with hearing impairment and found that among the hearing aid types BTE users experience the most interference whereas ITC users experienced the least interference. As the gain setting of the BTE units made higher, interference becomes louder and hence more annoying. But surprisingly, CIC aid produced a higher interference than expected. This phenomenon has also been noted in other studies and requires further examination.

Levitt, Harkins, Singer, and Yeung (2001) investigated the acoustic and perceptual characteristics of the BTE hearing aid distortion generated by GSM digital technology using 217 Hz switching rate on 53 subjects with hearing impairment. For user interference, 80% of the subjects judged the digital wireless technology unusable with BTE hearing aid. Speech through digital wireless phones was rated as unintelligible by 60 to 70% of the subjects using BTE hearing aids. Study at NAL conducted by Strange, Byrne, Joyner, Wood, Burwood and Symons (1995) also supported the above findings that BTE is more susceptible to interference than ITE models. They reported that the interference produced by the GSM phones, operating at 900 MHz ranged from 2 W for a hand held phone to 8 W for a transportable unit is less for ITEs and the interference threshold for the ITEs requires a higher RF field than that of the BTEs (Preves, 2003).

The hearing aid users utilize either the microphone or the telecoil setting of the hearing aids. The electro-magnetic field which is produced by the RF emission consists of both audio signal and magnetic signal. This EM field was pulsing pattern. When the hearing aid is in microphone mode, or the telecoil mode, it is this pulsing energy that may potentially be picked up by the hearing aid's microphone or telecoil circuitry and causes interference in the form of buzzing sound (Kozma-Spytek, 2003). Telecoil users may experience another form of interference in addition to the electro magnetic interference known as base band, electromagnetic interference which originates from the cell phones electronics such as backlighting, display, keypads which increases the interference perceived by the hearing aid user under 'T' setting (Kozma-Spytek, 2003). So, the telecoil setting is usually worse because the digital pulse cause both radio waves and electromagnetic interference that makes the speech intelligibility more poor

(Killion, 2001; Marshall, 2005). The above study has also been supported by National Foundation for the Deaf Inc.

Byrne, and Burwood (2001) conducted a study at National Acoustic Laboratories (NAL) to determine how the use of GSM mobile telephone causes interference in hearing aid settings. It has been found that on microphone input, it would pick up interference at 10 meters and on telecoil input at about 17 meters that suggests that speech discrimination will be better in microphone setting than in telecoil setting. This interference may vary depending on the particular hearing aid. The interference may be worse for either telephone or microphone, or it may be much the same. In case of ITE hearing aids, the interference was audible at a distance ranging from 0.6 m to 0.15 m. The transfer of an inductive signal depends on proximity and position of the sending and receiving coil. Thus, positioning a telecoil in a hearing instrument is an important and sometimes challenging task, especially in custom products (Yanz, 2005). Vliet (2003) also supported the above study that wireless telephones have been the source of disruptive interference for many hearing aid users and are largely incompatible with the telecoil coupling.

c) Distance Between the Cellular Phone and the Base Station

More interference is experienced when a mobile phone is operating far from the nearest available base station because more power is required from the transmitter in the mobile phones for transmitting the signal. This means that freedom from interference at one location does not guarantee freedom of interference from other locations. The power transmission varies from GSM to CDMA to other wireless system and depending on that the level of interference will also be different. This problem may be minimized in the future if more low-power base stations are built for short range transmission (Kuk, & Nielsen, 1997; Kozma-Spytek, 2001).

Fry, Schlegel, and Grant (2000) used CDMA digital wireless system in order to find the effect of phone power on the interference with digital hearing aid. It has been found that as the power of transmission increases, interference also increases. The amount of improvement for a given power reduction depends on the radio frequency immunity of the hearing aids. For high immunity hearing aids, the level of audible interference remains low even at high phone power level thereby improving the speech intelligibility. Several other studies on EM interference in hearing aids were performed by varying the power transmission. Study done by Joyner, Burwood, Wood, Allison, and Strange (1993) at NAL and Telecom Research Laboratories (TRL) found that when the power level of the 2 Watt handheld unit and 8 Watt transportable unit of GSM system with pulse rate of 217 Hz were tested with BTE and ITE digital hearing aids. It has been found that as the power level increases, the interference also increases in both the type of hearing aids and in M and T positions. More increase in interference was seen in the T position of the hearing aid. It has been found that with 1 dB increase in radio frequency field strength causes 2 dB increases in the hearing aid output. (Strange, Byrne, Joyner, Wood, Symons & Burwood, 1995). This study has been confirmed by the study conducted by University of Oklahoma (Schlegel, Ravindran, Raman & Grant, 2001) with both a 900 -MHz RF carrier that was 80% amplitude modulated and a TDMA 50 Hz (IS-136) telephone. Input Referenced Interference Level (IRIL) was plotted as a function of RF field strength and alignment of the hearing aid in the RF field. Results showed a square law response to the magnitude of the electric field of the radio frequency field is exhibited which states that a 1 dB increase in the field strength results in a 2 dB increase in the IRIL. Study coated by Preves, (2003) showed that at least a 20 dB SNR is required with a 50 Hz buzz interference signal, and at least 25 dB SNR is required with a 217 Hz buzz interference signal for the telephone signal to be acceptable to the hearing aid wearers, regardless of degree of hearing loss.

The National Acoustic Laboratories (NAL) 1995 report also stated that for acceptable immunity to interference, a hearing aid would have to produce less than 40 dB SPL equivalent input signals, for both a wearer interference signal greater than 30 volt/ meter (v/m) and for a 9 to 30 v/m bystander interference signal.

The above fact has been supported by Killion (2001) who suggested that the antenna that stick out away from the head seem to cause a little less interference but the reduction appears to be only about 5 dB in the level of buzz.

d) Distance Between Hearing Aids and Mobile Phone:

It has also been found that as the distance between the hearing aid and the digital cell phones antenna increases, the interference heard by the hearing aid wearer will be reduced or eliminated (Kozma-Spytek, 2001). Separation between the phone and hearing aid was defined on the distance between the outermost surface of the hearing aid and the ear piece of the wireless phone (Skopec, 1998). Study done by Skopec (1998) using GSM, Personal Communication Services (PES-1900), North American Digital Cellular (NADC), TDMA (11 Hz) and CDMA (variable vocoder rate) system at 2 cm, 20 cm and then every 20 cm found that at 2 cm of the wireless phone for BTE aid, highest interference induced SPLs were measured. This was same for all the wireless systems, the SPL versus distance drop-off rate was two to three times more rapid for the CDMA system than the other wireless system which suggested that CDMA will help in better perception of speech.

Another study done by Ravindran, Schlegel, Grant, and Raman (2001) at the University of Okhalama suggested that the level of the interference was sensitive to small changes in relative alignment and orientation of the hearing aid and telephone. In fact, in 16% of the phone tests, hearing aid users reported no interference even when the phone was at a distance of less than 4 inches (10 cm).

e) Bystander effect

Interference occurring due to other person using the mobile phone nearby the hearing aid is called the bystander effect. A hearing aid wearer may experience interference from someone else's digital cellular phone if the person using the phone is close by. The interference decreases as the distance between the hearing aid and cellular phone increases (Kuk & Nielsen, 1997). This is because the electromagnetic field which is present near the antenna of the mobile phone will be picked up by the hearing aid circuitry causing the interference which makes the speech intelligible.

Byrne, and Burwood (2001) studied with the effects of distance between the hearing aid and mobile phones on interference. GSM system with a carrier frequency in 900 MHz band and a 217 Hz repetition rate were taken and BTEs and ITEs were used in this study. Results showed that the BTE hearing aid could detect the interference at a 4 m distance, which was maximum distance tested. However, contrary to this general finding, there was one person who could not detect interference until the telephone was within 0.3 m of the aid. None of the listeners could detect any interference at distance greater than 0.2 m with programmable BTE aids. In case of the ITEs, some people could detect interference at about 0.8 m. This study suggested the variable effects that can occur for people with similar hearing losses tested with the same hearing aid. Similar study done by Schlegel, Ravindran, Raman, and Grant (2001) study at University of Oklahoma suggested that the bystander interference was less noticeable than expected. More than 80% of the test involving hearing aid users resulted in either no interference or a detection threshold less than 1 meter (3.3 ft). For 16% of the tests, participants reported no interference even when telephone was, at a distance of less than 10 cm. They also found that the average distance of which any annoyance was reported was less than 2 feet. Only 2% of the tests at 1 meter and 12 percent of the tests at half a meter (1.8 ft) resulted in annoyance levels clarified as 3 or greater.

However, the results also varied by the hearing aid type, hearing loss configuration and telephone technology.

Levitt, Harkins, Singer, and Yeung (2001) used three brands of telephones on two types of digital systems to study the bystander effect. They are PCS 1900 (JSTD 0007) service and TDMA IS-54 service. Subjects were wearing BTE hearing aids. Result showed that bystander interference was unlikely to cause a great deal of annoyance to most hearing aid users. Two methods were used for this purpose - in the first, the researcher moved the telephone in horizontal arcs behind the subject on the same horizontal plane as the hearing aid and subject had to indicate the given level of interference (threshold, mildly annoying, annoying, very annoying, and unbearable) by rising a hand and distance will be measured accordingly. In this method, 25-38% of the hearing aid wearer' did detect interference of distance greater than 2 feet from the aid. A smaller percentage (8-14%) received a level of interference that they considered annoying at more than 2 feet away. In the second method, researcher placed call to local phone company while seated next to the subject. When phone was used on the side of the head closest to the hearing aid (ipsilateral to the aid), the interference was inaudible or audible but not annoyance to 70% of the subjects, mildly annoying to 9 to 15% of the subjects and annoying or worse to 15 to 17%. When the telephone was used opposite side of the researcher's head, interference was not detected at all by 85 to 90% of the subjects, was mildly annoying to 4 to 6%, and was annoying to only 2% which suggested that bystander effect do not interfere the speech to a large extent.

3) Remedies to Interference Caused by Mobile Phones

The issue surrounding hearing aid compatibility and resistant to interference from wireless phone are complex. Many procedures and techniques have been developed by the manufacturers of both hearing aids and mobile phones in order to reduce the interference effect. Those are:

v Shielding: Shielding the BTE hearing aids with a metallic coating effectively reduces user's interference as well as by standard interference at all distance (Ravindran, Schlegel, Grant, Matthews & Scates, 1997; Vliet, 2003). Placing a cupper shielding between the phone's antenna and the hearing aid reduced interference. But the technical feasibility and manufacturability of any shielding and its impact on phone and the system performance have not been evaluated (Ravindran, Schlegel, Grant, Matthews & Scates, 1997).

Electrostatic shielding was expected to be an effective way of making hearing aids to be less sensitive to interference. A study has been conducted by Strange, Byrne, Joyner, Wood, and Symons (1995) at NAL and Telecom Research Laboratories (TRL). They used a conductive coating brushed on the case of some of the hearing aids. Improvements in the interference of around 20 dB were readily obtained and over 30 dB in one case. When the case was only partly shielded, the improvements were much less. When the sputter silver was painted inside of the plastic case parts of the test hearing aid and using a coating of electroless nickel deposited on all sides of the two case halves, a reduction in the interference was also seen.

v Filtering: The shunt capacitor is a simple filter which is also used in the hearing aid circuitry to reduce the interference. It is an integrated circuit chip with very short wires that is placed very near to the amplifier. Study done by Strange, Byrne, Joyner, Wood, Burwood and Symon at NAL and TRL used shunt capacitors. The capacitors are placed at the input leads of the BTE integrated circuit amplifier and at the end of the wires connected to the audio input socket of the aid. They are connected so as to shunt the three microphone leads together at radio frequencies. Results showed an improvement of 11 to 17 dB in the immunity of the hearing aid. Wearing small hearing aids such as ITEs and ITCs rather than BTEs away from the phones antenna are shielded by the user's head and may have less gain. Digital hearing aids resist interference better than that of analogue hearing aids (Strange, Burwood, Byrne, Joyner, Wood & Symons, 1995).

v Accessory: If the hearing aid wearer uses a telecoil for telephone communication or have a telecoil equipped hearing aid(s). They can also use hands-free headsets as the telecoil position will cause more interference with digital wireless audio input (DAI) capability, then through DAI boots, they can use hands-free ear bud /microphone accessory to provide more accessible to cell phone communication (Kozma- Spytek, 2001). In addition to this, neck loop system can also be used. These loop sets include a built-in microphone and permit hands-free use of the phone and binaural listening if the user has two hearing aids with telecoils. The phone itself can be carried in a pocket or clipped on a piece of clothing, away from the hearing aids, so the effects of the interference are lessened or eliminated. There are many third-party hearing aids compatible (HAC) accessories available for purchase by hearing aid wearers who have telecoil options on their aids. There are devices similar to the neck loop described, which have a silhouette inductor that slips on the ear behind the hearing aid and produces a strong magnetic signal for pick-up by the hearing aids telecoil. Hearing aid compatible headsets are also available in many styles and with features such as in-line volume control. There are devices designed to strap onto the phone allowing the phone to work with the hearing aid's telecoil. It may be particularly useful to the hearing aid user who does not experience interference from digital wireless phones. Built-in HAC is available in some analogue wireless phones. Some digital wireless phones may also have built-in HAC, but due to potential interference problem, they are not advertised as such.

Another accessory that might reduce interference is an external antenna accessory which effectively changes the location of the antenna away from the user's head or directs the electro magnetic field away from the user's ear. The accessory which is used for the car is dashboard antenna that also moves the antenna away from the user's head.

Although there are many remedies that may be used to reduce the interference, not all the hearings aids have the facilities to incorporate it. So it becomes important to study the performance of those hearing aids with different input settings (M and T) while using the digital wireless systems in order to predict which hearing aid will perform better with which type of digital wireless system (GSM or CDMA).

METHOD

The purpose of this study was to evaluate Speech Recognition Score (SRS) with GSM and CDMA technology, in subjects with sensorineural hearing loss, using digital and analogue hearing aid. The speech recognition score was evaluated in microphone (M) and telecoil (T) settings of both the digital and the analogue hearing aids.

Subject inclusion criteria

Thirty subjects with hearing impairment in the age ranging from 15 to 55 years participated in the study. Among these subjects, sixteen were males and fourteen were females who passed the following selection criteria:-

1) Fluent in Kannada language, with acquired hearing impairment.

2) Moderate to moderately - severe degree (Pure Tone Average ranging from 41 up to 60 dBHL) of sensorineural hearing loss in the test ear.

3) Speech recognition score greater than or equal to 80% in the test ear.

4) Normal middle ear functions as assessed by tympanometry and acoustic reflex threshold.

5) No complaint of neurological disorder.

6) Naive user of hearing aid.

Instruments used

1) A calibrated dual - channel diagnostic audiometer (Madsen Orbiter 922, Version 2) with TDH 39 head phones fitted into ME 70 noise-excluding headset, and bone vibrator (Radio ear B71), was used for evaluating pure tone audiometry and speech audiometry.

2) A calibrated immittance meter (GSI Tympstar version 2) was used to assess middle ear function.

These two instruments were used during selection of subjects for the study. The following instruments were used to evaluate the objectives of the study:-

3) A digital BTE hearing aid having dual channels with a fitting range of mild to moderately-severe degree of hearing loss, and a linear analogue BTE hearing aid having microphone setting, telecoil setting and gain ranging from mild to moderately severe degree were used for this study. These two hearing aids were selected as these hearing aids have the fitting range for the degree of hearing loss being studied.

4) A personal Computer with Connexx software, version 5.6, incorporated in NOAH 3.0 version and Hi Pro was used for programming the digital hearing aid.

5) Fonix FP 40-D hearing aid test system with digisp - ANSI (version 3.5) was used for the insertion gain optimization of the analogue BTE hearing aid.

6) Two types of mobile technologies in digital wireless systems were -

a) Mobile phone using GSM technology:

· Motorola Timex 1503731S using GSM system of 1800 MHz carrier frequency for delivering the speech stimuli.

· Nokia 2100 model using GSM system of 1800 MHz carrier frequency and

b) Mobile phone using CDMA technology:

· Reliance RD 203 f15 model using CDMA wireless system were used for receiving the speech stimuli.

All the mobile phones were fully charged and had full signal coverage during testing.

Test environment

1) Routine audiological evaluation, hearing aid optimization / programming and verifications were carried out in a sound treated double room set-up. The ambient noise levels inside the test room were within permissible limits (re: ANSI, 1991, cited in L.A. Wilber, 1994).

2) The speech recognition testing through the mobile phones were carried out in a quiet environment where full power for GSM and CDMA transmission was obtained. The data were collected in Mysore city, India, in the winter of 2005. The base stations of GSM and CDMA were located within 2 km of the site of the testing area.

Test material

1) Kannada word lists developed by A. Yathiraj and C.S. Vijayalakshmi (2005) (personal communication, 26th of November, 2005) to estimate speech intelligibility using GSM and CDMA mobile phone system with digital and analogue hearing aids. There were total eight lists of words. Each list consisted of twenty words. All the word lists were phonetically balanced.

2) Every day questions in Kannada, developed at the Department of Audiology, All India Institute of Speech and Hearing, (AIISH) Mysore, was used to estimate

the Speech Recognition Score (SRS) using GSM and CDMA mobile phone system with digital and analogue hearing aids. There were a total of ten lists. Each list consisted of five questions such that most of the speech sounds of Kannada language were present in each list.

Procedure

The study was carried out in three stages. They were:

Stage I: Subject selection

Stage II: Hearing aid fitting

Stage III. Evaluation of the objectives of the study.

Stage I: Subject selection

a) Pure tone audiometry: Pure tone thresholds were obtained at octave intervals between 250 Hz and 8000 Hz for air conduction stimuli and between 250 Hz and 4000 Hz for the bone conduction stimuli using Hughson-Westlake method (Carhart & Jerger, 1959). Madsen Orbiter 922 was used for this purpose.

b) Speech audiometry: Routine speech recognition score in quiet condition were carried out at 40 dBSL (re: SRT) using Madsen Orbiter 922 diagnostic audiometer.

c) Immittance audiometry: Tympanogram and acoustic reflex thresholds were measured by using GSI Tympstar immittance meter.

Stage II: Hearing aid fitting

a) Digital and analogue BTE hearing aids were used in this investigation. For the fitting of the digital BTE hearing aid, it was programmed based on the hearing threshold and NAL- NL1 fitting formula using Connexx software version 5.6 through NOAH 3.0 version and Hi Pro. Programming was done for both microphone and telecoil settings and fitted to the ear that showed better speech recognition score in case of bilateral hearing loss. In case of unilateral hearing loss, the better ear was blocked with the EAR foam ear plug to avoid participation of that ear. BTE ear tips were used to couple the hearing aid to the subject's ear. Fine tuning was done based on aided threshold and the feedback obtained from the subject.

b) For the fitting of the analogue hearing aid, real ear insertion gain optimization using Fonix FP 40-D with digisp-ANSI stimuli was conducted using the NAL- R target fitting.

Stage III: Evaluation of the objectives of the study.

The speech recognition measurements were conducted in the real life situation with the female tester with normal vocal quality presenting the word list and questions with live voice. The tester was fluent in Kannada language. For all the subjects while obtaining the data for the objective of the study, care was taken to maintain the tester's voice constant with normal vocal effort. The following steps were used for evaluation of the objectives of the study:-

a) Speech Recognition Score (SRS) through the GSM mobile phone system when the subject was wearing digital hearing aid in M setting. After fitting the hearing aid in M setting, any one phonetically balanced (PB) word list was selected randomly from eight PB word lists and was presented by the tester using live voice. Each word list consisted of 20 words. Speech stimuli were presented through a mobile phone having GSM system. Subjects received the speech stimuli through the Nokia 2100 GSM mobile phone system and were instructed to repeat those words. Mobile phones through which subjects were receiving the speech stimuli were positioned within 1 to 3 cm of the subject's aided ear according to their comfort. Positioning was done by holding the mobile phone at an angle of 45 degree (re: nose, which is the normal position). The response was scored with one point for each correct repetition of the word, maximum score being twenty. Speech recognition was also measured by presenting a list of every day questions. One set was selected randomly and presented to the subject by the same tester. The subject was made to listen to the speech through the same mobile phone and was instructed to answer to those questions. The response was scored with one point for each correct answer of the question.

b) SRS was measured through the GSM mobile phone when the subjects wore the digital hearing aid in T setting. After changing the programming of the hearing aid from M to T, the above procedure was repeated for getting the SRS.

c) SRS was obtained through GSM mobile phone system when the subjects wearing the analogue hearing aid in M setting. After fitting the analogue hearing aid in M setting, same procedure described above was repeated for obtaining the SRS.

d) SRS was measured through GSM mobile phone system when the subject wore the analogue hearing aid in T setting. After changing the setting from M to T setting, the above procedure was repeated.

e) SRS through CDMA mobile phone system was measured when subject wore digital hearing aid in M setting. After fitting of the digital hearing aid in M setting, the above procedure was repeated.

f) SRS through CDMA mobile phone system was measured when the subject wore digital hearing aid with T setting. After changing the programming from M to T, same above procedure was repeated.

g) SRS was obtained through the CDMA mobile phone system when the subject was wearing the analogue hearing aid in M setting. After fitting the analogue hearing aid in M setting, the above procedure was used.

h) SRS through the CDMA mobile phone system was obtained when the subject was wearing the analogue hearing aid in T setting. After changing the setting from M to T setting, same procedure was repeated.

For fifty percent of the subjects, the testing was first done with GSM and for the other fifty percent of the subjects testing was first done with CDMA mobile phone system. This procedure was repeated for each subject. The data thus obtained was subjected to statistical analysis.

RESULTS AND DISCUSSION

The aim of the present study was to evaluate the Speech Recognition Score (SRS) with GSM and CDMA using digital and analogue hearing aids in M and T settings. The data obtained from thirty subjects were analyzed and compared under the following test variables. They are:

1) Use of GSM system while aided with digital hearing aid in M setting and PB words used as stimulus (GSM-D-M-PB).
2) Use of GSM system while aided with digital hearing aid in M setting and questions used as stimulus (GSM-D-M-Q).
3) Use of GSM system while aided with digital hearing aid in T setting and PB words used as stimulus (GSM-D-T-PB).
4) Use of GSM system while aided with digital hearing aid in T setting and questions used as stimulus (GSM-D-T-Q).
5) Use of GSM system while aided with analogue hearing aid in M setting and PB words used as stimulus (GSM-A-M-PB).
6) Use of GSM system while aided with analogue hearing aid in M setting and questions used as stimulus (GSM-A-M-Q).
7) Use of GSM system while aided with analogue hearing aid in T setting and PB words used as stimulus (GSM-A-T-PB).
8) Use of GSM system while aided with analogue hearing aid in T setting and questions used as stimulus (GSM-A-T-Q).

9) Use of CDMA system while aided with digital hearing aid in M setting and PB words used as stimulus (CDMA-D-M-PB).
10) Use of CDMA system while aided with digital hearing aid in M setting and questions used as stimulus (CDMA-D-M-Q).
11) Use of CDMA system while aided with digital hearing aid in T setting and PB words used as stimulus (CDMA-D-T-PB).
12) Use of CDMA system while aided with digital hearing aid in T setting and questions used as stimulus (CDMA-D-T-Q).
13) Use of CDMA system while aided with analogue hearing aid in M setting and PB words used as stimulus (CDMA-A-M-PB).
14) Use of CDMA system while aided with analogue hearing aid in M setting and questions used as stimulus (CDMA-A-M-Q).
15) Use of CDMA system while aided with analogue hearing aid in T setting and PB words used as stimulus (CDMA-A-T-PB).
16) Use of CDMA system while aided with analogue hearing aid in T setting and questions used as stimulus (CDMA-A-T-Q).

The statistical analyses were carried out using Statistical Package for Social Sciences for windows version 10.0 (SPSS). The results are discussed under the following headings:

1) Comparison between GSM and CDMA system
2) Comparison between analogue and digital hearing aids in M and T settings.

1) Comparison Between GSM and CDMA System

Mean and standard deviation (SD) for each variable were found out. Table 4.1 depicts the mean and SD of each group. The data was statistically analyzed using paired samples t-test for obtaining the pair-wise comparison among the groups. The results from Table 4.2 showed that for all the paired variables, between GSM and CDMA with digital hearing aid in M setting using PB words, digital hearing aid in T setting using PB words, digital hearing aid in T setting using questions, analogue hearing aid in M setting using PB words, analogue hearing aid in M setting using questions, analogue hearing aid in T setting using PB words and analogue hearing aid in T setting using questions, there was a significant differences ($p < 0.05$) with CDMA shows better performance than GSM. Only in one condition i.e., comparison between GSM system with digital hearing aid in M position and CDMA system with digital hearing aid in M position, there was no significant difference ($p>0.05$) found when questions were presented as a stimulus. The performance was almost same for both the conditions.

Table 4.1. Mean and standard deviation of speech performance for sixteen test conditions

Sl. No.	Mobile phone technology	Hearing aid technology	M/T settings of hearing aids	Speech material used	N	Mean	SD
1.	GSM	Digital	M	PB	30	15.9667	1.129
2.	GSM	Digital	M	Q	30	4.9333	.254
3.	GSM	Digital	T	PB	30	9.3667	2.251
4.	GSM	Digital	T	Q	30	2.4333	.774
5.	GSM	Analogue	M	PB	30	14.000	2.068
6.	GSM	Analogue	M	Q	30	4.3333	.7581
7.	GSM	Analogue	T	PB	30	8.0333	3.112
8.	GSM	Analogue	T	Q	30	2.0667	1.015
9.	CDMA	Digital	M	PB	30	17.3667	1.159
10.	CDMA	Digital	M	Q	30	4.8667	.3457
11.	CDMA	Digital	T	PB	30	16.9333	2.559
12.	CDMA	Digital	T	Q	30	4.7667	.6261
13.	CDMA	Analogue	M	PB	30	16.3333	2.089
14.	CDMA	Analogue	M	Q	30	4.9000	.3051
15.	CDMA	Analogue	T	PB	30	15.2000	3.134
16.	CDMA	Analogue	T	Q	30	4.4333	.8584

Note: PB = Phonetically balanced wordlist; Q = Questions.

M = Microphone setting; T = Telecoil setting.

Table 4.2: Paired comparison of the different test conditions.

Pair of conditions compared	t	Sig.
GSM-D-M-PB vs. CDMA-D-M-PB	8.226	0.000
GSM-D-M-Q vs. CDMA-D-M-Q	0.812	0.423
GSM-D-T-PB vs. CDMA-D-T-PB	12.689	0.000
GSM-D-T-Q vs. CDMA-D-T-Q	14.456	0.000
GSM-A-M-PB vs. CDMA-A-M-PB	6.372	0.000
GSM-A-M-Q vs. CDMA-A-M-Q	4.264	0.000
GSM-A-T-PB vs. CDMA-A-T-PB	8.629	0.000
GSM-A-T-Q vs. CDMA-A-T-Q	10.906	0.000

Note: Full forms of the abbreviation in this table are already mentioned earlier.

Figure 4.1: Mean SRS from GSM and CDMA while using digital and analogue hearing aid in M setting.

Figure 4.1 shows the mean of SRS obtained by GSM and CDMA system while using digital and analogue hearing aid in M position and PB words used as stimuli. The average speech performance (SRS) with CDMA system was found to be better than GSM system while using both analogue and digital hearing aids. It has also been found that the performance with CDMA was much better than with

GSM in T settings of both analogue and digital hearing aids when PB words was used as stimulus. This is depicted in Figure 4.2.

Figure 4.2: Comparison between the SRS of GSM and CDMA system, with digital and analogue hearing aid in T setting for PB words.

When questions were presented, the overall performance of the CDMA was better than GSM with analogue hearing aid in M setting and with digital haring aid, in M setting the performance of CDMA and GSM were almost same as shown in Figure 4.3 which shows that CDMA will give better speech perception than GSM.

Figure 4.3: Comparison between the SRS of GSM and CDMA system, with digital and analogue hearing aid in M setting for everyday questions.

The Figure 4.4 shows that CDMA gave significantly better performance than GSM for both digital and analogue hearing aids in T setting when questions were used as a stimulus. The overall result of comparing GSM and CDMA mobile system revealed that the speech performance of hearing aid users with the CDMA wireless system is much better than GSM wireless system. Skopec (1998) measured the performance with five hearing aids with GSM and CDMA system with 70 dB SPL white noise in order to bias the hearing aid as well as to approximate the speech. Results showed that GSM produces maximum interference induced sound pressure level of 122.5 dB whereas interference was very less for CDMA. This suggested that speech perception will be better with CDMA. The findings of the present study supported that of other studies. Kozma-Spytek (2001) has reported that CDMA service causes less audible interference than GSM technology which will cause less interference and performance will be better. The present study was done in more natural condition where stimulus were presented through live voice which gives much better speech perception than recorded samples. Study done by Schelgel, Ravindran, Raman and Grant (2001) where they have used NU-6 recorded speech stimuli whose finding was similar with the performance with CDMA being better that GSM.

The marked difference was seen with GSM and CDMA system in the performance between M and T settings of digital and analogue hearing aids was due to the pulsing pattern of the GSM transmission that may potentially be picked up by the microphone and telecoil of the hearing aids (Kozma-Spytek, 2003).

Figure 4.4: Comparison between the SRS of GSM and CDMA system, with digital and analogue hearing aid in T setting for everyday questions

2) Comparison between analogue and digital hearing aids in M and T settings.

Since testing was done in the same subjects, repeated measures ANOVA and Bonferroni's multiple comparison test were performed to compare the performance of digital and analogue hearing aids in M and T settings within the GSM and CDMA system when PB words and questions were used as stimuli.

a) Performance of speech while using GSM system with digital and analogue hearing aids in M and T settings and PB words were used as stimulus. It was found that there was significant difference seen between the SRS obtained with digital and analogue hearing aids [$F (3, 87) = 132.01$, $p<0.05$]. The SRS of digital hearing aid was found to be much better in both M and T settings compare to that of the analogue hearing aid. Study done by Kuk, and Neilsen (1997) showed that with GSM system, conventional analogue BTE hearing aid produces spikes with large amplitude compare to that of digital hearing aid which also suggests that digital hearing performance was better than analogue hearing aids. It has also been found that M setting was significantly better than T setting ($p<0.05$) for digital and analogue hearing aids. This difference of M and T settings were more seen for analogue hearing aid and with GSM system. Figures 4.1 and 4.2 depict the results.

b) Repeated measure ANOVA showed that when questions were used, the performance of speech using GSM system with digital and analogue hearing aids were significantly different with the SRS obtained with digital hearing aid performed better than analogue ($p<0.05$) except in one condition i.e., same at T setting, digital and analogue hearing aids performs the same[$f (3, 87) = 143.55$, $p>0.05$]. Within M and T settings, M setting performs significantly better than T setting ($p<0.05$) within both digital and analogue hearing aids as well as across digital and analogue hearing aids. Figures 4.3 and 4 shows that, overall performance of digital hearing aid was better than analogue. For M setting, the performance was much better than T setting.

c) Repeated measures ANOVA showed that, when PB words were used, the performance of speech using CDMA system with digital hearing aid was better in M and T settings than with analogue hearing aid. There was significant difference obtained between digital and analogue in m setting and between digital and analogue hearing aid in T setting ($p<0.05$). Within digital and within analogue hearing aid, in M and T settings, there was no significant difference in the performance ($p>0.05$). Figures 4.1 and 4.2 show that for CDMA , with PB words, the performance with digital hearing aid was better than analogue in both M and T settings. Within digital and analogue hearing aids, M and T performance were almost same.

d) Repeated measure ANOVA showed that, when questions were used as stimulus, with CDMA system, there was no significant difference between digital and analogue hearing aids in M setting and digital and analogue hearing aid in T settings. Performance within digital hearing aid at M and T settings were also having no significant difference ($p>0.05$) whereas performance within analogue hearing aid at M and T setting, significant difference was seen with M performs better than T ($p<0.05$). Figure 3 and 4 shows that the performance of digital hearing aids was very similar to analogue in M setting and in T settings. Within digital hearing aid, in M and T settings, performance was same where as within analogue hearing aid; the performance of T was lower than M setting.

The overall performance of the present study with GSM and CDMA system using digital and analogue hearing aids in M and T settings suggested that when PB words were used, there was significant difference in the performance between M and T settings of the hearing aids with M performs better. This is due to the fact that in addition to the electromagnetic interference, the T setting of the hearing aid also produces base band interference that further reduces the speech recognition score (Kozma-Spytek, 2003).

The findings of the present study supported that of Byrne, and Burwood's (2001) findings which found that on microphone input, it would pick up interference at 10 meters and with telecoil input at about 17 meters. Together this study of GSM and CDMA wireless system with digital and analogue hearing aid in M and T settings suggested that speech understanding difficulties expressed by hearing impaired subjects was more with GSM than CDMA mobile technology. The problems appear to be compounded when subjects were using the hearing aids in telecoil setting due to the additional base band interference. The reduction in speech recognition was more when the subjects were using analogue hearing aids.

SUMMARY AND CONCLUSION

The mobile phone use has become one of the rapidly growing segments in the communication. Individuals with hearing impairment, who use mobile phone of either GSM or CDMA transmission system while wearing digital or analogue hearing aids, face problem in understanding speech. This is due to the electromagnetic interference that occurs and affects the understanding of speech. Research findings showed that this interference is more when a subject with hearing impairment uses GSM wireless system than CDMA wireless system (Skopec, 1998; Kuk & Nielsen, 1997). There are other factors that may increase or decrease this interference such as the hearing aid used. The uses of analogue BTE hearing aids cause more interference than digital BTE hearing aids irrespective of the mobile phone technology (Kuk & Nielsen, 1997). In addition to that, interference at T position was found to be more than at M position, due to the additional base band interference (Kozma-Spytek, 2001). There is a dearth of studies reported in literature, evaluating the speech reception score using live voice, in natural situation that is most often faced by everybody including subjects with hearing impairment.

The present study was undertaken to investigate the Speech Recognition Score of the subjects with hearing impairment aided with analogue or digital hearing aids, using GSM and CDMA wireless system. Evaluation was done under the following conditions:

1) Use of GSM system while aided with digital hearing aid in M setting and PB words was used as stimulus, i.e., GSM-D-M-PB.
2) Use of GSM system while aided with digital hearing aid in M setting and questions were used as stimulus, i.e., GSM-D-M-Q.
3) Use of GSM system while aided with digital hearing aid in T setting and PB words was used as stimulus, i.e., GSM-D-T-PB.
4) Use of GSM system while aided with digital hearing aid in T setting and questions were used as stimuli, i.e., GSM-D-T-Q.
5) Use of GSM system while aided with analogue hearing aid in M setting and PB words was used as stimulus, i.e., GSM-A-M-PB.
6) Use of GSM system while aided with analogue hearing aid in M setting and questions were used as stimulus, i.e., GSM-A-M-Q.
7) Use of GSM system while aided with analogue hearing aid in T setting and PB words was used as stimulus, i.e., GSM-A-T-PB.
8) Use of GSM system while aided with analogue hearing aid in T setting and questions were used as stimulus, i.e., GSM-A-T-Q.
9) Use of CDMA system while aided with digital hearing aid in M setting and PB words was used as stimulus, i.e., CDMA-D-M-PB.
10) Use of CDMA system while aided with digital hearing aid in M setting and questions were used as stimulus, i.e., CDMA-D-M-Q.

11) Use of CDMA system while aided with digital hearing aid in T setting and PB words was used as stimulus, i.e., CDMA-D-T-PB.

12) Use of CDMA system while aided with digital hearing aid in T setting and questions were used as stimulus, i.e., CDMA-D-T-Q.

13) Use of CDMA system while aided with analogue hearing aid in M setting and PB words was used as stimulus, i.e., CDMA-A-M-PB.

14) Use of CDMA system while aided with analogue hearing aid in M setting and questions were used as stimulus, i.e., CDMA-A-M-Q.

15) Use of CDMA system while aided with analogue hearing aid in T setting and PB words was used as stimulus, i.e., CDMA-A-T-PB.

16) Use of CDMA system while aided with analogue hearing aid in T setting and questions were used as stimulus, i.e., CDMA-A-T-Q.

The overall results indicated that speech recognition with CDMA system was better than with GSM system for both digital and analogue hearing aids. The overall results are as follows:

a) Speech recognition with GSM and CDMA system :

The paired samples t-test showed that the overall performance of the CDMA wireless system was found to be better in understanding the speech than GSM system while using analogue and digital hearing aids.

b) Speech recognition with digital and analogue hearing aids in M and T settings:

Repeated measures ANOVA and Bonferroni pair-wise comparison test showed that overall performance with digital hearing aid was better than with analogue hearing aid while using GSM as well as CDMA mobile phone system. With GSM system, the overall performance in M setting was better than T setting, where as with CDMA system using digital hearing aid in M and T setting and using analogue hearing aid in M and T setting, performance were same for PB words. When questions were presented while using CDMA system with analogue and digital hearing aids, the performance was almost similar with the digital hearing aid in M and T settings, whereas, in analogue hearing aid in M setting, the speech recognition score was better than T setting.

The following inferences can be drawn based on the following results:-

Speech understanding through CDMA wireless system is better than that of GSM wireless system in subjects with hearing impairment aided with digital and analogue hearing aids. The overall performance of speech understanding was better with digital hearing aids than analogue hearing aids when subjects with hearing impairment are using either GSM or CDMA wireless systems. In addition to that, the performance of speech recognition in M setting was found to be better than T setting for GSM wireless system whereas for CDMA wireless system, the performance of M setting is better than T but the difference was not so significant as GSM system.

Implications

It is necessary to advice the individuals with hearing impairment about the hearing aid type and facilities that can be availed with that particular hearing aid. Based on the present study, subjects with hearing impairment can be advised to use digital hearing aid and CDMA wireless system as it gives more clear speech and less interference. M setting was more advisable than T setting for both analogue and digital hearing aids. Such information would be useful during counseling a hearing aid user.

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