Speech Identification through Mobile Phone Coupled to Hearing Aids, With and Without Wireless Technology

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CERTIFICATE

This is to certify that this master's dissertation entitled **'Speech identification through mobile phone coupled to hearing aids, with and without wireless technology'** is a bonafide work submitted in part fulfillment for the degree of Master of Science (Audiology) of the student with **Registration No: 18AUD008**. This has been carried out under the guidance of the 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 **'Speech identification through mobile phone coupled to hearing aids, with and without wireless technology'** is the result of my own study under the guidance of Dr. Manjula P, Professor of Audiology, Department of Audiology, All India Institute of Speech and Hearing, Manasagangothri, Mysore, and has not been submitted earlier to any other university for the award of any diploma or degree.

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Abstract

Individuals with sensorineural hearing loss have difficulty communicating through mobile phones. The hearing aid users are not satisfied with their hearing aid when listening through mobile phones. Generally, this problem is not focused during the routine audiological evaluation. Wireless hearing aid technology may help in speech identification through mobile phones. In the present study, speech identification and quality through mobile phone using three different coupling modes of the hearing aid (microphone, telecoil, and direct Bluetooth coupling) was evaluated in 15 individuals with moderate to moderately severe sensorineural hearing loss. The different coupling inputs were stored in the receiver in the canal (RIC) and behind the ear (BTE) hearing aids.

The assessment was carried out in quiet using Speech Identification Scores (SIS) in quiet and in the presence of noise using SNR 50, i.e., signal to noise ratio required to achieve 50% of speech identification. Apart from this, the assessment was done using a speech quality rating scale. The SIS, SNR 50, and speech quality ratings were obtained in five aided conditions (A1, A2, A3, A4, & A5), i.e., RIC hearing aid coupled with a microphone input without a mobile phone (A1). The following four aided conditions (A2, A3, A4, & A5) were tested using a mobile phone, i.e., the RIC hearing aid coupled with a microphone input (A2), and the RIC hearing aid coupled with direct Bluetooth streaming (A3). The BTE hearing aid coupled with a microphone input (A4), and the BTE hearing aid with telecoil coupling (A5).

Friedman test was used to compare the scores in five aided conditions, followed by Wilcoxon Signed rank test (when indicated) for pairwise analysis. The results revealed that best scores and ratings were obtained for direct Bluetooth streaming(A3) compared to the other aided conditions. Thus, additional Bluetooth streaming is required for better speech identification through the mobile phone when using a hearing aid. However, there was no significant difference between direct Bluetooth coupling (A3) and telecoil coupling(A5) on speech identification in the presence of noise, suggesting that a properly programmed telecoil improves speech recognition, in the presence of noise, using a mobile phone.

Keywords: hearing aid, speech identification, quality, mobile phone, Bluetooth streaming, telecoil.

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Chapter 1

INTRODUCTION

Communication through external devices, such as telephones/mobile phones, by hearing aid users is often possible through various technologies. Yet, telephone usage is often a challenge for individuals with hearing impairment, particularly in a noisy situation, and can lead to social and work-related problems (Au et al., 2019). The popular technologies that are useful in enhancing communication through telephone/mobile phones include the use of electromagnetic fields, frequency modulation (FM), and Bluetooth (Mroz, 2019).

The telecoil in hearing aids picks up the electromagnetic field generated by the telephone / mobile phones and amplifies it for the hearing aid user. With the advancements in hearing aids, telecoil can be useful to a greater advantage. The Bluetooth hearing aids wirelessly connect to the telephone or mobile devices.

In a study by Sanju et al. (2018), hearing aid wearers were satisfied with conventional hearing aids in terms of day-to-day communication and cost but were dissatisfied and frustrated with unwanted sounds. However, it reported that most of them were satisfied with hearing aids in telephone conversations, which attributes to the advancement in technology. This technological advancement in hearing aid models reduces the background noise and improves telephone conversation (Bhat et al., 2015).

Though telecoil in hearing aids are known to provide a better signal to noise ratio (SNR) while listening through telephone, it is of limited use to landline telephones and hearing aid compatible cell phones due to problems like a) the amount of electromagnetic signal emission from the telephone or mobile phones, i.e., converted and amplified, b) the recent loudspeaker technologies used in mobile phones do not produce electromagnetic field and therefore exhibit practical constraints for modern mobile phones (Picou & Ricketts, 2013).

1.1 Need for the Study

The wireless technology provides a significant improvement in speech recognition for hearing aid users in such adverse situations (Au et al., 2019). According to Kim et al. (2014), though there are many wireless connections to hearing aids, the Bluetooth is considered as a standard connection for digital signal transmission in audio electronic devices. It could be because of the advantages of the wireless transmissions like reduced noise levels and increased SNR, which is not just by microphone noise attenuation but because of the Bluetooth technology itself. Hence the authors report Bluetooth to be more effective than acoustic telephone condition. They have found that hearing aid with Bluetooth feature is useful for speech recognition (subjective and objective) with the use of a cell phone or loudspeaker system. However, this fact lacks sufficient, documented evidence.

Picou and Ricketts (2011) examined the performance of speech recognition in individuals with hearing impairment in seven telephone listening conditions, which included six conditions with wireless transmission and one condition with an acoustic telephone. The wireless transmission was 1) The signal was given unilaterally without hearing aid in the opposite ear and with foam plug inserted; 2) The signal was given unilaterally with hearing aid turned off in the opposite ear; 3) The signal was given unilaterally with hearing aid turned on in the opposite ear and with the external microphone of the wireless transmitter activated; 4) The signal was given unilaterally with hearing aid turned on in the opposite ear, and external microphone of the wireless transmitter turned off; 5) The signal was given to both ears simultaneously, and external microphone of the wireless transmitter activated; 6) The signal delivered bilaterally, and external microphone and the wireless transmitter turned off; 7) The signal was delivered through the handset of the telephone to the test ear only. They found that the speech recognition for bilateral wireless conditions was significantly better than the unilateral conditions and acoustic phone. The study concluded that newer technologies of wireless transmission have advantages over wireless transmission with a telecoil. The advantage of modern wireless technologies is that it is free from positioning constraints. The distance of the transmitting telephone position to that of the hearing aid is the only constraint with the protocols for wireless transmission used.

Further, the latest wireless transmission technologies are compatible with digital cell phones, making it easier to switch between multiple audio devices and efficiently deliver the wireless signal to either one or both the hearing aid(s). However, the study by Picou and Ricketts (2011) showed the advantage of bilateral conditions than acoustic phone only when the hearing aid users are fit with occluding domes. Thus, the advantages expected from the new wireless streaming technology over telecoil will be clinically evident only in hearing aid users who need considerably limited venting than those fitted with open canal fittings. Another drawback of this study is that the participants included were from 47 to 84 years of age with the mean age of 67 years, which shows a possible presbycusis component as a variable. The average hearing thresholds of the participants show a sloping configuration with better thresholds at low frequencies. Thus the results cannot be generalized to all configurations of the audiogram. Hence, there is a need to evaluate the speech identification performance in other configurations of audiogram as well.

A similar study by Picou and Ricketts (2013) compared speech recognition as well as subjective ratings by individuals with a moderate-to-severe degree of sensorineural hearing loss in six telephone listening conditions. The six telephone listening conditions were 1) The signal delivered to the test ear through an acoustic coupling with hearing aid in the contralateral ear activated for background noise; 2) The signal delivered to the test ear through an acoustic coupling with plug in the contralateral ear; 3) The signal was given to the test ear through telecoil coupling with hearing aid in the contralateral ear activated for background noise; 4) The signal delivered to the test ear through telecoil coupling with plug in the contralateral ear; 5) Wireless routing through wireless transmitter was given to the test ear with hearing aid in the contralateral ear activated for background noise, and 6) Wireless routing of signal through wireless transmitters was given to both ears. The results suggested that the acoustic coupling strategy of telephone with a hearing aid was not desirable in the presence of noise. The best speech recognition performance and best subjective ratings were found in wireless routing through wireless transmitters to both ears. The study concluded that wireless signal routing to be a useful telephone listening strategy, only for those individuals fitted with limited venting and with bilateral telephone signal routing.

In the studies of Picou and Ricketts (2011, 2013) suggested that venting in hearing aid as a factor that could contribute to limit the additional wireless benefit to both ears when compared to acoustic telephone condition. In other words, the wireless routing of signal to both ears can give significantly better speech recognition when compared to the acoustic telephone only when there is limited venting in hearing aid for a broader range of hearing losses, i.e., from mild to severe degree of hearing loss. Though the later study (Picou & Ricketts, 2013) had used the subjective ratings to compare the hearing aid conditions, they have included only experienced hearing aid users, which could influence the test results due to familiarity with their hearing aid alone.

Most of the studies reported in the literature are for landline telephone usage. However, in today's world, mobile phones are more often used for telecommunication. Hence, there is a need to evaluate wireless technologies for listening through mobile phones. Further, hearing aids usually are programmed for input through a microphone. The telecoil in hearing aids is programmed rarely. Studies have documented that the sensitivity of input through microphone and telecoil modes in a hearing aid is different. Present-day hearing aids are used with telephones/mobiles with microphone input, telecoil input, or streaming/direct Bluetooth connection.

Putterman and Valente (2012) reported on the difference between a microphone and telecoil performance behind the ear (BTE) type of hearing aids. The telecoil in hearing aids provides numerous advantages than the microphone setting when a hearing aid wearer listens over the telephone. The advantages of telecoil include: 1) Unlike the microphone of the hearing aid, the telecoil will only detect electromagnetic (EM) signals, i.e., EM signals, and not any other unwanted sounds, thereby provide the hearing aid wearer an ideal listening condition for better speech understanding through telephone.2) Telecoil allows for the positioning of the telephone receiver near the hearing aid and the ear without acoustic feedback or squeal. 3) The telephone communication in microphone alone condition is associated with the low-frequency attenuation when the hearing aid user increases the distance between the hearing aid and the telephone receiver to eliminate the feedback caused.

Tannahill (1983) compared the performance of hearing aid in microphone and telecoil mode and reported less output of the telecoil than microphone mode in both the low and high frequencies. A recent study by Ledda et al. (2019) compared the speech recognition for sentences and monosyllabic words between default and programmed telecoil program. They took twenty experienced hearing aid users with slight to severe degree of sensorineural hearing loss (SNHL) in both ears and ten participants with hearing sensitivity within normal limits. The study used real ear measurements to confirm the hearing aid fitting/programming in microphone mode using the NAL-NL1 prescription formula. One of the telecoil programs was according to the manufacturer's default setting and the second telecoil program was programmed or optimized in such a way that the sound pressure level of the frequency response of the telephone simulator matches with the frequency response of the microphone to get a 0 dB simulated telephone sensitivity value. They found significantly better performance in speech recognition for the optimized telecoil program when compared to the default telecoil program. Thus, properly programmed/optimized telecoil provides better signal-to-noise ratio (SNR), reduces acoustic feedback, and aids in clearer telephone communication. However, this study has several limitations, such as the use of only one telephone headset may not be a representation of telephone variability within the same model as well as across models that hearing aid users usually face. Second, this study assessed only one manufacturer and one model of hearing aid, and every manufacturer uses a programming algorithm that is different from generating the default telecoil response. Third, this study used only behind-the-ear (BTE) type of hearing aids, and the results would differ for custom hearing devices. Finally, they had done the testing using telecoil instead of wireless streaming devices to cellphones. In recent years, the use of cell for communication has increased, and landline device usage has decreased. Hence, there is a need to focus on the current and newer technology and strategies with several hearing aid manufacturers and models, which would provide a complete understanding of the variation seen in default programming algorithms.

Kim et al. (2014) evaluated the speech recognition performance in hearing aids through Bluetooth. They took 30 individuals with symmetric moderate sensorineural hearing loss (SNHL). They obtained objective measurements of word recognition and sentence recognition scores and subjective measurement with questionnaires in four aided conditions. The four aided conditions were the wireless transmission of the signal into hearing aid (wireless mode) in quiet and noisy conditions; and signal transmission in conventional microphone mode, i.e., acoustic coupling (conventional mode) in quiet and noisy conditions. The testing was done with a cellular phone and a loudspeaker system set up. The cell phone was to evaluate the performance of the hearing aid using a cell phone. The loudspeaker system was to evaluate the Bluetooth function in hearing aids on electronic devices like an audio system and a television. The results revealed significantly better performance in sentence recognition and word recognition scores through wireless mode than the conventional mode, in both quiet and noisy conditions, for cellular phone and loudspeaker system situations. Additionally, some benefits like improved sound quality, less noise interference, and natural sound quality were reported when using the wireless mode. However, this study is done in the Korean language, and research needs to be in Indian languages and for more evidence.

Thus, it would be interesting to investigate if these input/coupling modes have a different effect on the speech identification and quality of speech through hearing aid while listening through mobile phones. This, in turn, will help clinicians to program the hearing aid and counsel the hearing aid user in terms of the extent of benefit from the type of coupling.

1.2 Aim of the Study

The present study aimed to evaluate the speech identification and quality through mobile phone using different coupling modes of the hearing aid.

1.3 Objectives of the Study

1. To evaluate speech identification through mobile phone in hearing aid users with a microphone input.
2. To evaluate speech identification through mobile phone in hearing aid users with telecoil input.
3. To evaluate speech identification through mobile phone in hearing aid users with direct Bluetooth coupling.
4. To evaluate speech quality through mobile phone in hearing aid users with a microphone input.
5. To evaluate speech quality through mobile phone in hearing aid users with telecoil input.
6. To evaluate speech quality through mobile phone in hearing aid users, with direct Bluetooth coupling.

1.4 Hypotheses of the Study

The hypotheses were constructed for listening to mobile phones through hearing aid in different coupling modes.

1. There is a significant difference in speech identification, in quiet, between direct Bluetooth coupling and microphone and telecoil coupling.
2. There is a significant difference in speech identification, in noise, i.e., between direct Bluetooth coupling and microphone and telecoil coupling
3. There is a significant difference in speech quality between direct Bluetooth coupling and microphone and telecoil coupling.

Chapter 2

REVIEW OF LITERATURE

Mobile phones/ smartphones are one of the widely used devices today. The usage of these phones is considered a necessity for all. However, individuals with hearing loss find it difficult to understand speech through these cell phones. Effective communication through speech using mobile phones/ smartphones is an essential aspect of modern life. It eases social interaction, which otherwise gets hampered in those with hearing loss (Recker & Kalluri, 2009). This is one of the prime reasons for them to seek amplification devices (Nesgaard Pedersen & Kirkwood, 2014).

Some statements of hearing aid problems from the hearing aid owner's perspective show that they have difficulty in hearing clearly over the mobile phone, especially in noisy situations. They were also doubtful to use the hearing aid in combination with the mobile phone, using phone programs, and where to hold the phone for the best benefit (Bennett et al., 2018). However, an Indian study in older adults about self-reported satisfaction with digital hearing aids shows that about 86% of the hearing aid users were satisfied with the performance of hearing aid with telephone/mobile but were frustrated from pick up of unwanted sounds by the hearing aid (Sanju et al., 2018). The wireless technology in hearing aid has enhanced the mobile phone experience of hearing aid users over the past years. The literature on phone usage with hearing aid relevant to the present study is given in the following headings:

2.1 Wireless Hearing Aid Technology

2.1.1 Telecoil Technology

2.1.2 FM System Technology

2.1.3 Bluetooth Technology

2.1.4 Benefits of Using Wireless Hearing Aids

2.1.5 Localization

2.2 Mobile Phone and Hearing Aid Compatibility

2.2.1 Microphone and Telecoil as Sources of Interference

2.2.2 Standards

2.2.3 Hearing Aid Immunity

2.3 Performance if Individuals with Hearing Impairment Through Mobile Phones

2.1 Wireless Hearing Aid Technology

In order to keep ourselves connected to society, we depend more on mobile phones, tablets, and other wireless devices on an everyday basis. These are the devices that use wireless technology to transmit signals through the air without any wires. This technology is successfully used in hearing aids. Digital wireless technology improves hearing aids' performance in two ways, i.e., by connecting with our favorite devices, like smartphones, and by connecting the two hearing aids and hence can perform together. It is essential to know how the hearing aids wirelessly connect to our modern devices. The hearing aids can be connected wirelessly to the external devices via telecoils (t-coils), frequency modulation (FM), and Bluetooth (Mroz, 2019).

2.1.1 Telecoil Technology

A t-coil/ telecoil is a coil wounded with a wire placed in several hearing aids as well as cochlear implants to function as wireless receivers in miniature size. (Kim & Kim, 2014). This is one of the most commonly used technologies to connect hearing aids with the telephone, making use of electromagnetic fields. Electromagnetic fields are picked up by an antenna in the hearing aid called a telecoil. The electromagnetic fields can also be installed in a room and thereby acts as an induction loop. A hearing aid user can shift the program to the telecoil setting of the hearing aid for ease of listening. Many public places like movie theatres and airports use this technology for individuals fitted with hearing aids. With the developments in wireless hearing aids, telecoil is used with more significant benefits. When placed near a phone, the wireless hearing aid with a telecoil can pick up the signal and stream it to the hearing aid in the opposite ear. Thus, it helps the hearing aid user to hear the caller in both the ears and thereby successfully omits any noise in the room (Mroz, 2019).

2.1.2 FM System Technology

The wireless FM sound systems send signals directly from a wireless transmitter to a receiver in the form of radio waves. It is the most commonly used sound systems like television, radio, and stereos. The receivers can also be fit to hearing aids through direct audio input (DAI)/ neck-loop/ telecoil induction coupling, which converts the signal to magnetic signals and gets picked up by the telecoil. The FM system technology help children to perform well in the classroom situation. (Kim & Kim, 2014; Mroz, 2019).

2.1.3 Bluetooth Technology

Bluetooth was invented in 1998 by Haartsen. It is a standard wireless technology used to exchange information like audio or pictures over short distances. It connects with several fixed and mobile devices using ultra-high-frequency radio waves in the range of 2.4 to 2.485 GHz, the Industry Science Medical (ISM) band (Kim & Kim, 2014).

Bluetooth is a new technology that has a significant effect on hearing aids. Previous wireless hearing aids can pair with Bluetooth devices via an intermediate device called a streamer. This streamer converts the Bluetooth signal into a signal which can be picked up by a receiver of the FM system or a telecoil in the hearing aid. For example, when the hearing aid is wirelessly connected to a streamer, it connects to the mobile phone via Bluetooth.

When a hearing aid user gets a call from their mobile phone, the streamer indicates it as an incoming call and lets the person direct the audio signal directly to the hearing aid. However, the latest Bluetooth-compatible hearing aids can directly communicate with mobile phones, such as Apple's latest iPhone devices, without a streamer. Android mobile phone, too, is working on direct communication with hearing aids. (Mroz, 2019). Hence, the telecoil and Bluetooth are used mostly for mobile phone usage along with hearing aids. The present study has also included these two technologies as aided conditions.

2.1.4 Benefits of Using Wireless Hearing Aids

The better sound quality of hearing aids with wireless technology is observed. It allows two independent hearing aids to function as one whole system and provides combined information from both the hearing aids. For example, if one of the hearing aids is turned on to directional mode, both the hearing aids switch into that mode simultaneously. The data transfer speed for wireless hearing aids are much faster, i.e., in nanoseconds, and helps the hearing aid user to perceive the changes in real-time. Thus, the synchronized sound processing between the hearing aids improves the overall sound quality (Mroz, 2019).

Wireless technologies improve the convenience of hearing aid use. For example, in some wireless hearing aids, when the hearing aid user changes a program or pushes the volume control of only one of the hearing aids, this change is applied to the other hearing aid automatically (Mroz, 2019). These arrangements require only limited space for buttons on each hearing aid and reduce the number of changes needed to be done by half. In brief, Jespersen (2012) stated the benefits of wireless hearing aid technologies such as

a) synchronous operation with hearing aids through program change settings and volume control of both the hearing aids or remote control

b) another convenience benefit is the interface with electronic devices such as mobile phones, music players, televisions, and personal computers

c) wireless exchange of information between the hearing aids fitted bilaterally to automatically select or change the program setting suitable for listening situations.

2.1.5 Localization

This binaural hearing helps the hearing aid user locate the sound source much better and faster. This is because of the brain's ability to analyze the timing difference, and level difference received from each side of the head. Thus, these wireless hearing aid technologies improve localization, which is often difficult with traditional hearing aids (Mroz, 2019).

2.2 Mobile Phone and Hearing Aid Compatibility

Hearing aid compatibility (HAC) for digital wireless phones is required from the Federal Communications Commission (FCC) (Kozma-Spytek, 2006).

2.2.1 Microphone and Telecoil as Sources of Interference

The compatibility issues between hearing aids and mobile phones are mainly due to electromagnetic interference. This interference between mobile phones and hearing aids in microphone mode is associated with the radio frequency (RF) transmission, which occurs during a call between the mobile phone and its network. Though the frequency range of the RF transmissions is beyond the audio frequency range (800 - 1900 MHz), the modulation rate is within the audio frequency range, i.e., 217 Hz. This modulation generates audible interference with a fundamental frequency and causes interference of harmonics of the fundamental frequency. The strength of the RF transmissions can differ depending on the distance between the mobile phone and the nearest cell tower. Thus, the degree of interference that is experienced during a call also varies accordingly from one call to another with the same mobile phone.

The hearing aids set in the telecoil program can be affected by both RF transmission interference and magnetic sources of interference. The components of a mobile phone stored in the battery handset, which supplies current also generate magnetic fields as a by-product and thereby results in interference for hearing aids. The interference is also called baseband interference, which is known to be challenging because telecoils are sensitive to magnetic fields irrespective of whether the source of interference is from the handset or the calling person's speech on the phone call. Because of these interferences, there is a need for considerations for HAC in Cell Phones, which investigate the handset’s interference potential. HAC depend on the following factors:

- The situation within which the call is made, as it causes undesirable noise.

- The strength and direction of the magnetic field produced by the telephone must be acceptable for use by the telecoil of the receiving hearing aid.
- There should be a larger magnetic source size to keep the hearing aid user's natural positioning between the mobile phone and the telecoil of the hearing aid.
- Unwanted noise interference levels must be lower to allow the use of the mobile phone.

These levels of interference by noise is defined by establishing a lower signal to noise ratio. The hearing aid compatibility must be tackled through the standard government procedure or regulation.

2.2.2 Standards

Industrial standards set the requirements of Electromagnetic Compatibility (EMC). A standard is a document recognized by an expert and approved by an established body, which specifies the methods of measurement and the suitable performance criteria to meet compatibility needs. These standards help in assessing whether a product is following the performance criteria. Some of the standards for checking the HAC are given below:

a) American National Standards Institute (ANSI) C63.19.

ANSI specifies the method of measurement and performance criteria for the compatibility of the hearing aid with digital mobile phones. The performance criteria are set based on research conducted on Telecommunications Access and Hearing Enhancement, Wireless Electromagnetic Compatibility Center, and Etymotic Research. For mobile phones, RF emissions must be reduced, and the of hearing aid’s internal immunity to those emissions must be increased. This is carried out independently for microphone and telecoil coupling in hearing aids.

b) ASHA Hearing Aid Compatibility Requirements.

ASHA standard involves two parts: one standard for microphone compatibility and the other standard for telecoil compatibility denoted as M and T ratings, respectively (Wallber, 2011). Cell phones rated from M1 to M4, which indicates the amount of RF interference produced and how well the cell phone will function with a microphone of a hearing aid. The T1–T4 rating indicates the strength of electromagnetic induction in the telecoil of the hearing aid. According to this standard, a cell phone is compatible with a hearing aid if it gets an M and T rating of '3' (ANSI C63.19). The M2 and T2 is an intentional rating given by the hearing aid industry, which refers to the immunity of the hearing instrument to RF interference in the corresponding microphone mode (M rating) and its telecoil strength (T rating). These ratings help the hearing aid user to determine the probability of success in coupling their hearing aid with a cell phone. This is achieved by adding the hearing aid rating, usually M2 and T2, with the cell phone rating. For example, if a hearing aid rated as M2 (T2) is added with a cell phone rated as M3 (T3) would give a total rating of M5 (T5) and therefore be considered as ‘acceptable for normal use.' A total rating of M6/T6 is considered ‘excellent.' Therefore, a sum of M4/T4 ratings must be used whenever possible.

c) FCC Hearing Aid Compatibility Requirements.

Hearing aids designed to be used with digital mobile phones include an ANSI C63.19 immunity rating of at least 2. This rating is based on a scale from 1 to 4. The higher the number on the scale means more immunity for microphone and telecoil coupling of the hearing aids, denoted as "M" or "T" immunity rating. The immunity ratings from the cell phone and the hearing aid are summed together. E.g.

4 – usable, i.e., can complete a brief phone call but not suitable for phone use.

5 - suitable for regular phone use.

6 or greater - highly usable, with excellent performance.

These predictions hold good for most hearing aid users and would assist in hearing aid user's search for a cell phone. With M5 or higher rating, there is a reduced chance of annoyance due to interference from a mobile phone. With a total rating of M5/T5 or higher, there is a reduced chance of annoyance due to interference and improves effective coupling to the mobile phone. Only those mobile phones with a rating of at least M3 or M3 and T3 will be considered to have Hearing aid compatibility (HAC). The mobile phones without an "M" or "T" rating either mean that the mobile phone did not meet the requirements for microphone or telecoil coupling compatibility according to the Federal Communications Commission (FCC) rule (or) the mobile phone was not tested for compliance. Possible ratings for compliance testing include the following rating, i.e., M3; M4; M3/T3; M3/T4; and M4/T4.

2.2.3 Hearing Aid Immunity

According to the standard given by ANSI C63.19, hearing aids are supposed to have a rating called an immunity rating. This immunity rating refers to the susceptibility of hearing aid to RF emissions, which causes interference from a mobile phone. Hearing aid manufacturers are devoted to producing hearing aids that meet the requirements of level 2, 3, or 4 categories for immunity according to ANSI C63.19. Over the years, many of the hearing aid manufacturers have boosted their use of components that makes the hearing aid less susceptibility to RF emissions of the mobile phone. Conversely, hearing aids in telecoil mode is still more susceptible to interference from mobile phones when compared to hearing aids in microphone coupling mode.

2.3 Performance of Individuals with Hearing Impairment Through Mobile Phones

Recker and Kalluri (2009) administered a 48-item questionnaire to find the effect of the latest telephones and hearing aids on telephone use. They found that if issues like distortion, feedback, difficulty in understanding, unsatisfactory volume, and difficulty in coupling were resolved, the phone usage with a hearing aid might increase from around 30%-50% to 70%-80%. They also concluded that wireless technology plays a collective role in the advanced development of these solutions. However, the participants of this study completed this questionnaire without supervision, and therefore questions the accuracy and reliability of the responses. The present study has quality assessment as a measure done in real-time. Hence, the results could be better accepted.

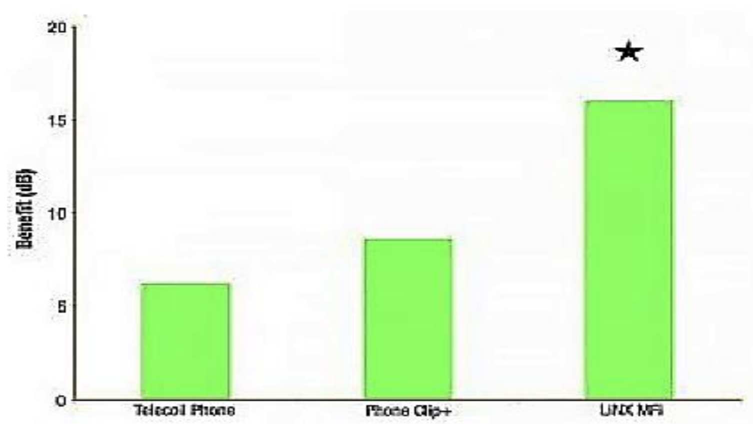
Desjardins and Doherty (2009) evaluated the ability of experienced hearing aid users in using their hearing aids properly with the help of a test called Practical Hearing Aid Skills Test (PHAST). They found more than 70 % of the hearing aid users were unsatisfied over telephone usage with their hearing aid. They also had difficulties in correctly positioning the telephone near the hearing aid’s microphone and in preventing acoustic feedback. Most of them with moderate to severe degrees of hearing loss reported of not using their hearing aid when speaking over the telephone. However, the majority of the hearing aid users included in this study had an experience of more than five years with the hearing aid and wore their hearing device for more than five hours each day.

Hence, the results cannot be applied for all hearing aid users.

Sahin et al. (2015) also found that hearing aid users' most frequent complaints after hearing aid usage was reduced telephone use. Nesgaard Pedersen and Kirkwood (2014) studied the levels of end-user benefit when using the phone in the presence of noise in controlled laboratory conditions. They took 10 participants with hearing sensitivity within normal limits. The listening conditions included were acoustic coupling in unilateral condition; telecoil coupling in unilateral condition; Bluetooth coupling in unilateral and bilateral conditions; and direct wireless streaming from mobile phone to hearing aids in unilateral condition. The Danish speech material was delivered through a receiver of a landline phone receiver for the acoustic and telecoil coupling conditions (or) for wireless Bluetooth streaming to the hearing aids via the phone clip (or) direct wireless streaming to the MFi hearing aids (combined with iPhone 5 mobile phone). The speech reception threshold (SRT) scores were obtained for each of the listening conditions.

Figure 2.1

Average Benefit (in dB) in Each Listening Condition, i.e., Telecoil Phone; Phone Clip = Wireless Streaming via Bluetooth; Mfi = Direct Streaming (Source: Nesgaard Pedersen, & Kirkwood, 2014)



As depicted in Figure 2.1, Nesgaard Pedersen and Kirkwood (2014) found that telecoil coupling, wireless streaming via Bluetooth coupling using phone clips, and direct wireless streaming had 6 dB, 9 dB, and 16 dB of average benefit. The performance with direct streaming was significantly better when compared to telecoil and Bluetooth streaming conditions. They stated that the poor performance via Bluetooth could be due to signal dropouts because of the deterioration in the quality of the signal caused by the additional link, i.e., phone clip, which is not needed in case of direct streaming.

Nesgaard Pedersen and Kirkwood (2014) concluded an average benefit of 8 to 16 dB in wireless technologies due to the robust wireless signal, which is not affected by the positioning constraint of a telephone receiver and can listen in both ears. Though this study evaluated speech recognition through iPhone mobile phones, only normal hearing individuals were included in the controlled condition. The present study aimed to evaluate the speech intelligibility and speech quality of individuals with hearing impairment, which could depict the real-life difficulties over the commonly used android mobile phone.

Tchorz and Schulte (2005) studied the use of Bluetooth technology for improved speech understanding over the mobile phone in 19 experienced hearing aid users. Two speech tests were conducted: The Monosyllabic German Rhyme Test and the Oldenburg Sentence Test. The stimulus was presented from a loudspeaker and picked up by a landline telephone receiver, which was at 0.5 meters from the loudspeaker. The signal was transmitted to the cell phone. The speech tests were conducted in four conditions. They were unaided, had own hearing instruments, with additional Nokia

Loop, set LPS-four (own hearing instruments set to telecoil position), and had additional FM transmitter (own hearing instruments set to FM). Compared to the hearing aids alone condition, the additional FM transmitter allowed a statistically significant improvement of speech understanding in noise. The hearing aid users were expected to rate the speech quality in different situations where they used the cell phone for two weeks. It was found that this subjective rating over the cell phone using the FM transmitter, support the objective data of speech test scores. They concluded that the additional FM transmitter leads to better speech understanding when using a mobile phone.

This study compared the speech understanding in two aided conditions of telecoil and FM, but they have used a landline phone to transmit the call. In today's world, the transmission is from one mobile to another mobile. The present study uses two mobile phones to check the speech identification in quiet and noisy conditions using speech identification scores (SIS) and signal to noise ratio (SNR 50).

Chapter 3

METHODS

The present study aimed to evaluate speech identification and quality of mobile phone conversation through hearing aids in microphone, telecoil, and direct Bluetooth coupling/input modes. The three objectives were to compare speech identification through mobile phone with three different coupling modes, i.e., microphone input, telecoil input, and direct Bluetooth coupling/input. The other three objectives of the study were to compare the speech quality through mobile phone with three different coupling inputs, i.e., microphone input, telecoil input, and direct Bluetooth coupling/input.

3.1 Participants

The participants included in the study were adults in the age range from 15 to 60 years with post-lingually acquired sensorineural hearing loss (SNHL). The native language of all the participants was Kannada, which is a Dravidian language spoken by people in the state of Karnataka. A total of 15 participants with moderate to moderately-severe (Clark, 1981) SNHL of flat audiogram configuration (Demeester et al., 2009) were included in the study. Purposive sampling was used for including the participants in the study.

All the participants underwent audiological evaluation followed by hearing aid evaluation through mobile phone, using audiological measures of Speech Identification Score (SIS), signal to noise ratio for 50% speech identification (SNR 50), and speech quality rating. For all these testing, either right or left ear was considered as the test ear if it was bilateral symmetrical SNHL. For individuals with asymmetrical hearing loss, the better ear meeting the above criteria was considered as the test ear. Two predetermined hearing aid models were selected for the data collection. Written informed consent was obtained for all the participants in a written form before the testing. AIISH ethical guidelines were followed.

3.1.1 Inclusion Criteria

Fifteen ears of 15 participants were considered in the study as the test ear (n=15) having SNHL with a pure-tone average (PTA) ranging between 41 to 70 dB HL of flat audiogram configuration. The flat audiogram configuration was defined as an audiogram where the difference between the mean of hearing thresholds at 250, 500 Hz, the mean of hearing thresholds at 1000, 2000 Hz and the mean hearing thresholds at 4000, 8000 Hz is less than 15 dB (Demeester et al., 2009). These test ears had 'A' type tympanogram and a Speech Identification Score of not less than 60%. The participants were naive hearing aid users.

3.1.2 Exclusion Criteria

Individuals with neurological/cognitive complaints were not included as participants. Individuals with Auditory Neuropathy Spectrum Disorder were also excluded from the study.

3.2 Test Environment

An acoustically treated single or double room test suite was used for the study to carry out all the audiological tests. The noise levels in the test rooms were within the permissible limits (ANSI S3.1-1999; R2013).

3.3 Equipment

A calibrated dual-channel diagnostic audiometer with an earphone, bone conductor, and loudspeaker, located at zero-degree azimuth and one-meter distance from the participant, was used for pure-tone audiometry and speech audiometry. A calibrated middle ear analyzer was used to check the middle ear status and to rule out any middle ear pathology.

One receiver in the canal (RIC) hearing aid and one behind the ear (BTE) hearing aid were considered test hearing aids for monoaural aided testing. Both the hearing aids had eight channels, and a fitting range from mild to severe degree of hearing loss. Features of the hearing aids include automatic programs in a quiet and noisy situation, whistle block, telecoil, frequency compression, and tinnitus management. Only the RIC hearing aid had a direct Bluetooth streaming feature for connectivity to iOS and Android smartphones for streaming phone calls and music. The RIC hearing aid was fitted with a power dome, and the BTE hearing aid was fitted with an ear tip. A personal computer, with the hearing aid programming interface, programming cables, and programming software, was used to program the test digital hearing aids.

A Lenovo Ideapad laptop with the Intel Core i7 core processor was connected to the audiometer's auxiliary input via an audio cable for presenting the recorded speech test material. The speech material was routed to the test ear of the participant through mobile phones. Two Android mobile phones were used, one for making outgoing and the other for receiving incoming calls. These mobile phones were kept the same for all the participants. The rating of these mobile phones and the hearing aid was not available. However, the mobile phone compatibility with the hearing aid was checked in the hearing aid's company website, suggesting an optimum Bluetooth version of 4.2 or higher for direct phone call streaming. The android mobile phone (Version 8.0) used in this study had a Bluetooth version of 4.2, and thus it is compatible with the hearing aid.

3.4 Test Stimuli/Tool

The following speech material was used.

- For SIS: Initially, the Phonemically Balanced (PB) Kannada word list (Yathiraj & Vijayalakshmi,2005) was used for obtaining Speech Identification Scores (SIS) in quiet.
  Recorded phonemically balanced (PB) word lists in Kannada for adults (Manjula et al., 2015) were used to find out the aided Speech Identification Scores (SIS) in quiet. This material had twenty-four lists, each with twenty-five phonemically balanced bisyllabic words. Out of which, the first five-word lists were used in this study, one for obtaining SIS in each aided condition.
- For SNR 50: Recorded sentence lists in Kannada for adults developed by Geetha et al. (2014) were used to measure SNR 50. The sentence material had twenty-five lists of Kannada sentences. Each list had ten sentences, and each of the sentences had four keywords. Of the twenty-five sentence lists, the first five lists were used in this study for obtaining SNR 50 in five aided conditions. The recorded sentences were mixed with a four-talker speech babble (Kumar et al.,2012) via the MATLAB code.

- For quality measurement: Five recorded Kannada passage segments were used for assessment of speech quality. Two passages titled ‘Bengaluru’ and ‘Sullina Phala’ were divided into five small segments, each with five sentences. They were used for quality assessment in five aided conditions.

  The speech quality rating test (Boike & Souza, 2000) was used (Appendix A) to rate the quality of aided speech based on four attributes of quality in terms of clarity, pleasantness, loudness, and overall impression. The rating test was conducted with translated and adapted instructions in the Kannada language (Appendix B). It used a rating scale from 0 to 10 points, where the lowest rating ‘0’ represents poor quality, the highest rating ‘10’ represents excellent quality, and the mid-point ‘5’ represents average quality.

3.5 Test Procedure

To confirm each participant's inclusion criteria, the air-conduction thresholds and bone-conduction thresholds at each octave frequencies were established from 250 Hz to 8000 Hz and 250 Hz to 4000 Hz, respectively, using a calibrated clinical audiometer. Modified Hughson and Westlake procedure (Carhart & Jerger, 1959) was used for the same. The immittance evaluation consisting of tympanometry and acoustic reflex threshold estimation was done to rule out middle ear pathology. The Speech Recognition Threshold (SRT) was found using the method given by Tilman and Olsen (1973). The Speech Identification Score (SIS) was obtained at 40 dB SL (re: SRT) using the Phonemically Balanced (PB) Kannada word list for adults (Yathiraj &

Vijayalakshmi,2005), where the participant had to repeat back the words that are presented. The number of words correctly repeated was noted as SIS. The uncomfortable level (UCL) for speech in the test ear was also obtained to include participants having no tolerance issues.

3.5.1 Hearing Aid Programming and Optimization

The two digital hearing aids, i.e., Model 1 (RIC hearing aid) and Model 2 (BTE hearing aid) were programmed using appropriate hearing aid software. The hearing aids were connected to the personal computer through the programming interface and programming cable. The NAL-NL1 fitting formula was used to program both the digital hearing aids according to the participant's pure-tone thresholds. A feedback test was initially done for both hearing aids.

Two programs were set in each of the hearing aids. The RIC hearing aid had microphone coupling as Program 1 (P1) and Bluetooth coupling as Program 2 (P2). The BTE hearing aid had microphone coupling as Program 1 (P1) and telecoil coupling as Program 2 (P2). For both the hearing aids, the whistle block was turned off, and directionality was set to omnidirectional mode. The other features, like frequency compression, tinnitus management, and volume control, were disabled in both the hearing aids. The program push button was enabled to change the program during the testing. The hearing aid optimization was done using the audibility of Ling's six sound test (Ling 1976, 1989; Agung et al., 2005). The six sounds [m], [ah], [oo], [ee], [sh], and [s] were orally presented in a randomized order and the audibility by the participant was ensured. All the tests were carried out in a monaural aided condition.

The five aided conditions, namely A1, A2, A3, A4, and A5, were included in the study, as shown in Table 3.1. In the first aided condition (A1), RIC hearing aid was coupled with a microphone input and tested, without a mobile phone. In the second (A2) and third (A3) aided conditions, the same RIC hearing aid was used with a microphone input and direct Bluetooth streaming, respectively. In the fourth (A4) and fifth (A5) aided conditions, the BTE hearing aid was used with a microphone input and telecoil coupling, respectively. Table 3.1 gives the five aided test conditions that were used in the present study.

Table 3.1

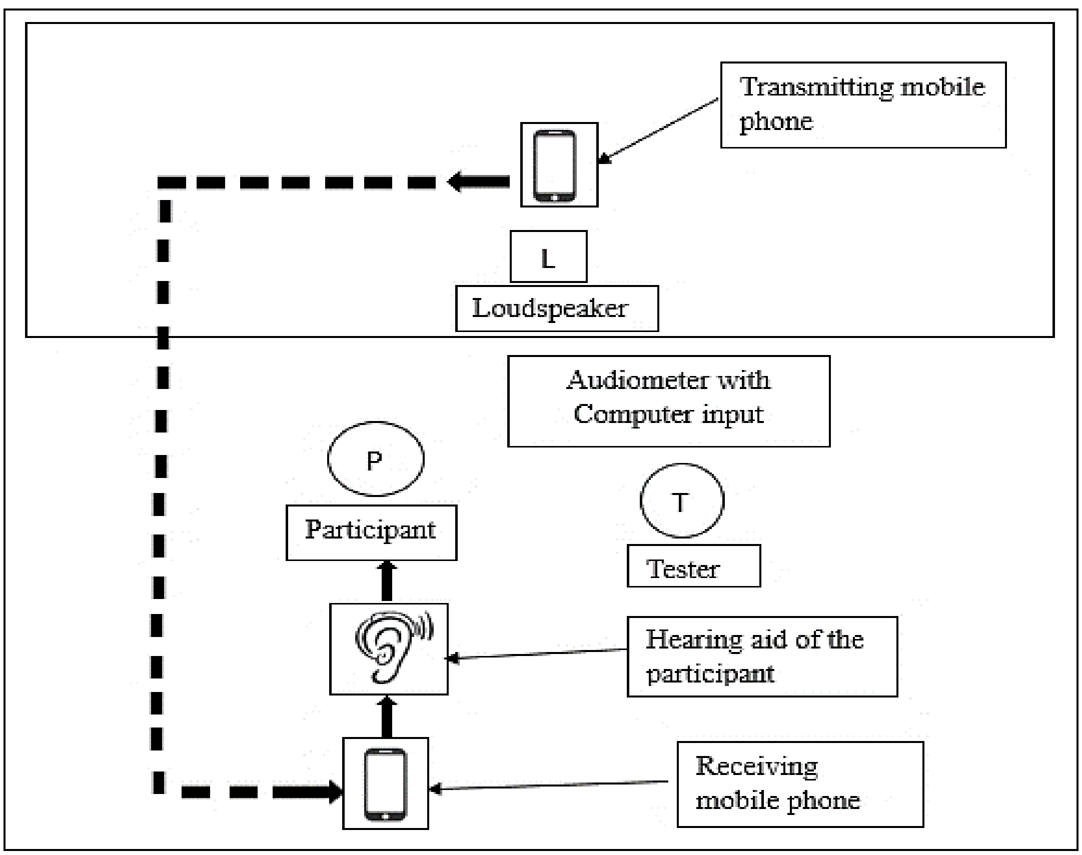
Details of the Five Aided Conditions

Aided condition	**Hearing aid**	**Hearing aid to mobile phone coupling mode**
Without a mobile phone		
A1	RIC hearing aid	Microphone
With a mobile phone		
A2	RIC hearing aid	Microphone
A3	RIC hearing aid	Direct Bluetooth streaming
A4	BTE hearing aid	Microphone
A5	BTE hearing aid	Telecoil

For the measurement of performance in the aided conditions, the participant was seated on an armchair inside the sound-treated double room. The loudspeaker of the audiometer was kept at zero-degree Azimuth and one-meter distance from the participant. Two mobile phones were used in the study. The transmitting mobile phone was connected to the receiving mobile phone by making a phone call. The transmitting mobile phone was kept at 8 inches from the loudspeaker to pick up the stimuli and transmit it to the participant's receiving mobile phone (Mueller et al., 1992), as depicted in Figure 3.1. The transmitting mobile phone and the receiving mobile phones were kept the same for all the participants.

Figure 3.1

Schematic Diagram of the Test Set-Up for Performance Evaluation Through Mobile Phone



Initially, the aided performance of the RIC hearing aid with microphone input, without a mobile phone, i.e., through the loudspeaker of the audiometer, was measured in the first aided condition (A1). The aided performance with the RIC hearing aid, coupled with a microphone input and direct Bluetooth steaming, using the mobile phone was then obtained in the second (A2) and third (A3) aided conditions. The aided performance of the BTE hearing aid, coupled with microphone and telecoil inputs, using the mobile phone was obtained in the fourth (A4) and fifth (A5) aided conditions. The performance was assessed using the audiological measures of speech identification score (SIS), signal to noise ratio required for 50% speech identification (SNR 50), and speech quality rating obtained in the five aided conditions.

3.5.2 Measurement of SIS

The recorded speech stimuli, i.e., PB word list in Kannada for adults (Manjula et al., 2015), were presented at 45 dB HL in a sound field via the loudspeaker of the calibrated audiometer. The participant was instructed to repeat the words heard. The number of correctly identified words was noted as SIS, in each of the five aided conditions, for each test ear for each participant. The five aided conditions included were A1, A2, A3, A4, and A5 where 'A1' denotes RIC hearing aid with a microphone input and tested via the loudspeaker of the audiometer, without a mobile phone; 'A2' denotes RIC hearing aid with microphone input; 'A3' denotes RIC hearing aid with direct Bluetooth streaming; 'A4' denotes BTE hearing aid with microphone input, and 'A5' denotes BTE hearing aid with telecoil.

3.5.3. Measurement of SNR 50

The recorded sentence lists (Geetha et al., 2014) were mixed with four talker speech babble (Kumar et al., 2012), at the required SNRs. The range of SNRs was from -

6 dB to +21 dB, in 3 dB step-size (i.e., 21, 18, 15, 12, 9, 6, 3, 0, -3, -6). The initial presentation level was 21dB, and the signal to noise ratio decreased from +21 dB SNR to -6 dB SNR in 3 dB steps from sentence 1 to 10 in each list. The participant was instructed that he/she will be presented with sentences in Kannada along with varying levels of multi-talker babble/noise in the background. The participant was asked to listen to the words in the sentence and ignore the speech babble. They were instructed to repeat the sentence presented verbatim. They were also told that the level of noise would be increased gradually, and they were required to try/guess and repeat the sentence heard. The total number of keywords identified correctly was calculated at each SNR. The SNR 50 was calculated using Spearman Karber equation given by Finney (1952), for each of the five aided conditions:

$$50\% = i + \tfrac{1}{2}(d) - (d)\ (\#\ \text{correct})/w$$

In the equation, *i* = the initial presentation level (dB S/B), *d* = the attenuation step size (decrement), *w* = the number of items per decrement, and # correct = total number of keywords repeated correctly. The SNR 50 was calculated in each of the five aided conditions for each test ear for each participant. The five aided included were A1, A2, A3, A4, and A5 where 'A1' denotes RIC hearing aid with a microphone input and tested via the loudspeaker of the audiometer, without a mobile phone; 'A2' denotes RIC hearing aid with microphone input; 'A3' denotes RIC hearing aid with direct Bluetooth streaming; 'A4' denotes BTE hearing aid with microphone input, and 'A5' denotes BTE hearing aid with telecoil.

3.5.4. Measurement of Speech Quality Rating

The adapted version of the speech quality rating test (Boike & Souza, 2000) in Kannada was used (Appendix C) to rate the perceived quality of aided speech based on four attributes of clarity, pleasantness, loudness, and overall impression. The quality was assessed for the recorded Kannada passages presented at 45 dB HL for each of the five aided conditions. Five different segments of the passages were used, one for each aided condition. The presentation order of the passages was randomized for the five aided conditions. The participant was instructed to listen to the recorded passage segment first, and rate the speech quality, in terms of the four attributes/ parameters of quality. It used a rating scale from 0 to 10, where the lowest rating of '0' represents poor quality; the highest rating of '10' represents excellent quality. The mid-point '5' represents the average quality. The ratings for different parameters of quality were:

1. For clarity: '0' - Not clear at all, '5' - Somewhat clear, and '10'- Very clear.
2. For pleasantness: '0' - Not at all pleasant, '5' - Somewhat pleasant, and '10'- Very pleasant.
3. For loudness: '0' - Very difficult, '5' - Somewhat difficult, and '10'- Very easy.
4. For overall impression: '0' - Very bad, '5' – Okay, and '10'- Very good.

Using the above quality rating measure, the quality of speech was assessed in each aided condition for each participant. The five aided conditions included were A1, A2, A3, A4 and A5 where 'A1' denotes RIC hearing aid with a microphone input and tested via the loudspeaker of the audiometer, without a mobile phone; 'A2' denotes RIC hearing aid with microphone input; 'A3' denotes RIC hearing aid with direct Bluetooth streaming; 'A4' denotes BTE hearing aid with microphone input, and 'A5' denotes BTE hearing aid with telecoil.

Finally, for test ear for each participant, the following audiological measures were obtained in each of the five aided conditions, as given in Table 3.2.

Table 3.2

Speech Identification Scores (SIS), Signal to Noise Ratio for 50% Speech Identification (SNR 50), and Speech Quality Rating in the Five Aided Conditions

Hearing aid	*Hearing aid coupling*	*SIS*	*SNR 50*	*Speech quality rating*			
				Clarity	*Pleasantness*	*Loudness*	*Overall Impression*
Without a mobile phone							
RIC hearing aid	A1-Microphone input						
Using a mobile phone							
RIC hearing aid	A2-Microphone coupling						
	A3-Bluetooth Coupling						
BTE hearing aid	A4-Microphone coupling						
	A5-Telecoil Coupling						

Note. RIC= Receiver in the canal; BTE=Behind the ear; A1 = RIC hearing aid with a microphone input and tested via loudspeaker, without a mobile phone; A2 = RIC hearing aid with microphone input; A3 = RIC hearing aid with direct Bluetooth streaming; A4 = BTE hearing aid was used with microphone input; A5 = BTE hearing aid was used with a telecoil.

The data obtained for each test ear of each participant were tabulated for statistical analyses.

3.5.5. Comparison across the Five Aided Conditions

Statistical Package for Social Sciences (SPSS version 22.0) was used for statistical analyses. To evaluate the objectives of the study, the tabulated data of the audiological measures obtained from SIS and SNR 50 for the five different aided conditions using the RIC and BTE hearing aids, for each participant, were compared. Apart from this, the tabulated data from measurement using speech quality rating based on four parameters of clarity, pleasantness, loudness, and overall impression for both the hearing aids, in five of the aided conditions for each participant, were also compared. Shapiro-Wilk test was carried out to check for normality of the data since the data did not follow a normal distribution ($p<0.05$), Friedman test was done to compare the SIS, SNR 50, and speech quality ratings in five aided conditions (A1, A2, A3, A4 & A5). Wilcoxon Signed Ranks test (when indicated0 was performed to check the pair-wise significance in the five aided conditions. This helped to compare the performance in the five aided conditions on SIS, SNR 50, and speech quality rating and to suggest which aided condition (coupling) gives the best speech identification.

Chapter 4

RESULTS

The aim of the present study was to evaluate the speech identification and speech quality through mobile phone, using different hearing aid coupling/input modes. The specific objectives of the study were:

1. To evaluate speech identification through mobile phone in hearing aid users with a microphone input.
2. To evaluate speech identification through mobile phone in hearing aid users with telecoil input.
3. To evaluate speech identification through mobile phone in hearing aid users with direct Bluetooth coupling.
4. To evaluate speech quality through mobile phone in hearing aid users with a microphone input.
5. To evaluate speech quality through mobile phone in hearing aid users with telecoil input.
6. To evaluate speech quality through mobile phone in hearing aid users with direct Bluetooth coupling.

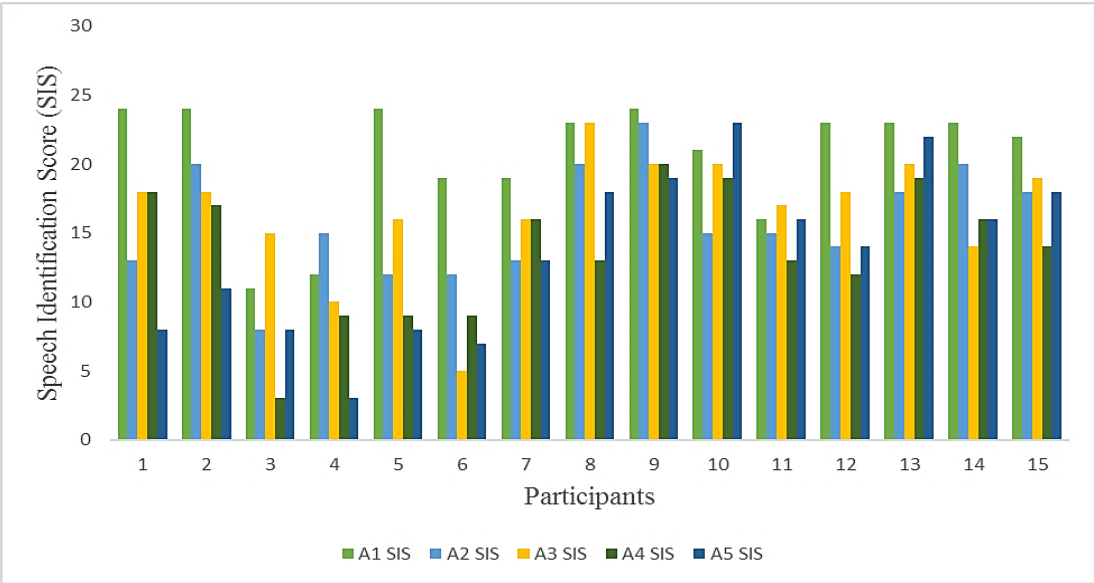
To achieve these objectives, data from 15 ears of 15 participants were tabulated for statistical analyses. The data included the speech identification score (SIS), signal to noise ratio for 50% speech recognition, i.e., SNR 50, and speech quality rating from each participant in five aided conditions.

In the first aided condition (A1), the RIC hearing aid was with a microphone input and tested via the loudspeaker of the audiometer, without the mobile phone. In the second (A2) and third (A3) aided conditions, the same RIC hearing aid was used with a microphone input and direct Bluetooth streaming, respectively. In the fourth (A4) and fifth (A5) aided conditions, the BTE hearing aid was used with a microphone input and telecoil coupling, respectively.

The data from 15 ears with moderate to moderately severe sensorineural hearing loss comprising of SIS, SNR 50, and speech quality rating (Clarity, Pleasantness, Loudness, and Overall impression) were tabulated and subjected for statistical analyses using Statistical Package for the Social Sciences (SPSS, version 22). Mann Whitney U test was carried out to check for comparison of data between males (n=8) and females (n=7), which revealed no significant difference ($p > 0.05$) between the data from male and female participants. Hence for all further analyses, the data from male and female participants were grouped together or combined. The SIS at 45 dB HL obtained from each of the 15 participants in A1, A2, A3, A4, and A5 conditions are shown in Figure 4.1.

Figure 4.1

Speech Identification Score (Max. SIS=25) Obtained from Each of the 15 Participants in A1, A2, A3, A4, and A5 Conditions



Note. A1 = RIC hearing aid with microphone input and tested via loudspeaker, without mobile phone; A2 = RIC hearing aid with microphone input; A3 = RIC hearing aid with direct Bluetooth streaming; A4 = BTE hearing aid with microphone input; A5 = BTE hearing aid with telecoil coupling.

Figure 4.1 shows that while comparing the SIS across all five aided conditions, the participants had the highest scores in A1, except for Participant nos. 3, 4, 10, and 11. It is to be noted that when comparing the SIS in aided conditions from A2 to A5, Participant Nos. 3, 5, 8, 11, 12, and 15 had better scores in A3 than in A2, A4, and A5. Participant nos. 1, 7, and 9 had similar scores in A3 and A4. Participant no.6 and 14 had the lowest scores in A3 when compared to A2, A4, and A5. The descriptive statistics of SIS, SNR 50 (Table 4.1), and speech quality attributes (Table 4.2) in five aided conditions are shown.

Table 4.1

Mean, Median, Standard Deviation (SD) and Range of SIS and SNR 50, in Five Aided Conditions (n=15)

Parameters	Aided test conditions	Mean	Median	SD	Range
SIS (Max. score =25)	A1	20.53	23.00	4.34	11 to 24
	A2	15.73	15.00	4.00	8 to 23
	A3	16.60	18.00	4.44	5 to 23
	A4	13.80	14.00	4.78	3 to 20
	A5	13.60	14.00	5.95	3 to 23
SNR 50 (in dB)	A1	9.85	10.50	3.34	5.25 to 15.00
	A2	13.25	15.00	3.46	7.50 to 18.75
	A3	11.65	11.25	3.44	7.50 to 18.00
	A4	13.55	13.50	3.50	7.50 to 18.75
	A5	13.95	14.25	3.77	6.75 to 20.25

Note. SIS = speech identification scores; SNR 50 = signal to noise ratio to achieve 50% speech identification; A1 = RIC hearing aid with microphone input and tested via loudspeaker, without mobile phone; A2 = RIC hearing aid with microphone input; A3 = RIC hearing aid with direct Bluetooth streaming; A4 = BTE hearing aid was used with microphone input; A5 = BTE hearing aid was used with telecoil coupling.

Table 4.1 shows the mean, median, standard deviation, and range of speech identification score (SIS) and signal to noise ratio for 50% speech recognition, i.e., SNR 50 of 15 participants in five aided conditions viz., A1, A2, A3, A4, and A5. In the first aided condition (A1), RIC hearing aid was coupled with a microphone input and tested via loudspeaker, without the mobile phone. In the second (A2) and third (A3) aided conditions, the same RIC hearing aid was used with a microphone input and direct Bluetooth streaming, respectively. In the fourth (A4) and fifth (A5) aided conditions, BTE hearing aid was used with a microphone input and telecoil coupling, respectively.

Table 4.2

Mean, Median, Standard Deviation (SD) and Range of Four Attributes of Speech Quality Rating (n=15), in Five Aided Conditions

Aided conditions	Speech quality Attributes (0-10)	Mean	Median	SD	Range
A1	Clarity	7.87	8.00	1.77	5 to 10
	Pleasantness	8.27	9.00	1.59	5 to 10
	Loudness	8.53	9.00	0.99	6 to 10
	Overall impression	8.73	9.00	1.49	5 to 10
A2	Clarity	7.87	9.00	1.99	5 to 10
	Pleasantness	7.93	9.00	1.67	5 to 10
	Loudness	8.27	9.00	2.25	4 to 10
	Overall impression	8.47	9.00	1.95	5 to 10
A3	Clarity	8.27	9.00	2.22	4 to 10
	Pleasantness	7.80	8.00	2.04	4 to 10
	Loudness	8.33	9.00	2.13	4 to 10
	Overall impression	8.27	9.00	1.90	5 to 10
A4	Clarity	7.00	8.00	1.81	5 to 10
	Pleasantness	6.80	8.00	1.89	4 to 9
	Loudness	6.53	6.00	1.93	4 to 10
	Overall impression	7.47	8.00	1.99	5 to 10
A5	Clarity	7.07	7.00	2.05	3 to 10
	Pleasantness	6.93	8.00	2.37	2 to 10
	Loudness	6.93	7.00	2.52	3 to 10
	Overall impression	7.33	8.00	2.29	4 to 10

*Note.*A1 = RIC hearing aid with microphone input and tested via loudspeaker, without mobile phone; A2 = RIC hearing aid with microphone input; A3 = RIC hearing aid with direct Bluetooth streaming; A4 = BTE hearing aid was used with microphone input; A5 = BTE hearing aid was used with telecoil coupling.

Table 4.2 shows the mean, median, standard deviation, and range of four attributes of speech quality rating of 15 participants in five aided conditions, namely A1, A2, A3, A4, and A5. In the first aided condition (A1), RIC hearing aid was coupled with a microphone input and tested via loudspeaker, without the mobile phone. In the second (A2) and third (A3) aided conditions, the same RIC hearing aid was used with a microphone input and direct Bluetooth streaming, respectively. In the fourth (A4) and fifth (A5) aided conditions, BTE hearing aid was used with a microphone input and telecoil coupling, respectively.

In order to see if the performance between the aided conditions differed significantly, non-parametric tests were administered as revealed by the Shapiro-Wilk test. The Shapiro-Wilk test of normality was carried out to check for normality of distribution of data on SIS, SNR 50, and speech quality rating. Except for the first aided condition of SIS, all the parameters followed non-normal distribution (i.e., $p < 0.05$). Hence, non-parametric tests were used for all the parameters or measures.

Table 4.3

Significant Differences Between Five Aided Conditions in SIS, SNR 50 and Speech Quality Attributes based on the Friedman Test

Parameters		**Chi Square**	**df**	**Significance level (*p*)**
Speech identification	SIS	28.36	4	0.00**
	SNR 50	17.04	4	0.00**
Speech Quality rating	Clarity	7.32	4	0.12
	Pleasantness	13.10	4	0.01**
	Loudness	15.14	4	0.00**
	Overall impression	11.19	4	0.03*

Note. * $p<0.05$. ** $p<0.01$

Friedman test was used to compare the parameters across all the five aided conditions (A1, A2, A3, A4, & A5). The result of the Friedman test is reported in Table 4.3. It was found that there was a significant difference across all the five aided conditions for SIS and SNR 50 (i.e., $p<0.05$), and in the attributes of quality, i.e., pleasantness, loudness, and overall impression in speech quality, except for clarity attribute ($p>0.05$).

The comparison of the parameters measured in five aided conditions is mentioned under the following headings:

4.1. Comparison of SIS in Five Aided Conditions

4.2. Comparison of SNR 50 in Five Aided Conditions

4.3. Comparison of Speech Quality Rating in Five Aided Conditions

4.1. Comparison of SIS in Five Aided Conditions

From Table 4.1, the first aided condition (A1) via microphone coupling, without the mobile phone, has the highest median SIS than the other four aided conditions (A2, A3, A4, & A5) with the mobile phone. Among the aided conditions with mobile phones, the third aided condition (A3), i.e., via direct Bluetooth streaming, is better followed by A2, A4, and A5. In order to know if these differences in SIS between the aided conditions were significant, the Friedman test was performed. Statistical analyses with the Friedman test revealed that the difference in SIS from A1 to A5 was statistically significant (p<0.01). To examine the aided conditions that differed significantly, the Wilcoxon Signed Ranks test was done with a pairwise comparison.

Table 4.4

Significant Differences in SIS Between the Aided Conditions based on the Wilcoxon Signed Ranks Test.

SIS between aided conditions	**Z**	**Asymp. Sig. (2-tailed) *p***
SIS in A2 - SIS in A1	-3.16	0.00**
SIS in A3 - SIS in A1	-2.74	0.01**
SIS in A4 - SIS in A1	-3.41	0.00**
SIS in A5 - SIS in A1	-3.17	0.00**
SIS in A3 - SIS in A2	-0.71	0.48
SIS in A4 - SIS in A2	-1.74	0.08
SIS in A5 - SIS in A2	-1.65	0.09
SIS in A4 - SIS in A3	-2.17	0.03*
SIS in A5 - SIS in A3	-2.14	0.03*
SIS in A5 - SIS in A4	-0.06	0.95

Note. * p<0.05. ** p<0.01.
A1 = RIC hearing aid with microphone input and tested via loudspeaker, without mobile phone; A2 = RIC hearing aid with microphone input; A3 = RIC hearing aid with direct Bluetooth streaming; A4 = BTE hearing aid was used with microphone input; A5 = BTE hearing aid was used with telecoil coupling.

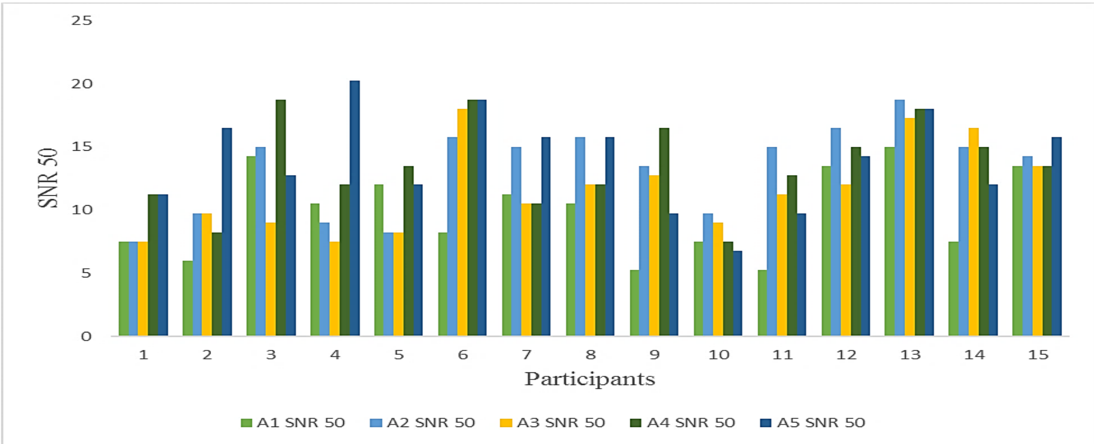
As depicted in Table 4.4, for the pairs A1-A2, A1-A3, A1-A4, and A1-A5, the SIS was significantly better in A1 ($p<0.01$) than in A2, A3, A4, and A5 conditions. Further, the SIS in A3 was significantly better ($p<0.05$) than in A4 and A5 conditions. From Table 4.1, it can be observed that among the five aided conditions (A1, A2, A3, A4, &A5), A1 exhibited the best median SIS followed by A3, A2, A4 and A5; the SIS in the A4 and A5 conditions were similar. Further, the first three aided conditions (A1, A2, & A3) exhibited better median SIS when compared to A4 and A5; i.e., A1>A3>A2>A4=A5.

4.2 Comparison of SNR 50 in Five Aided Conditions

In order to examine speech perception in the presence of noise with different coupling/input modes, the SNR 50 across the five aided conditions (A1 to A5) were compared. The SNR 50 obtained from each participant (n=15) in A1, A2, A3, A4, and A5 conditions are shown in Figure 4.2.

Figure 4.2

SNR 50 Obtained in A1, A2, A3, A4, and A5 from Each of the 15 Participants.



Note. A1 = RIC hearing aid with microphone input and tested via loudspeaker, without mobile phone; A2 = RIC hearing aid with microphone input; A3 = RIC hearing aid with direct Bluetooth streaming; A4 = BTE hearing aid with microphone input; A5 = BTE hearing aid with telecoil coupling.

Figure 4.2 depicts the SNR 50 of each of the 15 participants. From Table 4.1, the range of SNR 50 of each aided condition can be noted. Thereby the overall range of SNR 50 of all the five aided conditions is between 5.25 (best performance) and 20.25 (lowest performance). The individual data in Figure 4.2 shows that all the participants had the best performance in A1, except Participant nos. 4 and 5. Further, when comparing the aided conditions from A2 to A5, Participant nos. 3, 4, 12, 13, and 15 had better scores in A3 than A2, A4, and A5. Participant nos. 7, 8, and 15 had similar scores in A3 and A4. Participant no. 14 had the lowest scores in A3 when compared to A2, A4, and A5.

From Table 4.1, the first aided condition (A1) via microphone coupling, without the mobile phone, has the lowest median SNR 50 (median =10) than the other four aided conditions (A2, A3, A4, & A5) with the mobile phone. It must be noted that the lower the SNR 50 value, the better is the performance. That is, in order to state that the performance is better, the difference between the signal and the noise levels should be lower to achieve 50% correct word identification. It also shows an improvement in the third aided condition (A3) via direct Bluetooth streaming with a mobile phone than the other three aided mobile phone conditions (A2, A4, & A5).

Statistical analyses with the Friedman test revealed that the difference in SNR 50 from A1 to A5 are statistically significant ($p<0.05$). Based on the significance found in the Friedman test, pairwise comparison of SNR 50 was done using Wilcoxon Signed Ranks test. The same combination of ten comparisons that were used for SIS was used for SNR 50 also, in order to find out if there was any significant difference between the aided conditions.

Table 4.5

Significant Differences in SNR 50 for the Five Aided Conditions based on the Wilcoxon Signed Ranks Test.

SNR 50 of aided conditions	Z	Asymp. Sig. *p* (2-tailed)
SNR 50 in A1 – SNR 50 in A2	-2.65	0.01**
SNR 50 in A1 – SNR 50 in A3	-1.34	0.18
SNR 50 in A1 – SNR 50 in A4	-3.12	0.00**
SNR 50 in A1 – SNR 50 in A5	-3.02	0.00**
SNR 50 in A2 – SNR 50 in A3	-2.13	0.03*
SNR 50 in A2 – SNR 50 in A4	-0.47	0.64
SNR 50 in A2 – SNR 50 in A5	-0.38	0.70
SNR 50 in A3 – SNR 50 in A4	-2.01	0.04*
SNR 50 in A3 – SNR 50 in A5	-1.88	0.06
SNR 50 in A4 – SNR 50 in A5	-0.23	0.81

Note. * $p<0.05$. ** $p<0.01$.
A1 = RIC hearing aid with microphone input and tested via loudspeaker, without mobile phone; A2 = RIC hearing aid with microphone input; A3 = RIC hearing aid with direct Bluetooth streaming; A4 = BTE hearing aid with microphone input; A5 = BTE hearing aid with telecoil coupling.

From Table 4.5, for the pairs A1-A2, A1-A4 and A1-A5, the SNR 50 was significantly better ($p<0.05$) in A1 condition than A2, A4, and A5 conditions. In addition, SNR 50 was significantly better ($p<0.05$) in A3 than in A2 and A4. From Table 4.1, it is to be noted that among the five aided conditions (A1, A2, A3, A4, &A5), A1 exhibited the best median SNR 50 followed by A3, A4, A5, and A2.

4.3. Comparison of Speech Quality Rating in Five Aided Conditions

The four attributes of speech quality ratings, i.e., clarity, pleasantness, loudness, and overall impression, were compared in the five aided conditions. The comparison between the aided conditions was carried out between the same pairs of aided conditions (as that for SIS) on all the three attributes except for the clarity. The clarity attribute was not compared pairwise as the Friedman test did not reveal a significant difference between the aided conditions ($p>0.05$).

Table 4.6

Significant Differences between the Pairs of Aided Conditions on Three Attributes of Speech Quality Rating (Pleasantness, Loudness, & Overall Impression), based on the Wilcoxon Signed Ranks Test.

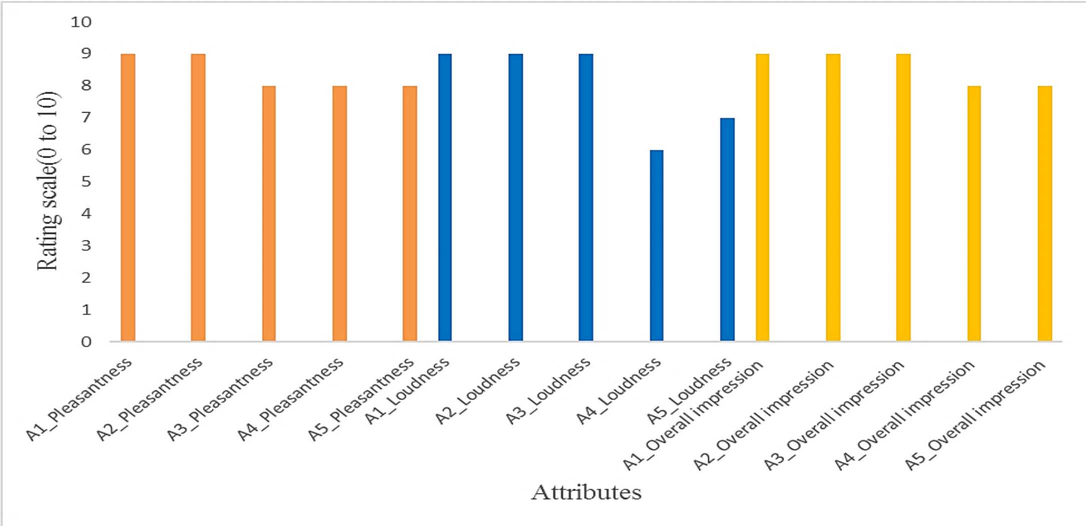
Quality Attributes	**Aided conditions**	**Z**	**Asymp. Sig. *p* (2-tailed)**
Pleasantness	A4 - A1	-2.83	0.01**
	A5 - A1	-2.04	0.04*
	A4 - A2	-2.49	0.01**
Loudness	A4 - A1	-2.78	0.01**
	A5 - A1	-2.05	0.04*
	A4 - A2	-2.36	0.02*
	A5 - A2	-2.39	0.02*
	A4 - A3	-2.79	0.01**
	A5 - A3	-2.54	0.01**
Overall impression	A4 - A1	-2.26	0.02*
	A5 - A1	-2.43	0.02*
	A4 - A2	-2.05	0.04*
	A5 - A2	-1.99	0.05*
	A4 - A3	-1.99	0.05*
	A5 - A3	-1.98	0.05*

Note. * p<0.05.** p<0.01.
A1 = RIC hearing aid with microphone input and tested via loudspeaker, without mobile phone; A2 = RIC hearing aid with microphone input; A3 = RIC hearing aid with direct Bluetooth streaming; A4 = BTE hearing aid with microphone input; A5 = BTE hearing aid with telecoil coupling.

There was a significant difference in the quality ratings among only the aided pairs mentioned in Table 4.6. The median values of the rating for the attributes in the aided conditions are shown in Figure 4.3

Figure 4.3

Median Rating (0-10) on Speech Quality Rating (Pleasantness -Orange, Loudness - Blue & Overall Impression - Yellow) in A1, A2, A3, A4, and A5.

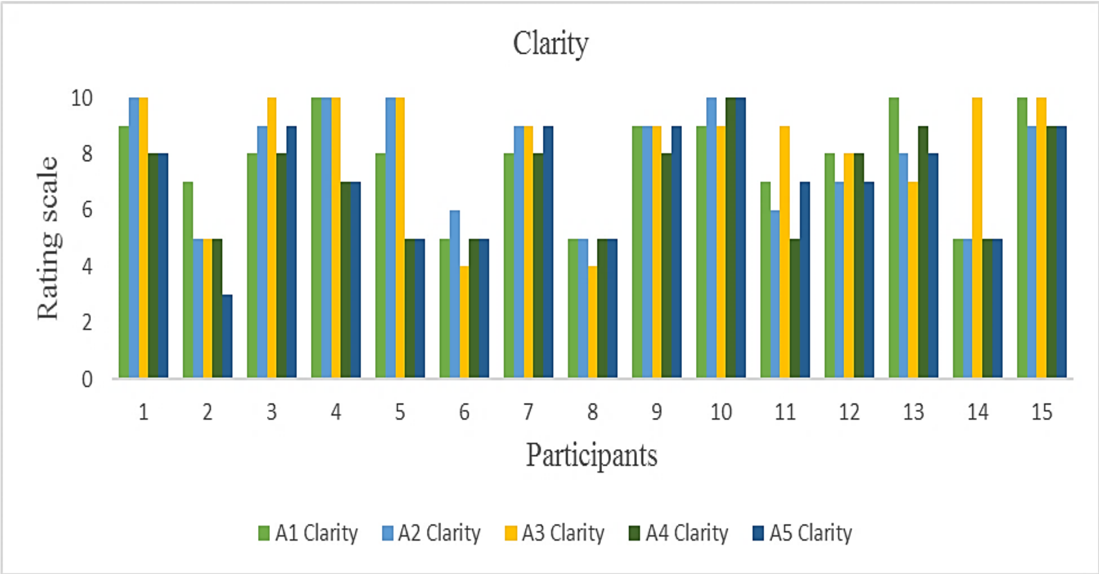


Note.A1 = RIC hearing aid with microphone input and tested via loudspeaker, without mobile phone; A2 = RIC hearing aid with microphone input; A3 = RIC hearing aid with direct Bluetooth streaming; A4 = BTE hearing aid with microphone input; A5 = BTE hearing aid with telecoil coupling.

From Figure 4.3, in terms of pleasantness, A1 had a better rating than A4 and A5. Also, a higher rating was given to A2 when compared to A4 in A2-A4. The same trend was seen for loudness and overall impression, where A1 had a higher rating than A4 and A5, and A2 had a higher rating than A4 and A5. It is to be noted that A3 had a better rating than A4 and A5 in loudness and overall impression attributes.

Figure 4.4

Speech Clarity Rating obtained from Each of the Participant in Five Aided Conditions

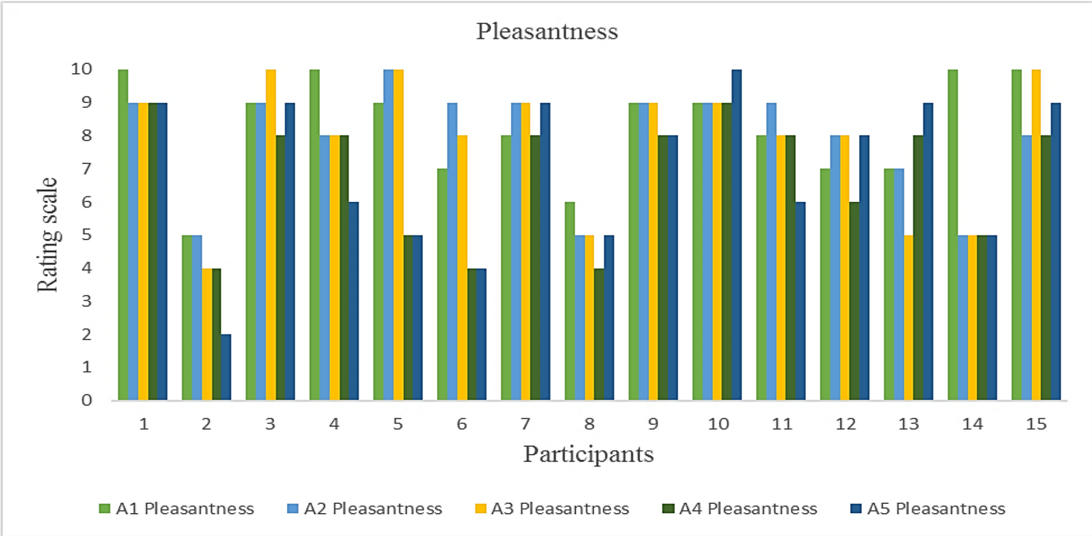


Note. A1 = RIC hearing aid with microphone input and tested via loudspeaker, without mobile phone; A2 = RIC hearing aid with microphone input; A3 = RIC hearing aid with direct Bluetooth streaming; A4 = BTE hearing aid with microphone input; A5 = BTE hearing aid with telecoil coupling.

Figure 4.4 shows the speech clarity rating by all the participants. The participant nos. 3, 11, and 14 had better scores in A3 than A1, A2, A4, and A5 conditions. The participant nos. 1, 2, 4, 5, 7, 9, and 15 had similar scores in A2 and A3. The participant no. 13 had the lowest scores in A3 when compared to A2, A4, and A5 aided conditions. From Table 4.2, the best rating for clarity was given for A2 and A3 (similar median value), followed by A1 and A4(similar median value), and then followed by A5.

Figure 4.5

Speech Pleasantness Rating obtained from Each of the Participant in Five Aided Conditions

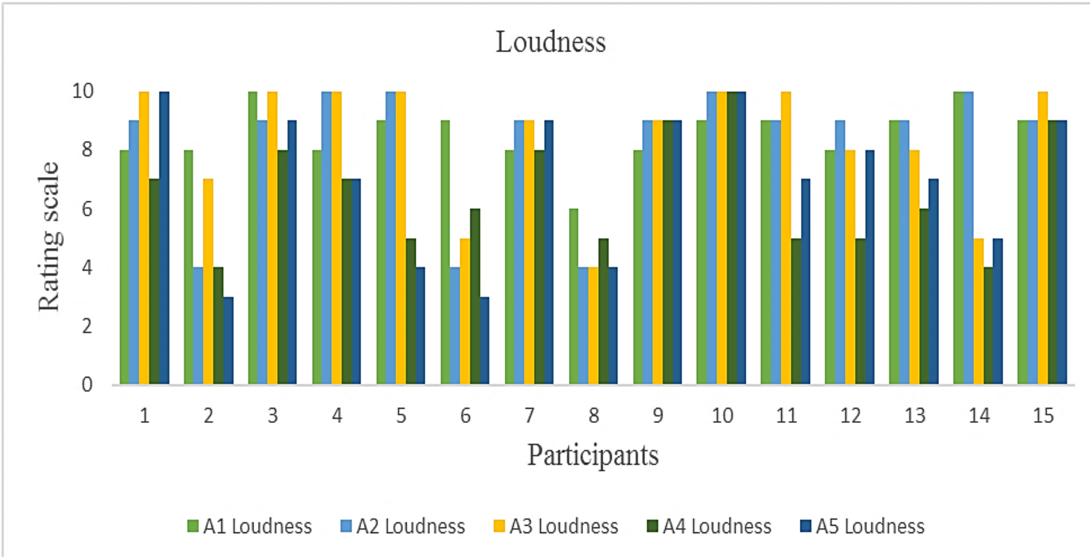


Note. A1 = RIC hearing aid with microphone input and tested via loudspeaker, without mobile phone; A2 = RIC hearing aid with microphone input; A3 = RIC hearing aid with direct Bluetooth streaming; A4 = BTE hearing aid with microphone input; A5 = BTE hearing aid with telecoil coupling.

Figure 4.5 shows the speech pleasantness rating by all the participants. Only participant no.3 had better scores in A3 than A2, A4, and A5. Most of the participants (participant nos. 1, 4, 5, 7, 8, 9, 10, 12, & 14) had similar scores in A2 and A3. The Participant no. 13 had the lowest scores in A3 when compared to A2, A4, and A5. From Table 4.2, the participants have given the best rating for pleasantness in A1 and A2 (similar median values), followed by A3, A4, and A5 (similar median values).

Figure 4.6

Speech Loudness Rating obtained from Each of the Participant in Five Aided Conditions

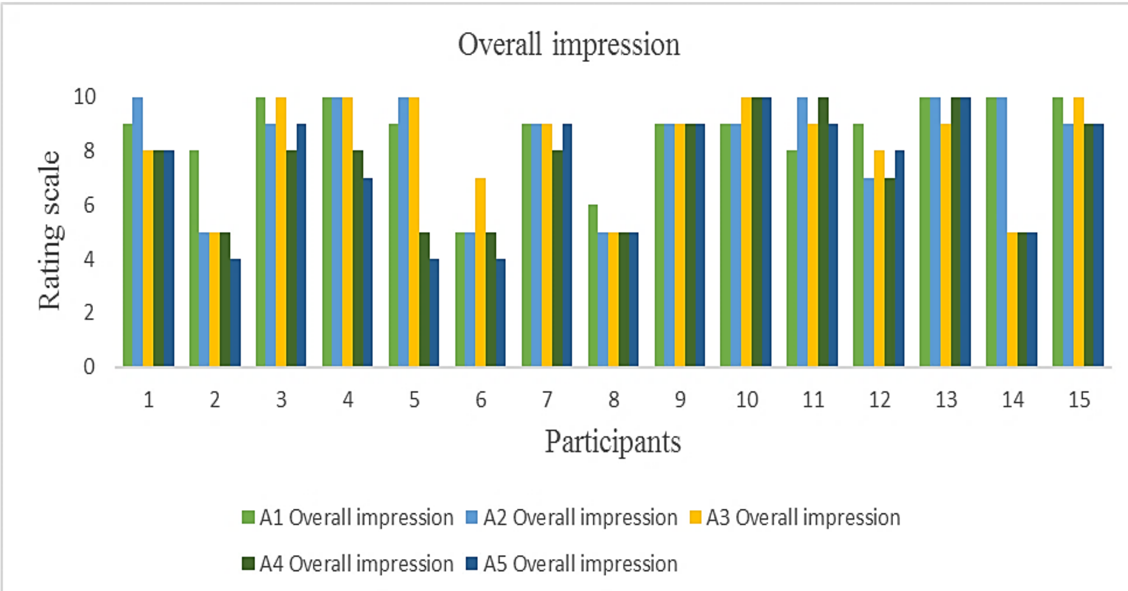


*Note.*A1 = RIC hearing aid with microphone input and tested via loudspeaker, without mobile phone; A2 = RIC hearing aid with microphone input; A3 = RIC hearing aid with direct Bluetooth streaming; A4 = BTE hearing aid with microphone input; A5 = BTE hearing aid with telecoil coupling.

Figure 4.6 shows the speech loudness rating by each of the 15 participants. Most of the participants (Participant nos. 4, 5, 7, 8, 9, &10) gave similar ratings for A2 and A3 conditions. Participant no. 11 and 15 had better scores in A3 than A2, A4, and A5. From Table 4.2, the participants have given the best rating for loudness in A1, A2, and A3 (similar median values), followed by A5 and A4.

Figure 4.7

Overall Impression Rating of Speech Quality obtained from Each of the Participants in Five Aided Conditions



Note. A1 = RIC hearing aid with microphone input and tested via loudspeaker, without mobile phone; A2 = RIC hearing aid with microphone input; A3 = RIC hearing aid with direct Bluetooth streaming; A4 = BTE hearing aid with microphone input; A5 = BTE hearing aid with telecoil coupling.

Figure 4.7 shows the speech quality rating in terms of overall impression by each of the 15 participants. Most of the participants (Participant nos. 2, 4, 5, 7, 8, and 9) had similar scores in A2 and A3 conditions. The Participant nos. 3, 6, and 15 had better scores in A3 than in A2, A4, and A5 conditions. From Figures 4.4 to 4.7, the speech quality ratings were better for A3, i.e., through direct Bluetooth streaming of RIC hearing aid than in other aided conditions. From Table 4.2, the participants have given the best rating for pleasantness in A1, A2, and A3 (similar median values), followed by A4 and A5 (similar median values).

To summarize the findings,

1. Speech identification in five aided conditions
    - SIS of A1 was better than A2, A3, A4, and A5.
    - Among the four aided conditions with mobile phones (A2, A3, A4, & A5), SIS was better in A3 condition, i.e., with direct Bluetooth condition.
    - Pair-wise comparisons of the aided conditions revealed significantly better SIS in A3 than in A4 and A5.
2. SNR 50 in five aided conditions
    - SNR 50 of A1 was better than A2, A3, A4, and A5.
    - Among the four aided conditions with mobile phones (A2, A3, A4 & A5), SNR 50 was better in A3 condition, i.e., with direct Bluetooth condition.
    - Pair-wise comparison of the aided conditions revealed significantly better SNR 50 in A3 than in A2 and A4.
3. Speech quality rating in five aided conditions
    - Speech quality rating was higher for A1
    - Speech quality rating significantly higher in A3 when compared to A2, A4, and A5.

Chapter 5

DISCUSSION

The present study aimed to evaluate the identification and quality of speech through mobile phones using hearing aids in microphone, telecoil, and direct Bluetooth coupling/input modes. The objectives of the study were achieved by obtaining speech identification scores (SIS), signal-to-noise ratio, i.e., SNR 50, and speech quality rating in the five aided conditions. In the first aided condition (A1), the RIC hearing aid with microphone input was tested without a mobile phone. In the second (A2) and third (A3) aided conditions, the same RIC hearing aid was used for listening through mobile phone, with microphone coupling and direct Bluetooth streaming, respectively. In the fourth (A4) and fifth (A5) aided conditions, a BTE hearing aid was used for listening through mobile phone, with a microphone and telecoil coupling, respectively. The results of the present study are discussed under the following headings:

5.1. Comparison of SIS in Five Aided Conditions

5.2. Comparison of SNR 50 in Five Aided Conditions

5.3. Comparison of Speech Quality Rating in Five Aided Conditions

5.1 Comparison of SIS in Five Aided Conditions

In the present study, SIS was better in majority of the participants in the first aided condition (A1), i.e., via microphone input to the hearing aid without a mobile phone compared to the other four aided conditions with mobile phone (A2, A3, A4, & A5). The scores were decreased when the SIS was obtained while listening through the mobile phone. This could be because the stimuli were presented through loudspeakers without a mobile phone, where speech identification was not affected. When comparing the aided conditions from A2 to A5, most of the participants, except two, showed an improvement in the third aided condition (A3) via direct Bluetooth streaming with a mobile phone than the other three aided conditions (A2, A4, & A5) with a mobile phone. The pair-wise comparison also revealed better scores in A3 when compared to A4 (BTE with microphone input) and A5 (BTE with telecoil). The participants who did not show any improvement in A3 had the same SIS in A3 and A4. Thus, a Bluetooth option showed improvement in speech identification in quiet in some participants, which confirms the study's hypothesis. In a few participants, though the SIS did not show any improvement, there was no decrease in scores with Bluetooth coupling.

The results of the present study agreed with the previous studies. Tchorz and Schulte (2005) reported better speech understanding through hearing aid with additional Bluetooth FM transmitter than hearing aid with microphone coupling conditions when tested using the Monosyllabic German Rhyme Test and Oldenburg Sentence Test. Nesgaard Pedersen and Kirkwood (2014) also reported similar results. Participants using direct Bluetooth streaming obtained lower speech reception threshold (SRT) compared to acoustic and telecoil coupling when measured using Danish monosyllabic word material. Au et al. (2019) also found that children showed better performance on CNC words in wireless streaming than the telecoil coupling to the hearing aid.

The results of the present study were in concurrence with the results reported by Kim et al. (2014) with better word and sentence recognition scores through Bluetooth-implemented hearing aids (wireless mode) when compared to microphone coupling (conventional mode) for listening through cell phone, in quiet. Similar findings were reported by Picou and Ricketts (2011, 2013), i.e., better performance on Connected Speech Test (CST) for the wireless streaming condition compared to acoustic telephone coupling. The additional benefit obtained in wireless Bluetooth streaming on speech identification in quiet was reported across different types of speech material like word recognition (Nesgaard Pedersen & Kirkwood, 2014; Au et al., 2019) and sentence recognition (Tchorz &Schulte, 2005; Kim et al., 2014; Picou & Ricketts, 2011, 2013), in both children and adults. In the present study, phonemically balanced bisyllabic words were used to test SIS. The Bluetooth benefit may be due to faster sound processing and better sound quality in hearing aids with wireless streaming (Mroz, 2019).

5.2. Comparison of SNR 50 in Five Aided Conditions

When SNR 50 was compared across the five aided conditions, the best median score was obtained in A1 (without mobile phone via loudspeaker), followed by A3 (RIC with direct Bluetooth input). The scores were decreased with the use of a mobile phone. This could be because the stimuli were presented through loudspeakers without a mobile phone, where speech identification was not affected in the presence of noise. Inferential statistics revealed that A3 (RIC with direct Bluetooth input) was significantly better than A2 (RIC with microphone input) and A4 (BTE with microphone input). However, there was no significant difference between A2 and A4 and A2 and A5. In addition, the difference between A3 and A5 (BTE with telecoil) was also not significant and thereby rejects the hypothesis of the study.

Hence, a direct Bluetooth streaming option was required for speech identification through mobile phone in the presence of noise. Although the A3 (RIC with direct Bluetooth input) resulted in a better median SNR 50 compared to the A5 (BTE with telecoil), the difference was not statistically significant. However, the individual data suggests better SNR 50 in A3 when compared to A5.

The results of the present study agreed with the results reported by Kim et al. (2014), which revealed better performance in wireless mode, i.e., when Bluetooth feature was implemented into the hearing aid and used with a cellular phone. The study was done on a group of adults with moderate symmetrical sensorineural hearing loss whose average thresholds ranged from 40 to 55 dB HL. The speech recognition performance was measured using word and sentence recognition scores in the Korean language. Thus, the study concluded that Bluetooth implemented hearing aid to have an essential role in speech recognition performance in noise individuals with moderate sensorineural hearing loss.

The present study also supports the findings reported by Au et al. (2019), which showed better improvement in speech perception in noise over the telephone using wireless streaming with hearing aids. The study was conducted in children with symmetrical mild to moderate sensorineural hearing loss. Three manual programs were programmed into the hearing aid, telecoil with and without microphone attenuation, and Duo phone program.

The previous studies examining the benefit of wireless technology was conducted in individuals using telephone receiver and better threshold in low frequencies. Whereas, the present study was done in adults with post-lingually acquired moderate to moderately severe sensorineural hearing loss. The procedure used was also different where two mobile phones were connected instead of using a telephone receiver. Despite the differences, the results of the present study agreed with the findings in literature recommending wireless technology in hearing aids for mobile phone use.

Though the direct Bluetooth coupling resulted in better performance with mobile phones in the present study, there was no significant difference between direct Bluetooth coupling (A3) of RIC hearing aid and telecoil coupling (A5) of BTE hearing aid. Ledda et al. (2019) studied the difference in speech recognition for sentences and monosyllabic words between a manufacturer's default and programmed telecoil program. They found a significant improvement in overall speech recognition for the programmed telecoil performance compared with default telecoil performance. This could be the reason why, though better SNR 50 was obtained in the present study with direct Bluetooth coupling (A3), there was no significant difference between direct Bluetooth coupling (A3) and telecoil coupling (A5). This means that when a properly programmed/optimized telecoils are used, it could improve the signal-to-noise ratio (SNR) and thereby improve speech recognition in the presence of noise when using a mobile phone.

5.3. Comparison of Speech Quality Rating in Five Aided Conditions

In the present study, the four attributes of speech quality ratings, i.e., clarity, pleasantness, loudness, and overall impression, were compared in the five aided conditions. The pair-wise comparison between the aided conditions was carried on all the three attributes except for the clarity. The clarity attribute was not compared pairwise as the Friedman test did not reveal a significant difference for the five aided conditions ($p>0.05$). Though there was no significant difference for clarity, the individual data suggests that most of the participants have given similar higher ratings for A2 (RIC with microphone input) and A3 (RIC with direct Bluetooth input). In terms of pleasantness, loudness, and overall impression, the highest rating was given for A1 (without mobile phone via loudspeaker). When comparing the aided conditions using a mobile phone (A2 to A5), a higher rating was given for A2 (RIC with microphone input) for pleasantness and a higher rating for A3 (RIC with direct Bluetooth input) in terms of loudness and overall impression. Similar ratings were given for A1 and A2 for pleasantness, and similar ratings were given for A1, A2, and A3 for loudness and overall impression.

The subjective rating scale of loudness and overall impression agreed with an objective assessment of SIS and SNR 50, where higher scores and ratings were obtained for A3, i.e., for direct Bluetooth streaming, which again confirms the hypothesis of the study. Though higher ratings were not given for clarity and pleasantness, the ratings of A3 did not drop down but had similar ratings like that for A1, A2, and A3. Thus, it can be inferred that the participants have given higher ratings for RIC hearing aid using a mobile phone when compared to the BTE hearing aid. Further, the additional direct Bluetooth coupling in RIC hearing aid helps to improve speech recognition when listening through mobile phone.

Chapter 6

SUMMARY AND CONCLUSIONS

The study aimed to evaluate the identification and quality of speech in a group of adults through mobile phone using hearing aids in microphone, telecoil, and direct Bluetooth coupling/ input modes. In order to achieve the aim, the following objectives were formulated:

1. To evaluate speech identification through mobile phone in hearing aid users with a microphone input.
2. To evaluate speech identification through mobile phone in hearing aid users with telecoil input.
3. To evaluate speech identification through mobile phone in hearing aid users with direct Bluetooth coupling.
4. To evaluate speech quality through mobile phone in hearing aid users with a microphone input.
5. To evaluate speech quality through mobile phone in hearing aid users with telecoil input.
6. To evaluate speech quality through mobile phone in hearing aid users with direct Bluetooth coupling.

A total of 15 adults with moderate to moderately severe sensorineural hearing loss who were naïve hearing aid users were included in the study using purposive sampling. All 15 participants had a flat configuration of an audiogram and a Speech Identification Score of at least 60%. The two digital hearing aids, i.e., RIC hearing aid and BTE hearing aid, were programmed for NAL-NL1 prescriptive formula according to the pure-tone thresholds of the participant. Two programs were set in each of the hearing aids. The RIC hearing aid had microphone coupling as program 1 (P1) and Bluetooth coupling as program 2 (P2). The BTE hearing aid had microphone coupling as program 1 (P1) and telecoil coupling as program 2 (P2). The Speech identification score (SIS), Signal to noise ratio for 50% speech recognition, i.e., SNR 50, and speech quality rating in five aided conditions were obtained. In the first aided condition (A1), RIC hearing aid with a microphone input and tested without mobile phone via the loudspeaker of the audiometer. In the second (A2) and third (A3) aided conditions, the same RIC hearing aid was used with microphone coupling and direct Bluetooth coupling, respectively. In the fourth (A4) and fifth (A5) aided conditions, BTE hearing aid was used with a microphone and telecoil coupling, respectively.

The data obtained were subjected to statistical analyses using Statistical Package for the Social Sciences (SPSS, version 22). Descriptive and inferential statistics (based on the test of normality) were used to compare the scores between the five different aided conditions. The following were the results of the present study:

1. Speech identification in five aided conditions
    - The SIS of A1 was significantly better than A2, A3, A4, and A5, i.e., A1>A2, A3, A4, & A5. The performance with a microphone input to the hearing aid was better than the telecoil or Bluetooth coupling.
    - Among the four aided conditions using a mobile phone (A2, A3, A4, & A5), the SIS was better in A3 condition, i.e., Bluetooth coupling.

- Pair-wise comparisons of the aided conditions revealed significantly better SIS in A3 when compared to A4 and A5, i.e., A3>A4; A3>A5.
- There was an additional benefit of direct Bluetooth streaming on SIS using a mobile phone, indicating significantly better performance in A3 when compared to A4 and A5.

2. SNR-50 in five aided conditions
    - The SNR-50 of A1 was significantly better than A2, A3, A4, and A5, i.e., A1>A2, A3, A4, & A5. The performance with a microphone input to the hearing aid was better than the telecoil or Bluetooth coupling.
    - Among the four aided conditions using a mobile phone (A2, A3, A4, & A5), SNR-50 was better in A3 condition, i.e., Bluetooth coupling.
    - Pair-wise comparison of the aided conditions revealed significantly better SNR-50 in A3 than in A2 and A4, i.e., A3>A2; A3>A4.
    - The additional Bluetooth streaming benefit was also observed on SNR-50 using a mobile phone, indicating that it was significantly better in A3 than A2 and A4. However, there was no significant difference between A3 and A5 for achieving 50% of speech recognition in the presence of noise.

3. Speech quality rating in five aided conditions
    - The speech quality rating was higher for A1. The performance with a microphone input to the hearing aid was better than the telecoil or Bluetooth coupling.

- Speech quality rating significantly higher in A3 when compared to A4 and A5, i.e., Bluetooth coupling.
- The subjective evaluation of speech quality rating follows a similar trend where higher ratings were given for Bluetooth coupling. The ratings were higher for RIC hearing aid (A1, A2 & A3) compared to BTE (A4 & A5) hearing aid.

From the results of the study, it can be stated that the addition of the Bluetooth option in hearing aids provides better speech identification while using mobile phones. This may be due to faster sound processing and better sound quality in Bluetooth coupling in hearing aids. Further, the study also suggests that there was no significant difference between direct Bluetooth coupling (A3) of RIC hearing aid and telecoil coupling (A5) of BTE hearing aid on speech identification in the presence of noise, i.e., SNR 50. However, it needs to be noted that a properly programmed/optimized telecoils could improve the signal-to-noise ratio (SNR) and improve speech recognition in the presence of noise using a mobile phone.

6.1 Clinical Implications of the Study

From the findings of the study, the following can be inferred-

- Individuals with moderate to moderately severe sensorineural hearing loss benefit from direct Bluetooth coupling when attending phone calls using a mobile phone. In the presence of noise, they could benefit from direct Bluetooth streaming as well as from programmed telecoil coupling. Hence, they need to be recommended and counseled about the different coupling inputs and their effect on speech identification and quality while listening through mobile phone.

- Thus, clinicians should program the different coupling inputs of the hearing aid and counsel the hearing aid user in terms of the extent of benefit from the type of coupling for using a mobile phone.

6.2 Future Directions of the Study

1. Studies need to be carried out involving more participants in older children and different hearing loss configurations to study the extent of benefit from wireless coupling technology for mobile phone usage.
2. In the present study, the speech quality rating was administered only in a quiet situation. Further research is required to assess the speech comprehension in noise using mobile phone with different coupling modes to the hearing aid.
3. The wireless benefit with a mobile phone and wireless streaming to the contralateral ear needs to be investigated.

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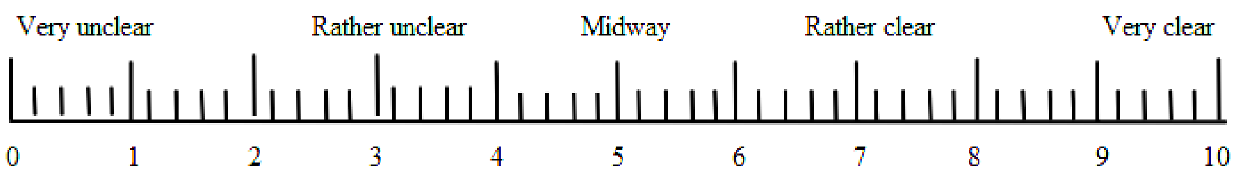
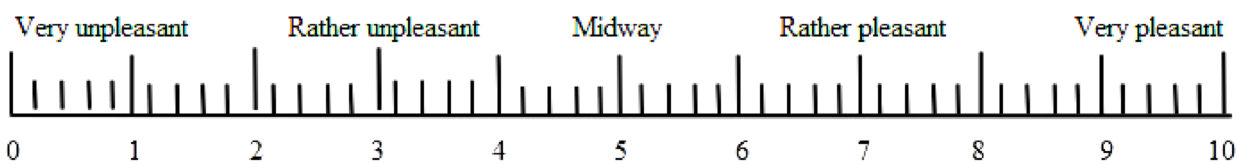
APPENDIX A: Speech Quality Rating Scale (Boike & Souza, 2000)

<u>*Instruction for rating*</u>: Circle the number that in your judgment, best correlates with the corresponding different attributes of speech quality:

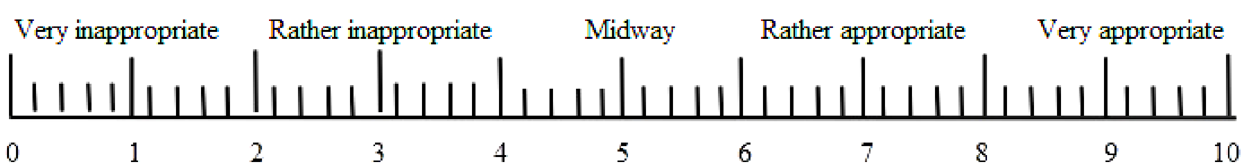
a. *Speech clarity:* How clear, distinct, and sharp is the sound? The opposite of clarity is blurred, fuzzy, and obscure.



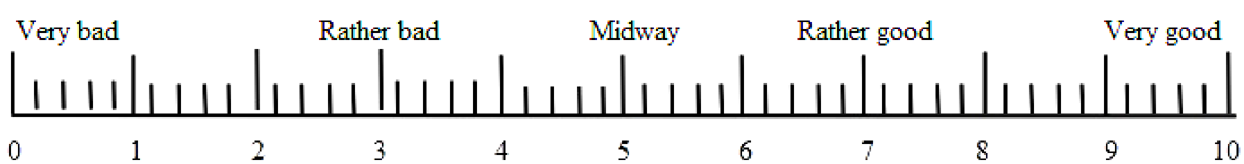
b. *Sound pleasantness:* How agreeable, comfortable, and bright is the sound? The opposite of pleasant is disagreeable, uncomfortable, and dark.



c. *Loudness appropriateness*: How adequate, comfortable, and tolerable is the loudness of the sound? The opposite of the loudness appropriateness is inadequate, uncomfortable, and intolerable.



d. *Overall impression:* Considering everything you have heard, what do you think about the sound?



APPENDIX B: Translated and Adapted Version of the Speech Quality Rating Scale in Kannada.

Speech Quality Rating Scale

ಮಾತಿನ ಗುಣಮಟ್ಟದ ಅಳತೆ

__ಸೂಚನೆ:__ ಮಾತಿನ ವಿಶಿಷ್ಟತೆಯನ್ನು ಹೋಲುವ ಸಂಖ್ಯೆಯನ್ನು ಗುರುತು ಮಾಡಿ.

1. __ಮಾತಿನ ಸ್ಪಷ್ಟತೆ:__ ಶಬ್ದವು ಎಷ್ಟು ಸ್ಪಷ್ಟವಾಗಿದೆ, ನಿಖರವಾಗಿದೆ, ಹಾಗೂ ಸ್ಫುಟವಾಗಿದೆ? ಸ್ಪಷ್ಟತೆಯ ವಿರುದ್ಧ ಪದ ಮಸುಕಾಗಿ, ಮಂಕಾಗಿ, ಅಸ್ಪಷ್ಟವಾಗಿ.

2. __ಶಬ್ದದ ಹಿತ:__ ಶಬ್ದವು ಎಷ್ಟು ಸರಿಯಾಗಿದೆ/ಸಮ್ಮತವಾಗಿದೆ? ಹಿತ ಶಬ್ದದ ವಿರುದ್ಧ ಪದ ಹಿತವಲ್ಲದ, ಅಸಮ್ಮತ, ಕೇಳಲಾಗದ.

3. __ಶಬ್ದದ ಮಟ್ಟ:__ ಶಬ್ದವು ಎಷ್ಟು ಸರಿಯಾಗಿದೆ/ಹಿತವಾಗಿದೆ/ಸಹಿಸಿಕೊಳ್ಳಬಹುದಾಗಿದೆ? ಈ ಪದದ ವಿರುದ್ಧ ಪದ ಶಬ್ದದ ಮಟ್ಟ ಸಾಕಷ್ಟು ಇಲ್ಲ, ಅಹಿತಕರವಾಗಿದೆ, ಸಹಿಸಿಕೊಳ್ಳಲಾಗದು.

4. __ಒಟ್ಟಾರೆ ಅಭಿಪ್ರಾಯ:__ ಕೇಳಿದ ಶಬ್ದಗಳನ್ನು ಪರಿಗಣಿಸಿ, ಶಬ್ದದ ಬಗ್ಗೆ ನಿಮ್ಮ ಆಲೋಚನೆ ಏನು?