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Comparison of speech intelligibility over the telephone using a hearing aid micorphone and telecoil

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Comparison of Speech Intelligibility Over the Telephone Using a Hearing Aid

Microphone and Telecoil

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Dedication

I would like to dedicate this paper to my wife, family, and friends for their love and patience as I complete my degree. You all mean so much to me. Thank you and Love you!!

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Abstract

The purpose of the current study is to determine if the smaller, modern hearing aid has affected the speech intelligibility over the telephone using a telecoil and hearing aid microphone. Six hearing impaired listeners were situated in a quiet office and were asked to repeat aloud Connected Speech Sentences (CST) they heard through the telephone while wearing their hearing aid in telecoil only mode, microphone only mode, and without their hearing aid. The CST sentences were presented in three different signal-to-noise ratios (Quiet, +10dB, & +5dB) with the recorded speech babble of the CST test. It was discovered that the listeners performed, on average, better in all listening conditions without their hearing aid in. However, no statistical significance was seen between any of the test conditions. Implications of this will be discussed.

Introduction

Telephone communication is an important part of everyday life. This critical mode of communicating can be very difficult for those with a hearing loss. There are several different reasons for this difficulty. The most obvious is that the individual with a hearing loss cannot detect the phone signal at the appropriate level to be able to understand speech. Another reason is that the telephone does not allow for the use of visual cues. All of the cues are auditory and this can cause difficulties for those with a hearing impairment. Yet another reason is that the telephone transmits a narrow frequency bandwidth (300 Hz – 3400 Hz), which limits high frequency information that is important to speech intelligibility (Kepler, Terry, & Sweetman, 1992). Previous research on this topic revealed that 69% of the respondents to 43- item questionnaire indicated that their hearing loss discourages them from using the telephone. When the authors questioned the respondents about hearing aid use, 94% of the respondents indicated using a hearing aid, while only 55% indicated that they used their hearing aid coupled to the telephone. Their reasoning for this is that coupling their hearing aid to the telephone is problematic. For some 30 respondents it was so problematic that they stopped wearing their hearing aid while talking on the telephone due to feedback issues and electromagnetic interference while in telecoil mode (Kepler, Terry, & Sweetman, 1992).

There are several different ways to couple a hearing aid to a standard telephone receiver. The two most common coupling strategies are acoustic and electromagnetic or induction coupling. Acoustic coupling involves the routing of the telephone signal directly from the telephone receiver to the hearing aid microphone. This form of coupling, in the past, has resulted in various difficulties with the biggest difficulty being in the form of acoustic feedback. However, with advances in hearing aid technology and feedback cancellation, this difficulty is usually only a problem when the hearing impairment of the individual requires a high amount of gain in the hearing aid. Another problem with acoustic coupling is that the hearing aid microphone also picks up and amplifies any background noise that is present in the room at the time of the telephone conversation making it more difficult for the individual to hear what is being said over the telephone. Electromagnetic or induction coupling involves the use of an induction coil (telecoil) to pick up and convert the electromagnetic energy leaked by the telephone receiver to electrical energy so that it can be amplified and manipulated by the hearing aid. One problem of this form of coupling is that electromagnetic interference from various sources such as electronic devices and fluorescent lighting can affect the signal received by the hearing aid. Another problem with this form of coupling is that the electromagnetic output of the telephone receiver is not standardized. This means that not all telephone receivers will work well with induction coils.

Several studies have looked at these two forms of coupling a hearing aid to the telephone in terms of speech recognition, frequency response, output, and gain (Lowe & Goldstein, 1982; Plyler et. al, 1998; Rodriguez et. al, 1993; Sung & Hodgson, 1971; Tannahill, 1983; & Terry et. al, 1992). Some researchers reported that induction coils tended to give better low frequency output and that acoustic input tended to provide better speech recognition scores in quiet (Tannahill, 1983; Holmes & Frank, 1984). Other researchers found that electromagnetic coupling results in reduced output levels and narrower frequency responses than acoustic coupling (Plyler et. al, 1998). Even though there were advantages and disadvantages to each coupling method these researchers recommended that each individuals communication needs be taken into consideration when fitting and adjusting hearing aids with a telecoil option.

The purpose of the current study is to determine the effect, if any, the small modern design of hearing aids has on speech intelligibility over the telphone through a induction coil and hearing aid microphone. Also the most current research on this topic was conducted in the late 1990's and there has been a tremendous amount of changes in hearing aid technology since that time. The current study is also investigating whether this progression of technology has led to better speech understanding on the telephone.

Literature Review

Telephone Use

The telephone is an important part of everyday life. It is relied upon for communication at work, and for social interactions and arrangements. Therefore, everyday living can be affected by not being able to use the telephone. Without access to telecommunication, social life may be reduced because friends and family cannot be easily contacted. Work opportunities may be limited and job role changes may be required. Telephone use is important because it empowers individuals to conduct their own business and personal activities. The ability to use the telephone promotes independent living, employment, socialization, and self-esteem. Verbal communication is also more efficient than written communication. A disadvantage of some telephone technology is that emotional intent may not be conveyed or perceived (Terry, Bright, Durian, Kepler, Sweetman, & Grim, 1992).

One of the most common complaints among hearing impaired individuals is the difficulty associated with using the telephone. There are three major contributors to telephone communication difficulties for the hearing impaired population: 1) the limited frequency range (300-3400 Hz), which reduces high frequency information that is important to speech intelligibility, 2) the elimination of visual cues and total reliance on auditory cues for understanding the spoken message, and 3) the reduced audibility of the telephone signal due to the decreased hearing sensitivity of the hearing impaired listeners. In one study, a 43-item questionnaire was sent out to hearing impaired individuals to determine what difficulties hearing-impaired individuals experience while talking on the telephone. They found that 69% of the respondents indicated that their hearing loss discourages them from using the telephone. They also found that 51% of the respondents reported they sometimes avoid using the telephone because of problems hearing speech and that 75% of the respondents indicated that hearing over the telephone ranges in difficulty from somewhat difficult to extremely difficult. When the authors questioned the respondents about hearing aid use, 94% of the respondents indicated using a hearing aid, while only 55% indicated that they used their hearing aid coupled to the telephone. Their reasoning for this is that coupling to their hearing aid to the telephone is problematic. For some 30 respondents it was so problematic that they stopped wearing their hearing aid while talking on the telephone due to feedback issues and electromagnetic interference while in telecoil mode (Kepler, Terry, & Sweetman, 1992).

Telephone Transmission

All the functions of a telephone depend on a pair of small twisted copper wires. These wires control the voltage to operate the telephone, the ring signal and voice transmission. There are several things that are important in telephone transmission of speech. These factors include: 1) length of local loop, 2) telephone type, 3) instrument impedance mismatch between the instrument line, and 4) line balance. The length of local loop refers to the actual length of telephone wire that comes from the local telephone exchange. The loop length usually varies anywhere from 1 to 10 miles with the average loop length of 3 miles. The longer a loop is the more resistance the signal has to travel therefore reducing the available current for the telephone and its attachments. Most telephone companies assure that the current will be no lower than 20 mA for long loops. Shorter loops can draw, however, as much 60 to 80 mA, providing more power for the telephone and accessories. It is reported that a standard carbon bell telephone can operate on currents as low as 14 mA but for new solid-state telephones a minimum of 20 mA is required for the telephone to even operate. This information is important in selecting assistive devices that require a large amount of power to operate. Telephone line impedance is also affected by the method of delivery. The impedance for the telephone system is between 300 to 900 ohms. If a device is attached that creates an impedance mismatch an echo or whistling can occur which will affect the ability to understand speech over the telephone. A telephone line must also have a balanced feed with each side equally grounded. If this does not occur a hum or buzz can be introduced to the line which can be an obstacle in speech recognition over the telephone (Slager, 1995).

Before the Carter Decision of 1968 (allowed the use on non AT&T phone to be connected to the telephone network), a standard network called the loop compensation (LC) device was used all over the world. This used carbon microphones on all telephones. Modern telephones do not use these very much anymore. They are using integrated circuits and transistors to relay the signal. These do not create an inductive field that allows the coupling of hearing aids equipped with a telecoil. To correct this, many devices have been developed to amplify the electromagnetic field of the telephone. Some of these devices require that a device be attached to the receiver of the telephone which can be cumbersome for the user, especially in public. Other amplifiers are designed to increase the volume of the acoustic output of the telephone receiver. These can be useful for those with mild to moderate hearing losses but offer little to no help for those requiring inductive coupling (Slager, 1995).

The Hearing Aid Compatibility Act of 1988 enacted by Congress, ensures that telephones manufactured or imported for use in the United States after August 16, 1989, and all "essential" telephones, are hearing aid-compatible. The Federal Communications Comission (FCC) refers to "essential" phones as one that are typically used in a public setting such as hosptials, coin-operated telephones, workplace phones, and phones that are operated in a hotel or motel. The FCC requires that all wireline (landline) telephones produce a magnetic field that is of sufficient strength and quality to all allow for coupling to hearing aids with a telecoil, and also that wireline telephones must have a volume control setting that provides 12 dB minimum gain to a maximum of 18 dB gain when measured in terms of Receive Objective Loudness Rating (ROLR) (FCC, Hearing Aid Compatibility for Wire-line telephones, 2008). More recently, on August 14, 2003, the FCC revised this statement allowing for the inclusion of wireless telephones (cellular telephones) to be hearing aid compatible. The FCC generalizes that the CDMA (Code Division Multiple Access) air interface systems generally used by Verizon Wireless and Sprint Nextel are easier to meet hearing compatibilty standards than GSM (Global System for Mobile) systems typically used by AT&T Wireless and T-Mobile. The FCC also generalizes that clamshell or flip design of phones make it easier to meet hearing aid compatibility standards. The American National Standards Institute (ANSI) developed a standard for digital wireless phone compatibility with hearing aids. The standard, C63.19, contains a set of standards. One of the standards pertains to acoustic coupling (M rating) and the other standard is for telecoil coupling (T rating). These ratings range from the number 1 to 4. The FCC requires that the rating must either be a M3 or T3 for the wireless phone to be hearing aid compatibile.

In addition to rating wireless phones, the ANSI standard also provides a methodology for rating hearing aids from M1 to M4, with M1 being the least immune to RF interference and M4 the most immune. To determine compatability between a hearing aid and wireless telephone, the RF rating of the hearing aid is added to the rating of the telephone. The FCC states, a sum of four would indicate that the telephone is usable; a sum of five would indicate that the telephone would provide normal use; and a sum of six or greater would indicate that the telephone would provide excellent performance with that hearing aid (FCC, Hearing Aid Compatibility for Wire-less telephones, 2008).

Microphone Technology

Acoustic coupling between the hearing aid and telephone occurs between the receiver of the telephone and the microphone of the hearing aid. Telephone receivers have not essentially changed over the past 15-20 years. However, hearing aid microphone technology has dramatically changed over the past 15-20 years. The relative size of a hearing microphone has also changed, decreased, over time. This decrease has allowed for unique and ever smaller designs of current hearing aids. Since the 1980's, most hearing aids contain electret microphones. An electret microphone contains a thin Teflon material that contains a permanent electric charge. When the diaphragm of the microphone is moved toward the electret material it begins to collect a charge and vice versa when it moves away from the electret material. This creates an electrical representation of the incoming sound wave. More recently, solid-state or integrated microphones are becoming common in hearing aids due to their small size and reliability (Dillion, 2001).

Induction Technology

Induction coils involve the use of copper wire wrapped around a conductive metal. The more turns of wire an induction coil has the more capacity it has to induce electrical current. Induction coils can have many uses. One common use is that they convert electro-magnetic current into electrical current. It is this use that makes them useful for hearing aid users. Induction coils can pick up the electro-magnetic current emitted from a telephone receiver. The coil then converts it to electrical input that can then be amplified and manipulated by the hearing aid. The orientation and size of the induction coil can affect its ability to pick up the electro-magnetic signal. The bigger and, as discussed earlier, the more turns of wire, an induction coil has the better it will function. In hearing aids, however, induction coils are limited in size. Today's induction coils are mainly found in hearing aids larger than completely-in-canal aids. According to (Ross, 2006), the position of the telecoil within the hearing aid also helps determine the overall strength of the aid. He states that for telephone reception the induction coil should be placed horizontal relative to the faceplate of the hearing aid or perpendicular to the receiver of the telephone. While a vertical induction coil placement is ideal for induction loops and FM systems.

Acoustic vs. Induction

Hearing aid technology over the past 10 years has improved dramatically. With this advancement in technology, has come a reduction in the size of the hearing aid, especially in Behind-the-Ear (BTE) products. This reduction would then require smaller components to be placed inside the hearing aid. Smaller microphones and induction coils have been developed for this purpose. Several studies have looked at comparing acoustic vs. induction coupling between the hearing aid and telephone. (Plyler, et. al., 1998) looked at the average word recognition scores on the telephone using acoustic and induction coupling. For this study, only In-The-Ear (ITE) hearing aids were used. For their experiment each subject adjusted the volume on their hearing aid until it was at a comfortable setting for telephone communication. This was done for each coupling method. They then measured word recognition scores in quiet for a W-22 50 list routed through a 2-channel audiometer and telephone simulator. They also recorded the frequency response of each coupling method using electro-acoustic analysis. They found that for word recognition scores in quiet, there is no significant difference between acoustic and inductive coupling over the telephone. They also discovered that there was no significant difference for frequency responses of the two coupling methods because the subject was allowed to adjust the volume for each coupling method to the most comfortable setting for the telephone. Another study (Sung & Hodgson 1971) also compared frequency response characteristics and speech intelligibility between acoustic and induction input to hearing aid. This study used two body-type hearing aids to complete the experiment. However, this study did not couple these inputs to a telephone to measure speech intelligibility. They instead measured speech intelligibility by having normal hearing listeners listen to the manipulated stimuli through a single TDH-39 earphone with added white noise creating a 6dB signal-to-noise ratio. They found that the two hearing aids differed in frequency responses for both acoustic and induction inputs. Aid 1 had a better high frequency response while Aid 2 had a better low frequency response for acoustic input. Aid 1 also had a better induction input frequency response than Aid 2. In terms of speech intelligibility, they discovered that Aid 1 showed less difference between input modes and provided better discrimination scores than Aid 2. They found significant interactions between discrimination scores and hearing aid used and also between modes of input. Furthermore, they found that subjects did significantly poorer in the induction input than the acoustic input of Aid 2. They reported no significant differences in Aid 1. They concluded that this difference was due to the different frequency responses provided by each aid for the different types of input.

One article, (Rodriguez et al 1993), looked at the real ear aided response for a group of hearing impaired listeners under acoustic and telecoil conditions. To accomplish this, a programmable hearing aid was used using a pool of 12 different frequency responses with differing parameters. The subjects were then instructed to select the preferred hearing aid settings by using a forced choice approach. They found that subjects preferred considerable gain in the low frequencies during telephone listening conditions. They discovered that a gradually rising to a flat frequency response was preferred for both acoustic and telecoil coupling to the telephone. Another study looked at 4 different hearing aid/telephone coupling methods to determine if one system was superior for all of the test subjects. They compared these four coupling methods by performing a speech recognition test (SPIN). The four coupling methods they compared were: 1) acoustic/standard phone receiver, 2) inductive/standard phone receiver w/coil installed, 3) inductive/standard receiver w/ Western electric strap-on adapter, and 4) inductive/standard receiver with Nuvox strap-on adapter. They discovered that there was no coupling method that worked best for all test subjects. However, they found that certain coupling methods worked best for certain test subjects. At the end of their study, they made recommendations to each subject about which coupling would work best for them. A similar study looked at the electro-acoustic and speech intelligibility of different coupling methods for acoustic and telecoil inputs for the telephone. This study used 2 hearing aids produced by different manufacturers. They set the aid to test-reference position (TRP) for all electro-acoustic analysis. The different coupling methods were: 1) acoustic coupling to hearing aids through standard telephone receiver, 2) inductive coupling through same telephone receiver with a Western Electric 100A coupler, 3) a modified receiver with a copper coil built in for inductive coupling. When they compared the electro-acoustic measurements for each of the coupling methods they found that both of the hearing aids microphones performed equally across the frequency range when they were set to TRP. They also found that both hearing aids performed equally in terms of frequency responses when inductively coupled to the telephone for all coupling methods. This study used normal hearing subjects to determine the effects on speech intelligibility of the different coupling methods. They recorded NU-6 words through the different coupling methods on a tape for playback. The normal hearing listeners determined which condition was most intelligible. They found that the acoustic input was non-significant from telephone to telephone conversation. They found that all inductive coupling methods produced poorer word recognition than the hearing aid microphone. One coupling method (receiver w/ built in coil), however performed significantly better than the other inductive coupling methods. They concluded that modified telephone receivers perform better in terms of standard telephone receivers when measured at the hearing aids TRP.

Hearing Aid Technology

The technology available in today’s current hearing aids has made it easier for the hearing impaired individual to hear better in background noise and enables them to have wireless communication with various electronic devices. One technology available that has progressed dramatically over the past 10 years is the concept of feedback cancellation. This is particularly important in telephone use. The absence of feedback allows the hearing aid user to place the telephone receiver directly against the ear which results in improved speech understanding and better overall satisfaction with hearing aid use.   The absence of feedback, however, is dependent on the style of hearing aid and amount of gain required for the hearing aid user (Latzel, Gebhart, & Kiessling, 2001).

Methods

Subjects

Six adults with sensorineural hearing loss were selected who had hearing thresholds no greater than a severe hearing loss and were hearing aid users. The subjects were given a hearing screening (air conduction) to ensure that their hearing thresholds were within the criteria of this study. A case history was taken to account for any current or past middle ear pathologies. Otoscopy was also completed to confirm no obstructions of the external auditory canal. All subjects were experienced hearing aid users and reported having a telecoil as an option in their hearing aids. Average hearing thresholds of the six subjects are given in Figure 1.

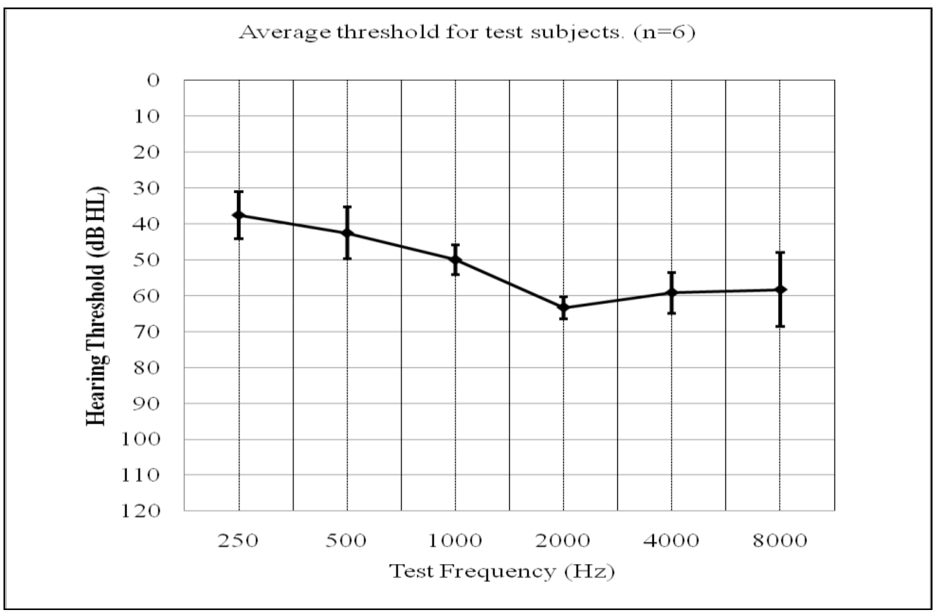

Figure 1. Average auditory threshold (250 Hz- 8000 Hz) for the test ear of all subjects. Error bars = +/-1SE.

Instrumentation

Pre-recorded CD of the Connected Speech Test (CST) by Cox et al. (1987), was streamed through a amplifier and mixed in a 2-channel GSI-16 audiometer to generate the signal-to-noise ratios required for this study of +10dB, +5dB, and Quiet. These signal-to-noise ratios were chosen because they simulate real-life listening situations that a hearing aid user might experience while trying to talk over the telephone. One end of a landline standard telephone handset was mounted in a horizontal plane 6 inches from the main driver of a Tannoy system 600 speaker (Figure 2). This distance was found to be optimal after a systematic sound quality check showed that a 6 inch distance provided the least amount of distortion and maximum amount of speech understanding. The output of the speaker was set through the audiometer to an average RMS level of 65 dBSPL using a sound level meter. A Fonix 7000 Hearing Aid Analyzer was used to perform electroacoustical analysis of each subject's hearing aid. The hearings aids were analyzed according to the ANSI S3.22-2003 standard. The subject's t-coil was analyzed by measuring the Sound Pressure Level in an Inductive Telecoil Simulator (SPLITS).

Figure 2. Standard landline telephone handset placed 6 inches from main driver of Tannoy 600 speaker.

Procedure

The subjects were first given a hearing screening to ensure they conformed to the hearing loss criteria for this study. Electroacoustical analysis was then performed on the subject's hearing aid to determine the output of the hearing aid microphone and SPLITS was used to determine the output of the t-coil. The test subjects were then seated in a quiet office with minimal background noise (~42dBA) to simulate real-world conditions. The subjects were instructed as to which coupling mode would be used first and that the order of the signal-to-noise ratio would be random. The subjects were allowed to set the volume of their hearing aid to the most comfortable setting but they were instructed to not adjust it once the testing had begun. The subjects were also allowed to place the telephone receiver in a comfortable position on their ear, but were instructed to try and not move the telephone receiver from that position for the duration of the testing.

The CST sentences were then presented through the speaker located in the sound treated booth at three different signal-to-noise ratios (+10dB, +5dB, and Quiet). The order of presentation was counterbalanced across the three signal-to-noise ratio conditions. The subjects were then asked to repeat the sentences they heard through the telephone while listening through their hearing aid while in the tele-coil program only; acoustic program only; and without their hearing aid. A research assistant was seated with the test subject and recorded what the subject repeated. The total test time for each subject was approximately 2 hours. The test subjects were given one carton of hearing aid batteries as compensation for their time.

Data Analysis

A one-way analysis of variance (ANOVA) was performed to compare the effects of the three hearing aid conditions (Acoustic input, Induction input, and No hearing aid) at the three signal-to-noise ratios used (+10dB, +5dB, and Quiet). The alpha level was set at 0.05 to determine statistical significance. Because nine dependent measures were collected on each of six subjects, and the response was measured across the 3-by-3 cross-classified factors of three listening conditions (tele-coil, hearing-aid, and unaided) and three signal-to-noise ratios (quiet, +10 and +5 dB), a multivariate approach to repeated measures was used to evaluate the statistical significance of the results. There was no interaction ($F_{4,20}$ = .94, p=.46) between the two within-subjects effects (listening condition and signal-to-noise ratio), so we can proceed to examine main effects separately. There was no effect of listening condition ($F_{2,10}$=2.5; p=.136), but there was a significant effect of signal-to-noise ratio ($F_{2,10}$=10.6; p=.003). There was also a significant between-subjects effect ($F_{1,5}$=10.9; p=.021), meaning that the subjects differed significantly one to another. Table 1 shows this difference in percent correct on the CST for all subjects in all conditions.

Table 1. Shows individual subject score (% correct) for the CST on each condition.

	T-Coil			***HA Mic***			***No HA***		
Subject	***Quiet***	***10***	***5***	***Quiet***	***10***	***5***	***Quiet***	***10***	***5***
S1	6	12	0	14	2	2	26	24	0
S2	4	0	4	0	2	0	0	2	0
S3	68	46	26	52	34	34	84	74	40
S4	78	18	0	10	20	0	74	52	18
S5	62	38	18	92	52	18	92	38	4
S6	10	8	0	60	12	14	64	14	10

Results

The subjects were asked to listen to passages from the CST over the telephone in three different signal-to-noise ratios while either wearing their hearing aid in either acoustic mode or telecoil mode or by not wearing their hearing aid at all. Figure 5 illustrates the average percent correct for each condition.

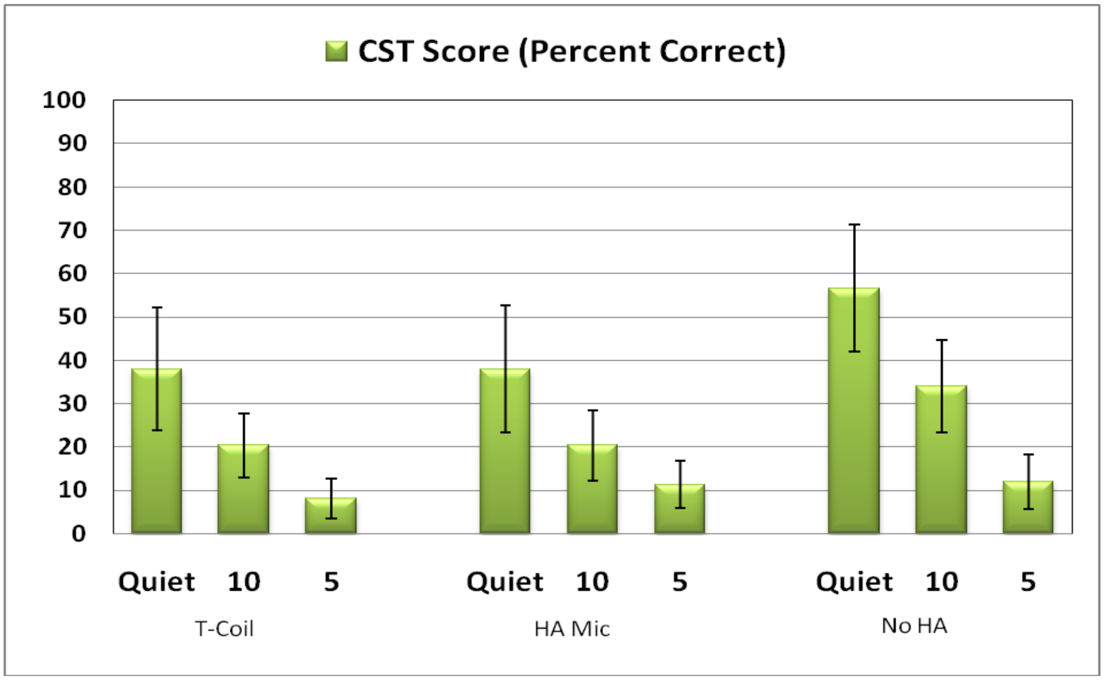

Figure 3. Shows that average % correct for each hearing aid condition (T-coil, HA, Mic, No HA) and for each SNR (Quiet, +10dB, +5dB). Error bars = +/- 1SE.

By visual examination of Figure 3, one might think that the subjects performed better when they were not wearing their hearing aid. However, a two-way analysis of variance (ANOVA) resulted in an insignificant main effect between hearing aid condition and the signal-to-noise ratio ($F_{4,45}=0.229$, $p>0.05$). The two-way ANOVA also found no significant interaction between the three hearing conditions (T-Coil, HA Mic, and No HA) ($F_{2,45}=1.266$, $p>0.05$). Since all of the subjects performed better in quiet than the +10 dB and +5 dB signal-to-noise ratios, a one-way ANOVA was performed to see if a significant interaction occurred between the 3 SNR's. The ANOVA yielded a significant interaction between the SNR of +5 dB and the Quiet listening condition ($F_{2,45}=8.116$, p<0.05). This interaction was expected due to the increased difficulty of the task. No other significant interactions were found.

Each subject's hearing aid was analyzed in a Fonix 7000 Hearing Aid Analyzer prior to the start of telephone conditions. This analysis yielded the frequency response curves for both the hearing aids microphone and telecoil. Figure 4 depicts the average output for test subjects' hearing aid microphone and telecoil using the test parameters of ANSI S3.22 (2003).

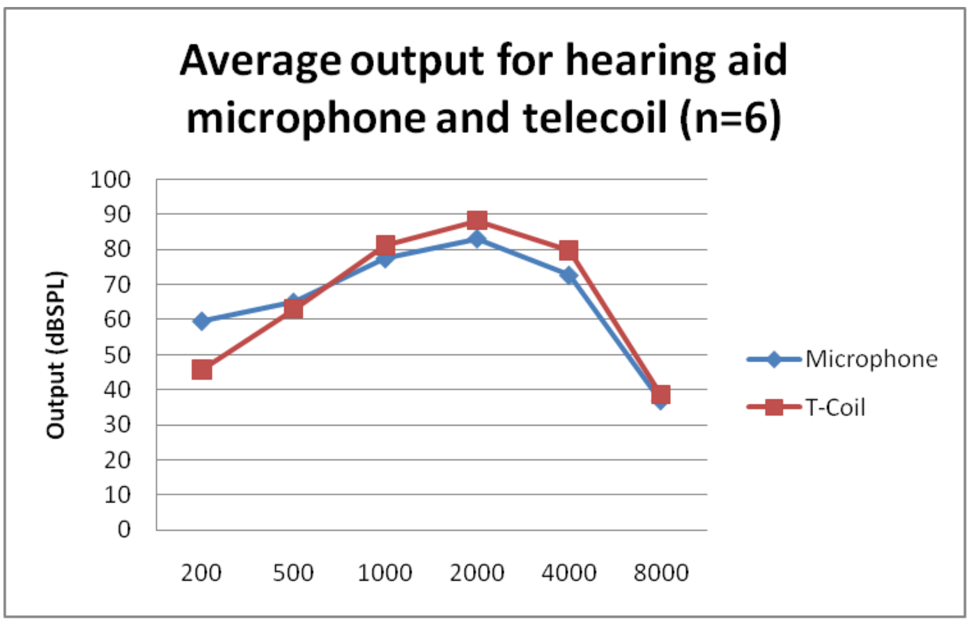

Figure 4. Shows the average output (dBSPL) for the subjects' hearing aid microphone (60 dBSPL input) and t-coil (31.6 mA/m input) using ANSI S3.22.

A visual comparison of the frequency responses of the subjects' hearing aids between the two input modes reveal that they are very similar with the exception of a difference of approximately 15 dB at 200 Hz. The hearing aid microphone on average provided more gain at this particular frequency. A one-way ANOVA was performed to look at the relationship between mode of input and frequency response. No significant main effect was seen ($F_{5,60}$=1.554, $p>0.05$). In conclusion there was no significant effect of using the hearing aid in regular or telecoil mode or not using the hearing aid at all. There was a significant effect of signal to noise ratio with patients doing better in the quiet as expected. The subjects were not homogeneous, as some did better than others in all of the conditions.

Each subject was also given a 7-point questionnaire that consisted of general difficulties of hearing aid use. (See Table 2). The subjects were asked on a 7-point rating scale their perceived difficulty with certain listening situations. 67% (n=4) of the respondents perceived a moderate or higher level of difficulty understanding conversations while wearing their hearing aids, while most of the respondents (n=5) perceived some level of benefit from their hearing aid. Half of the respondents (n=3) perceived moderate or higher difficulty understanding male and/or female voices. 67% of the respondents (n=4), reported moderate or higher difficulty using their hearing aid with the telephone with 50% (n=3) saying that this greatly affects their life.

Table 2. Subjects (n=6) responses to 7-point rating scale questionnaire.

	Rating scale response(n)						
Questions	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1.) Ability to understand conversation	1	0	0	1	1	3	0
2.) Perceived benefit from your hearing aid	1	1	0	0	1	0	3
3.) Difficulty understanding female voices	2	0	0	1	3	0	0
4.) Difficulty understanding male voices	2	0	0	1	1	2	0
5.) How much do communication difficulties affect your life?	1	0	1	0	2	2	0
6.) How much do telephone communication difficulties affect your life?	1	0	0	2	1	2	0
7.) Difficulty using your hearing aid over the telephone.	1	0	0	1	2	2	0

Discussion

This study investigated speech recognition for listeners with sensorineural hearing loss using hearing aids in either induction input, acoustic input, or with no hearing aid at all. The subjects were seated in a quiet office and asked to repeat aloud sentences they heard over the telephone. Three different signal-to-noise ratios (Quiet, +10dB, +5dB) were used to study to effect of background noise on the listener's ability to detect and repeat aloud the CST speech signal through the different input modes of the hearing aid.

Effect of hearing aid mode on speech understanding

Results from this study show that speech understanding is not significantly different between the hearing aid modes used (T-coil, acoustic, and no hearing aid). Previous studies have reported conflicting results pertaining to whether tele-coil input or acoustic input provided better speech understanding. (Lowe & Goldstein, 1982) showed that the speech recognition performance over the telephone was dependent upon many variables and that neither telecoil nor acoustic input modes are superior to the other. They determined that which one was better depended on the patient and their communication needs. (Plyler et al., 1998) showed no significant difference in word rcognition ability in quiet between acoustic coupling (75.1% correct) and electromagnetic or induction coupling (76.3% correct). (Tannahill, 1983) discovered that acoustic coupling between a hearing aid and telephone produced similar word recognition to that of standard telephone use without a hearing aid. He also showed that telecoil performance varied depending on which type of telephone receiver was used. He suggested that the use of telecoils should be considered on an individual basis dependent upon the patient's communications needs. The results found in the current study were unexpected. The telecoil and acoustic coupling methods were expected to significantly out perform the no hearing aid condition. The lack of difference in word recognition ability between the telcoil and acoustic coupling methods could be explained by several things. The first explanation is that both the telecoil and hearing aid microphones were found to have similar frequency responses. This is also enhanced by the fact that most telecoils in modern hearing aids are programmable and their frequency responses can be shaped to match those of the hearing aid microphone. This is felt to be the case in the present study. Another explanation could be the fact that with all of the modern technology available in today's hearing aids such as wireless connectivity and and smaller sizes, there simply is not enough room to put an adequate strength telecoil in the hearing aid (Kerckhoff et al., 2008).

The most intriguing finding of this study is that, even though nonsignificant, was the abilty of the subjects to perform almost as well without their hearing aid as when they were wearing either in telecoil mode or in acoustic mode. Some explanations for this could include the placement of the telephone handset. The test subjects were allowed to place the handset for each condition to optimally couple the hearing aid to the telephone. They could have moved the telephone receiver slighty resulting in poorer coupling with the hearing aid in general as compared to the no hearing aid condition where they firmly placed the receiver over the ear. Another possible explanation is that the CST contains enough cues for speech intelligibility within the telephone's limited bandwidth. (Sherbecoe & Studebaker, 2002) found that the CST 's frequency-importance function has nearly 70% of it's weight in two frequency regions. One is a low-frequency band (350 Hz to 700 Hz) and the other a mid-to-high frequency band (1100 Hz to 4400 Hz). They also state that about 50% of the weight comes from the mid-to-high frequency band. According to their study over 50% of the CST's frequency importance function falls within the telephone's transmission bandwidth. This could be an explanation for why subjects performed well without their hearing aids since most of the subjects presented just a mild to moderate hearing loss in the lower-to-mid frequency region of the CST.

Effect of signal-to-noise ratio in speech understanding

The present study found a significant interaction between the signal-to-noise ratio (SNR) of +5dB and the quiet listening condition. This type of interaction was expected due to the increased difficulty of the task for the subject. The three SNR's of Quiet, +10dB, and +5dB were selected to try and simulate real-world telephone communication situations. Several studies have looked at the effect of background noise on telephone communication, (Holmes, et al., 1983; Plyler, et al., 1998) showed that as background noise increased, speech intelligibilty decreased. This agrees with the data from the current study. (Cox, 1987) stated that the CST has a small range of useful speech-to-babble ratios of about 9 dB. They found that a change in S/B ratio from 0 to -9 dB can result in a performance change from full intelligibility to no intelligibility. These studies all concluded that the more difficult the SNR was that speech intelligibility decreased which if often evident in telephone communication.

New developments in telephone coupling with hearing aids

There have been many new developments in hearing aid technology in terms of telephone coupling. These recent developments include Bluetooth® technology which allows for the telephone signal to be transmitted wirelessly to both ears at the same time. This type of technology is currently available in devices such as the Oticon Streamer and Siemens e-connect. The only downside to this technology is that the telephone must be Bluetooth® compatible. Another version of wireless technology available to hearing aid users utilizes the wireless communication abilities between hearing aids. This feature is seen in mid and upper level Phonak hearing aids. This feature routes the telephone signal wirelessly from one hearing aid to the other giving the pt. the ability to hear the signal in both ears but without the need for Bluetooth®. Both forms of technology allow for binaural input of the telephone signal. This binaural input takes advantage of binaural summation which can add up to 6dB of gain to the telephone signal. This can be advantageous to the hearing impaired individual who struggles with telephone communication. A disadvantage of this technology may be the reduction in the ability for the hearing aid user to monitor their surrounding environment while talking on the telephone.

Limitations of current study

Limitations of the current study include the small sample size of hearing impaired subjects. The subjects had to fit a hearing loss and hearing aid criteria that limited the number of available subjects. Another limitation of the current study includes the type of hearing aid used. One style of hearing aid was preferred (BTE), but due to subject availability other styles such as custom full-shell and half-shell styles were also used. This introduced an uncontrollable variable in regards to the telecoil. The orientation and size of the telecoil was dependent upon the style of hearing aid used. Another limitation of this study is that one speaker was used to deliver the speech signal and speech babble noise. This results in both the speech and noise being delivered in "near-field" conditions, whereas in most real-life situations the speech is usually in the "near-field" while most background noise is "far-field" in terms of the telephone receiver. This study was aimed at determining the ability of the listener to repeat sentences they heard over the telephone. Had the background noise been in the same room as the listener instead of being controlled through the audiometer, much different intelligibility scores would have been expected.

Future directions of study

Future directions of study would include research on wireless technology opposed to conventional acoustic and telecoil inputs in regards to telephone communication. Since modern hearing aid technology now encompasses noise reduction circuits in hearing aids, future research should look at whether this makes an impact in regards to acoustic coupling of the telephone in terms of speech intelligibility in noise. Future research should also consider if telecoil's can still provide benefit over wireless technology or will they eventually be phased out.

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