AN EVALUATION OF USER PERFORMANCE WITH INDUCTIVE COUPLING OF HEARING AIDS AND TELEPHONE RECEIVERS INCORPORATING RECEIVER AMPLIFICATION.

By

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We accept this thesis as conforming to the required standard

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Previous research has shown the benefit obtained by hard of hearing people when using inductive means (T-switch) to couple their hearing aids to telephone receivers. Benefit provided by receiver amplification in the telephone handset has also been shown. Informal surveys of hard of hearing people indicate that many of them use telephones having a dual capability: magnetic coupling and receiver amplification. The objective of this investigation was to study user performance with this dual capability. In particular, the effect of receiver amplification on the speech perception ability (as measured by R-SPIN test items) of 10 hard of hearing subjects using inductive means to couple their hearing aid to a telephone receiver was examined under both good and poor telephone line conditions. The influence of the predictability of the speech material presented was also investigated by noting any difference between the subjects' performance on high predictability items and performance on low predictability items (of the R-SPIN test).

Results showed that the use of receiver amplification in conjunction with inductive coupling significantly improved the subjects' speech perception scores. Not surprisingly, good telephone line conditions also significantly improved the subjects' scores. Improvement due to receiver amplification was noted, irrespective of line conditions. Similarly, improvement due to good line conditions was observed, irrespective of whether amplification was used or not. Both receiver amplification and good line conditions had significant and positive effects on both low predictability and high predictability scores. We conclude that with speech either in or out of context, receiver amplification will be of benefit to those who use inductive coupling. Clinical implications and recommendations are discussed.
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CHAPTER 1
INTRODUCTION

1.1 The Problem of Telephone Use for the Hard of Hearing

According to the 1986 Statistics Canada Post-Census Survey on Disability, a hearing disability was reported by almost one million Canadians, at least half of whom wear hearing aids. Most hard of hearing people who wear a hearing aid, find that it provides adequate aid to hearing in face-to-face communication. There are situations, however, which are difficult for the hard of hearing person, no matter how carefully prescribed their hearing aid(s). One of these situations is communicating over the telephone, which is notably difficult for several reasons: (1) the hard of hearing individual must rely exclusively on his/her auditory channel, which is impaired; (2) the telephone signal is only routed monaurally; (3) the telephone has limited fidelity (in particular a response approximately limited to the range 300-3400 Hz as shown in Figure 1) and its signal carries noise as well as distortion.

Some hard of hearing people have no difficulty in perceiving speech over the telephone: for many people with mild-to-moderate hearing loss up to 40 or 50 dB, amplification is not always necessary for successful telephone use, as the output of the telephone at the receiver averages 86 dB SPL (Stoker, 1981). This level is approximately 15 dB higher than the level of normal conversational speech, which is approximately 60 to 70 dB SPL at a distance of three feet.

Nevertheless, a large proportion of hard of hearing people encounter difficulties when using telephones. Thomas, Lamont and Harris (1982) investigated the effect of hearing loss at work in adults suffering from acquired severe sensorineural hearing loss and found that 75% of the respondents reported difficulty with the telephone at
Figure 1. The frequency response of a typical telephone receiver (reproduced from Holmes & Frank, pre 1984-publication draft).
work. According to Martin (1983) one of the greatest barriers to employment and advancement in the workplace is the inability to use the telephone. Darbyshire & Vaghy (1979), in their pan-Canadian survey of the communication needs of hearing impaired people, found that 63% of the people in their sample had difficulty in using the telephone some or all of the time. In fact, 42% of the people in the sample had to ask others to make telephone calls for them some or all of the time. Since, today, the telephone plays a major role in both business and personal activities, such barriers to its use impose severe limits upon social and economic endeavors of the hard of hearing.

Prior to 1975, all telephones within Bell Canada's territory (servicing two-thirds of Canada's population in Ontario and Quebec) were compatible with hearing aids. Telephones serviced by other provincial telephone companies were largely incompatible. "Compatible" means a telephone whose receiver produces a magnetic field sufficient to activate a small coil of wire, known as a telecoil, in a hearing aid. Many hard of hearing people utilize this method of telephone-to-hearing aid, coupling known as inductive coupling (to be discussed in greater detail in section 1.3.2). In 1976, Bell Canada introduced a new cost-efficient telephone receiver, the Balanced Armature Receiver (BAR) that was no longer compatible with hearing aids. The BAR provided a high quality acoustic output but generated much less magnetic flux than the traditional receivers. Consumer groups informed Bell Canada of the negative consequences of such a move for hard of hearing people. As a compromise, Bell Canada agreed to the following: (a) to fit all pay phones with BAR receivers with a fluxcoil (a coil of wire which when inserted in the telephone receiver, renders the receiver compatible); (b) to provide compatible handsets upon request, at home or at work; (c) to provide portable, battery powered, adapters at low cost; and (d) to actively
pursue research into a permanent solution to telephone receiver compatibility. In 1980, Bell Canada admitted that research intended to provide an alternative to inductive coupling had been unsuccessful and agreed that, as of January 1981, all new telephones within its territories would be equipped with fluxcoils. Not long after, however, in 1982, the Canadian Radio-Television and Telecommunications Commission (CRTC) ruled that Canadian consumers would now be able to buy any telephone from companies other than the federally-regulated telephone companies and connect them into the telephone network. Non-compatible telephones began to flood the market. Hard of hearing consumers expressed their displeasure and four organizations serving or advocating for the hard of hearing (Canadian Hard of Hearing Association, Canadian Hearing Society, Canadian Coordinating Council for Deafness and Ottawa Hard of Hearing Club) petitioned the Federal Government to change this decision such that all new telephones sold within the jurisdiction of the CRTC be compatible with hearing aids. While the Federal Government refused to modify the 1982 CRTC ruling, in 1983 the Minister of Communications established an ad hoc committee to recommend measures which would ensure that hard of hearing persons have adequate access to telecommunication services in Canada. This committee reported back in 1984 that a standard for hearing aid compatible telephones was the best method of ensuring access to the telephone network for the hard of hearing. In 1985, the Canadian Standards Association (CSA) adopted as standard, CAN3-T515-M85, the document entitled "requirements for handset telephones intended for use by the hard of hearing". This standard specifies what constitutes adequate telephone compatibility with hearing aids. The CRTC refused, however, to demand that telephone companies change from their existing technical standards to one incorporating CAN3-T515-M85. Legal action was then sought by The Canadian Hard
of Hearing Association and The Canadian Hearing Society to challenge the CRTC. Under consumer pressure, in May of 1989, the CRTC decided to amend the technical standards for telephones such that all new telephones manufactured or sold in Canada would be compatible with hearing aids by August 16, 1989. After fourteen years, access to the telephone network by the hard of hearing was achieved in Canada. Similar legislation was passed in the United States in August of 1988 requiring that all corded telephones manufactured or imported into the country be hearing aid compatible by August 16, 1989.

1.2 Hearing aid components

Prior to discussing the different strategies of telephone coupling, a review of the basic hearing aid components is warranted. All modern hearing aids consist of six basic elements, as shown in Figure 2: a power supply, an input transducer (a microphone), an amplifier, a volume or gain control, an output transducer (the receiver) and an earpiece (the earmold). The power supply, a battery, provides the power necessary for the amplification process. The standard input transducer in hearing aids is the microphone, which converts the acoustic signal into an analog electric signal. This weak electric signal is routed to the amplifier which brings it to a suitable level to drive the final stage, the receiver, which converts the amplified signal back into an acoustic signal. This acoustical signal is then delivered to the ear canal via the earmold.
Figure 2. A simplified diagram of a hearing aid (reproduced from Lybarger, 1985, with permission).
1.2.1 The telecoil

As discussed above, many hearing aids, depending on available space, include an additional input component whose aim is to facilitate telephone communication. This component is a miniature coil of wire (called a telecoil) which picks up the electromagnetic field generated by the telephone receiver. The resulting voltage in the telecoil is directly related to the current in the telephone receiver. The telecoil voltage is amplified by the hearing aid's amplifier and converted into acoustic energy by the hearing aid's receiver. The inclusion of a direct inductive pick-up for telephone use was first recorded in the literature in 1947 (Lybarger, 1947). Most of the research on performance of individuals using a telecoil, however, has utilized induction loops rather than telephone receivers to generate the electromagnetic input to the telecoil. Induction loop amplification systems (ILA) consist of one or several microphones, an amplifier, a loop of ordinary wire and hearing aids equipped with a telecoil, as shown in Figure 3. An ILA system works under the same principle as inductive telephone coupling: the acoustic signal is converted into an analog electric signal by the microphone, then amplified and routed via a transformer, to a loop of wire (installed around the periphery of a room either on the ceiling or on the floor) around which it produces an electromagnetic field. This electromagnetic field induces a voltage into the telecoil of the hearing aid. The hearing aid then amplifies this voltage and converts it back into acoustic energy.

1.2.2 Microphone or telecoil?

A hearing aid user can select as the input device, the telecoil or the microphone
Figure 3. Block diagram of an induction loop amplification system (reproduced from Bellefleur & McMenamin, 1965, with permission).
via a switch (commonly known as the T-switch) which may have two or three positions as shown in Figure 4. When the hearing aid is set to the 'M' position, only the microphone is activated and the hearing aid will be responding to changes in sound pressure around the aid. This setting is used in most everyday listening situations. Some hard of hearing people choose to use the microphone mode for telephone communication. When the hearing aid is set to the 'T' position, only the telecoil is in circuit and the hearing aid will be responding only to changes in the magnetic field surrounding the telecoil of the hearing aid. Many hard of hearing people choose to use the telecoil mode for telephone communication. This setting can also be used when accessing induction loop group amplification systems (found in some public buildings, classrooms, theatres, places of worship and meeting halls) and several TV listening devices.

A few hearing aids have a third switch position labelled M/T or B. When selected, signals from both acoustic and magnetic sources are combined prior to amplification by the hearing aid (Erber, 1985). This feature was originally designed for use in classrooms, so that a child would be able to access the room amplification system via the telecoil input as well as hear his/her own voice via the microphone input (Castle, 1980).

1.3 Telephone Coupling Strategies

As mentioned in section 1.1, not all hard of hearing people need amplification when listening over the telephone. For those who require amplification, however, there are several alternative strategies or telephone coupling "modes" available to improve their telephone listening ability. These strategies are shown in Table I.
Figure 4. Hearing aid with a T-switch; M = microphone, T = telecoil and O = off.
Table I. Five strategies for telephone use available to hard of hearing people.

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<th>Aid used</th>
<th>Mic/Telecoil</th>
<th>Coupling</th>
<th>Strategy</th>
</tr>
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<tbody>
<tr>
<td>Regular</td>
<td>No</td>
<td>Neither</td>
<td>Acoustic</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>Microphone</td>
<td>Acoustic</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Telecoil</td>
<td>Inductive</td>
<td>5</td>
</tr>
<tr>
<td>Amplified</td>
<td>No</td>
<td>Neither</td>
<td>Acoustic</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>Microphone</td>
<td>Acoustic</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>Telecoil</td>
<td>Inductive</td>
<td>6</td>
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</table>

Strategy Legend: (1) Unaided with a regular handset (2) Unaided with an amplified receiver handset (3) Aided; microphone activated with a regular handset (4) Aided; microphone activated with an amplified receiver handset (5) Aided; telecoil activated with a regular handset (6) Aided; telecoil activated with an amplified receiver handset.
1.3.1 Acoustic coupling

(a) Acoustic coupling can mean one of two things. First, it can simply mean the coupling between an individual's ear and a telephone receiver emitting sound. Thus, during normal telephone use, the user is automatically acoustically coupled to the telephone receiver.

(b) Secondly, the coupling between a telephone receiver emitting sound and the microphone of the hearing aid is also called acoustic coupling. In this situation, a hard of hearing person, with his/her aid set to the 'M' (for microphone position), places the telephone receiver over the microphone port of the hearing aid, as illustrated in Figure 5.

1.3.2 Inductive coupling

The coupling between a telephone receiver emitting a magnetic field and the telecoil of the hearing aid is called inductive coupling. In this situation, the hard of hearing person switches his/her aid to the 'T' (for telecoil) position and places the telephone receiver against the hearing aid case in order to listen. The telephone receiver must be moved along the hearing aid casing to find the optimal position, which varies from hearing aid to hearing aid as shown in Figure 6.

1.3.3 Receiver amplification

An amplifier built into the handset is the most practical and popular way to amplify the output of the telephone. Such a handset or receiver amplifier is a device installed in the handset of the telephone; it is controlled by a volume wheel or touch bar, as shown in Figure 7. Handsets of this kind increase the intensity of both the magnetic and the acoustic signals. This device can be used with the unaided (without
Figure 5. Diagram of the telephone receiver location for optimal acoustic coupling between hearing aid and telephone receiver.
Figure 6. Diagram showing both the correct and incorrect receiver placement for inductive coupling.
Figure 7. A popular receiver amplified handset with volume wheel.
hearing aid) ear, or it may be used in conjunction with a hearing aid coupled to the telephone, either acoustically or inductively, for added amplification. When the volume is set at its minimum, the telephone provides no amplification.

All telephones must meet the requirements of, and be tested in accordance with, the CSA Standard CAN3-T510. They must also satisfy the magnetic output requirements of the CSA Standard CAN3-T515. In addition, all receiver amplified handset telephones intended for use by the hard of hearing (either by direct coupling to the ear or for acoustical and/or inductive coupling to hearing aids) must also meet all the requirements of, and be tested in accordance with, the CSA Standard CAN3-T515. This standard requires that with the volume control in the maximum gain position, the magnetic and acoustic outputs of the receiver be a minimum of 17 dB above the values measured with the volume control in the minimum gain position. The standard also requires that the total harmonic distortion in both the acoustic or the magnetic outputs be less than 10% (measured at 500 Hz and 1000 Hz), with the volume control in the maximum gain position.

In the chapters which follow, we will look at the above telephone coupling strategies in more detail. Having consulted the available literature, their advantages and disadvantages will be discussed, as will be their performance with actual hard of hearing people. We will also propose and provide the results of a study designed to compare the performance of a group of hard of hearing people using inductive coupling to couple their hearing aids to a telephone receiver, both with and without receiver amplification and under two different telephone line conditions.
CHAPTER 2
OPTIONS AND TECHNOLOGY FOR HARD OF HEARING PEOPLE USING THE TELEPHONE

In the sections which follow, we will present a review of the literature concerned with the technical and operational aspects of the major modes of telephone coupling introduced in Chapter 1.

2.1 Advantages and Disadvantages of Inductive Telephone-to-Hearing Aid Coupling

2.1.1 Advantages

Inductive coupling between the hearing aid and telephone receiver affords the hard of hearing person several advantages:

(A) Reduction in background noise. - Inductive coupling between hearing aids and telephone receivers reduces the amount of ambient noise that will be heard by the hard of hearing telephone user. Since the telephone signal is being transmitted via the magnetic field from the telephone receiver to the hearing aid telecoil, background noise and/or nearby conversations are neither transmitted to, nor amplified by the hearing aid (Castle, 1978). Some room noise will still be picked up by the microphone of the telephone handset and transmitted to its own receiver (this is known as side-tone feedback) but noise transmitted this way can be greatly reduced by covering the microphone of the handset with the hand while listening to the person on the line (Smith, 1974). Holmes, Frank & Stoker (1983) investigated the influence of side-tone feedback on the telephone listening ability of normal-hearing subjects in background noise varying in type and level. They found that telephone listening ability at higher
levels of ambient noise was significantly improved when the side-tone feedback was electronically disengaged or the handset microphone occluded with the palm of the hand. They also suggested that use of a receiver amplified handset would afford the listener an increased speech level to background noise level ratio as well as an increased speech level to side-tone level ratio.

(B) **Reduction in frequency distortion.** - Since the hearing aid microphone is disconnected, the inductive coupling mode does not introduce distortion that may arise from the acoustical mismatch between telephones and hearing aids (Fagerberg, 1978).

(C) **Frequency response independent of receiver position.** - The hearing aid's frequency response is essentially independent of the telephone receiver position when coupled via induction. This is not true of acoustic coupling (Arndt & Wojcik, 1981).

(D) **Reduction of feedback.** - Feedback, which is a common problem with acoustically coupled telephone receivers and hearing aids, is mostly eliminated when the telecoil is used in conjunction with the telephone (Castle, 1981).

2.1.2 Disadvantages

In terms of inconveniences and disadvantages, inductive coupling may alter the received signal significantly from that received in the microphone mode; can be influenced by environmental factors; requires that telephones with sufficient electromagnetic fields be available; and increases the cost of the hearing aid. The hard of hearing user must now monitor his/her voice indirectly, and is required to
increase his/her manipulation of both the hearing aid controls and the telephone receiver. These disadvantages will now be discussed in more detail.

(A) Alteration of the received signal. - Hearing aids are selected and fitted on the basis of their acoustic characteristics. Telecoil gain and frequency response characteristics do not necessarily mirror the gain and frequency response characteristics of the microphone. Sung, Sung & Hodgson (1973) reviewed the literature on the differences between telecoil and microphone electroacoustic performance in individual hearing aids. Their review revealed that:

(a) In several studies, the telecoil setting on hearing aids provided a better response to low frequencies than when using the microphone setting.

(b) In some instances, hearing aids which had similar frequency responses in their microphone mode produced quite different responses in their telecoil mode. It was generally noted that hearing aids which produced a good frequency response in their microphone mode were also likely to produce good responses in their telecoil mode.

(c) In several studies, with equivalent inputs and identical volume control settings, the relative gain of hearing aids has been compared between input modes. Depending on the sensitivity of the telecoil in a given hearing aid, the gain of an aid in the telecoil mode may be more, less, or equivalent to the gain in the microphone mode. If there is simply a decrease in overall gain, the "reserve" amplification could compensate for any decrement. If however, the frequency response changes significantly with this decrease in gain, increasing the volume of the hearing aid may not restore a signal which is appropriate for the individual's hearing loss. The research that led
to the above findings utilized induction loops rather than telephone receivers to generate the electromagnetic input to the telecoil.

Tannahill (1983) looked at the differences between telecoil and microphone electroacoustic characteristics using telephone receivers to provide the input to the hearing aid. The study compared the output of two hearing aids when: (1) the signal was routed from a transmitting telephone to a receiving telephone and then routed to a hearing aid microphone; and (2) the signal was routed from a transmitting telephone to a receiving telephone and then inductively coupled to a hearing aid telecoil. In the inductive conditions both hearing aids were inductively coupled to each of three telephone receiver types: (i) $R_S$ - a modern, standard receiver (not hearing aid compatible); (ii) $R_{100}$ - the same receiver adapted for telecoil use with a Western Electric 100A acousto-magnetic coupler$^1$; and (iii) $R_{md}$ - a receiver modified for telecoil use by means of a fluxcoil. Their results revealed the following:

(a) Inductive coupling conditions produced gain values that were 14 to 36 dB lower in comparison to microphone reception. Negative gain values were the rule rather than the exception. The amount of gain reduction was dependent on which receiver was employed with $R_S$ producing the largest amount of gain reduction while $R_{md}$ and $R_{100}$ receivers produced an output approximately 15 dB greater. As expected, the telephone receiver modifications did improve inductive coupling significantly. Tannahill accounted for the gain reduction in the inductive conditions by: a) loss in gain associated with telephone transmission (approximately 4 dB);

$^1$ The Western Electric 100A acousto-magnetic coupler is a battery-operated device which attaches to the telephone receiver. It was designed to convert the acoustic output from the telephone receiver into a strong electromagnetic field.
b) inefficiency associated with the conversion of an acoustic signal to an electromagnetic signal within the receiver; c) inefficiency associated with inductive coupling. He suggested that this gain reduction can be partially offset by the greater signal level associated with telephone communication (versus face-to-face communication) as well as any "reserve" gain which may be available in the hearing aid.

(b) The hearing aids' frequency response showed: a) a more 'peaky' configuration; b) variability depending on the receiver used (i.e., R100 produced a configuration reflecting a high frequency emphasis not present for the Rmd and Rs receivers); and c) a more restricted frequency response range in both high and low frequencies in inductive coupling conditions as compared to microphone conditions. This finding conflicts with the telecoil-induction loop literature reported by Sung, Sung & Hodgson (1973) which claims that telecoil reception provides a better low frequency response than microphone reception. These conflicting results may be accounted for by the different frequency responses of induction loops and telephone receivers. Tannahill suggested caution when generalizing from telecoil frequency response curves included in hearing aid specifications to actual telephone/telecoil use.

The conclusion to be drawn from this research is that the telecoil mode may vary from the microphone mode in terms of both loudness and quality of the signal.

(B) Electrical interference - Several environmental factors can influence the operation of the telecoil. Electrical interference from motors, transformers, fluorescent
lighting and computers in the vicinity of the telecoil may produce stray signals (Castle, 1978).

(C) **Availability of hearing aid compatible telephones.** - Inductive coupling requires that telephones with sufficient electromagnetic output be available. Although in North America recent legislation requires all new telephone receivers (with a few exceptions) to provide sufficient magnetic output, there exist many older telephones which do not meet this requirement. Also telephones in other countries vary with respect to magnetic output thus placing the hard of hearing traveller, wishing to use inductive coupling, at a disadvantage.

(D) **Increased cost.** - Inductive coupling requires the addition of an additional input component, a miniature coil of wire, within the hearing aid itself and thus increases the price of the hearing aid.

(E) **Indirect voice monitoring.** - When using the telecoil mode, the hard of hearing speaker can no longer monitor his/her voice through the hearing aid microphone, since the latter is bypassed, therefore he/she must monitor his/her voice via side-tone feedback and through the telephone receiver-telecoil combination. His/her speech, when monitored through the telecoil may sound quite different from his/her speech monitored through the microphone setting to which he/she is accustomed (Castle, 1981).

(F) **Need to manipulate controls.** - In order to couple a hearing aid and telephone receiver inductively, the hard of hearing person must first switch to the
appropriate position on his/her hearing aid (T position), locate the optimal receiver position relative to the hearing aid, and often increase the output of the hearing aid (as mentioned above, frequently for the same volume control setting the output of a hearing aid in the telecoil mode is less than its output in the microphone mode).

(G) **Receiver placement.** - The successful use of inductive coupling depends more heavily on correct telephone receiver placement vis-a-vis the hearing aid than does acoustic coupling (Arndt, 1976). Since the availability of space in the hearing aid casing is very limited, the placement of telecoils in hearing aids is not standardized. Receiver placement is critical, yet telecoil placement within the hearing aid case is often not optimal for telephone use (Castle, 1981). Optimal receiver placement for receiving sound may place the handset mouthpiece in an inconvenient location for the efficient transmission of sound. Tannahill (1983) noted in his study that the most efficient transfer of energy from telephone receiver to the hearing aid telecoil did not occur with a normal usage orientation. He noted reductions in gain from 2.3 to 24.6 dB (depending on receiver type) when hearing aids were changed from the orientation providing maximum gain to that of normal usage. He suggested that instructions to hearing aid users should emphasize the need to experiment with various hearing aid orientations in order to achieve maximal signal strength. Sung, Sung & Hodgson (1973) in their review of the telecoil-induction loop literature, reported a reduction in output of 7 to 30 dB when the placement of the hearing aid was changed from vertical to horizontal position relative to an induction loop.
2.2 Inductive Coils, Acousto-Magnetic Couplers, and Adapters

In the past, attempts were made to alleviate the problem of incompatible telephones (telephones without a built in fluxcoil). Two approaches have been offered, one being the retrofitting of incompatible telephone receivers with inductive coils, and the other being the development of acousto-magnetic couplers, and adapters. These two approaches will now be discussed in more detail.

(A) **Retrofitting.** - Where space permits, a coil can be fitted around the telephone receiver unit and wired either in parallel or in series with it. Thus the current generated by the telephone receiver is shared by the receiver and the coil. The coil current generates an electromagnetic field which is sufficient to activate many telecoils. A slight drawback is that the addition of this inductive coil does tend to reduce the acoustic output of the receiver slightly (Erber, 1985; Arndt & Wojcik, 1981).

(B) **Acousto-magnetic couplers and adapters.** - A number of couplers and adapters have been developed over the years to help alleviate the incompatibility problem. These are portable, battery operated, plastic encased units which fit over the telephone receiver, as shown in Figure 8. Acousto-magnetic couplers use microphones to pick up the acoustic signal from the receiver and convert it into an electric signal which then flows through the coupler's output coil to generate a magnetic field (Arndt & Wojcik, 1981). An adapter on the other hand, is an amplifier which amplifies the magnetic leakage from the telephone receiver (Castle, 1980). These devices provide the telecoil user with: (a) a frequency response which is independent of telephone receiver position; (b) reduced ambient noise; (c) reduced signal distortion; and (d) a reduced chance of acoustic feedback. For a number of
Figure 8a. Diagram showing an acousto-magnetic coupler. This device picks up the acoustic signal from the receiver and converts it into an electric signal which then flows through the coupler’s output coil to generate a magnetic field.

Figure 8b. Diagram showing an adapter. This device amplifies the magnetic leakage from the telephone receiver (reproduced from Castle, 1980, with permission).
reasons these devices have never achieved wide consumer acceptance and have led to the rejection of such approaches as a solution to the incompatibility problem. In particular: a) removal of the unit is required if a normal hearing person wishes to use the telephone; b) some handsets cannot be hung up with the unit in place; c) the battery could give out at any time; and d) it labels the user as handicapped (Lowe & Goldstein, 1982). It should be noted, however, that the issue of alleviating the incompatibility problem is no longer at the forefront, as almost all new receivers are now required by legislation in Canada and in the United States to provide sufficient magnetic output.

2.3 Advantages and Disadvantages of Acoustic Telephone-to-Hearing Aid Coupling

2.3.1 Advantages

Acoustic coupling between hearing aids and telephone receivers affords the hard of hearing person several advantages:

(A) Reduced cost of the hearing aid. - The telephone signal is transmitted acoustically from the telephone receiver to the hearing aid microphone and amplified by the hearing aid amplifier. No telecoil need be provided in the hearing aid, thus reducing its cost.

(B) Immunity to electrical interference. - Electrical interference, which is a common problem with inductively coupled receivers and hearing aids, is nonexistent when the two are acoustically coupled.
(C) **Reduction of the need to adjust the hearing aid.** - Acoustic coupling enables the hearing aid user to listen to speech over the telephone in the same microphone mode as in regular conversation (Erber, 1985). The hearing aid user therefore uses one mode for all situations, and less manipulation is involved.

(D) **Preservation of hearing aid "fit".** - Hearing aids are chosen on the basis of their acoustic characteristics, (i.e., their operation in the microphone mode). Maintaining the hearing aid in the microphone mode would, in theory, enable the hearing aid wearer to receive the telephone signal superimposed with the gain and frequency characteristics required by their hearing loss. In practice, this is only partially borne out (see discussion in section 2.3.2, part A).

(E) **Universal access to acoustic output.** - The major advantage of acoustic coupling is that it works with any telephone from any company, in any country (Smith, 1974). The acoustic output from a telephone is and always will be available. The acoustic output of telephones is specified with respect to level and frequency response by the International Telegraph and Telephone Consultative Committee (CCITT) and is therefore, relatively uniform internationally (Arndt & Wojcik, 1981).

"The one thing that is and always will be available from a telephone is its acoustic output, even when magnetic receivers and the power to operate them of magnetic radiation coils have disappeared--perhaps replaced by piezoelectric transducers and optical fibre transmission " (Lybarger, 1982, p.92).

2.3.2 Disadvantages

Disadvantages of acoustic coupling include the following:
(A) Distortion of incoming signal. - The telephone receiver was designed to couple with a closed cavity, the external auditory meatus or ear canal. For maximally efficient transfer of the acoustic signal, the receiver must be held firmly against the pinna, closing off the external auditory meatus and thus creating an acoustic seal (Smith, 1971). The hearing aid case prevents sealing the hearing aid microphone to the telephone receiver. Instead of being delivered to a relatively small acoustic volume (the ear canal), the telephone signal is delivered to a large acoustic volume. As a result, considerable frequency distortion results with a significant amount of low frequency energy lost, as illustrated in Figure 9. In fact, with the telephone receiver a mere one eighth of an inch away from the ear, "very large losses are introduced at frequencies below 1 kHz" (Smith, 1971). It is within this frequency region that most of the energy of vowel sounds is located.

(B) Background noise - The lack of a proper acoustic seal creates a second significant problem. In particular, the hearing aid microphone is exposed to background noise, which is amplified by the hearing aid's amplifier by the same amount as the telephone signal, thus leading to a poor signal-to-noise ratio. While acoustic coupling may be satisfactory in quiet locations, it can become unacceptable in noisier locations.

"It should be remembered that, in general, the usefulness of hearing aids suffers in noise...when hearing aids are designed which function well in noisy environments, telephone coupling via the acoustic mode will be facilitated "(Stoker, 1981, p.12).

It should be noted that the elimination of unwanted noise is still a major unsolved problem of hearing aid design.
If the telephone receiver does not touch the ear in such a way as to form a seal, low frequency response is lost. To obtain data for this graph tests were made with an artificial ear that simulates the sensitivity to sound of a normal human ear. If a hearing aid is used, the situation is more complicated and sounds that reach the ear are less intelligible.

Figure 9. The above graph shows the effects on the frequency response of a telephone receiver when it is held 1/8 of an inch from an artificial ear (reproduced from Goldberg, 1975, with permission).
(C) **Increased chance of acoustic feedback.** - A third major problem with acoustic coupling is the increased probability of acoustic feedback. When a high gain hearing aid in the microphone mode is brought close to a hard reflective object (in this case a telephone receiver), a "squealing" sound is often produced, due to acoustic feedback. In particular, if there is any signal leakage from the hearing aid receiver, the earmold, or both, it can be picked up by the hearing aid microphone and reamplified. The greater the intensity of the leaked signal when it reaches the hearing aid microphone, the greater the chances for feedback to occur. When acoustic coupling between hearing aid and telephone receiver is employed, there are three potential reasons for acoustic feedback: (a) the earmold may be loose; (b) there may be a crack in the hearing aid case or in the earmold tubing; or (c) the volume on the hearing aid or telephone amplifier may be too high. In most instances, acoustic feedback not due to a loose earmold or to cracked tubing can be eliminated by one of the following: a) reducing the volume of the hearing aid and/or handset amplifier; b) moving the handset away from the hearing aid case to reduce the overall sound pressure level at the hearing aid microphone; and/or c) holding the receiver at a slight angle near the microphone of the hearing aid (Selwyn, 1975).

(D) **Degradation of outgoing signal.** - Smith (1971) claims that acoustic coupling also affects the person on the other end of the line since acoustic feedback may be heard through the telephone. The speech signal received by the other communicator may also be substantially reduced because people who use acoustic coupling have a tendency to hold the telephone microphone far from their mouths, which can result in an up to 20 dB decrement in the outgoing speech signal level. For optimal
transmission, the distance from mouth to telephone microphone should be less than one-half inch (Smith, 1971).

(E) Disconnection of long distance connections. - Acoustic feedback may also generate some frequencies which, when transmitted to the telephone through the microphone, activate automatic equipment and can cause long-distance connections to be broken (C. Laszlo, personal communication).

2.4 Acoustic Tube Method and In-the-Ear Hearing Aids

Hearing aid researchers have been actively pursuing a solution to some of the problems associated with acoustic coupling namely ambient noise, acoustic feedback and reduced fidelity.

In 1977, Arndt and his associates at Bell Northern Research described a new concept in acoustic coupling. It involved a polyethylene tube originating at the microphone port of a behind-the-ear (BTE) hearing aid and terminating in the concha. The user would place the telephone receiver against the pinna in the usual manner. Acoustic feedback was a major problem with this design, however, since the telephone receiver enclosed both the entrance to the hearing aid microphone (the tubing) and the earmold. Later, a modification was proposed whereby the tubing would extend forward along the user's cheek in front of the ear where the tissue is fleshy, thus promoting efficient coupling between the telephone receiver and the tubing (Lybarger, 1982). This modification is illustrated in Figure 10. Beecher (1979) proposed a variation on this theme. He proposed a BTE aid with a separate microphone or 'tele-mic' for telephone listening located at the base of the hearing aid.
Figure 10. Diagram of a hearing aid with tube microphone modification. The appropriate telephone receiver placement is also shown (reproduced from Stoker, 1982, with permission).
Instead of activating the telecoil, the switch on the hearing aid case would deactivate the regular microphone and activate the tele-mic. A one and one half inch piece of polyethylene tubing extends from the tele-mic port to just below and behind the pinna. The tissue in this area is also quite fleshy, promoting a good seal, as illustrated in Figure 11. The acoustic tube was designed with the intention of reducing ambient noise interference, improving fidelity (decreasing loss of low frequencies) and decreasing feedback. It also had an advantage in that only one switch position, 'M', is required for all situations, (Arndt & Wojcik, 1981). The physical appearance of the tubing was considered a major disadvantage and this mode of telephone coupling never became popular.

The 1980's saw a surge in the popularity of the in-the-ear (ITE) hearing aid with the hard of hearing consumer. These hearing aids are completely contained within the concha of the ear, as shown in Figure 12. It is possible, when wearing this type of aid, to create an acoustic seal between the telephone receiver and the pinna. This results in minimal ambient noise interference and in an efficient transfer of the acoustical signal (Beecher, 1979). While this appears to be an ideal solution to the problems encountered with acoustical coupling, two points must be made: (1) as of yet, ITE hearing aids are not suitable for every individual, nor for every hearing loss; and (2) a portion of the amplified signal always escapes around the edges of the hearing aid or via the vent, resulting in some feedback with higher gain hearing aids (Arndt & Wojcik, 1981; Lybarger, 1982). In general, the greater the degree of hearing loss, the greater the degree of difficulty encountered in coupling ITE's and telephone receivers acoustically. Some help may be provided by affixing a foam "doughnut" shaped cushion around the telephone receiver's periphery, increasing the distance
Figure 11. (A) illustrates how sound leaks in and out when a telephone receiver is used with a behind-the-ear or eyeglass hearing aid; (B) illustrates acoustic coupling with an unaided ear or with an in-the-ear hearing aid; (C) illustrates acoustic coupling with a separate telephone-microphone (tele-mic) hearing aid neck coupler (reproduced from Beecher, 1979, with permission).
Figure 12. Diagram showing an in-the-ear hearing aid and telephone receiver.
between the hearing aid microphone and the reflective surface of the telephone receiver.

2.5 Advantages and Disadvantages of Receiver Amplifiers

2.5.1 Advantages

Receiver amplification has several advantages: (A) it is easy to use; (B) it gives faithful reproduction (Lybarger, 1982); (C) it improves communication in locations where background noise is excessive (i.e., it improves the signal-to-noise ratio by amplifying the message without increasing significantly the background noise level); (D) in many cases, it provides an amplified signal equivalent to that produced by a aid on its telecoil setting, approximately 104 dB SPL (Pichora-Fuller, 1981); (E) it provides a range of acoustic outputs sufficient for people with a hearing loss of up 70 dB (Martin, 1983); and (F) for those who do not wear their hearing aid(s) at all times, it provides access to the telephone in those instances when they are not wearing their hearing aid(s).

2.5.2 Disadvantages

Receiver amplification also has disadvantages: (A) it offers limited gain (although it can be combined with a hearing aid in either its telecoil or microphone mode to raise the signal level); (B) it requires specially equipped telephones and therefore does not fit the criterion of universal accessibility; (C) it lacks portability; (D) when combined with a hearing aid, it greatly increases the chance of feedback occurring; and (E) the user has to find the correct balance between the amount of
volume needed from each device (the amplifier and the hearing aid) without causing feedback (Castle, 1978).

In addition to built-in receiver amplification, battery-operated magneto-acoustic amplifiers which can be attached externally also exist, as illustrated in Figure 13. These amplifiers fit over the telephone receiver and use its magnetic output to produce a stronger acoustic signal than is normally generated. The advantage (for some users) of these units lies in their portability from telephone to telephone. As for disadvantages: (A) these units are reported to have less gain than built-in amplifiers (Castle, 1981); (B) they are not appropriate for inductive coupling with a hearing aid, as only a strong acoustic signal is produced; and (C) finally, these amplifiers do not always fit on all telephone receivers that one may wish to use.
Figure 13. Diagram of a magneto-acoustic amplifier. This device uses the magnetic output of the telephone receiver to produce a stronger acoustic signal than is normally generated.
CHAPTER 3
PERFORMANCE EVALUATION OF TELEPHONE COUPLING MODES

In Chapter 2, we looked at the technical and operational advantages and disadvantages of inductive coupling, acoustic coupling, and receiver amplification. This, however, tells us little about how hard of hearing people actually perform in the telephone listening situation with these available options. It is, therefore, appropriate at this point to review the literature concerned with the performance of individuals using various modes of telephone coupling.

3.1 Review of the Performance Literature

Prior to any direct evaluation of the coupling between telephones and hearing aids, researchers compared the intelligibility of speech reproduced by hearing aids operating in telecoil and microphone modes of operation. In these early studies, induction loops rather than telephone receivers were used to generate the electromagnetic input to the telecoil. Kortschot (cited by Hodgson & Sung, 1972) reported that hard of hearing children exhibited significantly better discrimination scores when using an induction loop amplification system than when using a conventional hearing aid in its microphone mode of operation. Vargo, Taylor, Tannahill & Plummer (1970) evaluated the intelligibility of speech reproduced by hearing aids operating on telecoil and microphone modes of operation. They found in contrast that speech signals were significantly less intelligible when the hearing aid was operated on the telecoil setting than on the microphone setting. Sung & Hodgson (1971) found that the hearing aid mode which produced the better high frequency response (i.e., in the region of 1500 to 3000 Hz) produced better intelligibility for
monosyllabic words, regardless of the input mode. Hodgson & Sung (1972) found that the better low frequency response (i.e., below 1000 Hz) afforded by the telecoil appeared to increase sentence intelligibility but did nothing for the intelligibility of monosyllabic words. Thus, it seems that it cannot be claimed that either input mode in itself produces a more intelligible speech signal, but that the frequency response of a hearing aid in each mode must be considered.

Arndt (1976) reported on a study conducted at Bell Northern Research which sought to gather information pertaining to the hard of hearing and their use of the telephone. The study involved 301 respondents from three major Canadian cities. According to this survey:

(a) 42.4% made use of their hearing aid telecoil for telephone coupling, 22.6% made use of their hearing aid microphone, 26.6% used the telephone unaided and 8.7% did not use the telephone at all.

(b) Those whose hearing aids contained a telecoil and who had received specific instruction on its use, preferred the telecoil rather than the microphone by a ratio of five to one. Those who had a telecoil but did not receive specific instruction on its use, preferred the telecoil rather than the microphone by a ratio of two to one.

(c) Both telecoil and microphone users reported similar degrees of satisfaction. Thus, according to this survey, the telecoil was found to be the most common mode of telephone coupling for hard of hearing users.

Nielsen & Gilberg (1978) tested 203 subjects on a number of telephone assistive devices (including hearing aids coupled either acoustically or inductively) under two line attenuation conditions, one simulating a good line, the other a poor quality line. The subjects' task involved answering five easy questions under various
telephone-assistive device options. The session was terminated when a subject had successfully responded to all five questions. The conditions were ordered such that the least expensive telephone-assistive device option was presented first and the most expensive last. The results indicated the following:

(a) those hard of hearing subjects with a speech reception threshold (SRT) of less than 40 dB in their better ear could successfully use the telephone without additional equipment. Those with an SRT between 40 and 60 dB obtained successful results unaided with receiver-amplified acoustic output. For those with a higher SRT, up to 70 to 75 dB, a standard telephone plus a hearing aid, primarily in the telecoil mode was preferred. For those with an SRT greater than 70 to 75 dB, a standard telephone with receiver amplification used in conjunction with a hearing aid primarily in the telecoil mode yielded the best results.

(b) This study revealed that not only does line attenuation, auxiliary equipment used and severity of hearing loss affect speech intelligibility by telephone, but so do the nature, the configuration, and the type of loss. Twelve subjects with sensorineural loss never attained three correct responses under any condition, whereas all of those with conductive and mixed losses attained at least three correct responses in at least one condition.

Stoker (1981) tested 205 subjects, all either moderately or severely hard of hearing, under four telephone coupling conditions: (1) acoustic coupling; (2) inductive coupling; (3) receiver amplification; and (4) acoustic tube method. Two levels of background noise were used. A speech perception task was administered and yielded the following results:
(a) Speech perception scores decreased with an increase in hearing loss severity.
(b) The receiver-amplified and inductive coupling conditions produced significantly better speech perception scores than either acoustic coupling or the acoustic tube method.
(c) The higher noise conditions resulted in lower scores, than the low noise conditions, for all hard of hearing subjects.
(d) The background noise was less debilitating under the receiver-amplified and inductive coupling conditions.
(e) The severely hard of hearing were more sensitive to changes in coupling modes and noise levels.

Stoker concluded that the most effective telephone coupling method in noise, for most hard of hearing people, is receiver amplification, unaided. When such an amplifier is not available, inductive coupling is the method of choice for most. It would have been interesting to see how inductive coupling with receiver-amplified output would have ranked with respect to the coupling methods tested in this study. Large individual differences were noted, therefore group data may not accurately reflect the preferred choice for a specific individual. Since low scores for certain modes may have been due to lack of familiarity, Stoker proposed that experience with a given coupling mode may be more important than any other factor.

Lowe & Goldstein (1982) tested ten subjects, all either moderately or severely hard of hearing, under four telephone coupling conditions: (1) standard receiver, acoustically coupled; (2) standard receiver with a retrofitted fluxcoil, inductively coupled; (3) standard receiver with a Western Electric 100A strap-on acoustomagnetic coupler, inductively coupled; and (4) standard receiver with Nuvox strap-on
acousto-magnetic coupler, inductively coupled. Speech recognition scores were obtained. Subjects were also required to make a quality judgement of the four modes. The speech recognition data revealed the following:

(a) No one mode was best for all subjects; some subjects performed equally well with several modes.

(b) Quality judgement results also revealed that not all of the subjects preferred the same mode and that one or two other modes seemed equally pleasant to some listeners.

(c) Based on both speech recognition scores and quality judgements, acoustic coupling was recommended for three out of ten subjects and one of the forms of inductive coupling for the other seven (four were recommended the retrofit fluxcoil, two the Nuvox coupler and one the 100A coupler).

Lowe & Goldstein concluded by remarking:

"Different people do better with and prefer different hearing aid-telephone coupling systems and because these differences exist, it is recommended that audiologists develop methods of evaluating the different coupling methods with each patient and notify the telephone companies, the hearing aid industry and the general public of the results." (Lowe & Goldstein, 1982, p. 234)

Cashman et al. (1982) tested seventeen subjects, each falling into one of two hearing loss groups (moderate or severe). Each group member was tested with two different standard hearing aids specific to his or her group, as well as with the acoustic tube modified version of each aid. Each subject was tested under the following four listening conditions: (1) unaided; (2) wearing standard aid #1; (3) wearing standard aid #2; and 4) wearing the modified version of either standard aid #1 or #2. Under
each condition, the following six measures were obtained; (i) thresholds for narrow band noise; (ii) SRT; (iii) word discrimination score in quiet; (iv) word discrimination score in a +5 dB signal-to-noise ratio noise; (v) uncomfortable loudness level (UCL) for speech; and (vi) order of preference of aids in terms of the quality and clarity of speech, appearance, and physical comfort of the aid. These measures revealed the following:

(a) the acoustic tube modification did not produce a significant psycho-acoustic change. This was a surprising result since an electroacoustic analysis had indicated that the acoustic tube modification had a weaker output in the high frequencies, when compared with its standard microphone counterpart.

(b) Subjects judged less often the acoustic tube modified aid to be the clearest of the three aids tried.

Within the same study, a second experiment was undertaken. Twenty-four subjects, all either moderately or severely hard of hearing, were tested under the following three receiver configurations: (1) U-1 receiver\(^2\) with a hearing aid in the telecoil mode; (2) Balanced Armature Receiver (BAR) with a hearing aid in the microphone mode; and (3) BAR with an acoustic tube modified aid in the microphone mode. Under each condition, speech recognition scores for words were obtained: (i) in quiet; (ii) with phone noise (white noise) only; (iii) with room noise only; and (iv) with phone noise and room noise combined. Quality judgements were requested. Cashman et al. were able to extract certain general findings from their data:

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\(^2\) The U-1 telephone receiver was in use by Bell Canada from 1951 until their introduction of the Balanced Armature Receiver (BAR) in 1976. The U-1 receiver provided a strong magnetic field in the vicinity of its casing.
(a) Listening in noise (either phone noise or room noise) was more difficult than
listening in quiet.
(b) Room noise was less detrimental than phone noise.
(c) When coupling was acoustic, with either a normal microphone or a modified
microphone, phone noise and room noise combined produced more
masking than either alone.
(d) In the acoustic conditions, a noisy background was more detrimental to
those with a severe loss than to those with a moderate loss; this was also
noted by Stoker (1981).
(e) For most conditions with noise, speech recognition scores were better for the
inductive condition than with either acoustic condition. In noise, the acoustic
tube modification did provide some improvement over the standard
microphone, however.
(f) Inductive coupling was ranked highest most often in terms of clarity for both
hearing loss groups followed by acoustic coupling (with the standard
microphone) and lastly tube-modified acoustic coupling.
(g) No differences in physical comfort were reported although there was some
opposition to the appearance of the tube-modified microphone.

Cashman et al. concluded that for those with a severe hearing loss, inductive coupling
is superior to acoustic coupling. Although both hearing loss groups achieved the
same mean word recognition in the inductive mode, the scores of those with a severe
hearing loss decreased in both acoustic conditions, due to the fact that they were
unable to obtain high enough signal levels in these conditions without creating
acoustic feedback. Inductive coupling, they concluded, is more essential for those with
a severe hearing loss.
Stoker, French-St. George and Holmes (1982) investigated the effect of altering the frequency response of incoming telephone stimuli on the discrimination performance of normal and hard of hearing subjects using acoustic coupling. Subjects were twenty hard of hearing persons (ten moderately and ten severely hard of hearing) as well as ten with normal hearing. Composite Boothroyd Test lists were routed through a hearing aid acoustically coupled to a telephone receiver and recorded. These lists were recorded at each of three presentation levels (85, 95 and 105 dB SPL) in quiet and in noise (60 dB SPL). The recorded lists were then routed through one of four filter configurations (flat, bimodal, low pass and high pass) and presented to the subjects via standard headphones. One inductive coupling condition was also used for comparison. In addition to the noise present in the recordings, subjects experienced the various conditions both with and without noise presented to the contralateral ear (60 dB SPL). These researchers found the following:

(a) In quiet, the flat, bimodal and low pass frequency shapings were just as effective as inductive coupling for all subjects.

(b) In a background of noise, magnetic coupling was superior to all frequency shapings.

(c) For the normal hearing and moderately hard of hearing groups, the results from the three acoustic coupling modes (flat, bimodal and low pass) were not significantly different from each other. The severe group found the flat response best.

(d) The high pass filtering condition caused performance to be degraded for all subjects in both quiet and in noise. It must be noted that a typical hearing aid amplifying circuit also acts as a high pass filter. This circuitry is effective in normal listening conditions (i.e. free field) but is detrimental for telephone
listening where it limits the low frequency information available. As discussed previously in section 2.3.2 part A, low frequency information is already lost prior to the signal reaching the hearing aid microphone due the lack of 'fit' between hearing aid microphones and telephone receivers.

They concluded that in order for acoustic coupling to be effective, a separate circuit must be provided in the hearing aid especially for telephone communication. This circuit should provide either linear or bimodal gain to the signals arriving at the hearing aid microphone. This would be as effective as inductive coupling in quiet situations and nearly as effective in moderate amounts of background noise. But, in high levels of noise, inductive coupling remains the method of choice.

Tannahill (1983) obtained word discrimination scores from 27 normal hearing subjects. The recorded word lists presented to these subjects had been processed through: (1) a transmitting telephone; (2) a receiving telephone; and (3) a hearing aid (two different hearing aids were compared) either inductively or acoustically coupled to the receiving telephone. Three different telephone receivers were used in the recording of the inductive coupling conditions and are described elsewhere (section 2.1.2). Word lists were recorded with competing noise (-5 dB S/N) and presented at a comfortable level over loudspeakers. The results were as follows:

(a) Both hearing aids produced the same rank ordering of reception modes i.e., microphone reception, R_md/telecoil, R_100/telecoil followed by R_s/telecoil. Only one out of the two hearing aids compared produced a significant difference between the microphone and R_md/telecoil conditions.

(b) For both aids, microphone reception produced significantly higher word discrimination scores than either R_100/telecoil or R_s/telecoil.
Tannahill concluded that switching from microphone reception to telecoil reception is not likely to increase word discrimination but might cause a significant decrease depending on which receiver provided the telecoil input. Also in this study, word lists were processed from transmitting telephone to a receiving telephone and then recorded (to simulate unaided telephone reception). No significant difference was found between telephone/telephone reception and microphone/telephone reception in terms of word intelligibility scores.

Holmes & Frank (1984) tested fifteen subjects falling in one of three hearing loss categories, under the following three experimental conditions: (1) unaided, TDH-39 earphone; (2) unaided with handset amplification; and (3) aided, acoustically coupled, plus handset amplification. Under each condition, a speech discrimination score was obtained with: (i) the output of the earphone or telephone set to 86 dB SPL at 1000 Hz, simulating the output level of a standard telephone handset at 1000 Hz; and (ii) the output of the earphone or telephone set to their most comfortable level (MCL), somewhere between 86 and 103 dB SPL at 1000 Hz, simulating the output range of a receiver amplifier at 1000 Hz. The results were as follows:

(a) For those in the precipitous hearing loss group, use of a standard telephone handset without receiver amplification was found to be appropriate. This group outperformed the other two groups in all three experimental conditions, regardless of the presentation level (86 dB SPL or MCL); they performed similarly to normal listeners. The fact that this group had relatively normal thresholds up to 2000 Hz seemed to preserve their telephone listening ability. Holmes & Frank explain that one would not expect an improvement in word discrimination at MCL for this group, since a presentation level of 86 dB SPL (67 dB HL) would place the speech material
at a sensation level favorable enough to achieve PB-max, the best possible score that an individual can attain on a test of auditory discrimination using phonetically balanced words.

(b) Despite their differing audiometric configurations the groups with gradual sloping hearing loss and with flat hearing loss, respectively, had similar word discrimination scores. Both groups had similar pure tone thresholds in the 1000 to 2000 Hz frequency range, indicating that they received similar speech cues. For both the gradual sloping loss and the flat loss groups, both receiver amplification and acoustic coupling were found to be fairly equivalent in quiet situations. Better word discrimination was achieved at MCL than at 86 dB SPL for these two groups. Their use of the receiver amplifier enabled them to achieve a more favorable presentation level, and hence better word discrimination scores, due to the greater sound pressure level available.

(c) Both TDH-39 earphones and the telephone transducers produced fairly similar scores within a given level for each group. Note that although the bandwidth of the TDH-39 earphone is significantly broader (130-6500 Hz vs. 300-3300 Hz), both cover the critical frequency range (500-3300 Hz) needed for speech understanding.

In summary, unaided telephone use is adequate for those with a precipitous drop loss in quiet situations. Those with a gradual slope or flat hearing loss would do about equally well with either a receiver amplified phone with an unaided ear, or with their hearing aid acoustically coupled to a receiver amplified handset.

Stoker et al. (1985) tested twelve subjects falling in one of three hearing loss categories, under four experimental conditions: (1) U-1 receiver with an aid
inductively coupled; (2) BARC receiver (balanced armature receiver with a fluxcoil), inductively coupled; (3) dynamic receiver\(^3\), inductively coupled; and (4) dynamic receiver with an acousto-magnetic coupler, inductively coupled. Under each condition, a speech discrimination score was obtained at five signal levels (80, 85, 90, 95, and 105 dB SPL) as well as with three different hearing aids. The hearing aids differed in telecoil location, type and/or orientation. According to their results:

(a) There does not seem to be an optimal size, location or sensitivity for the telecoil. However, subjects were free to manipulate the receiver against their hearing aid case such that the magnetic signal would be the strongest. This often resulted in a receiver placement inappropriate for effective transmission of a phone message by the hard of hearing person.

(b) There was a significant improvement in discrimination scores across all hearing loss groups as the signal level was increased from 80 dB SPL to 105 dB SPL. Note that receiver-amplification was not a focus of this study, nor was an actual receiver amplifier used to increase the signal level. Upon discovering this improvement in discrimination scores, no reference was made to the potential benefit that dual inductive and receiver-amplified coupling could provide hard of hearing people.

(c) The U-1 and the BARC receivers resulted in identical word discrimination. The dynamic receiver with the acousto-magnetic coupler did not perform as well as the U-1 and BARC receivers however, particularly at high signal levels. A potential explanation may lie in the fact that the air-conducted

\(^3\) The dynamic receiver is a low-magnetic flux receiver made by Aprel Acoustics.
signals which emanate from the U-1 and BARC receivers are transmitted through the subject's earmold and tubing, thus augmenting the inductively transmitted signal with an acoustic one. Because the acousto-magnetic coupler is a rubber shaped cup, it would block any supplementary acoustic transmission.

Having reviewed the literature, can we equivocally conclude that there is a single mode of telephone coupling for the hard of hearing that is superior to all others? This question is difficult to answer because studies carried out in the past tend to vary in: (1) the types of telephone coupling used for comparison; (2) the criteria by which the hearing loss of subjects is defined (e.g., speech reception threshold (SRT), pure tone average (PTA), configuration of the loss); and (3) the experimental conditions which may have included the presence of noise (background or line) among other factors. Despite the lack of uniformity from study to study, certain general findings do emerge:

(i) group data is not necessarily predictive of individual success;
(ii) inductive coupling is superior to acoustic coupling especially under conditions of noise and/or severe hearing loss; and
(iii) most hard of hearing persons perform best with either handset amplification or inductive coupling.

3.2 Statement of Aim of the Experiment
Previous research has shown the benefit obtained by hard of hearing people when using direct magnetic coupling from the telephone receiver to the hearing aid. Receiver amplification has also been shown to provide benefits. In addition, it is
known from informal surveys of hard of hearing people that many of them use telephones with a dual capability, magnetic coupling and receiver amplification. While some studies have touched upon this topic, this mode of dual capability has yet to be investigated directly.

This study proposes to answer the following questions. Does the addition of receiver amplification in the telephone handset significantly improve the speech perception ability of the hard of hearing persons when using magnetic coupling to couple telephone and hearing aid? If there is significant benefit, will this benefit vary as a function of: (a) changes (attenuation) in line conditions; and/or (b) the predictability of the speech material encountered (high versus low)?
CHAPTER 4
MATERIALS AND METHODS

4.1 Subjects

There were ten adult subjects, seven females and three males, aged between 25 and 69, with a median of 58 years. Four subjects had a "moderate" sensorineural hearing loss, as defined by Goodman (see Yantis, 1985, p 164), i.e., a pure tone air conduction loss averaged at 500, 1000 and 2000 Hz greater than 40 dB HL but less than 55 dB HL in their test ear. Five subjects had a "moderately-severe" sensorineural hearing loss, again as defined by Goodman, i.e., a pure tone air conduction loss averaged at 500, 1000 and 2000 Hz greater than 55 dB HL but less than 70 dB HL in their test ear. One subject had a "profound" mixed hearing loss, again as defined by Goodman, i.e., a pure tone air conduction loss averaged at 500, 1000 and 2000 Hz greater than 90 dB HL in his test ear. (Mixed hearing loss is defined as a loss in which bone conduction thresholds are reduced but air conduction thresholds are even more reduced so that there is an "air-bone" gap greater than 10 dB at one or more frequencies). Etiologies of the hearing losses were diverse, including hereditary loss, head trauma, congenital rubella, prolonged noise exposure, and otosclerosis.

All subjects were experienced full-time hearing aid wearers; their experience ranged from 1 to 31 years, with a median of 14 years. They all used a behind-the-ear hearing aid with a telephone switch. Their unaided discrimination scores for the test ear ranged from 46 to 84% when measured with the Northwestern University Auditory Word List #3. For Subject #4, the audiometer limits precluded presentation of the test words at an adequate sensation level. Consequently, no valid estimate of speech discrimination was possible for this subject. Eight subjects were native English
speakers. Two subjects were native Hungarian speakers, with a native command of English. Six subjects reported they normally used their left ear for telephone listening; the other four reported using their right ear. Nine of the ten subjects reported using inductive coupling, either some or all of the time. Two of these nine subjects reported using inductive coupling with a handset amplifier. One subject reported using acoustic coupling with receiver amplification, but had never used inductive coupling. Two subjects rated their telephone communication ability as "good all of the time", three rated it as "good most of the time", four as "fair" and one as "poor". Table II presents a summary of the subjects' personal and auditory data.

All potential subjects were sent a letter of introduction outlining the project and a questionnaire requesting information on their hearing loss, hearing aid(s) and telephone communication ability (see Appendix A for the full questionnaire). After the questionnaires were returned, each selected subject was scheduled for a single three hour experimental session held at the School of Audiology and Speech Sciences, on the campus of the University of British Columbia. During the experimental session, measures were taken of each subjects' speech perception ability when listening to the telephone using their hearing aid inductively coupled to the telephone receiver both with and without the option of using receiver amplification. All measures were taken in a background of multitalker noise, in order to simulate a typical listening situation (Stoker, 1981). Holmes, Frank & Stoker (1983) have found that telephone listening ability is influenced by both the type and level of background noise. Regardless of level, multitalker noise was found to be significantly more deleterious to telephone listening than white noise. Subjects were presented test items (to be discussed below in 4.2) through a telephone receiver, at four levels (two predetermined by the examiner
Table II. Summary of subjects' personal and auditory data.

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Sex</th>
<th>Age</th>
<th>Mother tongue</th>
<th>Test ear</th>
<th>Hearing loss. (test ear)</th>
<th>Etiology</th>
<th>Discrim. (test ear)</th>
<th>Hearing aid use in years</th>
<th>Self rated telephone ability</th>
<th>Method(s) of coupling used</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>F</td>
<td>69</td>
<td>English</td>
<td>L</td>
<td>moderate sens.</td>
<td>hereditary</td>
<td>70% poor</td>
<td>8</td>
<td>mostly good</td>
<td>ac., ind.</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>63</td>
<td>English</td>
<td>L</td>
<td>moderate sens.</td>
<td>noise induced</td>
<td>58% poor</td>
<td>7</td>
<td>fair</td>
<td>ind., amp.</td>
</tr>
<tr>
<td>3</td>
<td>F</td>
<td>61</td>
<td>English</td>
<td>L</td>
<td>mod-severe sens.</td>
<td>hereditary</td>
<td>46% very poor</td>
<td>23</td>
<td>mostly good</td>
<td>ac. + amp.</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>55</td>
<td>Hungarian</td>
<td>L</td>
<td>profound mixed otosclerosis</td>
<td>CNT</td>
<td>31</td>
<td>mostly good</td>
<td>ind. + amp.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>53</td>
<td>English</td>
<td>R</td>
<td>moderate sens.</td>
<td>unknown</td>
<td>50% very poor</td>
<td>21</td>
<td>fair</td>
<td>ind., un.</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>33</td>
<td>English</td>
<td>R</td>
<td>mod-severe sens.</td>
<td>hereditary</td>
<td>60% poor</td>
<td>8</td>
<td>fair</td>
<td>ac., ind., amp.</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>66</td>
<td>English</td>
<td>R</td>
<td>mod-severe sens.</td>
<td>noise induced</td>
<td>84% good</td>
<td>12</td>
<td>fair</td>
<td>ind. + amp.</td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>36</td>
<td>English</td>
<td>L</td>
<td>moderate sens.</td>
<td>hereditary</td>
<td>74% fair</td>
<td>1</td>
<td>always good</td>
<td>ind.</td>
</tr>
<tr>
<td>9</td>
<td>F</td>
<td>68</td>
<td>Hungarian</td>
<td>L</td>
<td>mod-severe sens.</td>
<td>head trauma</td>
<td>78% fair</td>
<td>15</td>
<td>fair</td>
<td>ind. + amp., amp.</td>
</tr>
<tr>
<td>10</td>
<td>F</td>
<td>25</td>
<td>English</td>
<td>R</td>
<td>mod-severe PTA=60</td>
<td>congenital rubella</td>
<td>68% poor</td>
<td>20</td>
<td>always good</td>
<td>ind.</td>
</tr>
</tbody>
</table>

Legend:
sens. = sensorineural
ac. = acoustic coupling
ind. = inductive coupling
un. = unaided ear
amp. = handset amplifier; unaided ear
ac. + amp. = acoustic coupling + handset amplification
ind. + amp. = inductive coupling + handset amplification
and two selected by the subject). The average SPL for telephone transmission of speech has been reported as 86 dB SPL (Stoker, 1981). This presentation level was used for the *good telephone line* condition. A presentation level of 70 dB SPL corresponds to the maximum line attenuation allowable within the area serviced by a central telephone office i.e., 16 dB. The 70 dB presentation level was used for the *poor telephone line* condition. In addition, two subject-determined presentation levels were examined and used. In one condition, the output of the telephone was set initially to 86 dB SPL but then could be adjusted by the subjects to a maximum of 107 dB SPL, by manipulating the receiver-amplifier. This presentation level corresponds to *inductive coupling plus receiver amplification with a good telephone line* condition. In another condition, the output of the telephone was set initially to 70 dB SPL but then could be adjusted to a maximum of 91 dB SPL, again by manipulating the receiver-amplifier. This presentation level corresponds to *inductive coupling plus receiver amplification with a poor telephone line* condition.

4.2 Stimuli

Traditionally, measurement of speech recognition by listeners has consisted of the percentage of monosyllabic words recognized and repeated correctly. Such testing has been criticized for being a poor predictor of performance in everyday speech, in which phonological, lexical, syntactic and semantic cues influence speech recognition. This type of testing generally exhibits the following weaknesses: (1) an unrealistic testing environment (quiet); (2) unrealistic speech materials (isolated monosyllables); and (3) unreliable scores, due to live voice presentation as well as to the practice of presenting half instead of full lists. In the present experiment, in order to
avoid the weaknesses just mentioned, speech recognition was assessed by utilizing parts of the Revised Speech Perception in Noise (R-SPIN) test (obtained from its developer, Dr. Robert C. Bilger via a colleague). Previous research in the area of hearing aid-to-telephone coupling has also been conducted using the SPIN test (Stoker, 1981; Lowe & Goldstein, 1982). The SPIN test developed by Kalikow, Stevens & Elliot in 1977 (Kalikow et al., 1977) was revised and restandardized by Bilger, Nuetzel, Rabinowitz and Rzeczowski in 1984 (Bilger et al., 1984). The SPIN test was developed as a more useful index of everyday speech reception: it proposes to measure utilization of linguistic-situational information as well as acoustic-phonetic information by the listener. Its creators explained that two kinds of operations are involved in the understanding of everyday speech, one being the reception and processing of acoustic information through the auditory system, the other being the utilization of linguistic information that is stored in memory, specifically our knowledge of phonological, lexical, syntactic and semantic constraints that occur in language. It was the belief of Kalikow and colleagues that both the acoustic-phonetic and linguistic-situational components of speech processing should be assessed. In hopes of more closely replicating a real life listening situation, they designed a test which contained sentence material instead of monosyllables and was meant to be used in the presence of a multitalker noise (12-speaker babble) background. In order to assess the components of speech recognition (acoustic-phonetic and linguistic-situational), they varied the predictability of the key word in each test sentence. If the predictability of the key word (always the last word in each sentence of the test) is low (e.g., "Jane did not speak about the slice"), the listener must depend primarily on acoustic properties. If the predictability of the key word is high (e.g., "get the bread and cut me a slice"), the listener is aided in the identification of the key word by the
syntactic, semantic and prosodic cues available in the sentence, as well as by the acoustic cues of the word itself. The SPIN test, in its revised form, consists of eight forms, each form containing 50 items (25 high predictability sentences and 25 low predictability sentences) intermixed in random fashion. A single-word response (always the last word of the sentence) is required. The single-words are always monosyllabic nouns whose frequency of usage in English is neither very high nor very low. The listener's use of context is measured by the SPIN test difference score, namely the numerical difference between the score obtained on the high predictability items and that obtained on the low predictability items. However, it was concluded by Owen (1981) that the difference score was significantly related to the subject's hearing and to the signal-to-noise ratio used in the administration of the test rather than to the listener's language skills (as assessed by various syntactic and semantic measures). In the manual, accompanying the test, Bilger claims that the eight forms of the R-SPIN are psychometrically equivalent in terms of difficulty, variability and reliability; they are also balanced for syllable-, vowel-, and consonant type. The recordings of each form include the test sentences, spoken by an adult male of General American dialect on Track 1, and the 12-speaker babble on Track 2, at an r.m.s. level comparable to that in the test sentences. The babble noise level decreases by 10 dB just prior to the onset of the number cue for each sentence and is then restored to its original level; this helps the listener keep place. Calibration tones have been inserted on both speech and babble tracks before the recording of each test form. Bilger cautions that the nature of the development and standardization conducted on the R-SPIN test imposes limitations on its use. Its users must be aware of the following: (1) the SPIN test is what is recorded on the test tapes and is not any other utterance of the written sentences; copies of the magnetic tape recordings must be obtained from the investigator (Dr.
Robert C. Bilger) or the project officer (Dr. Earleen F. Elkins); (2) the R-SPIN test was standardized for a signal-to-noise ratio of +8 dB; the equivalence and high reliability of the test forms cannot be presumed to exist at other signal-to-noise ratios; and (3) the R-SPIN test was standardized on a group of American English native speakers and its use with non-native speakers, children, or the prelingually deafened cannot be recommended; (4) the R-SPIN test was developed and standardized with speech and babble mixed electronically. It was presented through a single transducer (earphone); if a different relation between the source location of the speech and that of the noise is used, the standardization may be inapplicable; (5) the scores obtained are valid estimates of the percentage of hearing for speech only if the client's scores on the high and low predictability subtests place him/her in the acceptance region of the scoring nomogram provided in the accompanying test manual; and (6) if the client consistently fails or refuses to respond to items on the R-SPIN test, his/her scores will seriously underestimate his/her ability to understand speech.

Considering the above caveats, we cannot claim that we used the R-SPIN test per se for the following reasons: (1) we used a transducer (telephone) different from that used in the standardization procedure; (2) we presented the babble in a way different from that used in the standard procedure; (3) we used two transducers instead of the recommended one; and (4) we used a different signal-to-noise ratio. Thus, we cannot use the scoring nomogram provided in the test manual nor can we claim that the forms are equivalent and retain their high reliability. We can claim, however, that we used the R-SPIN material. Despite the discrepancies from the standard procedure mentioned above, this material has several features which were considered more desirable for this experiment than those characteristic of the usual tests of monosyllabic word recognition: (1) test items are embedded within high and
low predictability sentences, therefore they are more representative of everyday speech, including telephone speech. In telephone conversations, we are confronted both with high predictability utterances, on topics we are familiar with, in conversation with people we are familiar with, and low predictability utterances, on unfamiliar topics, in conversation with unfamiliar people; (2) babble noise makes it a more realistic speech recognition assessment tool than other speech recognition materials that are administered in quiet or in the presence of unspecified noise which may be quite unrepresentative of everyday background noise; and (3) the forms are balanced for syllable-, vowel-, and consonant type; in fact, Kalikow et al. (1977) reported that the phonetic profile of the key words is not substantially different from the data reported from telephone conversations. The sentences used thus have a phonetic profile that is representative of English. Because of the advantages provided by the above features, four forms (1, 4, 6, 7) of the R-SPIN test were randomly chosen as sets of test stimuli. In addition, the practice tape provided with the test was used throughout the experimental session.

4.3 Procedure

The following four experimental conditions were selected for investigation:

C1: Inductive coupling with a good telephone line condition.
C2: Inductive coupling with a poor telephone line condition.
C3: Inductive coupling plus receiver amplification with a good telephone line condition.
C4: Inductive coupling plus receiver amplification with a poor telephone line condition.
From a practical standpoint, it was desirable to present together experimental conditions C1 & C2 on the one hand, C3 & C4 on the other hand, whether in this order or in reverse order. It was felt that it would be less confusing to the subject if similar tasks were in sequence rather than alternating between amplified and non-amplified conditions. Eight condition orders are possible, from which the following four orders were chosen:

\[
\begin{align*}
C1 & \quad C2 & \quad C3 & \quad C4 \\
C2 & \quad C1 & \quad C4 & \quad C3 \\
C3 & \quad C4 & \quad C1 & \quad C2 \\
C4 & \quad C3 & \quad C2 & \quad C1
\end{align*}
\]

It was originally hoped that there would be an equal number of subjects assigned randomly to each condition order. Having to exclude some subjects who either did not meet the criteria for inclusion or found the task too difficult led to an incomplete design in terms of subjects in each treatment order. Each subject, within a given condition order, was presented the four R-SPIN forms in the same presentation order. An experimental schedule was generated for each subject listing a randomization of each experimental condition and R-SPIN form.

<table>
<thead>
<tr>
<th>Subjects 1, 5 and 9</th>
<th>C1/Form 1</th>
<th>C2/Form 4</th>
<th>C3/Form 6</th>
<th>C4/Form 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects 2, 6 and 10</td>
<td>C2/Form 7</td>
<td>C1/Form 6</td>
<td>C4/Form 4</td>
<td>C3/Form 1</td>
</tr>
<tr>
<td>Subjects 3 and 7</td>
<td>C3/Form 4</td>
<td>C4/Form 1</td>
<td>C1/Form 7</td>
<td>C2/Form 6</td>
</tr>
<tr>
<td>Subjects 4 and 8</td>
<td>C4/Form 6</td>
<td>C3/Form 7</td>
<td>C2/Form 1</td>
<td>C1/Form 4</td>
</tr>
</tbody>
</table>

As a measure of test-retest variability, the experimental condition and form which was presented second for each subject was readministered at the end of the four
conditions. This test-retest method is similar to that employed by Holmes & Frank (1984).

The ear under test was that which was habitually used by the subject for telephone communication. Before the start of the experimental session: (1) the subject's ears were otoscopically examined, for cerumen in particular; (2) a tympanometric screening was performed; (3) a new battery was inserted in the hearing aid of the test ear; and (4) the subject's hearing aid was run through the test box and a print out obtained.

At the start of the experimental session, subjects were instructed to switch the hearing aid of the test ear to the T position and to turn off the hearing aid of the non-test ear, in order to reduce the deleterious effects of the background babble. They were informed that they would be hearing several sets of sentences through the telephone handset, accompanied by babbling noise through the loudspeakers. Their task was to repeat the last word of each sentence, even if they had to guess. Prior to each condition, the subjects were presented with several practice sentences (as many as required), at the same level as the ensuing test sentences. The subjects were instructed, both verbally and in written form, to perform the following during the presentation of the practice sentences: (1) move the receiver around the hearing aid casing, to locate optimum placement (strongest signal); and (2) adjust the volume control on their hearing aid. In the amplified conditions only, they were instructed to adjust the level of the telephone amplifier to the level they felt the most comfortable with (see Appendix B for instructions provided). They were also asked to maintain the optimal receiver position through each condition. The duration of each condition was approximately ten minutes. Subjects were encouraged to take a ten-minute break between conditions as needed.
The subjects' responses were recorded on the forms provided in the R-SPIN test manual. Whenever a subject failed to respond, the tape was stopped and he/she was instructed to guess. Whenever the experimenter was unsure of a response, the tape was stopped and the subject was asked to repeat and, in some instances, to spell out his/her answer. All responses were also tape recorded, for possible later verification.

After the experimental portion of the session was completed, a hearing test was administered. Each subject's pure tone air and bone conduction thresholds were obtained in accordance with ASHA (1978) guidelines for pure tone audiometry and the results were recorded in accordance with ASHA (1988) proposed guidelines for audiometric symbols. A speech discrimination score for the test ear was obtained using the Northwestern University Auditory Test #6 Form D List 3, in the version recorded by Auditec of St Louis, at the subject's MCL. MCL was determined with live voice, using a bracketing procedure outlined by Hemeyer (1980). Cassette tapes of the subject's responses were reviewed by the experimenter following the session.

4.4 Instrumentation

A Madsen GSI 33 (Version 2) middle-ear analyser was used (in its screening mode of operation) to obtain tympanometric measures for each subject. In addition, each subject's hearing aid was tested to verify the adequate functioning of the telecoil. A hearing aid measurement system consisting of a Fonix 5000 sound pressure chamber, electronics module, telecoil board, HA-2 earphone coupler, and battery simulator was used to verify the adequate functioning of the telecoil in each subject's hearing aid. Measurements were taken in accordance with ANSI S3.22-1982. The
gain on the hearing aid was adjusted to its full-on position and the aid was set to the T position and placed in a sinusoidal alternating magnetic field with an r.m.s. field strength of 10 mA/m at 1000 Hz. Each aid was oriented to produce the greatest coupler sound pressure level. Adequate functioning required that the coupler sound pressure level be within ±6 dB of the value specified by the manufacturer for that particular model of hearing aid. A graphic recording of the sound pressure level in the coupler over the frequency range of 200-5000 Hz was also obtained.

All speech perception testing was carried out in an IAC two-room sound treated booth suitable for ears-uncovered testing, as specified by ANSI S3.1-1977. Figure 14 shows the instrumental set-up. The set-up chosen was patterned after the following studies: Stoker, (1981); Holmes, et al. (1983) and Holmes & Frank (1984). R-SPIN Forms #1, 4, 6, 7 and the practice form, recorded on Track 1 of an audio cassette, were played from a high quality cassette tape deck into one of the line inputs of a Grason-Stadler GSI-16 audiometer; from the audiometer, they were routed to the input of an audiometer-telephone-interface, the Train-on-Phone™. The Train-on-Phone was developed by the Clinical Engineering Program and the Department of Electrical Engineering at the University of British Columbia and ALDS, Inc. of Vancouver, B.C. A similar device was developed at Bell Northern Research, as discussed in Stoker (1982), and has been used in the following studies: Stoker (1981), Cashman et al. (1982), Holmes et al. (1983), and Holmes & Frank (1984). The Train-on-Phone couples the audiometer output to the telephone, via a telephone jack located on the patch panel, on the control side of the sound-treated booth and via a second telephone jack installed on the patch panel, on the subject's side of the booth. This jack is connected to a telephone with a standard amplified handset, provided by B.C. Tel.
Figure 14. Instrumental set-up.
The receiver-amplifier handset provided 21 dB of amplification with the volume control turned up to its maximum gain position. In this way, the acoustic output requirements for receiver amplified telephones were met. These requirements state that, with the volume control in the maximum gain position, the acoustic output should be 17 dB more intense than with the volume control in the minimum gain position (CAN3-T515-M85). The magnetic output of the telephone was measured using the Magnatel 110™, a magnetic field strength meter, also designed and developed by the U.B.C. Clinical Engineering Program and ALDS, Inc. The magnetic output of the telephone was measured and compared to the acoustic output of the telephone, at 1 dB intervals, from 86 dB SPL to 107 dB SPL. Table III shows the results of these measurements. The readings in column two show the telephone receiver acoustic output in dB SPL at 1 kHz corresponding to the various amplifier volume settings, as measured in a 6 cm$^3$ coupler. The readings in column three show the telephone receiver magnetic field output (axial component) in mA/meter corresponding to those same amplifier volume settings. These readings were corrected for nonlinearity by subsequently rechecking the Magnatel 110 calibration at each point. Figure 15 shows a plot of these same measurements.

The output of the telephone handset was calibrated before data collection, using a Brüel & Kjaer (henceforth B & K) 4152 artificial ear with a B & K 4144 pressure microphone and a 6-cm$^3$ coupler. A B & K 2612 cathode-follower amplifier was used to connect the artificial ear to a B & K 2603 microphone amplifier. A B & K 4220 pistonphone was used to calibrate both the microphone amplifier and the sound level meter used for sound field calibration (see below). During calibration, the telephone receiver was held in place over the coupler by means of a custom made styrofoam holder which helped maintain the receiver in the correct and repeatable position on
Table III. Magnetic output of the telephone receiver correlated with its acoustic output.

<table>
<thead>
<tr>
<th>Amplifier Volume Setting</th>
<th>Receiver Output SPL (dB)</th>
<th>Magnatel 110 Reading (mA/meter)</th>
<th>Magnatel Calibration Voltage (V)</th>
<th>Corrected Reading (mA/meter)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>86</td>
<td>62</td>
<td>1.99</td>
<td>62</td>
</tr>
<tr>
<td>1</td>
<td>88</td>
<td>76</td>
<td>2.37</td>
<td>74</td>
</tr>
<tr>
<td>2</td>
<td>95</td>
<td>178</td>
<td>5.40</td>
<td>168</td>
</tr>
<tr>
<td>3</td>
<td>99</td>
<td>294</td>
<td>8.81</td>
<td>274</td>
</tr>
<tr>
<td>4</td>
<td>101</td>
<td>353</td>
<td>10.52</td>
<td>327</td>
</tr>
<tr>
<td>5</td>
<td>103</td>
<td>447</td>
<td>13.37</td>
<td>416</td>
</tr>
<tr>
<td>6</td>
<td>104</td>
<td>524</td>
<td>15.69</td>
<td>488</td>
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<td>7</td>
<td>106</td>
<td>657</td>
<td>19.67</td>
<td>612</td>
</tr>
<tr>
<td>8</td>
<td>107</td>
<td>727</td>
<td>21.8</td>
<td>678</td>
</tr>
<tr>
<td>9</td>
<td>107.75</td>
<td>800</td>
<td>24.1</td>
<td>751</td>
</tr>
</tbody>
</table>
Figure 15. Plot of the telephone receiver's magnetic output correlated with its acoustic output.
top of the coupler. The measurement error due to the variability of the receiver placement on the coupler was found to be in the order of 1 to 2 dB. The 1000-Hz calibration tone at the beginning of each R-SPIN tape was used to adjust the output of the cassette deck-audiometer-Train-on-Phone combination to the appropriate level of 86 dB SPL, as measured at the coupler. The calibration technique was patterned after Holmes & Frank (1984). A similar calibration technique could not be used for the poor line condition (70 dB SPL), due to the interference from ambient room noise. For this condition, since it was found that the correspondence between the audiometer dial reading and the sound pressure level in the coupler was linear, the audiometer dial was adjusted so that it read 16 dB less than for the favorable line condition.

The 12-speaker babble recorded on Track 2 of the R-SPIN recordings was played back from the cassette deck to the second line input of the audiometer, and from the speaker output to two wall-mounted Grason-Stadler loudspeakers, on the subject's side of the sound treated booth. The loudspeakers were oriented at +45° and -45° azimuth with respect to the subject. In all conditions, the babble noise was presented at 76 dB SPL (Stoker, 1981), as measured at the position of the subject's head, using a B & K 2203 sound level meter with a B & K 4145 free field microphone.

The subjects' responses were picked up by a clip-on microphone and channeled to the experimenter's headset. The subjects' responses were also recorded, via an AKAI ADM-80 microphone and an amplifier, onto a high quality cassette player.

The subject's air and bone conduction thresholds were obtained in an IAC single room sound treated booth suitable for ears-uncovered testing, as specified by ANSI S3.1-1977. A Madsen OB 802 audiometer was used with TDH-39 earphones.
mounted in MX41/AR cushions and a Radioear model B-71 bone oscillator. A cassette deck was used to present speech discrimination material to the audiometer.

4.5 Internal and External Validity of the Study

To generalize the findings of a research study it is necessary to carefully control specific variables in measurements. In our case, the internal validity of a study is defined as the degree to which the change in the dependent variable (R-SPIN scores) is in fact caused by the experimental treatment and not by other factors which may have simulated the treatment effects. The external validity of a study is defined as the extent to which the results of the study can be generalized from the study sample to the population of people from which it is drawn. The following discussion of these two types of validity, as they pertain to this study, is based on Ventry & Shiavetti (1983, pp 64-92).

4.5.1 Internal validity

(A) Fatigue and practice effects. - These are changes in subjects' performance due to fatigue and/or practice obtained through exposure to successive conditions. To control for these effects, the session was kept as short as possible (two hours of actual telephone listening including periods of rest). Subjects were randomly assigned to a given treatment order and the conditions were balanced, the assumption being that fatigue and practice effects if any existed would be distributed equally for all conditions and subjects.
(B) **Instrumentation.** - Appropriate and ongoing calibration of the equipment was performed. The test environment was maintained constant across all conditions (i.e. the multitalker babble was maintained at 76 dB SPL). In an effort to reduce rater bias at the time of the experiment, all subject responses were checked a second time by the rater at a later time.

(C) **Design balance.** - All conditions were experienced by each subject, thus minimizing the possibility that any changes in the dependent variable were due to differences in the subjects tested under the various conditions.

4.5.2 External validity

(A) **Subject selection.** - The generalizations and clinical implications of the study depend on the selection of subjects. The subjects used in this study, although few in number, comprised a heterogeneous group of hard of hearing individuals. The subjects varied in several respects: (a) their hearing loss severity which ranged from moderate to profound; (b) their hearing loss configuration which ranged from flat loss to steeply sloping loss; (c) the etiology of their hearing loss; (d) their discrimination ability which ranged from 46% (very poor) to 84% (good); (e) their hearing aid experience which ranged from 1 to 31 years; (f) the brand of hearing aid they wore; (g) the earmold type they wore; (h) the telecoil strength of their hearing aid; (i) their experience in using the various coupling methods examined; (j) their age which ranged from 25 to 69 years; and (k) their frequency of telephone use which ranged from a few calls per day to 150 calls per day for one subject who was a telephone operator! It is because of this heterogeneity that we feel confident in extending the
findings which emerge from this study to many hard of hearing people who use inductive coupling to couple their hearing aids to telephone receivers.

(B) **Barriers to generalization.** - These are considered to be the effects of the experimental arrangement which would preclude generalization of the results to those who might experience the dependent variable (amplification) in a nonexperimental setting. A goal in designing this study was to make the experimental conditions as generalizable to the real world telephone listening situation as possible without jeopardizing the internal validity of the study. Some features of this study which increase its external validity include: (a) provision of a background of noise similar to that which might be encountered in a busy area (mall or airport); (b) provision of telephone line conditions which are in accordance with the average as well as the minimum output available to telephone users; (c) allowance for subjects to themselves locate and maintain an optimal listening position for the telephone receiver; (d) allowance for subjects to themselves locate optimal levels of hearing aid gain and receiver amplification with aid of practice sentences prior to commencing the test condition; (e) use of sentence-length speech material with varying predictability which is similar to what one might encounter over the telephone (as discussed in section 4.2); and (f) allowance for subjects to use their own hearing aid and earmold combination instead of an experimental aid unfamiliar to them. Because of the above we feel that the level of performance that these subjects demonstrated over the telephone is comparable to a real life telephone listening situation.
CHAPTER 5
RESULTS

5.1 Data Analysis

The purpose of this study was to investigate the effects of (a) amplification; (b) telephone line condition; and (c) predictability of speech material, on the speech perception ability of hard of hearing people using the inductive method to couple their hearing aids to the telephone receiver. Speech perception ability was evaluated by means of R-SPIN scores. We will examine the results of the amplification and telephone line condition variables first.

A two-way analysis of variance (ANOVA) with repeated measurements (Winer, 1962, pp 289-290) was performed to determine if the amplification and telephone line condition significantly affected speech perception ability as quantified by R-SPIN scores. This also permitted us to identify any potential interaction effect between the two independent variables, amplification and telephone line condition.

The study was originally conceived as a balanced design in which an equal number of subjects (three) would experience each of the four condition presentation orders. As explained in Chapter 4, only ten subjects were used, therefore orders #1 and #2 were used for three subjects each whereas orders #3 and #4 were used for two subjects each. One solution to this unbalance (for statistical purposes) was to remove at random two subjects, one who experienced order #1 and one who experienced order #2. Prior to doing this, it was first ascertained that removing any combination of such subjects would not alter the mean group results significantly. This in fact was found to be the case. Removing any of the pairs of subjects (one who experienced order #1 and the other order #2 led to roughly the same results in terms
of group means. Thus, although the data was analysed with (a) Subjects 9 and 10 (arbitrarily chosen) removed; and (b) all ten subjects included, results will be reported only for the case where Subjects 9 and 10 were removed, unless otherwise noted. Although Subjects 9 and 10 were removed arbitrarily, it was noted that the elimination of these subjects never meant the elimination of the tail ends of the distribution of scores, i.e. there were always scores higher or lower than those of these two subjects (or equal, in the cases where their scores were 0% or 100%). Thus, it can not be said that elimination of these subjects caused a decrease in variance of the scores since the extreme scores always remained.

5.1.1 Raw data - amplification & line condition

Table IV contains individual and group R-SPIN scores for each experimental condition tested. Group R-SPIN statistics are shown for N=8 as well as for N=10. Figure 16 shows the same group mean information in graphic form.

5.1.2 Statistical analysis - amplification & line condition

To determine if amplification and telephone line condition significantly affected speech perception ability (measured by R-SPIN scores), a two-way ANOVA with repeated measures was performed. Table V shows the results of the ANOVA.

As seen in Table V, amplification did have a significant (p < 0.01) main effect on R-SPIN score values (F = 40.47, d.f. = 1, p < 0.001). The main effect of line condition on R-SPIN score values was also significant (F = 50.50, d.f. = 1, p < 0.001). There was no significant interaction of the two variables, amplification and line condition (F = 4.17, d.f. = 1, p > 0.1). The effects of amplification and line condition do behave independently of each other. It cannot be claimed, for instance, that one needs to
Table IV. Individual and group R-SPIN scores for each experimental condition for N =8 and N=10.

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Inductive no amplifier good line</th>
<th>Inductive amplifier good line</th>
<th>Inductive no amplifier poor line</th>
<th>Inductive amplifier poor line</th>
<th>test/retest condition</th>
</tr>
</thead>
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<tr>
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<td>82%</td>
<td>78%</td>
<td>12% **</td>
<td>74%</td>
<td>40% *</td>
</tr>
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<td>74%</td>
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<td>56%</td>
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<td>62% *</td>
</tr>
<tr>
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<td>0%</td>
<td>44%</td>
<td>74% *</td>
</tr>
<tr>
<td>5</td>
<td>92%</td>
<td>86%</td>
<td>0% **</td>
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<td>98%</td>
<td>74%</td>
<td>88%</td>
<td>88% *</td>
</tr>
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<td>7</td>
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<td>90%</td>
<td>46%</td>
<td>58% **</td>
<td>60% *</td>
</tr>
<tr>
<td>8</td>
<td>38%</td>
<td>48% **</td>
<td>4%</td>
<td>36%</td>
<td>54% *</td>
</tr>
<tr>
<td>9</td>
<td>82%</td>
<td>92%</td>
<td>0% **</td>
<td>74%</td>
<td>2% *</td>
</tr>
<tr>
<td>10</td>
<td>84% **</td>
<td>88%</td>
<td>42%</td>
<td>64%</td>
<td>92% *</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
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<td>mean</td>
<td>62</td>
<td>76.8</td>
<td>21.5</td>
<td>63.8</td>
<td></td>
</tr>
<tr>
<td>S.D.</td>
<td>23.3</td>
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<td>27.6</td>
<td>18.7</td>
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</tr>
<tr>
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<td>14.8</td>
<td>26.3</td>
<td>16.8</td>
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Figure 16 a. Group mean scores for the four experimental conditions (N = 8).

Figure 16 b. Group mean scores for the four experimental conditions (N = 10).
Table V. Results of two-way ANOVA with repeated measures.

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>M.S.</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>amplification</td>
<td>1</td>
<td>6498.00</td>
<td>40.47</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>error</td>
<td>7</td>
<td>160.57</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>line condition</td>
<td>1</td>
<td>5724.50</td>
<td>50.50</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>error</td>
<td>7</td>
<td>113.36</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>line x amplif.</td>
<td>1</td>
<td>1512.50</td>
<td>4.17</td>
<td>&gt;0.1</td>
</tr>
<tr>
<td>error</td>
<td>7</td>
<td>362.50</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
encounter a poor telephone line condition in order for amplification to be of significant benefit.

5.1.3 Intra-subject reliability - amplification & line condition

For each subject, intra-subject test-retest reliability was assessed. For this purpose the second condition performed by each subject (and this varied from subject to subject) was repeated and the Pearson product-moment correlation coefficient was calculated for the two sets of scores. Table IV shows the scores for the test-retest condition. For each subject, double asterisks indicate the test conditions that were correlated with the re-test condition. The correlation coefficient between these two sets of scores was \( r = 0.90 \). This correlation was tested (Adler & Roessler, 1972, pp 211-218) and was found to be significant \( (p < 0.01) \), thus indicating a very high retest reliability.

5.1.4 Raw data - predictability of speech material.

Table VI contains individual and group mean scores for high predictability (HP) items, for each of the experimental conditions tested. These scores were obtained by calculating the percent correct of the 25 high predictability sentences found in each of the R-SPIN forms. Conversely, Table VII contains individual and group mean scores for low predictability (LP) items, for each of the experimental conditions tested. These scores were obtained by calculating the percent correct of the 25 low predictability sentences found in each of the R-SPIN forms. In both tables, group statistics are provided for \( N = 8 \) as well as for \( N = 10 \). Figures 17 and 18 show the same information in graphic form for \( N = 8 \) only.
Table VI. Individual and group mean R-SPIN scores for high predictability (HP) sentences for N = 8 and N = 10.

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Inductive no amplifier good line</th>
<th>Inductive amplifier good line</th>
<th>Inductive no amplifier poor line</th>
<th>Inductive amplifier poor line</th>
<th>test/retest condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>96%</td>
<td>96%</td>
<td>12%**</td>
<td>92%</td>
<td>56%*</td>
</tr>
<tr>
<td>2</td>
<td>88% **</td>
<td>92%</td>
<td>52%</td>
<td>84%</td>
<td>88% *</td>
</tr>
<tr>
<td>3</td>
<td>68%</td>
<td>96%</td>
<td>0%</td>
<td>80% **</td>
<td>76% *</td>
</tr>
<tr>
<td>4</td>
<td>44%</td>
<td>92% **</td>
<td>0%</td>
<td>64%</td>
<td>96% *</td>
</tr>
<tr>
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<td>100%</td>
<td>100%</td>
<td>0%**</td>
<td>100%</td>
<td>52% *</td>
</tr>
<tr>
<td>6</td>
<td>100% **</td>
<td>96%</td>
<td>96%</td>
<td>100%</td>
<td>100% *</td>
</tr>
<tr>
<td>7</td>
<td>84%</td>
<td>100%</td>
<td>68%</td>
<td>72% **</td>
<td>72% *</td>
</tr>
<tr>
<td>8</td>
<td>64%</td>
<td>72% **</td>
<td>4%</td>
<td>52%</td>
<td>84% *</td>
</tr>
<tr>
<td>9</td>
<td>92%</td>
<td>100%</td>
<td>0%**</td>
<td>80%</td>
<td>0 %*</td>
</tr>
<tr>
<td>10</td>
<td>92% **</td>
<td>100%</td>
<td>48%</td>
<td>84%</td>
<td>96% *</td>
</tr>
</tbody>
</table>

N = 8
mean 80.5 93.0 29.0 80.5
S.D. 20.11 9.01 37.75 17.16

N = 10
mean 82.8 94.4 28.0 80.8
S.D. 18.38 8.47 35.23 15.18
Table VII. Individual and group mean R-SPIN scores for low predictability (LP) sentences for N=8 and N=10.

<table>
<thead>
<tr>
<th>Subject #</th>
<th>Inductive no amplifier good line</th>
<th>Inductive amplifier good line</th>
<th>Inductive no amplifier poor line</th>
<th>Inductive amplifier poor line</th>
<th>test/retest condition</th>
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<tr>
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<td>68%</td>
<td>60%</td>
<td>12%**</td>
<td>56%</td>
<td>24%*</td>
</tr>
<tr>
<td>2</td>
<td>36%**</td>
<td>56%</td>
<td>20%</td>
<td>28%</td>
<td>32%*</td>
</tr>
<tr>
<td>3</td>
<td>28%</td>
<td>36%</td>
<td>0%</td>
<td>56%**</td>
<td>48%*</td>
</tr>
<tr>
<td>4</td>
<td>12%</td>
<td>56%**</td>
<td>0%</td>
<td>24%</td>
<td>52%*</td>
</tr>
<tr>
<td>5</td>
<td>84%</td>
<td>72%</td>
<td>0%**</td>
<td>72%</td>
<td>36%*</td>
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<td>100%</td>
<td>52%</td>
<td>76%</td>
<td>76%*</td>
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<td>80%</td>
<td>24%</td>
<td>44%**</td>
<td>48%*</td>
</tr>
<tr>
<td>8</td>
<td>12%</td>
<td>24%**</td>
<td>0%</td>
<td>20%</td>
<td>24%*</td>
</tr>
<tr>
<td>9</td>
<td>72%</td>
<td>76%</td>
<td>0%**</td>
<td>68%</td>
<td>4%*</td>
</tr>
<tr>
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<td>76%**</td>
<td>76%</td>
<td>36%</td>
<td>44%</td>
<td>88%*</td>
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<td>63.6</td>
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<tr>
<td>S.D.</td>
<td>27.66</td>
<td>22.19</td>
<td>18.40</td>
<td>20.20</td>
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</tbody>
</table>
Figure 17. Group mean scores for HP data for the four experimental conditions.

Figure 18. Group mean scores for LP data for the four experimental conditions.
5.1.5 Statistical analysis - predictability of speech material

To examine the interaction between amplification and telephone line condition (independent variables) and the predictability of the speech material encountered by the subject, a two-way ANOVA with repeated measures was performed. Either the high or low predictability R-SPIN scores were used as the dependent variable in this analysis. Table VIII shows the results of the ANOVA for the high predictability speech material. Table IX shows the results of the ANOVA for the low predictability speech material.

The results in Tables VIII and IX indicate that, first, amplification did have a significant main effect on R-SPIN LP scores. It had a significant effect on R-SPIN HP scores as well. Second, line condition had a significant effect on R-SPIN LP scores. It also had a significant effect on R-SPIN HP scores. Finally, the interaction of the two independent variables, amplification and line condition was nonsignificant for both R-SPIN LP and HP data.

5.1.6 Intra-subject reliability - predictability of speech material

The asterisks in Tables VI and VII show the scores which were correlated in order to test for test-retest reliability for the HP and LP data respectively. The test-retest correlation coefficient for the two sets of scores was $r = 0.83$ for the low predictability material and $0.91$ for the high predictability material. The correlation between the two sets of high predictability data was found to be significant, ($p < 0.01$) while the correlation between the two sets of low predictability data was not. Thus, when the scores were broken down into high and low predictability subscores, we found that the high predictability speech stimuli yielded scores which were repeatable to a significant degree whereas the low predictability speech stimuli did not.
Table VIII. Results of an ANOVA with the high predictability (HP) scores as the dependent variable.

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>M.S.</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>amplification</td>
<td>1</td>
<td>8192.00</td>
<td>18.10</td>
<td>p &lt; 0.005</td>
</tr>
<tr>
<td>error</td>
<td>7</td>
<td>452.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>line condition</td>
<td>1</td>
<td>8192.00</td>
<td>30.63</td>
<td>p &lt; 0.001</td>
</tr>
<tr>
<td>error</td>
<td>7</td>
<td>267.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>linexamplif.</td>
<td>1</td>
<td>3042.00</td>
<td>8.71</td>
<td>p &gt; 0.01</td>
</tr>
<tr>
<td>error</td>
<td>7</td>
<td>349.43</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table IX. Results of an ANOVA with the low predictability (LP) scores as the dependent variable.

<table>
<thead>
<tr>
<th>Source</th>
<th>d.f.</th>
<th>M.S.</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>amplification</td>
<td>1</td>
<td>5100.50</td>
<td>78.38</td>
<td>p &lt; 0.001</td>
</tr>
<tr>
<td>error</td>
<td>7</td>
<td>65.07</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>line condition</td>
<td>1</td>
<td>3784.50</td>
<td>26.83</td>
<td>p &lt; 0.005</td>
</tr>
<tr>
<td>error</td>
<td>7</td>
<td>141.07</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>linexamplif.</td>
<td>1</td>
<td>544.50</td>
<td>1.38</td>
<td>p &gt; 0.2</td>
</tr>
<tr>
<td>error</td>
<td>7</td>
<td>395.93</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
CHAPTER 6
DISCUSSION

The purpose of this study was to examine the effect of receiver amplification on the speech perception ability of hard of hearing persons using the inductive method to couple their hearing aid to telephone receivers. This was examined under two telephone line conditions, one good and one poor (representing the maximum line attenuation allowable within an area serviced by a central telephone office). Also examined was the interaction between receiver amplification and: (a) telephone line condition; (b) the predictability of the speech material encountered, high versus low predictability (representing the range of conversations that one might encounter).

Results obtained showed that receiver amplification with inductive coupling did significantly improve the speech perception scores of the subjects. As well, subjects' scores significantly improved from the poor line conditions to the good conditions. The above results seem logical in view of the greater magnetic flux available to the subjects under both types of conditions (amplified and good). The fact that a greater than normal acoustic signal was also generated might have also contributed somewhat to the above results. In particular, air-conducted signals may have been transmitted through the subjects' earmold and tubing, thus augmenting the larger magnetically induced signal with a larger acoustic one. There were a few cases namely Subjects #1 and 5 where a slight decrease in speech perception scores was noted with amplification under a good line condition. Such a result may have been due to the telecoil being overdriven by the greater magnetic flux. This suggests that there is a point up to which a greater magnetic flux is beneficial after which any additional magnetic flux may have deleterious effects. There were no interaction
effects between amplification and line condition, meaning that the improvement due to amplification was noted regardless of the line condition under question. The reverse is also true in that improvement due to a favorable line condition was noted regardless of whether an amplified receiver was used or not. Both amplification and line condition had a significant effect on low predictability and high predictability scores. When listening to utterances either in or out of context, amplification will be of benefit to those using inductive coupling, as would a good line condition. There was no significant interaction between amplification and line condition, either for LP or HP stimuli. Specifically, both LP and HP scores improved with amplification regardless of the line condition. The reverse is also true, both LP and HP scores improved with a good line condition regardless of whether or not amplification was used. Prior to commencing the study, we hypothesized that amplification may not be of significant benefit in HP sentences, where contextual cues abound, but that it may be of more benefit where those cues are absent as in LP sentences. This was not the case, however, as the extra magnetic flux (and possibly the extra acoustic output) provided by the receiver amplification, and by the good telephone line condition, was of advantage irrespective of the availability of contextual cues. In fact, visual inspection of Figures 17 and 18 shows that under the poor line condition, amplification provided a greater benefit for the HP items than for the LP items. Interpreting this finding, perhaps amplification was able to increase the telephone receiver output to a level where more contextual cues were audible and this aided in the interpretation of the stimulus word in the HP sentences. With the LP sentences however, the added signal strength may still have left subjects using a random guessing strategy.
6.1 Implications of the Research and Recommendations

The results of this study as well as some observations made throughout the testing have led to the following conclusions and recommendations:

(A) Recommendations to clients - The most obvious recommendation that follows from this research is that it is important that audiologists be made aware of this dual capability telephone coupling strategy and recommend it as a possible mode to their clients who are having difficulty with inductive coupling.

(B) Increased availability of receiver amplifiers - Presently, there is no legislation pertaining to the provision of handset amplifiers. Bell Canada has equipped approximately 2700 (Bell Canada, 1987 statistic) pay telephones in high usage areas where a bank of pay telephone is installed (e.g. airports and shopping malls) with volume controls in the handset. Bell Canada will generally reply to any request to install amplified telephones in public places and will do so in private homes for a small fee. The adoption of CSA Standard CAN3-T515 as a standard for all telephones sold and manufactured in Canada was a great victory for hard of hearing telephone users. This study suggests that incorporation of a receiver volume control in all new telephone sets would also be a worthy goal. This study has substantiated the benefits of such a device under adverse as well as under good telephone line conditions across a broad span of hearing loss severities. The addition of this feature would not only be of use to those who use inductive coupling, but also to those hard of hearing people who use the amplified receiver without a hearing aid, and to those people with minimal or no hearing loss, in situations where the background noise is high. There is no inconvenience to the telephone user with normal hearing since the
telephone operates normally when the volume control is on its minimum setting. All new telephones manufactured in Sweden, have such amplified receivers.

(C) **Standardization of telecoils** - At the present time, no hearing aid standard exists which specifies the inductive coupling requirements for their use with telephone sets which comply with the CSA Standard CAN3 - T515. Lack of such a standard leads to insufficient coupling and awkward handset orientations in some cases. Although all hearing aids used in this study met their manufacturers' specifications as per ANSI S3.22, it was observed on several occasions that the optimal receiver orientation chosen by a subject placed the handset at a poor position for telephone transmission. This was also reported by Stoker (1985) in his investigation of inductive coupling of hearing aids and telephone receivers. If national standards were developed which defined the magnetic coupling requirements of hearing aids for their use with telephone sets, the access to telecommunication services would have to be a consideration when designing hearing aids to be sold in Canada. At the present time, telecoils vary in their alignment within the hearing aid casing, their placement often based on the availability of space.

A committee on hearing aid/telecoil standards has been formed as a result of a request by the Canadian Hard of Hearing Association and by the Canadian Hearing Society to create such a standard. The magnetic field emitted by a receiver can be decomposed into three separate components, the axial, radial and tangential fields, two of which are illustrated in Figure 19. The axial field, which is perpendicular to the plane of the telephone receiver, is most important for the coupling of BTE hearing aids to telephone receivers. The radial field is most important for room and neck loop
Figure 19. Diagram showing two of the components (radial and axial) of the magnetic field emitted by a telephone receiver (reproduced from CSA, 1985, with permission).
amplification. The tangential field is not considered to be of great importance. So, although it could be suggested that hearing aid telecoils should be positioned within the hearing aid casing such that normal usage orientation would produce maximal signal strengths, different uses seem to require different orientations. As well, size limitations inherent in ITE hearing aids would preclude such a specification. The Canadian Association of Speech-Language Pathologists and Audiologists (CASLPA) has requested that the specifications of all three field strengths as well as orientation of the telecoil (at least for BTE hearing aids) be made available on hearing aid specification sheets. In this way, audiologists will have more information with which to select a hearing aid based on the probable needs of the individual. The committee on hearing aid/telecoil standards has proposed a standard which addresses this request. The standard would also specify that a change of at most 10 dB would be considered as acceptable in a hearing aid output when switched from acoustic to inductive input or vice versa. The above standard is currently being reviewed by the Bureau of Radiation and Medical Devices and further revisions prior to it becoming law should be completed by the end of 1991 (Chasin, 1990). Such a standard should improve the two major difficulties associated with telecoil/telephone use, namely the variability in sensitivity of telecoils among hearing aids and undesirable telecoil orientations. Although such a standard would improve the situation, it is still up to audiologists to:

1. recognize the need for telecoil provision and discuss the option with the hard of hearing client; the consumer must be made aware that in choosing an ITE instrument, he/she is often sacrificing the benefits of inductive coupling;

2. choose an appropriate hearing instrument, in accordance with the potential uses of the individual;
(3) take measurements to assure that the telecoil strength meets the manufacturers specifications; Townsend & Wavrek (1983), in their survey of 310 clinics in the U.S, investigated the extent to which audiology clinics utilize ANSI S3.22 "specifications of hearing aid characteristics"; they found that only 7% of clinics surveyed routinely measured the coupler SPL with telecoil input; the least important measures were consistently considered to be battery current drainage and coupler SPL with the telecoil input; these practices and attitudes must change.

(D) Evaluation of telephone use and aural rehabilitation.- Another observation made during testing by this experimenter, was that many subjects did not realize that, when coupling their hearing aid inductively, one must hold the receiver to the hearing aid casing and not up to the earmold. The only explanation for this confusion is a lack of adequate instruction and follow through by hearing professionals. Instructions, demonstrations and repeated follow-up appointments must be provided to assure successful use of the hearing aid telecoil. When combinations of amplifiers and telecoils are considered, there is an increase in user difficulty and thus an increase in the importance of adequate instruction (Pichora-Fuller, 1981).

As mentioned in Cashman (1982) and in Stoker (1982), the audiometer telephone interface has the potential to be a powerful diagnostic tool in evaluating the performance of hard of hearing individuals over the telephone, both in research and in clinical settings. Such a device makes it possible to use standardized speech tests (like the R-SPIN) to evaluate the performance of an individual with a given telephone coupling mode, so that objective comparisons and recommendations can be made. It could be used to evaluate the performance of patients when choosing among hearing
aids when telephone performance is an important consideration and to train and counsel clients on the proper positioning of the telephone for most efficient communication. In cases where more extensive telephone rehabilitation is undertaken such as instruction in listening and/or conversational repair strategies, it would permit teaching of the above.

6.2 Concluding Remarks
In conclusion, this study points to the following conclusions and recommendations:
(A) the telephone-hearing aid coupling strategy examined in this study (inductive coupling with receiver amplification) should be recommended by audiologists to their hard of hearing clients who have some difficulty with inductive coupling;
(B) the availability of receiver amplifiers in telephone handsets should be increased;
(C) telecoils should be standardized; and
(D) there should be an increased focus on telephone aural rehabilitation by audiologists.

We have shown that dual capability hearing aid-to-telephone coupling (inductive plus receiver amplification) can improve telephone speech perception ability in those people who use inductive coupling. This finding confirms the reports of many experienced hearing aid users. A secondary point which we would like to stress, is that although the potential for better telephone communication by the hard of
hearing is available through such coupling methods as inductive coupling, receiver amplification and as this study has shown, the combination of these two modes, it is up to hearing professionals to make these options known to their clients and to adequately instruct them in their use. Sufficient follow up services need to be provided in order to make sure that these methods are being used to their greatest advantage.
REFERENCES


Appendix A

Questionnaire

Please complete and return in the attached, self-addressed stamped envelope at your earliest convenience:

1) Name: _______________________

2) Telephone number: __________

3) Date of Birth: _______________________

4) Mother tongue: _______________________

5) Tell me about your hearing:

________________________________________________________________________________

________________________________________________________________________________

________________________________________________________________________________

________________________________________________________________________________

6) When was your hearing last tested? _______________________

7) Where was your hearing tested? _______________________

8) Do you wear one hearing aid or two? 1. _____ 2. _____

9) If only one, in which ear?  Left _____ Right _____

10) How long have you been wearing a hearing aid(s)? _______________________

11) When did you purchase your present aid(s)? _______________________

12) What is the make of your present aid(s)? (if known) for example: Siemens, Unitron, Danavox, Starkey _______________________

13) Is your hearing aid(s) a behind-the-ear type or in-the-ear?

   Behind-the-ear _______ In-the-ear _______
14) Do you have a T-switch on at least one hearing aid?
   Yes _____  No _____

15) Please write down any letters and/or numbers which may appear on the
    hearing aid(s) case itself if possible. ____________________________

16) Which ear do you usually use for the telephone?
    Left _____  Right _____

17) How do you usually access the telephone?
    a) by using the T-switch only _____
    b) by using a handset amplifier only _____
    c) by using the T-switch and a handset amplifier together _____
    d) by using the hearing aid in the usual way (no T-switch) _____

18) How would you describe your telephone communication ability?
    a) very poor _____  d) good most of the time _____
    b) poor _____  e) good all of the time _____
    c) fair _____

19) When would be the most convenient time for you to come to U.B.C. for the
    session?
    a) which day or days (including weekends) ______________________
    b) morning, afternoon or evenings? ____________________________

20) Additional comments:
    ____________________________
    ____________________________
    ____________________________
    ____________________________
Appendix B
Instructions

You are going to hear several sets of sentences through the telephone. During this time, there will also be babbling noise played through the two loudspeakers. For every sentence you hear, your task will be to repeat the last word of each sentence. For example, if the sentence you hear is: "We shipped the furniture by truck", you should say "truck" into the telephone receiver, just as you would if you were speaking on the phone. Some of the sentences you will be hearing will make more sense than others. Don't let this concern you. Simply say what you think you heard at the end of each sentence. It is important that you guess, even if you are not sure of the word. Do you have any questions?

We will start with a little practice. Switch the hearing aid which you normally use for the telephone to the "T" position and turn off your other hearing aid, if you have another one. While you are listening to these practice sentences, 1) adjust the volume control on your hearing aid and 2) place the receiver against you hearing aid. You want to find the volume and the receiver position which makes the man's speech seem the clearest to you. You may need to move the receiver around a fair bit. Once you have found the best volume setting and the best receiver position, do not touch the volume wheel again and try your best to keep the receiver in that "best" position. Repeat only the last word of each sentence and take a guess when you are unsure of what you have heard. Do you have any questions?
In this part of the experiment, you will be using the amplifier. First of all, you will hear some practice sentences. Take this time to turn both the volume control of your hearing aid and the amplifier to the most comfortable level for you, to a level where you hear speech the most clearly. Move the receiver to the best possible position against your hearing aid. When you feel that you are ready for the test sentences, tell me. You will then hear 50 sentences. Repeat the last word of each sentence, remembering to guess if you have to. It is very important that once you have 1) adjusted your hearing aid volume, 2) adjusted the telephone amplifier, and 3) placed the receiver at the best position on your hearing aid, you do not make any further adjustments until I come back into the booth. Try to hold the receiver in the same place, to the best of your ability, until the 50 sentences are over. Do you have any questions?

In this part of the experiment, you will not be using the amplifier. First of all, you will hear some practice sentences. Take this time to adjust both the volume control of your hearing aid and the position of the receiver for clearest listening. When you feel that you are ready for the test sentences, tell me. You will hear 50 sentences. Repeat the last word of each sentence, remembering to guess if you have to. Do not touch your hearing aid volume control during the test sentences and try your best not to move the receiver until the 50 sentences are over. Do you have any questions?