The Use of Faceplate Assemblies as Facsimiles of Custom Hearing Instruments

James A. Fenwick
Portland State University

Recommended Citation

10.15760/etd.6619

This Thesis is brought to you for free and open access. It has been accepted for inclusion in Dissertations and Theses by an authorized administrator of PDXScholar. For more information, please contact pdxscholar@pdx.edu.
THESIS APPROVAL

The abstract and thesis of James A. Fenwick for the Master of Science in Speech Communication: Speech and Hearing Science were presented July 1, 1994 and accepted by the thesis committee and the department.

COMMITTEE APPROVALS:

Thomas G. DoXan, Chair
James F. Maurer
Douglas R. Martin
William Fischer
Representative of the Office of Graduate Studies

DEPARTMENT APPROVAL:

Stephen A. Kosokoff, Chair
Department of Speech Communication

* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *

ACCEPTED FOR PORTLAND STATE UNIVERSITY BY THE LIBRARY

by [Signature] on 23 August 1994
ABSTRACT


Title: The Use of Faceplate Assemblies as Facsimiles of Custom Hearing Instruments.

Custom-designed hearing instruments comprise the majority of those dispensed in the United States today. Because of their custom nature, there has been no means of evaluating them until they have been completed. There would be advantages to evaluating custom instruments prior to their completion.

This study investigates a means of evaluating custom instruments prior to their final assembly into the customized shell. This is done by having the subject listen to the circuitry of the instrument while it is still mounted on the faceplate, which is accomplished by coupling the faceplate assembly to the subject’s ear with foam earplug.

To determine if the faceplate assembly, when coupled to the subject’s ear, is a facsimile of the completed instrument, the insertion gain of the faceplate assembly was compared to the insertion gain of the completed instrument.
Real ear measurements were obtained for both conditions (faceplate assembly vs. custom instrument) on twelve subjects. Once insertion gain was measured, the faceplate assemblies were then converted into custom instruments and insertion gain remeasured.

A two-way Analysis of Variance test revealed no significant difference between the two test conditions at five representative test frequencies. A tolerance template, as specified by ANSI S3.22 1982, was used as a second criterion for similarity between two conditions. The tolerance template was superimposed over the insertion gain curves of the twelve faceplate assembly conditions to determine if the insertion gain curves of the completed instrument fell within acceptable variances. None of the insertion gain curves for the completed instruments fell completely within the tolerances allowed by the template. Based on this criterion, it was concluded there was a significant difference between the insertion gain of the two conditions and therefore the faceplate assembly was not a facsimile of the completed instrument, where insertion gain was concerned. However, from a subjective standpoint the faceplate assembly might still have some utility in the fitting of the custom in-the-ear hearing instruments. For example, it could be used to allow potential hearing aid wearers to experience different technologies during the preselection phase of the fitting process.
THE USE OF FACEPLATE ASSEMBLIES AS FACSIMILES
OF CUSTOM HEARING INSTRUMENTS

by
JAMES A. FENWICK

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE
in
SPEECH COMMUNICATION:
SPEECH AND HEARING SCIENCES

Portland State University
1994
ACKNOWLEDGEMENT

Dedicated with admiration and gratitude to James Maurer whose sincere interest in my future inspired me to "stick with it." To Bob Johnson, a dear friend, who has offered his unconditional support in all my endeavors. And, to Tom Dolan whose technical rigor and tenacity enabled me to complete a thesis of which I can be proud. Finally, to Diane Lettau, whose insuperable talents allowed me to pull it all together.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>ACKNOWLEDGEMENTS</th>
<th>iii</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF TABLES</td>
<td>vi</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>vii</td>
</tr>
</tbody>
</table>

## CHAPTER

<table>
<thead>
<tr>
<th>I</th>
<th>INTRODUCTION</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>II</td>
<td>REVIEW OF THE LITERATURE</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Early Fitting Methods</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Prescriptive Methods</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Verification and Adjustment of Fit</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td>Pre-evaluating Custom Instruments</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>Under-utilization of Present Technology</td>
<td>23</td>
</tr>
<tr>
<td></td>
<td>Subjective Considerations in the Fitting Process</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Summary</td>
<td>32</td>
</tr>
<tr>
<td>III</td>
<td>METHODS</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Faceplate Assemblies/Hearing Aids</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Procedures</td>
<td>39</td>
</tr>
<tr>
<td>IV</td>
<td>RESULTS</td>
<td>45</td>
</tr>
<tr>
<td>V</td>
<td>DISCUSSION</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>Interpreting the Results</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>Possible Sources of Variability Observed</td>
<td>54</td>
</tr>
<tr>
<td></td>
<td>The Future of the Faceplate Assembly</td>
<td>57</td>
</tr>
</tbody>
</table>

REFERENCES | 59 |
APPENDICES

Figure 8 ........................................... 66
Figure 9 ........................................... 67
Figure 10 .......................................... 68
Figure 11 ........................................... 69
Figure 12 .......................................... 70
Figure 13 .......................................... 71
Figure 14 .......................................... 72
Figure 15 .......................................... 73
Figure 16 .......................................... 74
Figure 17 .......................................... 75
LIST OF TABLES

<table>
<thead>
<tr>
<th>TABLE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Means and Standard Deviations for Insertion Gain Measures</td>
</tr>
<tr>
<td>II</td>
<td>Analysis of Variance for Insertion Gain Measures</td>
</tr>
<tr>
<td>III</td>
<td>Correlation of Faceplate Insertion Gain with Custom Instrument Insertion Gain</td>
</tr>
</tbody>
</table>
## LIST OF FIGURES

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>PAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
</tr>
<tr>
<td>4</td>
<td>38</td>
</tr>
<tr>
<td>5</td>
<td>41</td>
</tr>
<tr>
<td>6</td>
<td>46</td>
</tr>
<tr>
<td>7</td>
<td>47</td>
</tr>
</tbody>
</table>
CHAPTER I

INTRODUCTION

Custom, in-the-ear hearing instruments currently comprise nearly 80% of all hearing instruments dispensed in the United States (Duffy, 1990; Mynders, 1991; Kirkwood, 1993). One explanation for the popularity of custom instruments, in addition to their more cosmetic appeal, is the fact they can now be designed with most of the advanced technology once available only in the larger, behind-the-ear style of instrument (Beck, 1991; Mueller, 1993).

Another aspect in which custom hearing instruments are changing is that more dispensers are assembling their own custom instruments (M. Martek, Magnatone Hearing Instruments, personal communication, March 23, 1994). In-office assembly of custom hearing instruments has become so popular among dispensers, some manufacturers now provide classes for dispensers in the assembly and repair of custom instruments (J. Hanshaw, Orlando Hearing Instruments, personal communication, Feb. 10, 1994). Some custom instrument manufacturers, recognizing the increasing popularity of in-office assembly, provide dispensers with faceplates on which is mounted the electronic circuitry for the custom instrument (C. Pope, Siemen's Hearing Instruments, personal communication, 1994). The plastic
faceplate, with its attached electronic circuit, is then bonded to an acrylic shell which the dispenser fabricates from an impression taken of the client's ear. Figure 1. shows a typical in-the-ear faceplate with its attached amplifier circuit, microphone and receiver. Once bonded to an acrylic shell, the faceplate assembly is trimmed, shaped and then polished, resulting in a completed custom, in-the-ear hearing instrument.

There are some distinct advantages offered by dispensers who assemble their own custom instruments. Perhaps the main advantage is service to the client (Robilotta, 1993). Typically, dispensers who have the ability to assemble their own hearing instruments are also able to make necessary repairs and modifications to these instruments (J. Hanshaw, Orlando Hearing Instruments, personal communication, April 4, 1994). This often avoids sending the instrument back to the manufacturer for repairs or modifications (Mueller, 1989). In addition, some dispensers are able to make most modifications and repairs to instruments while the client waits, eliminating a return trip to the dispenser's office. For hearing impaired clients are very reliant on their instruments, immediate in-office repairs avoid the need for them to be without their instruments.

Another potential advantage to in-office assembly of custom instruments is that it affords dispensers more
Figure 1. This is a schematic diagram of a typical, in-the-ear faceplate with its attached amplifier circuit, microphone and receiver (marked A, M and R respectively). The heavy dark lines are the connection wires for the components. The receiver is not attached to the faceplate and is free-floating for coupling (via a foam plug) to the subject's ear canal. The B indicates the battery compartment which provides power for the amplifier circuit. The faceplate is 2 inches in diameter and about 1/8 inch in thickness.
control over the selection of a particular technology for a client. Specifically, different circuits can be evaluated by having clients listen to various faceplates, each with a different circuit mounted on it. While doing so, the dispenser can measure the circuit’s output in the client’s ear and possibly make inferences about the output of a completed, custom instrument utilizing the same type of circuitry.

A possible means of evaluating faceplate assemblies on a client would be to couple the faceplate (with its attached electronic circuitry) by way of the receiver tubing, to a foam earplug which can be compressed and inserted into any client’s ear. The major reason for evaluating faceplate assemblies before the custom instrument is completed is, because of their custom nature, in-the-ear instruments can only be evaluated once they are completed. If modifications need to be made to the custom instrument once it is completed, which is often the case, this may necessitate returning it to the manufacturer.

However, if the faceplate assembly is assessed before it is bonded to a completed, custom shell, its acoustical response might be different from that of a completed custom instrument. One possible explanation for any acoustical differences seen when the faceplate is coupled to the client’s ear might be related to the fact that the faceplate (5 cm in diameter) will cover the outer surfaces of the
Figure 2. shows how the faceplate assembly will be attached to a velcro headband so that it hangs directly over the client’s ear. It is well known that the outer surfaces of the pinna, as well as the concna and canal of the ear, possess certain resonance properties (Møller, 1983). If the faceplate is covering the outer part of the ear, and thus exerting a possible baffle effect, these resonance properties might be altered, if not completely eliminated. Therefore, any baffle effect caused by the faceplate assembly might account for differences in frequency response seen between the coupled faceplate condition and the completed custom instrument.

The purpose of this study is to determine if the faceplate assembly, when coupled to the client’s ear using a foam plug, represents a facsimile of a completed, custom instrument. This will be examined by measuring the acoustic response of the faceplate assembly while coupled to the ear. The results of these physical measurements will then be compared to the same physical measurements of a completed, custom, in-the-ear instrument. Specifically, frequency/gain curves of the two conditions will be obtained and compared.

The acoustic differences between the two conditions will be assessed in the following manner. First, measurements will be made of the faceplate condition by placing a small probe microphone tube into the ear canal and measuring the sound pressure generated by the faceplate
Figure 2. The photograph above shows the faceplate in proper position over the subject's left ear. It is attached to the head by way of a velcro tab which extends from the top of the faceplate. This velcro tab, in turn, attaches to another velcro head band around the subject's head (this is seen as the black band around the subject's head). Note how the faceplate completely covers the outer surface of the subject's ear.
coupled to the ear by an earplug. Second, the same type of measurements will be performed on a completed, custom instrument made from the originally measured faceplate assembly and electronic circuit.

If the faceplate assemblies are determined to have similar acoustic properties to the completed custom instrument, this could have important implications. For example, if faceplates can be considered facsimiles of a completed, custom instrument, it might be easier for the dispenser to demonstrate different technologies to the client during the pre-selection process. This would be advantageous because it has been asserted that much of the available hearing aid technology today is highly under-utilized (Burton, 1993; Henoch, 1991; Killion and Villchur, 1993 and Stypulkowski, 1993). Evaluating the faceplate assembly coupled to the ear would preclude having to manufacture a custom instrument first. This would allow the dispenser the freedom to evaluate different technologies as well as pre-validate a particular insertion gain target response. This, in turn, could make the faceplate assembly a valuable part of the dispenser's armamentarium in the pre-selection and fitting of custom, in-the-ear hearing instruments.
CHAPTER II

REVIEW OF THE LITERATURE

Early Fitting Methods

Ever since hearing aids have been dispensed in this country (from about 1904), several methods have been proposed for the prescription, selection and evaluation of the most appropriate hearing instrument for a given hearing loss (Zelnick, 1987). These three procedures are generally considered the main components of the fitting process. Nevertheless, despite a 90-year history, there still remains little consensus as to the best means for fitting hearing instruments (Loven and Zachman, 1990; Van Vliet, 1994).

Some of the earliest procedures for fitting hearing instruments based the required amplification characteristics of the hearing instrument on a patient's audiometric data only. Specifically, these early methods prescribed the hearing aid response based on the listeners' pure tone thresholds, how well they understood speech with amplification, the level where speech was comfortable and, finally, the level where speech became uncomfortably loud. The slope of the audiogram was also used to determine the hearing aid's frequency response. While these early methods did afford a means of prescribing hearing aid amplification
characteristics, there was still no means of comparing different hearing aid responses. Thus, this method did not allow for verification of the fitting.

In 1946, Carhart developed a means of augmenting the above prescription method. This procedure allowed the client to select one hearing instrument from a group of different instruments whose amplification characteristics were close approximates of what might be appropriate for a given individual. The intent of Carhart's method of selection was to find a hearing instrument which provided optimum benefit to the hearing impaired client. However, instead of just using audiometric data to prescribe the hearing aid's characteristics, Carhart had the client listen to and evaluate different instruments through the use of speech audiometry. This method, commonly referred to as the comparative method, assessed hearing instruments in terms of four basic features. The hearing aid finally selected for a client was generally the one that provided amplification which afforded the best discrimination of fifty monosyllabic words, did not exceed the client's tolerance for loud sounds and, finally, performed the best in the presence of background noise (Walden, Schwartz, Williams, Holum-Harden and Crowley, 1983).

Today, many dispensers still use Carhart's method or similar methods when selecting hearing instruments for their clients (Zelnick, 1987). However, it should be noted that
comparative methods of preselecting hearing aids lend themselves only to body-level and behind-the-ear styles of instruments. Because these instruments can be mass-produced ahead of time, it is relatively easy to compare several of them during the selection part of the fitting process. When Carhart devised his method of comparing different hearing aids, in-the-ear instruments, which are custom-designed to fit in a given client's ear, had not yet been developed. In contrast, because in-the-ear instruments are custom made, it is not feasible to mass produce several of them ahead of time to evaluate during the selection process. It is hoped, instead, that the completed custom instrument will have amplification characteristics close to the prescribed "target" response (Skinner, 1988). Nevertheless, Carhart's comparative method of selecting hearing aids was used rather extensively prior to the development of the in-the-ear style of instrument (Burney, 1972).

Because the use of speech discrimination tests for evaluation of different hearing aids has proved to be fairly laborious, many dispensers have modified Carhart's procedure and instead now compare other features in addition to speech discrimination ability. For example, some dispensers compare insertion gain and functional gain as well as the user's subjective judgments about sound quality and intelligibility of a particular hearing instrument response (Zelnick, 1987).
The various comparative methods, based on Carhart's early work, were a means of selecting the most appropriate hearing aid from a group of instruments. However, this group of instruments was prescribed from audiometric data of the client, such as pure tone thresholds (Duffy, 1987). Therefore, most comparative methods were based on some type of prescriptive rationale.

Another early means of selecting hearing aids for clients was the use of the master hearing aid. This device was designed to simulate the response of a hearing instrument and provide a means by which the clinician could manipulate certain amplification characteristics. The master hearing aid essentially allowed the client to evaluate different parameters and, as such, provided a comparative means of selecting hearing aids. The clinician could use the master hearing aid to find a response which provided the best speech discrimination for the client as well as the response that elicited the client's most favorable subjective response (Zelnick, 1987). As with the previous comparative methods of hearing aid selection, the master hearing aid was also based on some type of prescriptive rationale. The underlying principle of the master hearing aid was that, when a response was found which provided optimum amplification, a hearing aid with similar characteristics could be ordered from a manufacturer. However, the master hearing aid has fallen into disuse as a
result of some inherent shortcomings. First of all, master hearing aids generally utilized headphones which completely covered the outer part of the ear. Due to the larger volume of air under the headphones, the master hearing aid could not be considered identical to an ear-level hearing aid which utilizes a smaller volume of air. Secondly, the electronic components which comprised the master hearing aid were usually different from the components used in the custom hearing aid, resulting in different response characteristics. The microphone on the master hearing aid was usually not at ear-level as it was in the completed hearing aid. As a result, the difference in microphone location on the master hearing aid accounted for diffraction effects significantly different from those of an ear-level hearing aid. It was for these reasons that the master hearing aid generally has not been considered a very representative facsimile of a hearing aid. As a result, it is not widely used today in the fitting of hearing aids (Zelnick, 1987).

The master hearing aid was popular during a period when body-level and behind-the-ear instruments lacked flexibility. However, today many different responses can be obtained from one instrument, whether it is a behind-the-ear or a custom, in-the-ear instrument. (Traynor, Wallace and Mueller, 1994). Such flexibility has essentially obviated the need for the master hearing aid. Being able to change
the response characteristics of one instrument, through the use of potentiometers or digital programming, essentially allows the client to compare different instruments without having to physically change instruments. Therefore, clinicians are still able to use some aspects of the comparative methods of hearing aid evaluation by adjusting different parameters of the hearing aid.

Programmable instruments possibly afford even more flexibility in the different responses which can be obtained from one hearing instrument. (Traynor, Wallace and Mueller, 1994). In fact, some programmable instruments have multiple channels which allow the client to essentially have several different instruments in one. As a result, during the comparative process, the client can select more than one instrument response unlike the original Carhart method of comparison.

Many of the early selection methods, including the comparative methods, have been considered to be somewhat subjective in nature because they relied, in part, on the client's contribution to the evaluation process (Walden, Schwartz, Williams, Holm-Hardegen & Crowley, 1983). Because of this inherent subjectivity, comparative methods have been considered by some to be unreliable in selecting hearing aid responses. (Loven and Zachman, 1990).
Prescriptive Methods

In an effort to provide a more objective means of prescribing and selecting the most appropriate response of a hearing aid, new prescriptive rationales have been developed over the last several years (Preves, 1987). The use of prescriptive rationales is not a new concept. According to Preves (1987), the notion of prescribing a hearing aid response has been in existence since Lydbarger's work in the 1940's. Some of the early prescriptive approaches to hearing aid selection were aimed at optimizing what was known as the articulation index (Leijon, Lindkvist, Ringdahl and Israelsson, 1991). The articulation index is used to predict how much amplified speech should be audible to a person, based on the particular nature of their hearing loss. At one time, it was believed that optimizing the articulation index would result in maximizing the client's speech recognition. However, the index has since been called into question as an unrealistic means of prescribing the hearing aid response (Skinner, 1988).

While each of the several recently developed prescriptive methods has its own particular theoretical rationale for prescribing insertion gain, all of these methods share some common goals. All the prescriptive methods attempt to provide the type of amplification which would optimize the wearer's ability to understand speech (Surr and Fabry, 1991). Also, these methods attempt to
prescribe a hearing aid response that will be most acceptable to the wearer. (Magilen, 1991). All prescriptive formulas specify what a hearing aid’s gain, SSPL-90 and slope-configuration should be for a given hearing loss (Valente, Valente and Goebel, 1991).

Perhaps the main advantage to prescriptive methods of hearing aid selection, according to Skinner (1988), is that they specify preselection criteria that can be followed by any practitioner. While there are to date several different prescriptive formulae in use, all of which calculate the prescribed gain in different ways, they all utilize the wearer’s pure tone thresholds, most comfortable loudness levels and uncomfortable loudness levels to determine real ear gain (Leijon, Lindkvist, Ringdahl and Iraelsson, 1991).

Some prescriptive formulae base their target insertion gain on the patient’s pure tone thresholds (Skinner, 1988). Most of these threshold methods are based on a half gain rule (Lybarger, 1944) which states that the optimum frequency threshold values are from 1 kHz through 4 kHz and about one half of the threshold value at 500 Hz. A popular method for prescribing a target hearing aid response is a procedure known as the POGO method (McCandless and Lyregaard, 1983). POGO stands for: prescription for gain/output. This method, a variation of the half-gain method, reduces the amount of insertion gain in the lower frequency region. The purpose of the POGO method is to
shift speech and environmental sounds into a range that is most comfortable to the listener. The prescribed gain at 500 Hz and 250 Hz is reduced to minimize the amount of low frequency background noise amplified.

Berger, Hagberg and Rane (1977), also used threshold data when they developed their "prescribed operating gain" method of prescription. It, like other procedures, attempts to optimize the speech spectrum being delivered by the hearing aid. Specifically, the Berger et al. procedure calculates what the gain should be between 500 Hz and 2000 Hz so that they are perceived as equally loud by the listener. This procedure also recommends less gain at 4000 Hz and 6000 Hz to avoid any further damage to the cochlea.

Byrne and Tonisson (1976) based their prescriptive procedure on levels of speech which children tend to prefer. It also applies to a formula to threshold information in calculating loudness levels of speech. One drawback to this method is that it does not take into account any conductive components of the hearing loss (Skinner, 1988).

Byrne and Dillon (1986) developed a slightly different approach to prescribing proper insertion gain. Their method uses the slope of the pure tone audiogram in prescribing the "optimal" response of the hearing aid. Their procedure, also referred to as the National Acoustics Laboratory procedure, was a modification of the Byrne and Tonisson procedure which Byrne and Dillon felt prescribed too little
amplification around 400 Hz to 500 Hz and too much gain for the higher frequencies. Their method prescribes an insertion gain that will amplify long-term levels of speech to comfortable levels between the frequencies of 250 Hz to 6,000 Hz (Skinner, 1988).

Unlike the previously mentioned prescriptive methods, which base their computations around audiometric threshold data, another group of prescriptive procedures bases insertion gain on the listener’s suprathreshold data. Of interest to these methods are the listener’s most comfortable level and uncomfortable level (Skinner, 1988). The Pascoe method, for example, bases the target insertion gain on a percentage of difference between the listener’s thresholds and the most comfortable loudness level (Pascoe, 1978). This method is intended to provide amplification which does not distort sound and is most acceptable to the listener. Because this method is predicated on a listener’s most comfortable level, it is not limited by the degree of hearing loss as some of the previously mentioned methods are (Skinner, 1988).

Finally, another method, based on comfort levels (Cox, 1983) calculates insertion gain as a midpoint between the listener’s thresholds and the upper limit of their comfortable range in an attempt to provide amplified speech at levels where intelligibility is optimized as well as overall listener comfort for extended periods.
The above mentioned prescriptive procedures for estimating target gain are only a few of the methods developed within the last several years. There are numerous other methods also in use, which like those discussed, attempt to maximize speech intelligibility while at the same time providing acceptable sound quality (Leigion et al., 1991; Skinner, 1988). Secondary to prescribing the appropriate frequency response to meet the above objectives, most of the prescriptive methods also attempt to estimate the overall gain that will be required for a particular hearing loss.

There is no consensus among dispensers today as to which of the several prescriptive methods now in use is the "best" for most amplification candidates (Jones, Wynne and Kasten, 1993; Zelnick, 1987). There is even some debate that different prescriptive methods may yield the same intelligibility ratings by wearers (Leijon et al., 1991). While one method may seem theoretically better than another for preselection of a hearing aid's response, clinicians often find one response may or may not be rated as more intelligible than another (Byrne and Dillon, 1986). Leijon et al., (1991) caution that, while from a theoretical standpoint, these methods are integral to the preselection process, many hearing aid users base the "success" of the fitting more on the quality of sound rather than their perception of intelligibility.
Nevertheless, despite this lack of unanimity among audiologists as to which prescriptive method provides the best amplification for a given hearing loss, there does appear to be a general agreement that prescription formulae provide the most scientific approach to date in the preselection of hearing aids. As Gottermeier et al. (1991) explain, the prescriptive approach is invaluable to the proper selection of hearing aids. And, Skinner would also support the use of prescription formulae because they are not only scientifically based but they, unlike the subjective approaches to hearing aid fitting, can also be objectively verified (Skinner, 1988).

Selecting a target gain also allows the clinician a means of comparison in the verification process. As a result, it allows the clinician to make systematic changes to the hearing aid’s response either in response to the wearer’s subjective impressions or to more closely approximate the target response (Zelnick, 1987).

Verification and Adjustment of Fit

Many researchers and dispensers today agree that hearing aid fitting is a three-phase process in which the preselection of the hearing aid (based on the prescriptive procedures discussed) is followed by verification and finally by comparison and adjustment (Seewald and Ross, 1988). In order to verify the prescription and measure the insertion response, a method of measuring sound pressure in
the ear canal was developed. The means of measuring in the ear canal, known as real ear measurements, is now being routinely used by audiologists around the country (Surr and Fabry, 1991). They use real ear measurements to compare the observed insertion gain (the gain provided by the hearing aid while being worn) with the prescribed gain.

Real ear measurements are obtained by placing a small probe tube (which is attached to a microphone) in the external ear canal. The probe tube allows the clinician to measure the normal resonance of the ear canal and then subtract this value from the amount of amplification provided by the hearing aid while it is worn in the ear. The difference between these two measurements is known as the insertion gain or in-situ gain and it is the actual amount of amplification provided by the hearing aid. All real ear measurements today are done automatically by a computer microprocessor.

Within the last ten years, these real ear measurements (also known as probe tube measurements) have greatly facilitated the prescriptive methods of preselection by allowing the dispenser to objectively measure the response of the hearing aid while it is in the client's ear. Today, the dispenser is able to create frequency/gain "targets" based on a particular prescriptive rationale (Jones, et al., 1993).

It has generally been thought that, because of their
custom nature, in-the-ear hearing instruments could only be verified once they were completed. This would be done by either real ear measurements or functional gain measurements. Functional gain measurements essentially compare a wearer's hearing thresholds with and without the hearing aid in his or her ear. These threshold measurements are made by presenting sounds via a loudspeaker. The difference between these two threshold measurements is known as the functional gain of the hearing aid.

Unlike behind-the-ear hearing instruments, which can be mass produced, custom instruments must be fabricated from an impression taken of the client's ear. In an effort to compare different in-the-ear hearing instruments, some dispensers would order custom instruments from several different manufacturers. Then they would try these different custom instruments on their client in an effort to select one instrument which provided the best amplification (B. Finney, Starkey Laboratories, personal communication, February 16, 1994). Those custom instruments which were not acceptable to the client, were then returned to the manufacturer for credit. This method of selecting custom instruments is considered an abuse of the return-for-credit privilege that dispensers enjoy with manufacturers. What is more, it was a very inefficient means of evaluating the performance of custom hearing instruments (Lowen and Zachman, 1990). Therefore, some audiologist believe that,
because of their inherently custom nature, in-the-ear hearing instruments cannot be pre-evaluated, per se, but only verified by real ear measurements once they have been completed.

Pre-evaluating Custom Instruments

A potentially valuable method of fitting in-the-ear hearing instruments would be to somehow measure the insertion response of the instrument (with a target insertion response in mind) before the instrument is completed. This would allow the dispenser to make necessary modifications to the instrument, such as incorporating the client’s ear canal resonance, prior to its final assembly. Every ear canal provides its own natural amplification to certain frequencies. In the human ear these frequencies generally lie between 2 kHz and 3 kHz (Møller, 1983). However, each individual ear canal has its own specific resonant frequency. This natural boost to sound provided by a specific ear canal should be taken into account when prescribing the amplification and frequency response of a hearing aid. This is to avoid too much amplification at a particular frequency which might already have been amplified by the ear canal’s resonance. Moreover, as Angeli, Seestedt-Stanford and Nerbonne (1990) found, there is a great variability in the amplification properties of custom instruments ordered from different manufacturers, despite the fact that each manufacturer received the same
audiometric data from the dispenser. Therefore, pre-evaluation of custom instruments with probe tube measures would give the dispenser more control over the final output of the instrument. This would be advantageous because as Angeli, et al. (1990) point out, "the actual electroacoustic properties of ITE (in the ear) units received from manufacturers still have an unacceptably high degrees of inconsistency."

**Under-utilization of Present Technology**

Despite the wide variety of technology now available in custom instruments, many authors point out how highly under-utilized this technology is (Crandell and Assman, 1991; Burton, 1993; Tyler and Kuk, 1990). Crandell and Assman (1991) believe that the available technology in custom instruments is not more wide-spread because audiologists have yet to establish adequate protocols for when to use the various technologies. (Bächler and Bürkli-Halevy, 1994). In addition, according to Crandell and Assman (1991), dispensers also lack an adequate means of demonstrating the various technologies to clients.

A good example of this under-utilization of present technology is input and output compression (Smriga, 1985). As Burton (1993) points out, most persons with sensorineural hearing loss (the predominant type of hearing loss) would benefit from this type of technology. However, ironically, the majority of custom instruments dispensed today utilize
mostly peak-clipping or linear circuitry (Burton, 1993). Only a small percentage of instruments utilize compression circuits.

Recent research of multi-channel compression circuits suggests that they provide improved speech discrimination for some clients (Killion & Villchur, 1993). However, according to Killion and Villchur, (1993), ninety percent of all custom instruments dispensed in the United States in 1991 were class A, linear circuits, which characteristically suffer from distortion at high input levels, (Hawkins, 1991; Van Vliet, 1994).

Henoch (1991) questioned whether dispensers have been able to keep up with the rapidly advancing technology. She also suggests that we need to make some significant changes in the way we preselect and evaluate this new technology or it will continue to be as under-utilized as it is today. And, despite significant strides we have made in hearing aid technology, many hearing aid wearers still continue to complain of background noise and other drawbacks to amplification (Killion and Villchur, 1993). Many authors imply that more people could benefit from this technology but just haven’t had the opportunity to evaluate it.

According to Sammeth and Ochs (1991), despite an increasing availability of noise-reduction circuits on the market, there is still much debate as to which circuit is "best" for a particular hearing loss. Interestingly, field
trials and anecdotal reporting from wearers seem to indicate that many hearing impaired clients appear to benefit from such noise cancellation technology (Tyler and Kuk, 1989).

Beck (1991) articulates a valid reason why the use of faceplate assemblies, as proposed in this study, might be of significant benefit. He explains that dispensers lack a consensus as to which technology is "best" for a particular client and it would be difficult to know which technology is best without somehow assessing it and qualifying it on an individual basis. Perhaps if dispensers could meaningfully demonstrate various technologies on clients prior to the manufacture of the custom instrument, they might be more likely to try different technologies (Tyler and Kuk, 1989).

Also, as the hearing impaired population becomes more sophisticated about various technologies now available, dispensers will be held more accountable to demonstrate the functional performance differences of these technologies. As the technology becomes more expensive, clients will also start to evaluate it more on a cost versus performance basis (B. Finney, Starkey Laboratories, personal communication, March 13, 1994).

Subjective Considerations in the Fitting Process

While selection of a particular hearing aid circuit will continue to rely heavily on the prescriptive rationales discussed earlier, Sammeth and Ochs (1991) stress the importance of using the objective data in conjunction with
some form of subjective information from the wearer. Moreover, Duffy (1990) makes the point which is central to this investigation. That is, if all this new technology is superior to the previous, linear, non-processing technology, then there should be some method of evaluating and demonstrating its performance to the client. In contrast, the use of real ear measurements should be viewed in the context that each hearing aid wearer has his or her own expectations of what the hearing aid should do (Mynders, 1991).

It was mentioned earlier that the hearing aid fitting process comprises three phases: the pre-selection phase (utilizes prescriptive methods); the validation phase (utilizes probe tube, real ear measurements); and a third phase which might be considered to be the subjective evaluation phase (Humes, Hipskind and Block, 1988). This is where the enhanced speech benefits and sound quality of the instrument selected are demonstrated to the wearer (Wolinsky, 1986).

However, it is difficult to clinically demonstrate the advantages of the various technologies. For example, our current speech recognition tests appear to lack the sensitivity to discern subtle differences in hearing aid performance (Sammeth and Ochs, 1991; Beck, 1991).

Despite the inability of speech tests to detect subtle differences in hearing aid performance, some of the new
technology may be demonstrable to the client in terms of listening comfort and the simple reduced annoyance from background noise that many hearing aid wearers complain of today. This author routinely allows clients to listen to noise-suppression circuits in the presence of loud background noises in order to demonstrate how these circuits can effectively reduce such noises. This demonstration usually elicits a favorable response from clients despite the fact that their speech intelligibility has not been demonstratively improved. Therefore, as Stein and McKee (1989) point out, the evaluation phase of the fitting process should also involve subjective evaluations in addition to speech intelligibility testing (Preves and Woodruff, 1990).

Some authors believe that speech enhancement afforded by various technologies can, in fact, be demonstrated to the client. Stein and McKee (1989) devised a test to clinically evaluate different circuits. Specifically, they demonstrated how various circuits can enhance speech perception in the presence of background noise. They reported that their test (Speech Intelligibility in Noise) allows the practitioner a valid tool with which to recommend a particular circuit for a given application. They concluded that certain noise suppression circuits were, in fact, effective in enhancing speech perception. If Stein and McKee's finding are accurate, this would support the use
of faceplate assemblies to allow the hearing aid candidate to evaluate different speech-enhancing circuits.

Other authors (Van Tassell and Yanz, 1987; Crandell, 1991; Killion and Villchur, 1993) have also devised tests which they believe can be used to determine the degree to which a particular circuit can help an individual hear in background noise. Many other authors agree with Stein and McKee, that various tests, such as the Speech Intelligibility in Noise Test, make it easier than once thought to demonstrate various signal processing strategies (Killion and Villchur, 1993; Crandell, 1991; Cox and Alexander, 1991). However, because not all noise-suppression circuits appear to benefit all hearing impaired listeners in everyday listening situations, their evaluation during the pre-selection process would seem to be potentially helpful (Henoch, 1991). It is possible to determine those clients, who during the evaluation phase, might respond favorably to noise suppression technology.

Where evaluation of various circuits is concerned, Sammeth and Ochs (1991), make the point that it must be considered within the context of the individual, not relative to mean data. This is because the majority of hearing impaired individuals have not shown very impressive results with noise suppression circuits. However, Horwitz, Turner and Fabry (1991), and Sammeth and Ochs (1991), have demonstrated that there appear to be some individuals
appear to show benefit from these technologies. Therefore, all potential hearing aid candidates should have the opportunity to evaluate this technology.

Mynders (1991) believes that the ultimate decision about which circuit is best for a particular hearing loss will rest with the individual. Rather than the dispenser making the ultimate decision as to which circuit is the "best" for a particular client, the selection process should be a mutual interaction between client and dispenser. This is especially true in light of the fact that the newer, non-linear signal processing circuits are no longer measurable by traditional real ear methods (Fabry, 1993; Johnson, 1993).

Crandell (1991) points out that the fitting process should also include some kind of assessment, when evaluating various circuits, of how susceptible a person is to noise. In addition Henoch (1991) and Graupe, Grosspietsch and Taylor (1986) note that the fitting process, if possible, should also assess how a hearing impaired listener will perceive speech in a number of different environments. In doing so, the clinician and client can possibly infer how various circuits might help in those situations. To this end, a client could listen to various faceplate circuits, as proposed in this investigation, while the clinician demonstrates various sound environments.

Jones, Wynne and Kastan (1993) assert that the proper
hearing aid evaluation should include more than just parameters such as gain, frequency response and overall power, if the optimal fitting is to be achieved. Their rationale is that the real world environment, for which the amplification is ostensibly designed, is an "unpredictable environment with its changing signal levels, background noise and reverberant conditions."

In view of the above considerations, the evaluation phase of the fitting process should include not only the subjective evaluations of the client but also an earnest attempt on the clinician's part to infer how various amplification strategies will assist in the client's everyday listening environments, (Van Vliet, 1994.) Such assessments might even include questionnaires which could help predict the client's potential benefit and performance (Cox and Gilmore, 1991). Sullivan, Levitt and Hwang (1988) found that a hearing aid wearer's performance changes relative to different input levels. This too would be something that could be assessed with the faceplate assemblies proposed in this study (Kates, 1986).

Killion and Tillman (1991) believe subjective rating of quality and pleasantness of sound are also good predictors of how well clients will accept amplification. This is another situation where faceplate assemblies might prove helpful in the evaluation of various technologies. But, as Honoch (1991) explains, we also have no well-defined methods
of assessing a client’s satisfaction with a hearing aid’s performance. This assertion is also supported by Jones, et al. (1993) whose study found that hearing aid circuits with identical amplification characteristics were often perceived differently by the same client. This is another example of why dispensers should not rely only on insertion gain measurements in deciding which circuit is best.

Mynders (1991) and Magilen (1991) also state that the dispenser should listen to the client’s subjective impressions as to which of the many new technologies such as automatic signal processing, multi-band compression and ultra-discrete frequency selection digital noise cancellation are best for his or her particular hearing needs. It is the thesis of this study that faceplate assemblies could be very helpful in the prescription, validation and evaluation of custom instruments. Allowing clients to listen to faceplate assemblies could facilitate the dispenser/client interaction which Mynders (1991) believes is more important than real-ear measurements, hearing aid analyzer results and speech discrimination testing. The faceplate assemblies would lend themselves to what Magilen calls the guided selection method (1991), where the clinician and client work as a team to find the optimum circuit for the particular hearing loss (Killion and Fikret-Pasa, 1993).
Summary

From the above review of the literature, it becomes apparent that hearing aid technology today is increasing so rapidly that it now poses a tremendous challenge to the dispensing profession (Preves, 1993). Today, audiologists and dispensers have numerous hearing aid circuits from which to choose for their hearing impaired clients. However, as the review of the literature also makes clear, there is yet no generally accepted protocol for determining which technology is the "best" for each situation.

While most authors accept real-ear measurements as the definitive means of determining that the "target" prescription response has been achieved, it is also clear from the literature that there is much more to the fitting process than just these objective criteria. It is becoming incumbent on the dispenser to be able to demonstrate and evaluate as many of the available technologies in the clinical setting as feasible. This would not only facilitate the verification of the target response, but would also allow the client to offer his or her subjective evaluations. If the faceplate assemblies can be used in the selection process, because they are found to be facsimiles of a completed instrument, this would be invaluable to the fitting process.

The literature also indicates that much of today's available technology is highly under-utilized. If
practitioners could more easily evaluate these rapidly changing technologies, by way of a faceplate assembly, they might be more likely to try new technological developments.

Finally, the literature indicates that the dispensing community's approach to selection and evaluation of hearing aid technology is still highly subjective and non-systematic. If the faceplate assembly proved to be a facsimile of the completed, custom instrument, this could make it easier for practitioners to approach fitting of custom instruments in a more meaningful, scientific manner. This, in turn, would greatly increase the likelihood of providing the hearing impaired client with truly optimum amplification.
CHAPTER III

METHODS

Subjects

Twelve adult subjects, from twenty-three years of age to forty-three years, participated in this study. Only one ear of each subject was utilized. Each subject’s middle ear system demonstrated normal immittance. This was demonstrated by obtaining tympanograms with an American Electromedics 86 AR typanometer. All tympanograms were within a normal range, defined as a peak pressure of between -100 and +100 daPa and an amplitude of at least .3 compliance units.

Faceplate Assemblies/Hearing Aids

The acoustic output of the faceplate assembly was measured by coupling the receiver tube to a 2-cc, HA-1 coupler. All receiver tubing was standard #13 polyethylene tubing (I.D. = 2.0 mm). Each receiver tube was cut to an exact length of 10 mm as measured from the nub of the receiver. While receiver tubing length varies in custom instruments, 10 mm can be considered within the range of tubing lengths normally seen. The output of the faceplate assembly was measured on a Fonix 6500 hearing aid test system with the faceplate’s output set at reference test position, as described by Skinner (1988) and as recommended
by the ANSI standard for hearing aid specifications (ANSI S3.22 1982). This 2-cc coupler measurement was made of all faceplate assemblies to ensure that all circuits were within the manufacturer's specifications. All faceplate assemblies used in this study were comprised of identical electronic components. Specifically, all amplifier circuits were model 182 high frequency linear amplifiers manufactured by Dyn Aura Engineering Laboratories. All microphones were Knowles Electronics model 3024 and all receivers were Knowles model 1913. The output of three faceplate assemblies in dB SPL as a function of frequency of a test signal, as measured in a 2-cc, HA-1 coupler, is shown in Figure 3. Note the similarity of their response curves. The coupling of the faceplate assembly to the subject's ear was done using a standard foam earplug manufactured by the EAR Corporation. The tubing of the receiver was passed through the axis of the earplug so the end of the receiver tubing was flush with the medial surface of the earplug. The receiver tube was then inserted into the opening of the external ear canal by compressing the foam plug in the same manner as recommended by the manufacturer. The experimenter could see where the foam plug terminated in the ear canal. All depths of insertion into the canal were approximately 5 mm. To accomplish this depth of insertion, the foam EAR plug was inserted about halfway into the external canal as measured from the tragus (the foamplugs are approximately 10 mm in
Figure 3. The three graphs above are frequency/output curves of three faceplate assemblies (all with the same type of components) chosen at random. The faceplates are measured in a 2-cc, HA-1 coupler and are coupled to the coupler with a foam ear plug as described in the methods section. All three faceplates have identical gain settings as measured on the screw-set potentiometer. Note the similarity of response among the three faceplate assemblies.
length when connected to the receiver tubing).

Before the foam plug was compressed for insertion into the ear canal, a small silicone probe tube was passed through the plug along the side of the receiver tubing so that it extended out of the medial end of the plug. The silicone probe tube was then positioned so that it extended past the end of the opening of the receiver tube by approximately 15 mm. This was to ensure that the probe tube was not subject to pressure minima which occur close to the opening of the receiver tube (Skinner, 1988). This also ensured that, when the foam plug is inserted into the ear canal, the silicone probe tube extended into the ear canal approximately 20 mm. (The deeper the probe tube can be inserted into the canal, the less variability in real ear measurements will be encountered, especially for frequencies greater than 3 kHz (Skinner, 1988). Preliminary measurements with the probe tube along side the foam plug indicated that the expansion pressure of the foam plug did not affect the sensitivity of the silicone probe tube. On the other hand, the foam plug held the silicone probe tube in place snugly enough so that its placement remained stable during real-ear measurements, which is critical to the reliability of such measurements.

Figure 4. shows the method for coupling the faceplate assembly to the subject’s ear. Neither the foam plug nor the completed custom instrument contained any venting to
Figure 4. The photograph above shows how the faceplate is coupled to the subject's ear (experimenter is holding the faceplate). A foam plug is used to couple the receiver of the faceplate to the ear canal. Hanging just below the subject's ear lobe is the microphone for the probe tube. The probe tube extends directly up from the probe microphone and into the foam plug. Once the foam plug has been inserted half way into the subject's ear, the faceplate is then placed directly over the ear and attached to the velcro band around the subject's head. Also note the reference microphone of the Fonix 6500 which is attached to the velcro headband just in front of the subject's ear.
minimize variations in the amount of low frequency amplification which is dissipated during normal venting.

The completed custom instrument was made from the faceplate assembly used in the first part of this study. The completed instrument was made from an acrylic shell fabricated from an impression made of the subject's ear. The custom shell was then bonded to the faceplate and trimmed in the same manner as used by most manufacturers of custom, in-the-ear instruments (B. Finney, Starkey Laboratories, personal communication, Jan. 10, 1994) resulting in a completed, custom instrument.

**Procedures**

The first session of this study involved obtaining histories and performing otoscopic examinations to ensure all test ears were free from any significant amount of cerumen (which could affect real ear measurements by plugging the probe tube). Tympanometry was also performed to ensure normal middle ear function. Each subject received oral and written instructions regarding the purpose of this study. Next, an elastomer impression was made of the test ear and was subsequently used to fabricate the customized shell.

The second part of the first session consisted of obtaining real-ear, unoccluded ear canal resonance measurements and insertion gain measurements of the faceplate assembly when coupled to the client's ear. For
all soundfield measurements, starting with ear canal resonance, the subject was seated next to a Realistic, Minimus -7 speaker. The subject’s head was oriented at 45° to minimize any variances in sound pressure in the ear canal (Killion and Revit, 1987). Head orientation of 45° was maintained by having the subject visualize an object in the 45° plane. The speaker was located at ear level and was 18 inches from the subject’s ear, as measured from the ear to the speaker. Once ear canal resonance measurements were obtained in the manner recommended by the manufacturer of the FONIX 6500 hearing aid test system, the faceplate assembly was coupled to the subject’s ear using the foam earplug described earlier. The faceplate, which was connected to the receiver by about 25 cm of small gauge earphone wire, was attached to a velcro band which was placed around the subject’s head. Figure 5. shows a subject in proper orientation for real ear measurement of a coupled faceplate assembly. The attached faceplate was then carefully placed over the subject’s ear so that the microphone port of the faceplate was in approximately the same orientation that it would be in the completed, custom instrument.

Once the faceplate was in its proper orientation over the ear, the gain of the amplifier was set to a level where normal conversational speech (an average of 65 dB SPL at ear level) was heard comfortably by the subject. To ensure that
Figure 5. The photograph above shows the subject in proper orientation for real ear measures of the faceplate coupled to his left ear. He is sitting at a 45° angle, 18 inches from a loudspeaker.
the amplifier gain remained constant for both conditions, a 25 kΩ, screw-set potentiometer was used in place of a conventional volume control. Once the most comfortable amplifier setting on the potentiometer had been established, it was not changed throughout the study. This avoided any possible variances in the hearing aid’s output due to non-linearity of either the potentiometer or the amplifier.

Unoccluded ear canal resonance and insertion gain (the gain provided by the hearing aid in the subject’s ear) was obtained using a Frye Electronics, FONIX 6500 hearing aid test system. Real ear measurement technique was that described by Skinner (1988). This technique involves first measuring the effect of ear canal resonance. The second measurement, according to Skinner (1988), is with the hearing aid inserted in the ear (in this case, the faceplate assembly) and set to the subject’s most comfortable listening level.

The stimulus presented by the FONIX 6500, via the speaker, was a speech-weighted, composite noise which was automatically calibrated relative to the reference microphone. The reference microphone was attached just in front and above the pinna to a velcro band which was worn around the subject’s head (the same velcro band to which the faceplate assembly was attached). The probe microphone was then calibrated by placing the tip of the tube at the reference microphone and re-presenting the composite
stimulus at 65 dB SPL. The probe microphone was held in place by hanging it from the subject's pinna.

The frequency-gain curve, the curve of interest for this study, was automatically calculated by the FONIX 6500's microprocessor. The system processor subtracts the gain enhancement of the ear canal's resonance from the gain of the faceplate assembly (set at the subject's most comfortable level). The arithmetic difference of these measurements is the amount of insertion gain provided by the faceplate assembly (Skinner, 1988). The analog results of all measurements were displayed on a video monitor and were printed out for comparison to subsequent measurements. The FONIX 6500's microprocessor can also convert all analog data into numerical form for easier statistical comparison.

Once frequency/gain values had been obtained for the faceplate assembly coupled to the subject's ear the faceplate assemblies were removed. Next, an elastomer impression of the subject's left ear was made, from which a customized acrylic shell was fabricated.

The second session (a return visit) involved obtaining real ear insertion gain values of the completed custom, in-the-ear hearing aid made from the elastomer impression of the subject's ear. All custom instruments utilized the same faceplate that was used in the prior faceplate/plug condition. Real ear insertion gain measures of the custom instrument were obtained using the same technique as
described above and as discussed by Skinner (1988). These insertion gain values were also printed out in analog and graphic form for statistical comparison to those values obtained from the faceplate/plug condition.
CHAPTER IV

RESULTS

Figure 6 shows the insertion gain curves for a faceplate assembly and a completed instrument for subject DC. The dotted line represents the insertion gain of the faceplate and the solid line is the insertion gain of the completed instrument. Even though the average insertion gain of the completed instrument is greater than the faceplate for some frequencies and less for other frequencies, there is still an apparent similarity of response for the two curves. The greatest difference between the two conditions was approximately 15 dB at 7.5 kHz. This subject showed the most similarity between the two insertion gain curves of any of the twelve subjects in this study.

Figure 7 shows data from a subject (TM) for whom there is an obviously greater disparity between the insertion gain curves of the two conditions. Notice that at about 5 kHz there is a difference in the gain between the conditions of nearly 30 dB. The Appendix shows the comparison of the two conditions for the remaining ten subjects. Most of the subjects showed an apparent dissimilarity in insertion gain between the two conditions.
Figure 6. Faceplate and plug versus completed ITE (insertion gain) for subject, DC.
Figure 7. Faceplate and plug versus completed ITE (insertion gain) for subject, TM.
For five of the subjects (Figures 7, 9, 10, 13 and 17), the average insertion gain of the faceplate condition was greater than the insertion gain of the completed instrument. In contrast, for the remaining seven subjects (Figures 6, 8, 11, 12, 14, 15 and 16), the average insertion gain of the completed instruments was greater than the faceplate condition.

Insertion gain was compared at five frequencies (2 kHz, 3 kHz, 4 kHz, 5 kHz and 6 kHz) using a faceplate assembly and a completed, custom instrument. Means and standard deviations for these measurements are displayed in Table I.
TABLE I

MEANS AND STANDARD DEVIATIONS FOR INSERTION GAIN MEASURES

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Faceplate</th>
<th>Custom Instrument</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>18.68 dB</td>
</tr>
<tr>
<td>2 kHz</td>
<td>SD</td>
<td>4.03 dB</td>
</tr>
<tr>
<td>3 kHz</td>
<td>M</td>
<td>17.53 dB</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>8.23 dB</td>
</tr>
<tr>
<td>4 kHz</td>
<td>M</td>
<td>22.71 dB</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>7.63 dB</td>
</tr>
<tr>
<td>5 kHz</td>
<td>M</td>
<td>26.82 dB</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>7.32 dB</td>
</tr>
<tr>
<td>6 kHz</td>
<td>M</td>
<td>27.35 dB</td>
</tr>
<tr>
<td></td>
<td>SD</td>
<td>8.18 dB</td>
</tr>
</tbody>
</table>

A two-way Analysis of Variance (test condition by frequency) with independent measures on both factors revealed a significant difference in gain across frequencies, (p<.05). No significant difference was found between the two test conditions, (p>.2) and there was no interaction between test conditions and frequencies, (p>.5). A summary of the analysis of variance is shown in Table II.
A Pearson’s Product Correlation Coefficient was prepared at each of the five frequencies to examine any correlation between the gain in the two conditions. A significant positive correlation was found for 3 kHz ($r = .83$, $p = .001$) but for none of the other four frequencies measured. Table III summarizes the Pearson’s Correlation Coefficients for the five frequencies tested.

**TABLE II**  
ANALYSIS OF VARIANCE FOR INSERTION GAIN MEASURES

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Sum of Squares</th>
<th>DF</th>
<th>Mean Square</th>
<th>F</th>
<th>Significance of F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Effects</td>
<td>751.534</td>
<td>5</td>
<td>150.307</td>
<td>2.806</td>
<td>.020</td>
</tr>
<tr>
<td>FREQ</td>
<td>679.769</td>
<td>4</td>
<td>169.942</td>
<td>3.173</td>
<td>.016</td>
</tr>
<tr>
<td>COND</td>
<td>71.765</td>
<td>1</td>
<td>71.765</td>
<td>1.340</td>
<td>.250</td>
</tr>
<tr>
<td>2-way Interactions</td>
<td>454.435</td>
<td>4</td>
<td>113.609</td>
<td>2.121</td>
<td>.083</td>
</tr>
<tr>
<td>FREQ/COND</td>
<td>454.435</td>
<td>4</td>
<td>113.609</td>
<td>2.121</td>
<td>.083</td>
</tr>
<tr>
<td>Explained</td>
<td>1250.969</td>
<td>9</td>
<td>113.997</td>
<td>2.502</td>
<td>.012</td>
</tr>
<tr>
<td>Residual</td>
<td>5891.608</td>
<td>110</td>
<td>53.560</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>7097.577</td>
<td>119</td>
<td>59.644</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TABLE III

CORRELATION OF FACEPLATE INSERTION GAIN WITH CUSTOM INSTRUMENT INSERTION GAIN

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Pearson's r</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>.4774</td>
</tr>
<tr>
<td>* 3000</td>
<td>.8286 *</td>
</tr>
<tr>
<td>4000</td>
<td>.2063</td>
</tr>
<tr>
<td>5000</td>
<td>-.5483</td>
</tr>
<tr>
<td>6000</td>
<td>-.4012</td>
</tr>
</tbody>
</table>

A tolerance template (as specified by ANSI 3.22 1982) was superimposed over each of the twelve subject’s faceplate insertion gain curves. This revealed that none of the completed instrument gain curves were completely within the ± 6 dB as allowed by the template for frequencies 2 kHz through 6 kHz. Neither were they within the ± 4 dB allowed for frequencies below 2 kHz. Because the tolerance template was exceeded for all subjects, the two conditions (faceplate assembly vs. custom instrument) were concluded to be significantly different for all twelve subjects.

A third criterion for similarity was subjective reporting. During the study this experimenter asked subjects to rate the two conditions in terms of their similarity of sound quality. Ten of the subjects indicated that the faceplate and completed instrument sounded either "very similar" or "indistinguishable" in terms of sound quality.
CHAPTER V

DISCUSSION

Interpreting the Results

The purpose of this study was to determine if a faceplate assembly, when coupled to the ear, could be considered a facsimile of a completed custom instrument made from the same faceplate. The criterion for what would be considered a facsimile, was the similarity in insertion gain responses between the two conditions. Similarity was assessed by two methods. First, an ANOVA and Pearson's correlation were computed for comparison between both conditions. Secondly, a variation tolerance template, as recommended by the American National Standards Institute, S3.22 1982 was used to compare the insertion gain of the completed instrument to the insertion gain of the faceplate condition.

From a purely statistical standpoint, the ANOVA results would lead one to believe that there is not a significant difference in mean insertion gain between the two conditions. However, visual inspection of the graphs (Figures 6 through 17) comparing the two conditions reveals that there is considerable disparity in insertion gain between the two conditions for most of the subjects (Figures 8 through 17 are in the Appendix).
The tolerance template, which allowed for a variation of not more than ± 6 dB for frequencies between 2 kHz and 6 kHz and ± 4 dB for frequencies below 2 kHz, revealed that there were no subjects for whom these tolerances were not exceeded for at least one of the measured frequencies. Therefore, based on the tolerance template criterion, the two conditions could not be considered similar.

The tolerances for acceptable variation between hearing aid responses, as spelled out by ANSI S3.22 1982, seem a more meaningful criterion to use in this study. This is because this criterion addresses itself to the same type of frequency/gain response curves as measured in this study. Although the ANSI S3.22 1982 standards apply more to manufacturing variances allowed, a ± 6 dB for frequencies from 2 kHz to 4 kHz and ± 4 dB for frequencies less than 2 kHz are also applicable to comparing one hearing aid response to another. The ANSI S3.22 1982 criterion was modified in this study to include 5 kHz and 6 kHz inasmuch as the circuit being investigated was a high-frequency amplifier.

In addition, a variation of ± 6 or 4 dB can also be used when comparing insertion gain response to a prescribed "target" response. In other words, the template criterion of ± 6 or 4 dB is more tailored to comparing hearing aid responses and, hence, seems to be a more useful means for determining similarity in this study. Therefore, based on
the template criterion, one must conclude that there are significant differences between insertion gain responses of the faceplate condition vs. the completed, custom instrument condition.

Ten of the subjects indicated that the faceplate and completed instrument sounded either "very similar" or "indistinguishable" in their sound quality. This would lead one to believe that the faceplates would have some utility in letting clients listen to different circuits. In the same token, it is not surprising that most of the subjects thought the two conditions sounded similar. This is because the literature indicates that hearing instrument responses must be considerably different before the wearer can tell a difference between two responses. Therefore, differences between two instruments, in terms of their insertion gain, is far more likely to be detected with real ear measurements than by subjective reporting.

Possible Sources of Variability Observed

Possible sources of the variability observed between the two conditions in this study should be explored. Valente et al. (1990) and Hawkins & Mueller, (1986) concluded that real ear measurements are very reliable and, any differences greater than 3 dB, between test-retest on the same instrument, can be attributable to differences in the hearing aids themselves. Valente et al. (1990), who used the same real ear system as used in this study, listed
some variables which should be closely controlled. Some of these variables, such as speaker distance, head angle and probe tube insertion depth, were discussed in the methods section, with specific reference to how they would be controlled.

Another possible source of variation in gain curves of the two conditions could have been due to the probe tube being pinched off by pressure from the hearing aid against the ear canal wall, since some of the completed custom instruments seemed to fit quite snugly against the probe tube. Such pinching was observed during real ear measurements. Occasionally the hearing aid had to be reinserted in order to obtain a proper real ear measurement. Pinching was deduced from reduced or completely eliminated insertion gains. This problem could possibly be eliminated in future studies by inserting the probe through a channel in the hearing aid as provided by some custom instrument manufacturers. This would ensure that there is no pressure exerted on the probe tube.

Another potential problem with inserting the probe tube between the hearing aid and the canal wall is that it can also adversely affect tube placement in the canal (Libby, 1991). This can happen by the canal portion of the hearing instrument causing the tip of the probe tube to move laterally within the ear canal, even to the point of impinging upon the canal wall. As Valente et al. (1990)
explained, tube placement is critical to the variability of real ear responses. If a probe tube were inserted through a canal in the hearing aid, one could be more confident that tube placement remained stable.

It was mentioned in the introduction that differences between the two conditions might be expected due to the possible baffle effect of the faceplate which covers the outer surface of the ear. This baffle effect, again, would be an altering of the outer ear’s natural resonance properties. If the variations observed across all twelve subjects were, in fact, due to the baffle effect of the faceplate, it would seem reasonable to see a more systematic alteration to the faceplate condition. Since the differences seen between the two conditions showed no particular trends, it seems unlikely that these differences were due solely to faceplate effects, which should be similar for all twelve subjects. If, on the other hand, all twelve faceplate conditions showed an alteration which was frequency related, especially where the higher frequencies are concerned, this could be more attributable to the faceplates. Such a phenomenon was not observed, however.

Finally, another potential source of the variation between the two conditions is differences in ear canal volume. This experimenter tried to control the depth of insertion of the earplug and the hearing aid to 5 mm. However, the differences seen in insertion gain between the
two conditions could be explained by differences in ear canal volume. Larger volumes of air would lower the gain of either the faceplate assembly or custom instrument, depending on which one extended further into the ear canal.

**The Future of the Faceplate Assembly**

Even if subsequent studies continue to reveal significant differences (using the ANSI S3.22 1982 criterion) between the faceplate assembly and a custom instrument, that does not necessarily mean the faceplate assembly is without some utility in the fitting process. While significant differences between the two conditions might rule out the use of the faceplate in measuring a target insertion gain, the faceplate can have other important applications.

As mentioned earlier, the faceplate assembly can still be very useful in allowing clients to experience the various noise-cancellation technologies (Martin, 1993). It can also serve to give the client a "general" idea of what his or her completed hearing aid might sound like. Therefore, from a purely subjective standpoint, the faceplate assembly can possibly give the client some useful information about his or her completed, custom instrument. It is certainly this investigator's experience that most clients are very interested in listening to what their hearing aid will sound like prior to its construction.

Additional investigation with the faceplate assembly is
warranted. However, regardless of the outcome of real ear measures, there still seems enough value to the assembly to merit its use in the fitting process. This is especially the case among those dispensers who design and build their own custom instruments. As the technology in custom hearing instruments continues to burgeon, as in the last several years, the faceplate assembly should continue to have utility in the fitting of custom, in-the-ear hearing instruments.
REFERENCES


KILLION, M.C., and VILLCHUR, E. (1993). Kessler was right-partly: but SIN test shows some aids improve hearing in noise. THE HEARING JOURNAL, 46, 31-34.


RIPPY, J.V. (1993). Programmables provide better hearing, so why are we fitting so few? THE HEARING JOURNAL, 46, 44-45.


APPENDICES
Figure 8. Faceplate and plug versus completed ITE (insertion gain) for subject, MF.
Figure 9. Faceplate and plug versus completed ITE (insertion gain) for subject, SM.
Figure 10. Faceplate and plug versus completed ITE (insertion gain) for subject, JN.
Figure 11. Faceplate and plug versus completed ITE (insertion gain) for subject, RS.
Figure 12. Faceplate and plug versus completed ITE (insertion gain) for subject, RJS.
Figure 13. Faceplate and plug versus completed ITE (insertion gain) for subject, DM.
Figure 14. Faceplate and plug versus completed ITE (insertion gain) for subject, JF.
Figure 15. Faceplate and plug versus completed ITE (insertion gain) for subject, LS.
Figure 16. Faceplate and plug versus completed ITE (insertion gain) for subject, TD.
Figure 17. Faceplate and plug versus completed ITE (insertion gain) for subject, SF.