SATURATION SOUND PRESSURE LEVELS (SSPLs) AS MEASURED IN THE HA-1 2 CC COUPLER AND IN REAL EARS

by

Kim M. Sykes

B.S., Kansas State University, 1983

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements of the degree of Master of

Arts in the Department of Speech

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1985

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ACKNOWLEDGEMENTS

Acknowledgement and gratitude is extended to my major professor and friend, Dr. Harry Rainbolt, for his guidance, assistance, and encouragement throughout this research project. I would also like to acknowledge Dr. Bruce Flanagan, Dr. Ken Kallail, and Dr. Harold Nichols, for their constructive criticism and continual support in this project. In addition, I would like to thank Dr. George Milliken, Jeff Crabb, and Dr. James Higgins for all their time and assistance in data programming and analysis.

Specific acknowledgement is extended to Peggy Nelson, my instructor and friend, who was a major influence in the undertaking of this project and of great assistance from beginning to end.

This thesis is dedicated to my parents, sisters, and grandparents, for the strength and confidence they gave me.

SATURATION SOUND PRESSURE LEVELS (SSPLs) AS MEASURED IN THE HA-1 2 CC COUPLER AND IN REAL EARS

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Many clinics today still employ a 2 cc coupler for obtaining electroacoustic characteristics for a hearing aid. However, the audiologist can not be certain that this is the true response of the hearing aid as delivered to the human ear. When determining where to set the saturation sound pressure level (SSPL 90), it is critical that we have a valid estimate of the level in order to prevent sounds from being amplified at an intensity that may be damaging.

The purpose of this study was to compare the SSPL 90 of adults' behind-the-ear and in-the-ear hearing aids when measured in a modified 2 cc coupler which utilizes the individual's earmold, and when measured in the external canal utilizing the Starkey RE 4 probe microphone system. In addition, data were also collected on the standard 2 cc coupler and maximum output measurements with a 60 dB SPL input. It was anticipated that these data would provide information concerning the accuracy of the modified 2 cc coupler measurements as compared to the real-ear measurements.

The results of this study have shown that the actual sound pressure measured in the external auditory meatus was significantly different from that measured in the modified or 2 cc coupler. Since the modified 2 cc coupler accounts for individual differences in ear canal length and bore diameter of the earmold, it is a more accurate estimate of real-ear performance than the standard 2 cc coupler. Therefore, from a clinical standpoint, the modified 2 cc coupler is a more accurate indicator of real-ear performance than the standard 2 cc coupler and should be utilized for maximum output measurements rather than the standard 2 cc coupler. However, it appears that real-ear data should be obtained whenever possible because individual differences still exist in acoustic impedance of the tympanic membrane, volume of the external auditory meatus, and earmold venting effects, that no 2 cc coupler can reliably account for to date.

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INTRODUCTION

Many clinics today still employ a 2 cc coupler for obtaining electroacoustic characteristics for a hearing aid. However, the audiologist can not be certain that this is the true response of the hearing aid as delivered to the human ear. When determining where to set the saturation sound pressure level (SSPL 90), it is critical that we have a valid estimate of the level in order to prevent sounds from being amplified at an intensity that may be damaging.

The primary goal of amplification is to fit the individual with a hearing aid that will provide the optimal acoustic information necessary to receive speech and environmental sounds to the ear. However, the method employed by the audiologist, whether it be traditional/conventional, modification of the traditional/conventional, or prescriptive/formula continues to be a controversial issue. One significant precept to hearing aid fitting is to "keep the higher intensity sounds that reach the hearing aid from being amplified to intolerable levels" (Carhart, 1980, p.

xxvi). One of the electroacoustic characteristics inherent in all hearing aids relating to this tenet is the saturation sound pressure level (SSPL 90), also referred to as the saturation output, acoustical maximum output, maximum output, and maximum power output (MPO). This is defined as the maximum sound pressure level a hearing aid can generate. Any sound pressure that would exceed this level is saturated, independent of the signal's intensity reaching the hearing aid and the amount of gain (Pollack, 1980). In order that the amplified sounds of the hearing aid will not be intolerable, it has been well established that the SSPL 90 should not exceed the listener's uncomfortable loudness level (UCL), also referred to as the loudness discomfort level (LDL), or threshold of discomfort (TD) (Berger, 1980; Kasten and Franks, 1981; McCandless and Miller, 1972; Pollack, 1980) The LDL may be assessed by one of several methods including presentations of pure tones, speech, or narrow bands of noise stimuli to the listener in increasing intensity until he/she indicates when the level is discomforting. Alternative procedures, such as utilizing acoustic reflex thresholds, may be used when individuals and/or children are unable to indicate their intolerance of the amplified sound.

In addition to preventing sounds from becoming uncomfortable, there is the risk of causing damage to the auditory system of the individual. The Food and Drug Administration put into regulation on August 25, 1977, national standards on hearing aid devices, and professional patient labeling (Food and Drug Administration, 1984). In this regulation, a warning to the hearing aid dispenser must be included as follows:

> Special care should be exercised in selecting and fitting a hearing aid whose maximum sound pressure level exceeds 132 decibels because there may be risk of impairing the remaining hearing of the hearing aid user. (This provision is required only for those hearing aids with a maximum sound pressure capacity greater than 132 decibels (dB).) (p. 27).

The American National Standards Institute (ANSI, 1976) provides standard procedures to obtain the electroacoustic characteristics of a hearing aid. These procedures measure the sound pressure developed by the hearing aid in a 2 cc coupler. However, a number of studies (Burkhard and Sachs, 1977; Goldstein, 1982; Harford, Leijon, Ringdahl, and Dahlberg, 1983; Hawkins and Haskell, 1982; Leijon, Harford, Liden, Ringdahl, and Dahlberg, 1983; Nelson, 1982; Pascoe, 1975; Sachs and Burkhard, 1972; Van Eysberger and Groen, 1959; Wetzell and Harford, 1983) have shown that measurements of the hearing aid's output in a 2 cc coupler were not reflective of those obtained from real ears. Furthermore, individual differences in the volume of the external auditory meatus, acoustic impedance of the tympanic membrane, and utilization of earmolds were not accounted for by the 2 cc coupler measurements (Pollack, 1980). McCandless (1982) pointed out the need for real-ear measurements due to the increased use of earmolds, tubing, filters, and vents to alter the acoustic signal. In addition, the 2 cc coupler functions as a closed-mold system which inadequately measures hearing aid performance with open or vented earmolds and no mold or sound tubes in the ear. McCandless (1982) reported that over 50% of the earmold fittings are open mold, therefore the real-ear measures are useful for identifying the effects of these types of earmold fittings. Furthermore, the high frequencies are enhanced as a result of the properties of the ear canal, pinna, and effects of the ear canal diameter which the real-ear measures could identify (McCandless, 1982). McCandless (1982) also stated that one of the projected needs for real-ear measurements is to "examine electroacoustic characteristics" and also "to quantify SSPL 90 for each patient's hearing aid" (p. 172).

At the present time, there are few studies on the saturation sound pressure levels utilizing real-ear measurements. In view of the previous studies, we know the 2 cc coupler does not account for individual differences in the earmold utilized, acoustic impedance of the tympanic membrane, and volume of the external auditory meatus. However, ANSI specifies that the 2 cc coupler be utilized to obtain SSPL 90 measurements and the Food and Drug Administration requires that all hearing aids be labeled with a risk of damage warning when the aid's SSPL 90 is 132 dB or greater. Obviously, if the 2 cc coupler is inaccuraterly measuring SSPL 90, then the level which determines utilization of a warning label is also inaccurate.

The current study investigated the SSPL 90 measurements on adult ears wearing behind-the-ear or in-the-ear hearing aids, utilizing the Starkey RE 4 probe microphone system, as compared to those made on the HA-1 2 cc coupler. The HA-1 2 cc coupler is a modified version of the standard HA-2 2 cc coupler, in that it allows the subject's earmold to be utilized for electroacoustic measurements. Throughout the rest of the thesis the HA-1 2 cc coupler will be referred to as the modified 2 cc coupler and the HA-2 2 cc coupler will be referred to as the standard 2 cc coupler, to prevent any confusion between the two. It is hypothesized that the modified 2 cc coupler measurements will underestimate the real-ear measurements. If a decrement is revealed in the modified 2 cc coupler measurements, then sounds becoming louder may be damaging to the ear as measured by the current ANSI specifications and the SSPL 90 may exceed the published specification for that model hearing aid.

REVIEW OF THE LITERATURE

Estimating Real-Ear Performance with the Standard 2 cc Coupler

As previously mentioned, the standard 2 cc hard-walled coupler does not accurately reflect the response of the real ear, nor was this the intent when it was designed 37 years ago (Pollack, 1980). The original purpose was to establish a means of quality control and a standard for repeating electroacoustic measurements of hearing aids between laboratories, rather than for selecting a hearing aid that matches an individual's loss. Pollack (1980) pointed out that the volume from the tympanic membrane to the earmold tip in the average adult ear is approximately 1.2 cc, not 2 cc. Furthermore, the standard 2 cc coupler and the human ear do not have the same acoustic impedance (Pollack, 1980). Although the inappropriateness of the standard 2 cc hard-walled coupler is apparent from the above knowledge, it is still used today in clinics for obtaining electroacoustic measurements in the selection of hearing aids.

There are studies, however, that have investigated the shortcomings of the standard 2 cc coupler in measurements of the electroacoustic characteristics of an aid. One of the earliest studies (Van Eysbergen and Groen, 1959) investigated the frequency response of an aid measured on the standard 2 cc coupler and on the ear of a normal listener. Pure tone thresholds were then obtained from ten listeners in monaural free field at 17 frequencies within the range of 90-8000 Hz. Next, pure tone thresholds were obtained with a miniature condenser telephone receiver utilizing both a wide and a narrow insert tip to couple the receiver to the ear. Pure tone thresholds obtained from the telephone receiver were converted into sound pressure units by connecting the standard 2 cc coupler to the telephone receiver, and then compared to the pure tone thresholds obtained from the audiometer. Van Eysbergen and Groen (1959) found the standard 2 cc coupler overestimated real-ear gain at frequencies from 90 to 1000 Hz. Peaks and troughs were apparent at 1000-3000 Hz of different magnitudes and they believed this to be due to the physical properties of the ossicles. At 3000-4000 Hz, a significant difference between the standard 2 cc coupler and real-ear gain was observed. The standard 2 cc coupler underestimated the real-ear gain by approximately 20 dB. The authors noted that the difference might be responsible for poor tone quality complaints due to excessive high frequency tone emphasis. In view of their findings, Van Eysbergen and Groen suggested that the standard 2 cc coupler be used for exchanging information between clinics only.

Sachs and Burkhard (1972) investigated sound pressure level measurements in a standard 2 cc coupler and compared them with real-ear measurements utilizing a probe tube microphone as well as different insert earphones (hearing aid receivers). Their results indicated that the sound pressure levels in the 2 cc coupler were 4 dB lower at 500 to 5000 Hz.

Pollack (1980) pointed out,

> the ratio increase is understandable at higher frequencies because the effective volume control of the tympanic membrane which is a significant portion of the total effective closed volume, decreases. Therefore, the ear impedance does not decrease as rapidly with frequency as does the 2 cc impedance (p. 71).

Hawkins and Haskell (1982) compared functional gain to standard 2 cc coupler gain with occluding and non-occluding earmolds. They utilized narrow bands of noise to obtain the unaided and aided sound field thresholds of 20 adults employing Bekesy tracking procedure. The use of narrow band noise stimuli allowed the entire frequency range from 200-6000 Hz to be defined. Unaided sound-field thresholds were obtained first, then aided occluded thresholds, followed by a standard 2 cc coupler measurement, and finally, aided unoccluding thresholds followed once again by the standard 2 cc coupler measurement. From these various conditions, functional gain was determined by subtracting aided from unaided sound-field thresholds. The standard 2 cc coupler gain was determined by subtracting a 60 dB SPL input from the SPL developed in the standard 2 cc coupler. The results obtained were as follows: 1) occluded functional gain was 0-5 dB less than standard 2 cc coupler gain for frequencies below 100 Hz, similar in the range of 1000-1500 Hz, and substantially less (5 to 15 dB) in the higher frequencies of 2000-6000 Hz; and 2) non-occluding median functional gain was 5 to 20 dB less than the standard 2 cc coupler gain in the low frequencies below 2000 Hz, and 10 dB less in the higher frequency region.

The differences between the median functional versus standard 2 cc coupler gain were revealed due to the inability of the standard 2 cc coupler to quantify earmold differences and non-occluding earmolds reduced gain below 2000 Hz. In addition, the free field to eardrum transfer sound pressure function, caused by microphone location, was not accounted for by the standard 2 cc coupler (Hawkins and Haskell, 1981). Hawkins and Haskell also acknowledged individual variability in the functional gain measures. They concluded that "verification of an individual's performance with a specific hearing aid must be made empirically" (p. 76).

More recently, Wetzell and Harford (1983) compared real-ear performance and standard 2 cc coupler measurements of hearing aid performance on two groups of subjects with long canal/short bore and short canal/large bore unvented earmolds. Real-ear performance was determined by utilizing probe tone microphones for obtaining insertion gain. Insertion gain was defined as the difference between sound pressure level in the ear with and without the hearing aid. Harford utilized a 70 dB SPL pure tone with a sweep frequency range of 100 to 10000 Hz for both standard 2 cc coupler and real-ear measures. The results from this study were in agreement with Hawkins and Haskell's (1982) results regarding the overestimation and underestimation of the real-ear performance. In all cases, the standard 2 cc coupler measurements differed from the real-ear measurements. Wetzell and Harford (1983) also found intersubject variability with both types of unvented earmolds at the frequencies observed. In addition, differences were found between the groups of unvented earmolds. They pointed out that the individual variability could be related to differences in ear canal volume with regard to the earmold's diameter and length.

Goldstein (1982) studied the effects of filtered earhooks on the electroacoustic responses of adult's hearing aids utilizing the standard 2 cc coupler and real-ear measurements. The results of her study indicated that both measurements were reliable in meeting the manufacturer's specifications of eliminating/decreasing the resonant peaks at 1000 Hz. In agreement with the previous two studies, Goldstein (1982) found that the standard 2 cc coupler overestimated and underestimated the real-ear measurements of sound pressure for the low and high frequencies, respectively. However, she indicated that the test-retest reliability was not adequate with the real-ear procedure.

Two studies (Harford, et al., 1983; Leijon, et al., 1983) have investigated real-ear and standard 2 cc coupler measures considering the SSPL 90. One study (Harford, et al., 1983) investigated real-ear SSPL 90 and standard 2 cc coupler SSPL 90 measurements of four hearing aids in 22 adults. They used a 90 dB SPL input and measured the sound pressure over the range of 100 to 10,000 Hz for both conditions. The real-ear measures utilized a miniature electret microphone that was placed in the ear canal. Recordings were obtained for aided and unaided conditions. Additional recordings were made under the same conditions but with the reference point of the microphone near the helix of the ear, fastened with tape to the hearing aid's microphone port. These recordings were repeated for each subject wearing occluded and vented earmolds. The results indicated significant differences for the two procedures with the real-ear measurement producing a higher SSPL 90. Again, these results were indicative of the greater impedance of the tympanic membrane as opposed to that in the standard 2 cc coupler. Harford, et al. (1983) also pointed out that this diminished at the high frequencies because of the low-pass effect of the average earmold which had a smaller canal diameter than that of the standard 2 cc coupler. They also indicated that the venting on the second earmold had no effect on the real-ear measures.

Another study (Leijon, et al., 1983) investigated the problem with matching the uncomfortable level of loudness to the SSPL 90 measurement. They measured the real-ear SSPL 90 under a supra-aural earphone (TDH 39) which was used to establish the uncomfortable level of loudness. They also measured the real-ear SSPL 90 on nine subjects with three different hearing aids. These real-ear SSPL 90 measurements were then compared to the standard 2 cc coupler SSPL 90 measurements of the hearing aid and to the 6 cc coupler measurements utilized to establish the UCL under headphones. The 6 cc coupler was used in calibrating the headphones. As with the other studies, the real-ear measurements varied from the standard 2 cc coupler SSPL 90 measurements. The real-ear measurements were different from the standard 2 cc coupler measurements with the median SSPL 90 indicating a greater sound pressure level when measured on the real ear for the frequency range of .25 to 5 kHz, except at 2.5 kHz. In addition, the earphone measurements differed from the 6 cc coupler measurements with the earphone measurements showing a 5 dB greater SPL in the frequency range of 1 to 2.5 kHz. The earphone measurements were lower than the 6 cc coupler measurements at .25 kHz, and at 3.5 kHz there was greater variability. Furthermore, the real-ear and earphone measurements revealed similiar results when compared to the standard 2 cc and 6 cc couplers, respectively. However, with the exception of 2.5 kHz, the real-ear hearing aid output produced higher median SPLs than the earphone at frequencies above 1.6 kHz. From the real-ear hearing aid and earphone median SPLs, Leijon, et al. (1983) indicated that the sound pressure level had the potential of being greater if the SSPL 90 of the aid was matched equally to the UCL established under the earphone at frequencies above 1.6 kHz. They suggested that a 5 dB SPL safety margin be subtracted from the 6 cc coupler for the earphone when converting the desired SSPL 90 of a hearing aid if the SSPL 90 was obtained from the standard 2 cc coupler.

The literature on the standard 2 cc coupler has revealed that it inaccurately estimates the real-ear performance because the standard coupler does not have the same volume and acoustical impedance of real ears, nor does it account for different individuals' earmolds. The standard 2 cc coupler has been shown to underestimate the gain at the high frequencies and overestimate gain at the lower frequencies. The standard 2 cc coupler was also found to under- and overestimate sound pressure levels and SSPL 90 levels at the high and low frequencies, respectively. In studies investigating the SSPL 90, the standard 2 cc coupler measurements were lower than those obtained by real-ear measurements. In view of these inherent problems found in a standard 2 cc coupler, alternate methods have been sought in estimating real-ear performance.

Estimating Real-Ear Performance by Alternative Methods

Zwislocki (1971 a, b) recognized the general dissatisfaction of the standard 2 cc coupler when utilized in the clinic and developed an alternative coupler. This coupler, measuring 1.2 cc, more realistically estimated to the volume of the average adult human ear canal when occluded with an earmold. It approximated the acoustic impedance of the human adult ear with its four side-branch resonators compromising the inertance, resistance, and compliance of the ear canal.

In the previously mentioned study, Sachs and Burkhard (1972) stated that the "Zwislocki coupler is essentially identical to pressures in real ears (with no earmold leaks) below 500 Hz" (p. 183). They reported that, between 500 and 5000 Hz, the Zwislocki coupler varied no more than +/- 2 dB in comparison to real ears. Although this investigation provided evidence that a coupler could be developed that approximated the human ear canal and its acoustic impedance, the fact still remained that individuals do not have exactly the same physical dimensions. In addition, the Zwislocki coupler could not account for other variables, such as head and pinna diffraction or body baffle effects, since it was used in a hearing aid test box. These problems led to the development of the Knowles Electronics Mannequin for Acoustical Research (KEMAR) in 1974 by Knowles Electronic, Inc. (Pollack, 1980).

KEMAR is an anthropometric mannequin designed to utilize the Zwislocki coupler, that enables measurements of hearing aid performance to be obtained by the in situ (on the head) condition. The mannequin is composed of the head and torso with the size and shape of an average human adult. It allows for data to be uniformly exchanged among laboratories since it is a reproducible test subject which does not fatigue or show physiologic changes during testing (Pollack, 1980).

There are limitations with the KEMAR device, in spite of its advantages. Pollack (1980) pointed out that an aneochic chamber was necessary for testing with KEMAR so that sound reflections and standing waves were eliminated. For most clinics, the space and money for such a chamber was infeasible. Pollack (1980) also looked at response curves of SSPL 90 as well as reference test gain as measured on KEMAR and the standard 2 cc coupler with two different hearing aids. The response curves from one hearing aid revealed KEMAR produced more output/gain than the standard 2 cc coupler in the mid-frequency range for both SSPL 90 and reference test gain measurements. The second hearing aid's SSPL 90 and reference test gain response curves showed more output/gain for almost the entire frequency range on KEMAR as compared to the standard 2 cc coupler. Pollack (1980) pointed out that it may not be possible to utilize a constant correction factor to convert standard 2 cc coupler curves to KEMAR since inconsistent differences occurred. The most significant problem with KEMAR was that the measurements obtained were estimates of adult mean ear responses. Since individuals differ from the average in their tympanic membrane impedances, ear canal size, and head size, Millin

(1980) stated, "only real-ear measurements of some kind will determine what pressures will accurately occur in a given patient's ear" (p. 168).

Killion and Monser (1980) introduced CORFIG: Coupler Response for Flat Insertion Gain (correction figures) to predict how a hearing aid would perform on KEMAR. This eliminated the need for a mannequin and an anechoic chamber. Due to the fact that hearing aids are not designed to produce a flat insertion gain frequency response curve on KEMAR, these CORFIG curves are predicted from the unaided sound pressure level produced at the eardrum; the sound pressure level produced at the microphone inlet of the hearing aid in situ; and the difference between the response of the Zwislocki ear simulator and standard 2 cc coupler response. A problem with using CORFIG to predict insertion gain from standard 2 cc coupler responses is that the correction factors used are based on mean data and do not account for individual differences that may occur (Preves, 1984).

Although the shortcomings of the standard 2 cc coupler were improved by the Zwislocki coupler, it still was inadequate due to individual differences in real ears. In addition, the Zwislocki coupler could not account for body baffle effects or head and pinna diffraction. KEMAR was then developed taking into consideration these problems found with the Zwislocki coupler. However, the cost and space needed to utilize KEMAR is infeasible for most clinics. Furthermore, measurements were variable when comparing differences between KEMAR and the standard 2 cc coupler and were based on mean ear responses. CORFIG correction factors used to predict hearing aid performance on KEMAR eliminated the cost of a mannequin and aneochic chamber; however these CORFIG figures were based on mean data. The fact still remained that real ears differ from individual to individual. This has resulted in studies turning to methods of real-ear measures.

Real-Ear Measures

Hearing aid performance utilizing real-ear measures were first reported by Weiner and Ross (1946). For almost 40 years, probe microphone measures have been studied but until recently their use in the clinic has been limited. This paucity of clinical use with real-ear measures was due to the belief that an aneochic chamber was necessary for these measurements and because of the inconvenience and obtrusiveness of the probe microphone assembly (Harford, 1980).

Real-ear measurements have originally been obtained by inserting a hollow tube into an individual's ear canal which led to a transducer outside the ear canal (Harford, 1980). Knowles Electronics has devised a wide-range, flat-response miniature electret microphone, measuring 5 x 4 x 2 millimeters, to be utilized in real-ear measurements. These tiny microphones can easily be inserted into the ear canal with some practice. The real-ear measurement is obtained by measuring the difference in sound pressures in the ear canal (test microphone) and at some point near the pinna (regulator microphone), thereby compensating for standing waves.

Harford (1980) utilized Starkey miniature probe microphones in the ear canal to verify electroacoustic measurements of hearing aids. The reliability of real-ear performance was determined by obtaining five different measurements from the same tester on two subjects. He found that the real-ear measurements were inconsistent at the higher frequencies.

Recently, McGugin (1983) investigated the test-retest reliability measures of sound pressure levels in the ear utilizing miniature probe microphones. The results were similar to Harford's (1980) in that deviations were seen in the high frequencies. However, McGugin pointed out that even though a slight deviation of 2.4 dB was present in the data, real-ear measurements were clinically applicable because hearing aid selection procedures and pure tone threshold tests allow for a difference of +/- 2 dB.

McCandless and Lyregaard (1983) proposed a prescription of gain/output (POGO) for selectively fitting hearing aids on individuals with sensorineural hearing impairments no greater than 80 dB HL. The POGO method consists of obtaining calculations for gain and output from audiometric data, selecting a hearing aid with electroacoustic characteristics that match the required (calculated) gain/output, and verifying the acoustical performance of the aid selected in-situ utilizing real-ear measurements or differences in unaided/aided soundfield thresholds. The required insertion gain is obtained by calculating 1/2 of the hearing threshold level at .25, .5, 1, 2, 3, and 4 kHz with a correction factor of -10 dB at .25 kHz and -5 dB at .5 kHz. The required maximum power output is calculated from the uncomfortable loudness level at .5, 1, and 2 kHz with a correction factor of +4 dB HL for converting HL to dB SPL in a standard 2 cc coupler. The second step of the POGO method is to select a hearing aid whose: maximum/minimum published MPO specifications are within the range of the required MPO and whose maximum/minimum published insertion gain specifications (allowing for 10 dB reserve gain) are within the range of the required maximum insertion gain at .5 through 2 kHz. In addition, the published frequency response of the aid selected should be compared to the required insertion gain frequency response. McCandless and Lyregaard (1983) also provide approximate values to be added to the published specification data that is obtained from a standard 2 cc coupler and not insertion gain (obtained on KEMAR). Furthermore, they also provide correction factors to be added to the closed earmold (gain obtained from KEMAR or the standard 2 cc coupler) for other earmold types that are typically used by individuals. The final step in the POGO method is to verify the acoustical performance of the required characteristics, from which the aid was selected, to the actual "in-situ" MPO/gain performance. This in-situ response (functional gain) is obtained by utilizing probe tube microphones (real-ear measurements) or by obtaining an estimate of the functional gain from the difference of aided and unaided thresholds at .25 through 4 kHz with narrow-band noise or frequency-modulated pure tones. The accuracy of the MPO setting can be determined by turning the hearing aid volume control full on with a 1 kHz narrow band noise input, gradually increasing the noise beyond 80 dB, without exceeding the listener's uncomfortable loudness level.

Real-ear measures have been employed for many years but not until recently has the equipment utilized been improved to eliminate the effect of standing waves and reduce the size of the probe tip microphone. There has been inquiries concerning the reliability of these measures, but these concerns have recently been investigated (McGugin, 1983) revealing reliable measures with only a 2.4 dB deviation in the high frequencies. The real-ear measures would then outweigh the disadvantages found in estimating the real-ear performance from a standard 2 cc coupler, Zwislocki coupler, or KEMAR.

In estimating real-ear performance, the standard 2 cc coupler does not account for differences in real ears in volume of the external auditory meatus, acoustic impedance of the tympanic membrane, or the type of earmold worn. The literature on comparisons of the standard 2 cc coupler and real-ear measurements pointed out that the standard 2 cc coupler overestimates the SPL developed in the external auditory canal at the low frequencies and underestimates SPL developed in the external auditory canal at the high frequencies. In addition, the standard 2 cc coupler showed a reduction in the SSPL 90 measurement as compared to real-ear measurements. The Zwislocki coupler was developed to eliminate the differences between the volume of the standard 2 cc coupler and that of the external canal by matching the standard 2 cc coupler to the average volume of the adult ear. The Zwislocki coupler also attempted to account for the acoustic impedance of the real-ear in its design. The literature has shown that the Zwislocki coupler did not estimate real-ear performance accurately because results were based on averages and did not account for individual differences. In addition, since it was utilized in a hearing aid test box, it could not account for body baffle effects or head and pinna diffraction. Although a mannequin was developed (KEMAR) utilizing the Zwislocki coupler and accounted for the effects of body baffle and diffraction from head and pinna, again the measurements were based on mean ear volumes. KEMAR also showed variation in frequency response and SSPL 90 measurements with two different hearing aids as compared to the standard 2 cc coupler. Real-ear measurements apparently solved the problem of individual differences and eliminated the neccessity of utilizing mean values.

The audiologist needs to be aware of what the relationship is between the standard 2 cc coupler and real-ear performance, since ANSI's specifications continue to require a standard 2 cc hard-walled coupler to be utilized in electroacoustic measurements of hearing aids. It remains to be established if the difference between the standard 2 cc coupler and real-ear performance would be significant enough to cause damage or would not match the published specification for the hearing aid.

The current study is proposed assuming the following to be true: that the miniature probe microphone is a clinically useful tool in obtaining real-ear SSPL measures; that the modified 2 cc coupler is of questionable value even while taking into account the earmold utilized with an aid; and that the more intense the sound, the more potentially damaging it is. If the SSPL 90, as measured in the modified 2 cc coupler, is significantly less than that obtained using a real-ear procedure, then SSPL 90 measurements from the modified coupler could be possibly damaging and the specifications for that model hearing aid could be inaccurate. The purpose of this study is to compare adults' hearing aid SSPL values in the following ways: on real ears utilizing the Starkey RE 4 probe microphone system as compared to those obtained from the modified 2 cc coupler, between subject's wearing behind-the-ear versus in-the-ear hearing aids, and between 60 and 90 dB inputs.

METHODS

Introduction

There is a growing concern among audiologists to obtain a more valid estimate of how the hearing aid, selected for a particular individual, performs on the real ear. Although the standard 2 cc coupler, Zwislocki coupler, and KEMAR provide a means for exchanging electroacoustic data of a hearing aid among clinics and laboratories, they do not account for individual differences of acoustic impedance of the tympanic membrane, volume of the ear canal, body and head baffle, earmolds, and earmold modifications. The individual differences are especially critical when considering the appropriate SSPL 90 setting for an individual's hearing aid so it will be acceptable and beneficial.

If the standard 2 cc coupler is not accurately measuring the SSPL 90, would the modified 2 cc coupler which takes into account the individual's earmold provide a more accurate measure of the hearing aid's output? The purpose of this study was to compare the SSPL 90 of adults' behind-the-ear and in-the-ear hearing aids when measured in a modified 2 cc coupler which utilizes the individual's ear-mold, and when measured in the external canal utilizing the Starkey RE 4 probe microphone system. The two methods of measurements were made with 60 and 90 dB SPL inputs. In addition, data were also collected on the standard 2 cc coupler for the subjects wearing behind-the-ear hearing aids. It was hypothesized that:

1. There is a difference in mean SSPL 90 levels between adult's real-ear SSPL 90 measurements and modified 2cc coupler SSPL 90 measurements.

2. There is also a difference in the hearing aid output level between the real-ear measurements and modified 2 cc coupler measurements with a 60 dB SPL input.

Subjects

Seventeen hearing impaired adult ears were utilized in this study. Data was obtained on nine behind-the-ear hearing aids and nine in-the-ear hearing aids. The listeners' ages ranged from 26 to 88 years with a mean of 65.6 and ear canal volumes from 0.9 to 3.2 cc. The audiograms showed a variety of flat and high frequency hearing loss configurations from the ears utilized.

All subjects were referred to the Kansas State University Speech and Hearing Center or the Audiology Center for either a hearing aid trial or an electroacoustic check of their hearing aid. Only those adults wearing a behind-the-ear or in-the-ear hearing aid with no history of ear surgery or no excessive amount of cerumen in the ear canal, and a normal, type A tympanogram were selected as subjects. All subjects completed the entire testing procedure.

Instrumentation

Real-ear measurements of each hearing aid's saturation sound pressure levels were obtained using the Starkey RE 4 probe microphone system in conjunction with the Phonic Ear HC 2000 hearing aid test box. The Starkey RE 4 probe microphone system consists of two miniature microphones, a regulator and test probe microphone, measuring 4 x 5.59 x 2.28 millimeters. Each microphone was used with a removeable acoustic damping screen and disposable plastic cover. These microphones were coupled to the Phonic Ear HC 2000 hearing aid test box and HC 2200 strip charter with a Starkey RE 4 interface system. The pure tone input signals were generated by the Phonic Ear HC 2000 hearing aid test box with the level recorded by the Phonic Ear HC 2200 strip charter. The output of the signals produced by the Phonic Ear HC 2000 hearing aid test chamber was fed through a speaker in a sound-treated test room (Industrial Acoustics Company) consisting of a double walled, single room test environment which meets the ambient noise level standards of ANSI (1969). The chair utilized in the test procedure was positioned one meter from the loudspeaker and tape was placed on the floor to ensure identical placement for all test sessions (see Figure 1).

The modified 2 cc coupler SSPL measurements were measured on the Phonic Ear HC 2000 hearing aid test chamber and were plotted on the accompanying Phonic Ear HC 2200 strip chart recorder. The ear canal of each adult's earmold was inserted into one of the four graduated rubber adaptors that provided the best seal. These rubber adaptors attached directly onto the coupler. In addition, it was necessary to cover any leaks around the earmold and/or vents with putty. The standard 2 cc coupler SSPL measurements obtained with behind-the-ear hearing aids were measured on the Phonic Ear HC 2000 hearing aid test chamber and were plotted on the accompanying Phonic Ear HC 2200 strip chart recorder.

Calibration

Prior to each subject's arrival for the testing, the Phonic Ear HC 2000 was calibrated in accordance to the manufacturer's specification. Calibration of the microphones were obtained as follows: a Bruel and Kjaer (Type 4230) sound level generator was attached to the test microphone emitting a 94 dB SPL readout in the test chamber by adjusting the chamber calibration. Next the chamber was calibrated by arranging the placement of the test microphone and regulator microphone to lay perpendicular to each other one-quarter of an inch apart. The Phonic Ear HC 2000 was set at inputs of 60 and 90 dB SPL for a 1000 Hz, pure tone

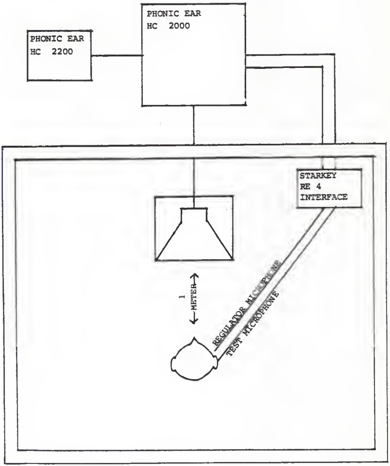


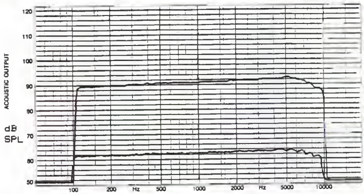
Fig. 1 - Block diagram of the subject and experimental situation for real-ear measurements.

signal. The chamber calibration was adjusted to read each of the input levels. This procedure was repeated by first replacing the test microphone of the Phonic Ear HC 2000 with the Starkey RE 4 system test probe (Channel B) and then regulator (Channel A) microphone. Finally, the Starkey RE 4 probe microphones output was plotted on the Phonic Ear HC 2200 strip chart to check the linearity of these microphones in the Phonic Ear 2000 test chamber (see Figure 2-a).

After calibration of the test chamber, Phonic Ear HC 2000 microphones and Starkey RE 4 system microphones in the closed field were completed, the Starkey RE 4 microphones were removed from the test chamber and placed in the sound-treated test room. The Phonic Ear HC 2000 was once again set for 60 and 90 dB inputs for a 1000 Hz, pure tone signal. The output from the Phonic Ear HC 2000 was channeled to the loudspeaker in the test room through the Starkey RE 4 interface system. A sound field condition linearity check was then obtained by situating the regulator and test probe microphones one meter from the loudspeaker with the Phonic Ear HC 2200 recording the output levels (see Figure 2-b).

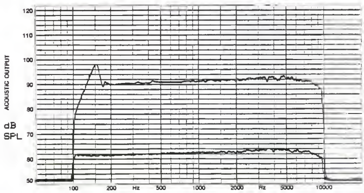
Procedures

Before collecting data for the study, each subject was informed of the procedure that was to be administered. Any concerns or questions the subject had were answered and their written consent was obtained (see Appendix A-Client



Frequency in Hz

a



Frequency in kHz

b

Fig. 2 - Linearity check of the probe microphones in closed field condition (a) and in sound field condition (b).

Consent Form).

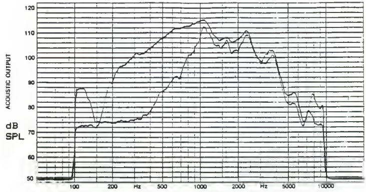
The external ear canal was evaluated by an otoscopic examination for any obstructions, infections, or excessive amounts of cerumen. Next, the Grason Stadler Automatic Tympanometer (Auto Tymp), Model GSI 28, was used to obtain a tympanogram on the test ear to provide an approximate volume of the ear canal. The subject's hearing aid battery was then checked for an appropriate voltage reading of +/- 1/10 volts or a hearing aid battery with the appropriate voltage reading supplied from the KSU Speech and Hearing Center was used. The hearing aid's SSPL 90 was adjusted so it did not exceed 115 dB SPL when measured on the modified 2 cc coupler. The volume control was set to the full on position. The subject's hearing aid and earmold were placed in the Phonic Ear HC 2000 test chamber. The earmold was inserted in one of the four rubber adaptors which provided the best seal and fitted on the coupler. Any leaks caused from the shape of the earmold and vents were also sealed with putty. The microphones were placed one-quarter of an inch apart perpendicular to each other. A 60 and 90 dB SPL input were utilized with a sweep frequency range of 100 to 10000 Hz and the outputs were recorded on the Phonic Ear HC 2200 strip chart. This procedure was then repeated for test-retest reliability. For those subject's with behind-the-ear hearing aids the modified 2 cc coupler was then replaced with the standard 2 cc coupler and the above procedure was repeated.

The second phase of the study began by seating the subject in the sound-treated chamber one meter from the loudspeaker for real-ear measurements to be obtained. The test probe microphone was positioned one centimeter into the subject's ear by using the end of the strain relief on the microphone's cord as a reference point. The distance from the tip of the test probe microphone to the end of the strain relief measured one centimeter. The subject's earmold was then inserted with any vents covered by putty and the hearing aid was placed behind his/her ear. The regulator microphone was placed directly over or to the side of the test ear's pinna one inch from the microphone of the hearing aid and taped in place to avoid displacement of the microphone throughout the testing. The real-ear maximum outputs from 100 to 10000 Hz were then charted by the Phonic Ear HC 2200 strip chart recorder for the inputs of 60 and 90 dB SPL. For each input level, the duration of the pure tone signal to sweep through the frequency range was no longer than 10 seconds. The test probe microphone, regulator microphone, earmold, and hearing aid then were removed. At this time, an inspection of the test microphone for cerumen accumulation and/or the plastic jacket for slippage was performed. The procedure described above for the placement and insertion of the microphones, earmold, and hearing aid were repeated and a second real-ear measure was obtained.

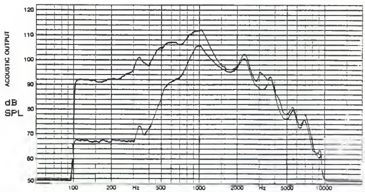
In summary, the procedures that were utilized in this study are as follows: an otoscopic examination was obtained to check for excessive cerumen in the subject's external auditory meatus, the tympanometric measures were utilized to obtain the approximate volume of the ear canal of each subject, the modified 2 cc coupler measurements followed by placing the subject's hearing aid with the earmold into the Phonic Ear HC 2000 test chamber presenting the inputs and recording the outputs on the Phonic Ear HC 2200 strip chart recorder. The modified 2 cc coupler measurements also were repeated for test-retest reliability to account for any electrical problems that could occur. The subject was then seated in the sound-treated chamber and the correct placement of the microphones was established. The inputs were presented and the outputs recorded utilizing the Phonic Ear HC 2000 test chamber and 2200 strip chart recorder. The real-ear devices and the subject's hearing aid were then removed and reinserted/placed to obtain a second measure. The average of the two measures was used for data analysis.

RESULTS

Hearing aid output levels were measured in the standard 2 cc coupler, modified 2 cc coupler, and the external canal of the listener using the Starkey RE 4 probe microphone system. Hereafter, the levels will be referred to as standard 2 cc coupler mean output level, modified 2 cc coupler mean output level, and real-ear mean output level. Figure 3 shows an example of a subject's modified 2 cc coupler mean output and real-ear mean output with 60 and 90 dB SPL inputs as charted on the Phonic Ear HC 2000 strip chart recorder. The frequencies 500, 1000, 1600, 2000, 2500, 3000, 3500, 4000, 4500, and 5000 Hz were chosen for comparisons of real-ear mean output levels with the modified 2 cc coupler and standard 2 cc coupler mean output levels on behind-the-ear and in-the-ear hearing aids. The comparisons were made on the frequencies stated above because they: include those specified in the standards of hearing aid characteristics for computing the saturation sound pressure level 90 curve, consist of the most useful range for speech, include those affected by earmold modifications, and are significantly amplified by hearing aids (Kasten and Franks, 1981).



Frequency in Hz
a



Frequency in Hz
b

Fig. 3 - Two maximum output curves with 60 and 90 dB SPL inputs recorded with the Phonic Ear HC 2200 strip chart recorder utilizing (a) Starkey RE 4 probe microphone system and (b) modified 2 cc coupler.

The sound pressure level generated in the ear canal and the couplers were read directly from the Phonic Ear HC 2200 strip chart recorder. The output with 60 and 90 dB SPL inputs at each frequency was estimated by computing the mean of the two trials as measured on real ears and the modified 2 cc coupler with the two types of hearing aids. In addition, the mean output levels with 60 and 90 dB SPL inputs were also obtained on the standard 2 cc coupler with behind-the-ear hearing aids. The mean output level was used because it could be argued that it is the best estimate for the subject's hearing aid. Mean output levels for the real-ear, modified 2 cc coupler, and standard 2 cc coupler measurements are shown in tables 1 a, b; 2 a, b; and 3 a, b respectively (see Appendix B).

Statistical analysis of the mean output was accomplished using the Statistical Analysis System (SAS) two-way analysis of variance (mode of measurement by type of hearing aid). Separate analyses were done for each frequency and input level. The Analysis of Variance Procedure (ANOVA) was utilized to compare balanced data groups of real-ear and modified 2 cc coupler mean output levels. The General Linear Models Procedure (GLM) was utilized to compare unbalanced data groups of real-ear, modified, and standard 2 cc coupler mean output levels. The TYPE III SS (GLM) and ANOVA results are summarized in tables: a) 4 through 13 for real-ear and modified 2 cc coupler mean output levels at .5 through 5 kHz with a 60 dB SPL input; b) 14 through 23 for real-ear and modified 2 cc coupler mean output levels at .5 to 5 kHz with a 90 dB SPL input; c) 24 through 33 for real-ear, modified 2 cc coupler, and standard 2 cc coupler mean output levels at .5 to 5 kHz with a 60 dB SPL input; and d) 34 through 43 for real-ear, modified 2 cc coupler, and standard 2 cc coupler mean output levels at .5 to 5 kHz with a 90 dB SPL input (see Appendix C).

Tables 4 through 23 show the modes of measurements (real-ear and modified 2 cc coupler) to have a significant effect with no significant mode by type interactions at the .05 level for both 60 and 90 dB SPL inputs.

Duncan's Multiple Range Test was applied to the F value to determine at which frequencies and inputs significant differences occurred when comparing the modes. Mean output levels represented by the same letter are not significantly different from each other. The bottom section of tables 4 through 23 show real-ear and modified 2 cc coupler mean output levels to be significantly different from each other at all frequencies and at both inputs with the real-ear mean output levels consistently greater than the modified 2 cc coupler mean output levels. Figures 4 and 5 are graphic illustrations of the real-ear and modified 2 cc coupler mean output levels with both inputs for all frequencies. The least amount of difference between the real-ear and modified 2 cc coupler mean output levels for both inputs were seen at .5 and 1 kHz. The difference

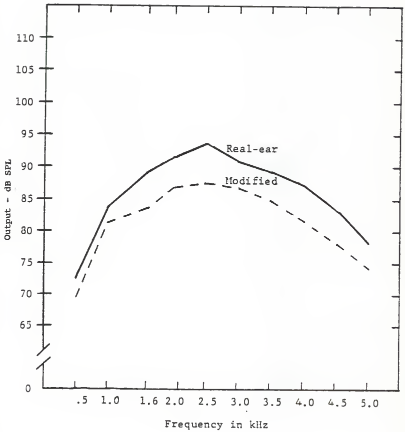


Fig. 4 – Real-ear and modified 2 cc coupler mean output level curves with a 60 dB SPL input.

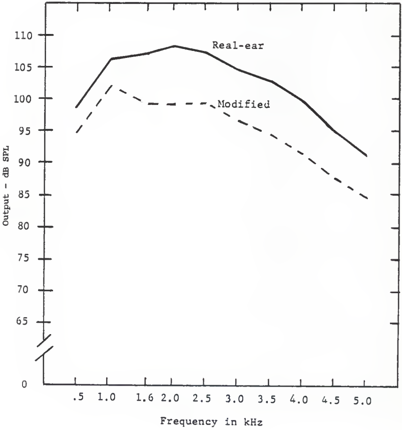


Fig. 5 – Real-ear and modified 2 cc coupler mean output level curves with a 90 dB SPL input.

between modes did not follow any systematic ascending or descending order beyond 1 kHz. The largest difference between the real-ear and modified 2 cc coupler mean output levels was 6.0 dB SPL at 2.5 kHz with a 60 dB SPL input and 9.0 dB SPL at 2 kHz with the 90 dB SPL input (see Appendix D). The differences between the real-ear and modified 2 cc coupler mean output levels were consistently higher with the 90 dB SPL input level than the differences in mean output levels with the 60 dB SPL input (see figure 6).

Results of mean output levels from real ears, the modified 2 cc coupler, and standard 2 cc coupler are given below. These data were collected to determine how the modified 2 cc coupler compares with the standard 2 cc coupler in estimating real-ear performance, as well as how the data from this study compares with that of previous studies. Tables 24 through 43 show a significant difference between modes of measurement with no significant mode by type interactions at the .05 level for all frequencies at both inputs.

Duncan's Multiple Range Test analysis again was applied to the F values to determine at which frequencies and inputs significant differences occurred between the modes. It can be seen in tables 29 through 33 that with a 60 dB SPL input, the mean output levels are significantly different from each other at 3 kHz and above. The greatest mean output level was obtained with the real-ear measurements

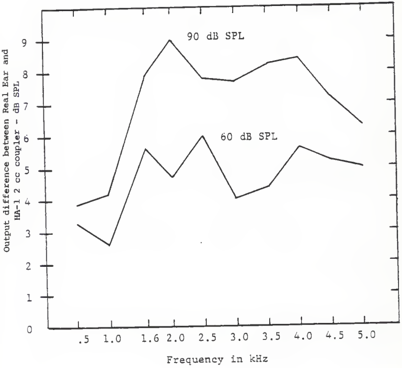


Figure 6 – Mean output difference levels for real-ear and modified 2 cc coupler measurements with 60 and 90 dB SPL inputs at .5 to 5 kHz.

followed by the modified and standard 2 cc couplers respectively. Tables 27 and 28 show the real-ear mean output levels to be significantly different from both types of 2 cc couplers at 2 kHz and 2.5 kHz. Furthermore, the standard 2 cc coupler mean output levels were slightly higher than the modified 2 cc coupler mean output levels. Tables 25 and 26 show that the standard 2 cc coupler and real-ear mean output levels were significantly different from the modified 2 cc coupler mean output levels at 1 kHz and 1.6 kHz for a 60 dB SPL input. It should be noted that although the differences in mean output levels between the standard 2 cc coupler and real-ear measurements were not significant, the standard 2 cc coupler mean output levels were slightly higher than the real-ear mean output levels. This is in agreement with studies previously mentioned (Van Eysbergen and Groen, 1959; Wetzell and Harford, 1983; and Goldstein, 1982) that estimated real-ear performance of frequency response, gain, and electroacoustical responses with the standard 2 cc coupler.

Table 24 shows significant differences between the modes at .5 kHz for a 60 dB SPL input with the Type III SS (GLM) analysis. However no significant differences were indicated at this frequency and input in the analysis from the Duncan Multiple Range Test. It should be noted, that this discrepancy of significance can apparently occur when there are only several means being compared (Milliken, 1985). Of the total 40 mean output comparisons, this is the only frequency and input at which a conflict between the two data analyses occurred.

Tables 34 through 43 show the comparisons of the real-ear, modified 2 cc coupler, and standard 2 cc coupler measurements for a 90 dB SPL input at .5 through 5 kHz with the real-ear mean output levels being significantly different from both types of 2 cc couplers mean output levels. At 3 kHz and above, the results with a 90 dB SPL input were similar to those obtained using a 60 dB SPL input. That is, the mean output levels for the three modes of measurements were significantly different from each other with the greatest mean output level obtained from the real-ear measurements followed by the modified and the standard 2 cc couplers respectively (seen in tables 39 through 43). All modes were also significantly different from each other at 1.6 kHz. The greatest mean output levels were from the real-ear, followed by the standard and modified 2 cc coupler measurements respectively. As with the 60 dB SPL input, the two types of 2 cc couplers mean output levels were not significantly different from each other at the lower frequencies (see tables 34-35 and 37-38). Although the results were not significantly different, the modified 2 cc coupler mean output levels were slightly greater than the standard 2 cc coupler mean output levels at .5 kHz and 2.5 kHz; and less at 1 kHz and 2 kHz.

Graphic illustrations of the real-ear, modified and standard 2 cc coupler mean output levels with both inputs for all frequencies are given in Figures 7 and 8.

Although statistical analyses were done to compare the outputs of the two types of aids utilized in the study, the results were not considered clinically relevant. The criteria for selecting an aid for the study consisted of adjusting the aid to the lowest possible saturation sound pressure level setting, and no hearing aid with a maximum output greater than 115 dB SPL as measured on the modified 2 cc coupler was used. As a result, all aids were of relatively low power. In addition, the analyses reported earlier revealed no significant mode by type interaction effects, suggesting no differences between the measurements observed on behind-the-ear versus in-the-ear hearing aids.

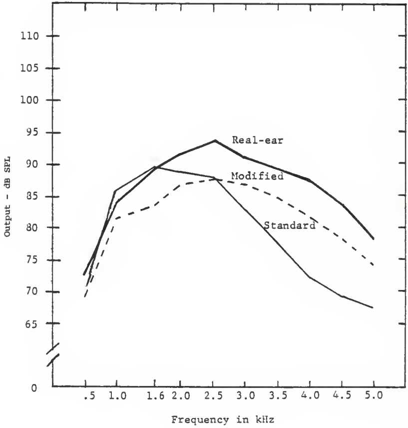


Fig. 7 – Real-ear, modified 2 cc coupler, and standard 2 cc coupler mean output level curves with a 60 dB SPL input.

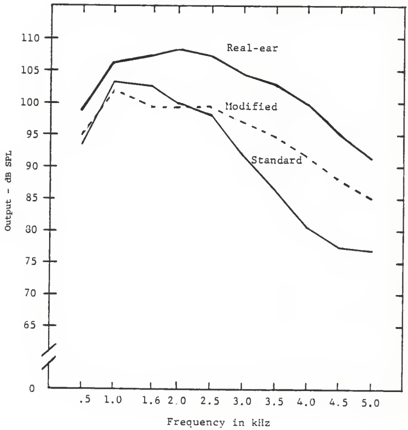


Fig. 8 – Real-ear, modified 2 cc coupler, and standard 2 cc coupler mean output level curves with a 90 dB SPL input.

DISCUSSION

The purpose of this study was to determine whether the saturation sound pressure levels (SSPLs 90), measured in the modified 2 cc coupler, were significantly different from measurements obtained on real ears, utilizing a probe microphone system. That is, is the hearing aid's maximum output measured in the modified 2 cc coupler a relatively accurate measure of real-ear performance, since it accounts for the individual's earmold, or do significant differences still exist which may be caused from body baffle effects and/or acoustic impedance of the tympanic membrane?

The SAS two-way analysis showed that there is a significant difference between the sound pressure level generated in the modified 2 cc coupler and that measured on real ears across all frequencies and inputs, with no significant mode by type interactions. In addition, the difference between the real-ear and modified 2 cc coupler mean output levels were consistently higher with the 90 dB SPL input level than with the 60 dB SPL input for all frequencies. The data from this study show that the modified 2 cc coupler underestimates the actual sound pressure developed in the external auditory meatus, as shown in tables 4 through 23.

The modified 2 cc coupler, as with the standard 2 cc coupler, does not account for individual differences in the acoustic impedance of the tympanic membrane, nor does it account for differences in the size of the individual's head and body. Although the modified 2 cc coupler does utilize the individual's earmold in the measurement of sound pressure level developed in the 2 cc coupler, the volume from the tip of the earmold to the diaphragm of the modified 2 cc coupler microphone is not the same as that from the tip of the earmold to the tympanic membrane. Furthermore, venting effects can not be accounted for due to the feedback that may occur if the vent is open on the earmolds when using the hard-walled modified 2 cc coupler. The venting effects can not be measured reliably on the modified 2 cc coupler because an artificial resonant peak in the lower frequencies has been found to exist in this condition (Preves, 1984).

In addition to the comparisons made between the real-ear and modified 2 cc coupler measurements, data were also obtained on the standard 2 cc coupler. Several studies have shown that the standard 2 cc coupler overestimates real-ear gain and sound pressure level at the lower frequencies and underestimates these electroacoustic characteristics at the higher frequencies (Van Eysbergen and Groen, 1959; Wetzell and Harford, 1983; Goldstein, 1982). Real-ear measures also have been demonstrated to generally produce higher maximum outputs than the standard 2 cc coupler at frequencies above 1 kHz (Harford, et al., 1983) and in another study (Leijon, et al., 1983) at all frequencies except 2.5 k Hz.

The results of this study revealed a significant mode effect between the real-ear, modified 2 cc coupler, and standard 2 cc coupler mean output levels, with no significant mode by type interaction for any frequency at both inputs, as shown in tables 24 through 43.

In general, the results showed that the standard 2 cc coupler slightly overestimated the actual sound pressure level developed in the individual's external auditory meatus at the lower frequencies for the 60 dB SPL input. At 2 kHz and above, however, the standard 2 cc coupler underestimated the sound pressure level developed in the real ear. For the 90 dB SPL input, the standard 2 cc coupler significantly understimated the sound pressure level developed in real ears across the entire frequency range. Leijon, et al., (1983) also has demonstrated an overall underestimation of maximum output sound pressure levels across the entire frequency range, except at 2.5 kHz, with standard 2 cc coupler measurements. Harford (1983), however, found a lower sound pressure level developed in the 2 cc coupler at frequencies of 1.0 kHz and above.

In general, the data show that the mean output level comparisons with the 2 cc couplers were significantly different from each other at the lower frequencies for the 60 dB SPL input with the standard 2 cc coupler showing a lower sound pressure level. In the middle frequency range, 1.6 kHz-2.5 kHz, the 2 cc couplers showed no significant differences, although the standard 2 cc coupler showed a higher mean output level. At the higher frequency range, 3 kHz to 5 kHz, the mean output levels for the 2 cc couplers were significantly different from each other, with the standard 2 cc coupler having the lower mean output levels.

At the higher input, 90 dB SPL, the 2 cc couplers did not show significant differences from each other in mean output levels at the lower frequencies. However, the standard 2 cc coupler generally showed a higher mean output level than the modified 2 cc coupler. In the range of 3kHz to 5 kHz, the standard 2 cc coupler showed a significantly lower mean output sound pressure level as compared to the modified 2 cc coupler.

Only two of the total forty mean output level comparisons measured on real ears and the 2 cc couplers, including both inputs tested, even approached the .05 level of significance for mode by type interactions. These two mean output level comparisons are shown in tables 5 and 35 with F values of 4.21 and 4.13 respectively. A closer look at the original data revealed fairly large differences between trial runs with the modified 2 cc coupler on subject RP's in-the-ear hearing aid output. A difference of 9 and 7 dB SPL was found to occur at 1 kHz with the 60 and 90 dB SPL inputs respectively. This could be contributed to experimental error resulting from differences in the amount of putty used to cover any leaks from the earmold, earmold vent, modified 2 cc coupler, and/or placement of the microphones between trials.

In conclusion, the actual sound pressure measured in the external auditory meatus was significantly different from that measured in the modified or standard 2 cc coupler. The real-ear performance showed the greatest sound pressure level. Since the modified 2 cc coupler accounts for individual differences in ear canal length and bore diameter of the earmold, it is a more accurate estimate of real-ear performance than the standard 2 cc coupler. Therefore, from a clinical standpoint, the modified 2 cc coupler is a more accurate indicator of real-ear performance than the standard 2 cc coupler and should be utilized for maximum output measurements rather than the standard 2 cc coupler. However, it appears that real-ear data should be obtained whenever possible because individual differences still exist in acoustic impedance of the tympanic membrane, volume of the external auditory meatus, and earmold venting effects, that no 2 cc coupler can reliably account for to date.

APPENDIX A

CLIENT CONSENT FORM

CLIENT CONSENT FORM

This study is undertaken to determine if the HA-1 2 cc coupler used in a hearing aid test box underestimates the output of the hearing aid as compared to measurements obtained on the real ear utilizing a miniature microphone placed in the ear canal.

The following information will be obtained:

a. tympanometric evaluation,
b. otoscopic evaluation,
c. measurements of hearing aid output using a hearing aid test box and measured directly within the ear canal. Both methods for obtaining the hearing aid output will be made twice on the same visit. The visit will take approximately thirty minutes.

Measurement of the hearing aid output at the ear canal is made by inserting a very small microphone directly into the ear canal. Next, the earmold and hearing aid is placed in the ear. Then various tones are presented through a loudspeaker and the amount of sound delivered by the hearing aid in the canal is measured. The hearing aid output will then be measured on an artificial ear that is commonly utilized in clinics.

The benefits of this study will be to learn what level of sound is actually being presented to the ear and if the artificial ear (HA-1 2 cc coupler) reflects this measure. This will enable audiologists to make a more valid determination of the cut-off level on the hearing aid to prevent sounds that would be discomforting or damaging to be delivered to the listeners ear.

I understand the potential risk involves: a) a possible mild discomfort in the ear canal and b) a very brief exposure to fairly intense sounds which are below the published standard for hearing aid outputs made by the Federal Drug Administration. The miniature microphone is the size of a tip of a small cardboard book match which can be placed comfortably in the ear canal along with a standard earmold for a hearing aid. This microphone will measure the actual output of the hearing aid in my ear. The size of the probe microphone and the soft coating over the microphone will minimize the discomfort.

Kim Sykes, Peggy Nelson, Staff Audiologist, or Dr. Harry Rainbolt, Project Supervisor, will be willing to answer any inquiries regarding the procedures involved. They can be contacted by calling the Kansas State University

Speech and Hearing Center at 532-6879. I understand that I am free to withdraw my consent and to discontinue participation in the study at any time with no loss of benefits to which I am otherwise entitled. All records will be kept confidential in accordance with the KSU Speech and Hearing Center policy.

I agree that emergencies will be handled through Lafene Student Health Center or through my personal physician.

I have read the above statement and have been fully advised of the procedures to be used in this project. I understand the potential risks involved and I hereby assume them voluntarily.

__________________ ___________________________________

Date Subject

APPENDIX B

SUBJECTS' MEAN OUTPUT LEVELS

TABLE 1-a. Real-ear mean output levels, with a 60 dB SPL input, from in-the-ear and behind-the-ear hearing aids.

IN-THE-EAR					SUBJECTS				
FQ KHZ	W C	E F	R P	WBL	WBL	O L	C D	HSR	HSL
.5	63.0	86.0	84.0	71.5	64.5	87.0	79.0	66.0	66.0
1.0	78.0	88.5	87.5	78.5	83.0	95.0	90.0	73.0	73.0
1.6	92.0	93.0	92.0	90.0	80.5	95.5	96.0	83.0	83.0
2.0	102.0	98.0	98.0	96.0	78.0	95.5	93.0	88.0	88.0
2.5	95.0	102.0	101.0	106.5	82.0	99.5	93.0	96.0	96.0
3.0	88.0	94.5	93.5	94.5	83.5	102.0	92.0	99.0	99.0
3.5	87.0	92.0	90.0	91.0	84.0	97.0	89.0	99.0	99.0
4.0	89.5	89.0	88.0	91.5	82.0	96.0	86.0	96.5	96.5
4.5	75.5	88.5	87.5	90.0	83.0	91.5	81.5	94.5	94.5
5.0	66.5	86.0	84.0	86.5	76.0	82.5	74.0	97.5	97.5

BEHIND-THE-EAR					SUBJECTS				
FQ KHZ	T B	R P	R W	R C	RTC	R T	F R	DTR	DTL
.5	71.5	70.0	74.0	80.5	65.0	87.5	66.0	67.0	60.0
1.0	67.5	84.0	95.0	100.5	74.0	108.0	84.5	81.0	70.0
1.6	85.5	96.0	94.9	101.0	86.0	106.0	80.0	77.0	74.0
2.0	87.5	96.0	100.5	101.0	92.0	103.5	80.0	75.5	74.0
2.5	88.0	89.0	104.5	101.5	92.5	103.5	78.5	80.5	75.5
3.0	94.5	88.0	101.5	99.0	85.0	94.0	72.5	78.5	76.0
3.5	96.0	89.0	97.0	94.0	87.5	97.5	69.5	72.5	74.0
4.0	89.0	81.0	93.5	92.5	94.5	94.5	65.0	66.0	78.0
4.5	83.5	78.0	92.5	90.0	96.0	84.0	63.0	58.0	69.0
5.0	74.5	71.0	92.5	86.0	92.0	80.0	60.0	57.0	60.0

TABLE 1-b. Real-ear mean output levels, with a 90 dB SPL input, from in-the-ear and behind-the-ear hearing aids.

IN-THE-EAR	SUBJECTS								
FQ KHZ	W C	E F	R P	WBL	WBL	O L	C D	HSR	HSL
.5	97.0	111.0	108.0	101.5	100.0	108.0	108.0	86.0	86.0
1.0	111.5	109.0	106.0	111.0	107.5	114.0	112.0	98.0	98.0
1.6	114.0	111.5	107.5	112.0	103.0	117.0	114.0	108.5	108.5
2.0	109.5	108.5	108.5	115.0	102.0	118.0	110.0	110.5	110.5
2.5	110.0	111.0	107.0	115.0	102.0	120.0	110.0	110.0	110.0
3.0	106.0	109.0	108.0	111.5	102.0	118.0	110.0	108.0	108.0
3.5	106.5	106.5	103.5	106.0	100.0	113.0	116.0	100.0	101.5
4.0	96.0	104.0	100.0	105.0	95.5	116.0	100.0	101.5	101.5
4.5	81.0	100.0	97.0	103.0	89.5	110.5	96.5	100.0	100.0
5.0	74.0	95.0	92.0	104.0	82.5	104.0	92.0	97.5	97.5

BEHIND-THE-EAR	SUBJECTS								
FQ KHZ	T B	R P	R W	R C	RTC	R T	F R	DTR	DTL
.5	91.5	99.5	94.0	104.5	89.5	108.0	99.0	97.5	90.0
1.0	99.5	101.0	97.5	109.0	106.0	112.5	110.0	107.0	101.0
1.6	101.0	105.0	98.5	104.0	111.0	106.0	101.0	104.0	103.0
2.0	100.0	110.0	110.5	109.5	111.5	106.0	103.0	100.0	103.0
2.5	101.5	101.0	106.0	106.0	113.5	106.0	95.0	101.0	103.0
3.0	99.0	100.0	107.0	103.0	106.5	96.0	92.0	96.0	100.5
3.5	97.5	97.0	105.0	97.0	111.0	103.0	88.0	96.5	102.5
4.0	96.5	92.0	97.0	98.5	122.0	97.5	88.5	88.5	98.0
4.5	92.5	86.0	96.0	92.5	116.5	90.0	86.0	84.5	88.5
5.0	86.5	83.0	98.0	92.5	114.5	84.0	81.0	82.5	80.5

TABLE 2-a. Modified coupler mean output levels, with a 60 dB SPL input, from in-the-ear and behind-the-ear hearing aids.

IN-THE-EAR					SUBJECTS				
FQ KHZ	W C	E F	R P	WBL	WBL	O L	C D	HSR	HSL
.5	64.5	80.0	67.0	73.0	67.5	96.0	78.0	61.0	59.5
1.0	79.5	84.0	79.5	79.0	79.0	87.0	84.0	67.5	67.5
1.6	93.0	88.0	85.0	83.0	75.5	88.5	90.0	77.0	78.0
2.0	93.0	92.5	92.0	90.5	74.5	91.0	88.0	84.0	83.5
2.5	91.0	95.0	93.5	90.0	74.0	92.0	88.0	90.0	89.5
3.0	88.5	92.5	91.5	90.0	77.0	90.0	91.0	93.0	92.0
3.5	85.0	87.0	87.0	87.0	74.5	88.5	83.5	96.0	88.0
4.0	79.0	89.5	86.0	86.0	69.5	89.0	83.0	93.5	87.0
4.5	73.0	90.5	88.5	87.0	67.0	84.0	74.0	91.0	84.0
5.0	67.0	88.0	88.0	84.5	63.0	77.0	67.0	88.0	81.5

BEHIND-THE-EAR					SUBJECTS				
FQ KHZ	T B	R P	R W	R C	RTC	R T	F R	DTR	DTL
.5	59.5	63.5	72.5	78.0	62.0	83.0	65.0	62.0	57.0
1.0	69.5	78.0	92.5	100.0	71.0	105.0	84.0	79.0	78.0
1.6	86.0	90.0	88.0	95.0	78.0	94.0	76.5	70.0	68.0
2.5	92.0	89.0	05.0	95.5	84.0	95.5	81.0	72.0	70.0
2.5	91.0	84.0	90.0	91.0	92.5	94.0	81.5	75.0	75.0
3.0	88.0	82.5	91.0	84.5	89.0	86.0	81.0	79.0	76.5
3.5	88.0	83.0	92.0	87.5	85.0	89.0	71.5	77.0	76.0
4.0	84.0	78.0	86.0	83.5	89.0	85.0	64.0	68.0	67.0
4.5	82.5	75.0	88.0	78.0	86.0	78.0	63.0	60.5	58.0
5.0	76.0	71.0	93.0	77.0	76.0	76.0	53.0	55.0	53.0

TABLE 2-b. Modified coupler mean output levels, with a 90 dB SPL input, from in-the-ear and behind-the-ear hearing aids.

IN-THE-EAR					SUBJECTS				
FQ KHZ	W C	E F	R P	WBL	WBL	O L	C D	HSR	HSL
.5	94.0	102.5	98.5	98.0	99.0	113.5	106.0	84.0	79.0
1.0	105.5	101.5	106.5	96.0	100.0	105.0	109.0	96.0	95.0
1.6	107.0	100.0	105.0	96.0	95.5	104.0	110.0	106.0	104.5
2.0	104.0	100.0	106.0	97.0	94.0	106.0	107.0	102.0	102.0
2.5	102.5	101.5	108.5	99.5	93.5	105.5	107.0	101.5	100.5
3.0	99.5	100.0	103.0	97.0	94.0	101.5	105.0	102.5	101.0
3.5	97.0	98.0	98.0	93.0	91.0	101.5	103.0	100.0	98.0
4.0	90.0	96.0	98.0	91.5	86.0	101.0	99.5	98.5	97.0
4.5	81.5	96.5	98.0	90.0	82.0	95.0	91.0	95.0	94.0
5.0	76.0	92.5	100.0	90.0	78.5	92.5	83.5	94.0	92.0

BEHIND-THE-EAR					SUBJECTS				
FQ KHZ	T B	R P	R W	R C	RTC	R T	F R	DTR	DTL
.5	90.0	93.0	93.0	99.0	86.0	104.0	96.0	88.0	84.0
1.0	91.0	102.0	92.0	108.0	100.5	112.0	111.0	102.0	102.0
1.6	93.5	102.0	90.0	95.5	101.5	96.0	98.0	92.0	90.5
2.0	94.0	101.5	96.5	95.0	103.0	97.0	98.0	90.0	90.0
2.5	93.0	97.0	92.0	94.0	111.0	96.0	97.0	94.0	94.0
3.0	90.0	91.5	91.5	91.0	106.0	92.5	91.5	92.0	93.0
3.5	90.0	86.5	93.0	89.0	102.0	91.0	84.5	93.0	94.0
4.0	86.0	85.0	86.5	86.0	105.5	87.0	82.0	85.0	87.0
4.5	85.0	85.0	88.0	81.5	101.0	82.0	78.5	77.5	78.0
5.0	77.5	83.5	95.0	80.5	92.5	78.0	68.0	77.0	77.0

TABLE 3-a. Standard coupler mean output levels, with a 60 dB SPL input, from in-the-ear and behind-the-ear hearing aids.

BEHIND-THE-EAR				SUBJECTS					
FQ KHZ	T B	R P	R W	R C	RTC	R T	F R	DTR	DTL
.5	62.0	71.0	72.0	84.5	74.0	84.0	62.5	63.5	61.0
1.0	74.5	78.0	92.0	105.0	75.0	104.5	82.0	82.0	80.5
1.6	96.0	90.0	93.0	105.0	85.0	101.5	84.0	77.0	75.0
2.0	99.0	84.0	97.0	96.0	89.0	95.0	81.5	79.5	78.0
2.5	94.0	84.5	91.0	90.5	88.0	92.0	81.0	85.0	85.0
3.0	83.5	80.5	91.0	80.5	84.0	81.0	74.0	85.0	86.0
3.5	78.5	72.0	90.0	73.0	79.0	78.5	64.0	84.0	80.0
4.0	71.0	63.5	85.0	75.0	81.5	77.0	55.0	72.5	69.0
4.5	70.0	58.0	87.5	68.0	77.0	71.5	54.0	71.0	66.0
5.0	65.0	55.5	90.0	64.5	74.0	70.0	52.5	70.0	66.0

TABLE 3-b. Standard coupler mean output levels, with a 90 dB SPL input, from in-the-ear and behind-the-ear hearing aids.

BEHIND-THE-EAR				SUBJECTS					
FQ KHZ	T B	R P	R W	R C	RTC	R T	F R	DTR	DTL
.5	91.0	96.5	86.5	104.5	89.0	104.0	93.0	89.0	88.0
1.0	95.5	99.5	93.0	110.0	101.5	111.0	109.0	104.5	105.0
1.6	104.0	105.5	94.0	106.0	109.0	103.0	105.0	98.0	98.0
2.0	102.0	99.0	98.0	96.0	110.5	97.0	99.0	98.0	98.0
2.5	97.0	97.0	92.5	92.0	107.0	93.5	96.0	104.0	104.0
3.0	86.5	87.5	91.5	84.0	103.5	85.0	86.0	101.5	102.0
3.5	81.5	79.0	91.0	75.5	97.0	81.0	75.0	99.5	99.0
4.0	74.5	70.0	87.0	75.0	97.0	78.5	66.0	88.5	87.0
4.5	72.0	66.5	87.0	68.0	94.0	72.0	66.0	87.0	84.5
5.0	68.5	66.0	92.0	65.5	87.5	72.0	59.0	90.5	89.0

APPENDIX C

ANALYSIS OF VARIANCE

TABLE 4. Analysis of variance mode by type with a 60 dB SPL input at .5 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	98.34027778		5.93*
MODE*TYPE	1	9.50694444		0.57
ERROR	16		16.59548611	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	72.694	Real Ear
B	69.389	HA-1

Means with the same letter are not significantly different.

TABLE 5. Analysis of variance mode by type with a 60 dB SPL input at 1 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	61.36111111		9.07*
MODE*TYPE	1	28.44444444		4.21
ERROR	16		6.76215278	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	83.944	Real Ear
B	81.333	HA-1

Means with the same letter are not significantly different.

TABLE 6. Analysis of variance mode by type with a 60 dB SPL input at 1.6 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	283.36111111		65.21*
MODE*TYPE	1	1.36111111		0.31
ERROR	16		4.34548611	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	89.139	Real Ear
B	83.528	HA-1

Means with the same letter are not significantly different.

TABLE 7. Analysis of variance mode by type with a 60 dB SPL input at 2 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	193.67361111		37.89*
MODE*TYPE	1	3.67361111		0.72
ERROR	16		5.11111111	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	91.472	Real Ear
B	88.833	HA-1

Means with the same letter are not significantly different.

TABLE 8. Analysis of variance mode by type with a 60 dB SPL input at 2.5 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	321.00694444		24.81*
MODE*TYPE	1	22.56250000		1.74
ERROR	16		12.94097222	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	93.583	Real Ear
B	87.611	HA-1

Means with the same letter are not significantly different.

TABLE 9. Analysis of variance mode by type with a 60 dB SPL input at 3 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	144.00000000		8.32*
MODE*TYPE	1	2.25000000		0.13
ERROR	16		17.31250000	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	90.833	Real Ear
B	86.833	HA-1

Means with the same letter are not significantly different.

TABLE 10. Analysis of variance mode by type with a 60 dB SPL input at 3.5 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	175.56250000		20.89*
MODE*TYPE	1	15.34027778		1.83
ERROR	16		8.40451389	

*Values are significant at the .05 level.

DUNCAN GROUPING		MEAN	MODE
A		89.167	Real Ear
	B	84.750	HA-1

Means with the same letter are not significantly different.

TABLE 11. Analysis of variance mode by type with a 60 dB SPL input at 4 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	283.36111111		29.89*
MODE*TYPE	1	0.44444444		0.05
ERROR	16		9.48090278	

*Values are significant at the .05 level.

DUNCAN GROUPING		MEAN	MODE
A		87.167	Real Ear
	B	81.556	HA-1

Means with the same letter are not significantly different.

TABLE 12. Analysis of variance mode by type with a 60 dB SPL input at 4.5 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	237.67361111		16.08*
MODE*TYPE	1	0.17361111		0.01
ERROR	16		14.78298611	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	83.361	Real Ear
B	78.222	HA-1

Means with the same letter are not significantly different.

TABLE 13. Analysis of variance mode by type with a 60 dB SPL input at 5 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	222.50694444		11.29*
MODE*TYPE	1	0.34027778		0.02
ERROR	16		19.70486111	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	79.083	Real Ear
B	74.111	HA-1

Means with the same letter are not significantly different.

TABLE 14. Analysis of variance mode by type with a 90 dB SPL input at .5 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	142.00694444		20.45*
MODE*TYPE	1	2.50694444		0.36
ERROR	16		6.94444444	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	98.833	Real Ear
B	94.861	HA-1

Means with the same letter are not significantly different.

TABLE 15. Analysis of variance mode by type with a 90 dB SPL input at 1 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	154.17361111		18.78*
MODE*TYPE	1	25.84027778		3.15
ERROR	16		8.21006944	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	106.08	Real Ear
B	101.94	HA-1

Means with the same letter are not significantly different.

TABLE 16. Analysis of variance mode by type with a 90 dB SPL input at 1.6 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	564.06250000		63.16*
MODE*TYPE	1	1.17361111		0.13
ERROR	16		8.93055556	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	107.19	Real Ear
B	99.28	HA-1

Means with the same letter are not significantly different.

TABLE 17. Analysis of variance mode by type with a 90 dB SPL input at 2 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	738.02777778		87.78*
MODE*TYPE	1	5.44444444		0.65
ERROR	16		8.40798611	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	108.11	Real Ear
B	99.06	HA-1

Means with the same letter are not significantly different.

TABLE 18. Analysis of variance mode by type with a 90 dB SPL input at 2.5 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	544.44444444		41.77*
MODE*TYPE	1	2.77777778		0.21
ERROR	16		13.03298611	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	107.11	Real Ear
B	99.33	HA-1

Means with the same letter are not significantly different.

TABLE 19. Analysis of variance mode by type with a 90 dB SPL input at 3 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	529.00000000		48.47*
MODE*TYPE	1	7.11111111		0.65
ERROR	16		10.91493056	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	104.47	Real Ear
B	96.81	HA-1

Means with the same letter are not significantly different.

TABLE 20. Analysis of variance mode by type with a 90 dB SPL input at 3.5 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	600.25000000		122.52*
MODE*TYPE	1	0.11111111		0.02
ERROR	16		4.89930556	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	102.75	Real Ear
B	94.58	HA-1

Means with the same letter are not significantly different.

TABLE 21. Analysis of variance mode by type with a 90 dB SPL input at 4 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	629.17361111		63.43*
MODE*TYPE	1	19.50694444		1.97
ERROR	16		9.91840278	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	99.889	Real Ear
B	91.528	HA-1

Means with the same letter are not significantly different.

TABLE 22. Analysis of variance mode by type with a 90 dB SPL input at 4.5 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	473.06250000		42.00*
MODE*TYPE	1	12.84027778		1.14
ERROR	16		11.26388889	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	95.000	Real Ear
B	87.750	HA-1

Means with the same letter are not significantly different.

TABLE 23. Analysis of variance mode by type with a 90 dB SPL input at 5 kHz and mean comparisons of modes.

SOURCE	DF	ANOVA SS	MS	F VALUE
MODE	1	354.69444444		15.65*
MODE*TYPE	1	32.11111111		1.42
ERROR	16		22.66840278	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	91.167	Real Ear
B	84.889	HA-1

Means with the same letter are not significantly different.

TABLE 24. Analysis of variance (GLM) mode by type with a 60 dB SPL input at .5 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	109.91435185		3.48*
MODE*TYPE	1	9.50694444		0.60
ERROR	24		15.78973765	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	72.694	Real Ear
A	70.500	HA-2
A	69.389	HA-1

Means with the same letter are not significantly different.

TABLE 25. Analysis of variance (GLM) mode by type with a 60 dB SPL input at 1 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	73.40277778		4.78*
MODE*TYPE	1	28.44444444		3.70
ERROR	24		7.67824074	

*Values are significant at the .05 level.

DUNCAN GROUPING		MEAN	MODE
A		85.944	HA-2
A		83.944	Real-Ear
	B	81.333	HA-1

Means with the same letter are not significantly different.

TABLE 26. Analysis of variance (GLM) mode by type with a 60 dB SPL input at 1.6 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	368.99074074		30.82*
MODE*TYPE	1	1.36111111		0.23
ERROR	24		5.98533951	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	89.611	HA-2
A	89.139	Real-Ear
B	83.528	HA-1

Means with the same letter are not significantly different.

TABLE 27. Analysis of variance (GLM) mode by type with a 60 dB SPL input at 2 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	198.41435185		10.08*
MODE*TYPE	1	3.67361111		0.37
ERROR	24		9.84182099	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	91.472	Real-Ear
B	88.889	HA-2
B	86.833	HA-1

Means with the same letter are not significantly different.

TABLE 28. Analysis of variance (GLM) mode by type with a 60 dB SPL input at 2.5 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	321.56712963		9.33*
MODE*TYPE	1	22.56250000		1.31
ERROR	24		17.23765432	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	93.583	Real-Ear
B	87.889	HA-2
B	87.611	HA-1

Means with the same letter are not significantly different.

TABLE 29. Analysis of variance (GLM) mode by type with a 60 dB SPL input at 3 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	201.04166667		4.53*
MODE*TYPE	1	2.25000000		0.10
ERROR	24		22.17708333	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	90.833	Real-Ear
B	86.833	HA-1
C	82.833	HA-2

Means with the same letter are not significantly different.

TABLE 30. Analysis of variance (GLM) mode by type with a 60 dB SPL input at 3.5 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	478.96990741		9.76*
MODE*TYPE	1	15.34027778		0.63
ERROR	24		24.53047840	

*Values are significant at the .05 level.

DUNCAN GROUPING			MEAN	MODE
A			89.167	Real-Ear
	B		84.750	HA-1
		C	77.667	HA-2

Means with the same letter are not significantly different.

TABLE 31. Analysis of variance (GLM) mode by type with a 60 dB SPL input at 4 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	760.40277778		22.20*
MODE*TYPE	1	0.44444444		0.03
ERROR	24		17.12268519	

*Values are significant at the .05 level.

DUNCAN GROUPING			MEAN	MODE
A			87.167	Real-Ear
	B		81.556	HA-1
		C	72.167	HA-2

Means with the same letter are not significantly different.

TABLE 32. Analysis of variance (GLM) mode by type with a 60 dB SPL input at 4.5 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	585.24768519		9.41*
MODE*TYPE	1	0.17361111		0.01
ERROR	24		31.10570988	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	83.361	Real-Ear
B	78.222	HA-1
C	69.222	HA-2

Means with the same letter are not significantly different.

TABLE 33. Analysis of variance (GLM) mode by type with a 60 dB SPL input at 5 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	365.91435185		4.82*
MODE*TYPE	1	0.34027778		0.01
ERROR	24		37.94251543	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	78.083	Real-Ear
B	74.111	HA-1
C	67.500	HA-2

Means with the same letter are not significantly different.

TABLE 34. Analysis of variance (GLM) mode by type with a 90 dB SPL input at .5 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	152.23379630		11.01*
MODE*TYPE	1	2.50694444		0.36
ERROR	24		6.91358025	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	98.833	Real-Ear
B	94.861	HA-1
B	93.500	HA-2

Means with the same letter are not significantly different.

TABLE 35. Analysis of variance (GLM) mode by type with a 90 dB SPL input at 1 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	154.63657407		12.35*
MODE*TYPE	1	25.84027778		4.13
ERROR	24		6.25964506	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	106.08	Real-Ear
B	103.22	HA-2
B	101.94	HA-1

Means with the same letter are not significantly different.

TABLE 36. Analysis of variance (GLM) mode by type with a 90 dB SPL input at 1.6 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	615.10416667		41.03*
MODE*TYPE	1	1.17361111		0.16
ERROR	24		7.49537037	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	107.19	Real-Ear
B	102.50	HA-2
C	99.28	HA-1

Means with the same letter are not significantly different.

TABLE 37. Analysis of variance (GLM) mode by type with a 90 dB SPL input at 2 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	748.25462963		36.34*
MODE*TYPE	1	5.44444444		0.53
ERROR	24		10.29552469	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	108.11	Real-Ear
B	99.72	HA-2
B	99.06	HA-1

Means with the same letter are not significantly different.

TABLE 38. Analysis of variance (GLM) mode by type with a 90 dB SPL input at 2.5 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	567.12962963		18.72*
MODE*TYPE	1	2.77777778		0.18
ERROR	24		15.14969136	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	107.11	Real-Ear
B	99.33	HA-1
B	98.11	HA-2

Means with the same letter are not significantly different.

TABLE 39. Analysis of variance (GLM) mode by type with a 90 dB SPL input at 3 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	659.66666667		18.64*
MODE*TYPE	1	7.11111111		0.40
ERROR	24		17.69675926	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	104.47	Real-Ear
B	96.81	HA-1
C	91.94	HA-2

Means with the same letter are not significantly different.

TABLE 40. Analysis of variance (GLM) mode by type with a 90 dB SPL input at 3.5 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	1095.29166667		35.60*
MODE*TYPE	1	0.11111111		0.01
ERROR	24		15.38425926	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	102.75	Real-Ear
B	94.58	HA-1
C	86.50	HA-2

Means with the same letter are not significantly different.

TABLE 41. Analysis of variance (GLM) mode by type with a 90 dB SPL input at 4 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	1537.73379630		40.02*
MODE*TYPE	1	19.50694444		1.02
ERROR	24		19.21219136	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	99.889	Real-Ear
B	91.528	HA-1
C	80.389	HA-2

Means with the same letter are not significantly different.

TABLE 42. Analysis of variance (GLM) mode by type with a 90 dB SPL input at 4.5 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	1177.22916667		22.15*
MODE*TYPE	1	12.84027778		0.48
ERROR	24		26.57870370	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	95.000	Real-Ear
B	87.750	HA-1
C	77.444	HA-2

Means with the same letter are not significantly different.

TABLE 43. Analysis of variance (GLM) mode by type with a 90 dB SPL input at 5 kHz and mean comparisons of modes.

SOURCE	DF	TYPE III SS	MS	F VALUE
MODE	2	779.73611111		8.53*
MODE*TYPE	1	32.11111111		0.70
ERROR	24		45.70601852	

*Values are significant at the .05 level.

DUNCAN GROUPING	MEAN	MODE
A	91.167	Real-Ear
B	84.889	HA-1
C	76.667	HA-2

Means with the same letter are not significantly different.

APPENDIX D

MEAN OUTPUT DIFFERENCE LEVELS OF REAL-EAR AND MODIFIED 2 CC COUPLER MEASUREMENTS

Table 44. Mean output difference levels of real-ear and modified 2 cc coupler measurements with 60 and 90 dB SPL inputs at .5 to 5 kHz.

	MEAN OUTPUT DIFFERENCE LEVEL	
FQ KHZ	60 DB SPL	90 DB SPL
.5	3.3	3.9
1.0	2.6	4.2
1.6	5.6	7.9
2.0	4.7	9.0
2.5	6.0	7.8
3.0	4.0	7.7
3.5	4.4	8.2
4.0	5.6	8.4
4.5	5.2	7.2
5.0	5.0	6.3

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