Journal of Speech and Hearing Disorders, Volume 51, 362–369, November 1986

COMPARISON OF IN-THE-EAR AND OVER-THE-EAR HEARING AID FITTINGS

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A custom in-the-ear (ITE) hearing aid fitting was compared to two over-the-ear (OTE) hearing aid fittings for each of 9 subjects with mild to moderately severe hearing losses. Speech intelligibility via the three instruments was compared using the Speech Intelligibility Rating (SIR) test. The relationship between functional gain and coupler gain was compared for the ITE and the higher rated OTE instruments. The difference in input received at the microphone locations of the two types of hearing aids was measured for 10 different subjects and compared to the functional gain data. It was concluded that (a) for persons with mild to moderately severe hearing losses, appropriately adjusted custom ITE fittings typically yield speech intelligibility that is equal to the better OTE fitting identified in a comparative evaluation; and (b) gain prescriptions for ITE hearing aids should be adjusted to account for the high-frequency emphasis associated with in-the-concha microphone placement.

Although in-the-ear (ITE) hearing aids have assumed the largest share of the hearing aid market in recent years (Mahon, 1985), many audiologists remain dubious about the acoustic benefits of these instruments relative to those obtainable from over-the-ear (OTE) instruments (e.g., Beck, MacNeil, & Larson, 1984). Improved speech understanding in difficult listening conditions is the major acoustic advantage claimed for ITE fittings (e.g., Griffing & Heide, 1983; Griffing & Preves, 1976; Hoke, 1976; Westermann & Topholm, 1985). Several investigators have sought to quantify this advantage by direct comparisons of ITE and OTE fittings.

Preves and Rumoshosky (1976), Murphy (1981), and Kasden (1984) described comparative evaluations of ITE and OTE hearing aids on groups of hearing-impaired persons. However, the ITE and OTE fittings for a given subject were not equated in a systematic way in any of these studies. No significant advantages were demonstrated for either type of instrument in these investigations. Jervall, Almqvist, Ovegard, and Arlinger (1983) reported a comparison of newly fitted ITE instruments with previously fitted OTE instruments. They demonstrated a significant advantage for the ITE instruments when listening to speech in a background of multitalker babble. However, these investigators do not report attempting to equate the ITE and OTE hearing aid fittings, thus raising the possibility that the newly fitted ITE instruments provided more appropriate electroacoustic performance than the previously fitted OTE instruments. No investigations have been found in which OTE and ITE hearing aid fittings have been compared after systematic and consistent procedures have been used to equate the two fittings and to adjust them appropriately for the individual subjects.

The proposed advantages of ITE hearing aid fittings relative to OTE fittings are all related to the placement of the ITE microphone within the concha area. It is well known that the normal (unfilled) concha acts to amplify incident sound by about 10 dB in the 4- to 5-kHz frequency range (Shaw & Teranishi, 1968). It has not been clearly established, however, whether this effect is maintained when the concha is partially or completely filled with an ITE hearing aid. If a microphone located in a partially filled concha receives substantially more high-frequency sound than one that is located above the pinna, as in the typical OTE hearing aid, the relationship between coupler gain and functional gain should be different in ITE hearing aids from that in OTE hearing aids. This would have significant implications for ITE hearing aid prescription schemes because these schemes often incorporate a coupler-to-real-ear correction. Although numerous investigators have reported the relationship between coupler and functional gain for OTE hearing aids (e.g., Hawkins & Haskell, 1982; Pascoe, 1975; Zemplenyi, Dirks, & Gilman, 1985), the analogous relationship for ITE instruments has received little attention.

As a result of these considerations, two investigations were undertaken in an attempt to answer the following questions.

1. When ITE and OTE aids are both adjusted for appropriate and equivalent amplification, is either type of instrument superior in terms of speech intelligibility?
2. What is the relationship between coupler gain and functional gain for ITE aids, and does this relationship differ from the analogous relationship for OTE aids?
3. Is the sound received at a microphone within a partially filled concha substantially different from the sound received at a microphone above the pinna for the average adult ear?

EXPERIMENT 1

To answer Questions 1 and 2 above, subjects were fitted with both OTE and ITE hearing aids, and the instruments were then compared in terms of both speech perception and gain. Because OTE hearing aid fittings

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0022-4677/86/5104-0362$01.00/0

typically involve comparisons between at least two OTE instruments, each subject was fitted with two OTE hearing aids, and the better one was determined for comparison with the ITE instrument.

METHOD

Subjects

A series of 10 clinic patients at the Memphis Speech and Hearing Center served in the study. However, because some data were missing for 1 subject, results for 9 subjects are reported here (inclusion of the 10th subject would not have changed the outcome). Five subjects were obtaining their first hearing aid. Four subjects were experienced hearing aid users. Of these, 2 wore ITE hearing aids, and 2 wore OTE instruments.

The 9 individuals were aged 36–71 and had sensorineural hearing impairments ranging from mild to moderately severe. Flat, gently sloping, and rising audiometric configurations were represented (threshold data for individual subjects are given, for reference, in Table B-1 in Appendix B). Figure 1 shows the mean and range of the unaided sound field thresholds in the test ear. Unaided (and aided) sound field thresholds were measured using 0-degree azimuth warble tones.

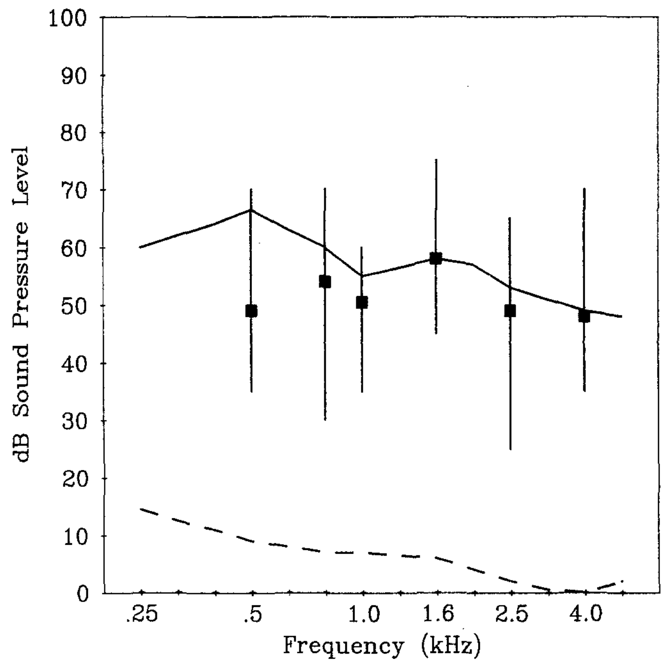

FIGURE 1. Filled squares give the mean unaided sound field thresholds (dB SPL) for the test ears. Vertical lines show the range of thresholds at test frequencies. The solid line (provided for reference) shows the one-third octave levels of a speech signal at 70 dB SPL overall level. The dashed line gives the normal, monaural sound field thresholds for 0-degree azimuth tones.

Procedure

A custom ITE hearing aid with tone control and maximum output controls was obtained for each subject. The full-on gain curve of the ITE aid was selected by the ITE manufacturer on the basis of the subject's audiogram and comfortable loudness data. Four different ITE hearing aid manufacturers were represented. ITE hearing aids were vented for subjects with thresholds better than 35 dB HL at 500 Hz (see Appendix A for rationale). In addition, acoustically appropriate custom earmolds were obtained for all subjects for use in fitting OTE hearing aids. Subjects who had vents in their ITE instruments also had vented earmolds for their OTE aids (see Appendix A for earmold prescription scheme).

Hearing aid fitting rationale. The MSU hearing aid fitting procedure, described by Cox (1983, 1985a), was used as the basis for equating the OTE and ITE hearing aid fittings. This procedure typically results in satisfactory hearing aid fittings; however, there is no evidence to indicate that it yields more appropriate prescriptions than other prescriptive procedures.

Six test frequencies were used: 500, 800, 1000, 1600, 2500, and 4000 Hz. It should be noted that because the frequencies 800 and 1600 Hz were not available on the clinical audiometer used (Saico, Model SC8), stimuli at 750 and 1500 Hz were substituted for these when audiometric measurements were made. This resulted in a 6.6% discrepancy between coupler and real ear measurements at these two frequencies. Because hearing aid gain typically changes no more than 1 dB between 750 and 800 Hz or between 1500 and 1600 Hz, the effect of this discrepancy was judged to be negligible. For each subject, unaided measurements of threshold and upper limit of comfortable loudness were obtained at each test frequency. These data were used to develop goals for aided sound field thresholds at each test frequency. According to the MSU hearing aid fitting procedure, appropriate amplification is obtained if aided sound field thresholds match these goals.

Adjustment of the OTE hearing aids. Implementation of the MSU procedure for the OTE hearing aid fittings was straightforward: A prescription for OTE hearing aid gain was derived for each subject using the tables provided (Cox, 1983). The prescription was expressed in terms of HA-2 coupler levels at the six test frequencies.

Two electroacoustically appropriate OTE hearing aids were then preselected for each subject. They were chosen from a pool of clinically proven instruments that were known to have provided successful fittings on many previous clients. Seven different OTE manufacturers were represented. The two OTE hearing aids were adjusted to match the subject's HA-2 coupler gain prescription as closely as possible. A Phonic Ear Series 2000 hearing aid test system was used for all hearing aid coupler gain measures.

Adjustment of the ITE hearing aid. Gain prescriptions could not be derived for the ITE instruments because appropriate tables had not been developed for this type of hearing aid [suitable tables are supplied in a subsequent revision of the MSU procedure (Cox, 1985b)]. Consequently, the following procedure was used for adjustment of the ITE instrument: First, with the ITE hearing aid attached to an HA-1 coupler, tone and volume controls were adjusted to approximately match the HA-2 coupler gain prescription derived for the OTE instruments. Second, with the subject wearing the ITE hearing aid, aided sound field thresholds were measured and compared with the aided sound field threshold goals at the six test frequencies (these goals are the same for a given subject regardless of the type of hearing aid used). Third, the volume and tone controls of the ITE instrument were adjusted and thresholds were retested until the best match was obtained to the aided sound field threshold goals. Ambient noise levels in the double-walled test room were low enough to permit measurement of sound field thresholds as low as 0 dB HL. The frequency/gain function of the ITE aid at the final settings was then measured in an HA-1 coupler. Any hearing aid vent was plugged for the coupler measurement.

Comparison of the ITE and OTE hearing aids. The three instruments (two OTE, one ITE) were then evaluated using the Speech Intelligibility Rating (SIR) test described by Cox and McDaniel (1984). For this test, subjects provide intelligibility ratings for 35-s continuous discourse passages on an equal-interval scale from 0 to 10 (ratings midway between the integer scale values are permitted). A rating of 10 indicates *all words understood;* a rating of 0 indicates *no words understood.* The higher the rating, the better the speech intelligibility provided by the hearing aid.

Procedures for administering the test are described in detail elsewhere (Cox, 1985a). Briefly, the continuous discourse is presented at 65 dB SPL overall, and the test is performed using a competing speech babble. The speech-to-babble ratio is adjusted for each individual to provide a mildly challenging listening condition. To prevent cosmetic issues from influencing the ratings, care was taken to ensure that subjects were not allowed to see the hearing aids during the rating procedure. (It was discovered that if subjects were not allowed to see or touch the hearing aids, they were not able to identify whether the particular instrument being worn was an ITE or OTE style.) The order in which hearing aids were presented was randomized across subjects. Two passages were rated per hearing aid. The final rating for each hearing aid was the mean of the two passages. The better rated of the two hearing aids was determined. The subject was then asked to judge, using additional comparisons if necessary, whether the ITE aid or the better rated OTE aid was preferred overall.

Aided sound field thresholds were measured for the higher rated OTE hearing aid.

RESULTS

Before comparing the preferred OTE and the ITE hearing aid fittings, the two instruments were equated as much as possible in terms of the aided sound field thresholds measured at the six test frequencies. To evaluate the extent to which the final fittings were equated, differences were derived for each subject between the aided sound field thresholds obtained at each frequency with the two instruments. Figure 2 shows the distribution of differences obtained when the aided sound field thresholds measured with the ITE hearing aids were subtracted from the aided sound field thresholds measured with the preferred OTE hearing aids. A negative value indicates that the aided sound field threshold obtained with the ITE instrument was higher than the corresponding threshold obtained with the OTE instrument; a positive value indicates that the ITE instrument gave the lower threshold. The figure reveals that 70% of the differences were within the range of ±5 dB, indicating that, on the whole, the OTE and ITE fittings yielded very similar aided thresholds. Also, the distribution is somewhat skewed toward positive values, indicating that when differences exceeded ±5 dB, the ITE instrument usually produced lower sound field thresholds than the OTE instrument. (It should be noted that production of lower aided sound field thresholds is not necessarily a desirable outcome because this can result in overamplification.)

Speech Intelligibility Rating Data

Table 1 shows the mean ratings obtained from the SIR test for the ITE and both OTE fittings. The mean rating given to the ITE instrument was 7.8 (SD = 1.5). For the better rated OTE instrument [OTE(1)], the mean rating was 7.9 (SD = 1.3), and for the poorer rated OTE instrument [OTE(2)], the mean rating was 6.0 (SD = 2.0).

In a comparative OTE hearing aid evaluation, the better rated OTE hearing aid would be the recommended instrument. Hence, the most clinically relevant comparison for the data given in Table 1 is between the ratings for

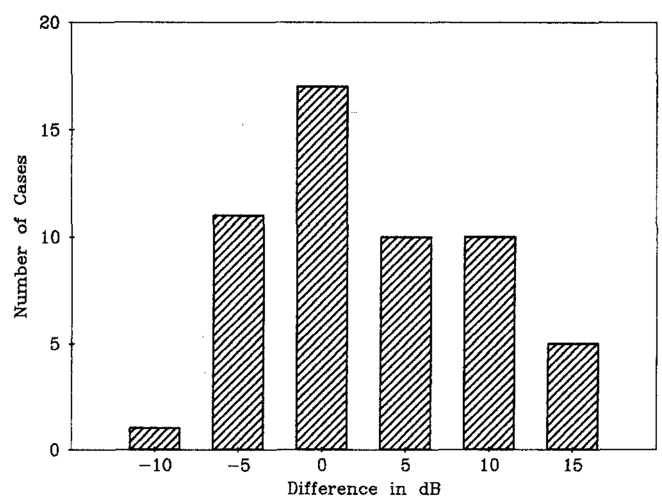

FIGURE 2. Distribution of differences obtained when aided sound field thresholds for ITE hearing aids were subtracted from corresponding aided sound field thresholds for preferred OTE hearing aids. The total number of cases is 54: 9 subjects at six frequencies.

TABLE 1. Mean speech intelligibility ratings for in-the-ear (ITE), higher rated over-the-ear [OTE (1)], and lower rated over-the-ear [OTE (2)] hearing aids.

	Hearing aids		
Subject	*ITE*	*OTE (1)*	*OTE (2)*
1	7.7	7.0	6.5
2	7.5	8.0	7.7
3	7.2	8.5	6.0
4	8.5	8.5	6.5
5	7.5[a]	5.2	3.7
6	10.0[a]	8.5	8.0
7	9.5	9.7[a]	6.0
8	7.0	7.7	7.5
9	5.0	8.0[a]	2.0

[a]Preferred hearing aid.

the ITE hearing aid and the corresponding ratings for the better rated OTE instrument. A t test on these data failed to reveal a significant difference between the ITE and OTE(1) ratings ($t = -0.26$, $df = 8$, $p > .1$). [Note: the OTE(1) data are treated as a random sample of OTE instruments that would be chosen on the basis of comparative OTE evaluations.] This outcome does not provide any evidence of a difference in speech intelligibility between the ITE hearing aids and the better rated OTE instruments. When asked to judge whether the ITE or the better rated OTE hearing aid was preferred overall, 5 subjects judged the intelligibility of the ITE aid to be equal to that of the better OTE instrument, 2 subjects (1 ITE wearer and 1 OTE wearer) slightly preferred the OTE instrument, and 2 subjects (both obtaining their first hearing aid) slightly preferred the ITE instrument.

Functional Gain/Coupler Gain Relationship

For each subject, functional gain (unaided sound field threshold minus aided sound field threshold) was determined at each of the six test frequencies for both the ITE and the preferred (better rated) OTE hearing aid fittings. (These values are given in Appendix B.) Coupler gain for the OTE fitting was measured in an HA-2 coupler with entrance through 25 mm of 2-mm i.d. tubing. Coupler gain for the ITE fitting was measured with the instrument attached to an HA-1 coupler. Figure 3 shows the mean functional gain obtained with each type of hearing aid relative to the mean coupler gain at each test frequency. A positive difference indicates that functional gain was greater than coupler gain. A negative value indicates that coupler gain exceeded functional gain.

For the OTE hearing aid, the results above 800 Hz are in substantial agreement with previous studies (e.g., Hawkins & Haskell, 1982; Pascoe, 1975; Zemplenyi et al., 1985). Below 800 Hz, mean functional gain exceeded mean coupler gain by a greater amount than seen in many previous studies. This occurred because a few hearing aids had negative coupler gain in the low frequencies. These types of hearing aids were always fitted to the ear

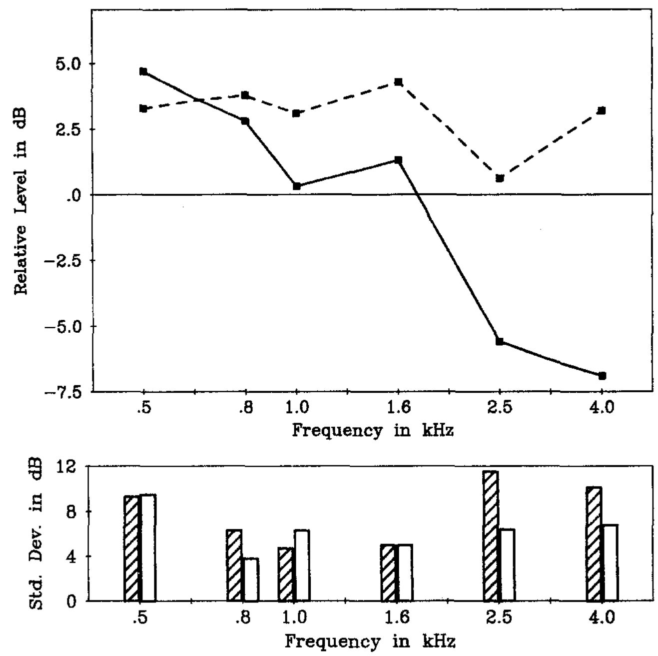

FIGURE 3. Upper panel shows mean functional gain relative to mean coupler gain for ITE hearing aids (dashed line) and OTE hearing aids (solid line). Lower panel gives standard deviations for ITE hearing aids (unshaded bars) and OTE hearing aids (shaded bars).

using a vented earmold that passed the low frequencies unamplified into the ear canal. As a result, the difference between aided and unaided low-frequency sound field thresholds was minimal and did not reflect the negative coupler gain values. When these subjects enter into the group average, mean functional gain exceeds mean coupler gain in the affected frequencies.

For the ITE hearing aids, the low-frequency data were very similar to those for the OTE instruments. However, in the high-frequency region, the functional gain/coupler gain relationship was substantially different from that seen in the OTE hearing aids. Above 800 Hz, a clear trend can be seen for ITE functional gain to exceed OTE functional gain when coupler gain is held constant. In other words, a given amount of coupler gain was associated with substantially more functional gain for ITE hearing aids than for OTE hearing aids in the high-frequency region. The mean difference between the two hearing aid types exceeded 10 dB at 4000 Hz.

Statistical analyses of the data (analysis of variance and tests of simple main effects) indicated that the functional gain advantage for ITE aids compared to OTE aids was significant at 2500 Hz [$F(1, 48) = 5.6$, $p = .02$] and 4000 Hz [$F(1, 48) = 15.2$, $p < .01$] but not statistically significant at other frequencies.

Furthermore, although the relationship between coupler and functional gains varied significantly across frequencies for the OTE data [$F(5, 80) = 5.9$, $p < .01$], this was not true of the ITE data [$F(5, 80) = 0.5$, $p = .79$]. For the ITE instruments, functional gain was greater than coupler gain by an average of 3 dB, and there were no significant differences among frequencies.

Additional Considerations

Several investigators have expressed concern that selection of a custom ITE hearing aid results in relative loss of control over the instrument's electroacoustic performance, thus abrogating the clinician's responsibility to select the most appropriate frequency/gain function (e.g., Navarro, 1980; Pollack & Robinson, 1981). Consequently, it was of some interest in the present study to determine the extent to which the custom ITE instruments could be adjusted to match the prescriptions for frequency/gain function.

The full-on gain performance of the custom ITE instruments was chosen by their manufacturers. Some modification of this basic performance could be accomplished through manipulation of the tone controls that were incorporated in all ITE instruments. By contrast, a wide variety of OTE instruments was available to match any prescription. It might be expected, therefore that prescriptions would be matched more accurately by choosing from the available OTE hearing aids than by using the custom ITE instrument.

Figure 4 shows data relating to this issue. This figure gives the mean aided sound field threshold goals for the six test frequencies. Also shown are the mean aided sound field thresholds for the preferred OTE hearing aid and for the ITE instrument. The average results are quite typical of the results for the individual subjects. Neither hearing aid type provided perfect correspondence to this prescription, but both types provided a fairly close match. The mean OTE aided thresholds were essentially identical to the aided goals at four of the six test frequencies. The mean ITE aided thresholds were identical to the aided goals in the three lowest frequencies but deviated progressively more from the goals at higher frequencies. Obviously, these ITE hearing aids provided somewhat more high-frequency gain than called for by the MSU prescriptive method.

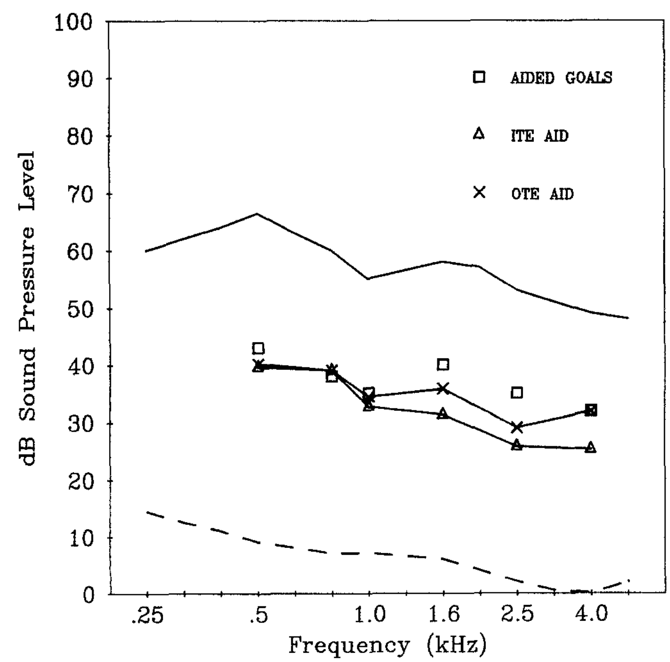

FIGURE 4. Mean aided sound field threshold goals, mean aided sound field thresholds for ITE hearing aids, and mean aided sound field thresholds for OTE hearing aids. The solid line shows the one-third octave levels of a speech signal at 70 dB SPL overall level. The dashed line gives the normal, monaural sound field thresholds for 0-degree azimuth tones.

EXPERIMENT 2

A second investigation was undertaken to explore the acoustic effects resulting from OTE and ITE microphone placements (the third research question noted earlier). Published reports relating to this issue encompassed either data from a single individual or manikin measurements only. To provide data delineating the effects of microphone placement for typical adult ears, measurements were made by the first author on a group of real ears.

METHOD

Subjects

Ten adults, 4 men and 6 women, served as subjects.

Procedure

The difference between a sound received at a typical ITE hearing aid microphone location and the same sound received at a typical OTE hearing aid microphone location was measured for one ear of each subject.

For ITE hearing aid measurements, the ITE hearing aid was simulated using a wad of putty with the same volume as an average ITE hearing aid. The putty was molded into the subject's concha, and a miniature microphone (Knowles XL9073) was embedded into the putty at a location somewhat above the middle of the concha (the typical location of an ITE microphone opening).

For OTE hearing aid measurements, an OTE hearing aid with a front-facing microphone was placed on the subject. The same miniature microphone as used for the ITE measurements was fixed to the top of the OTE hearing aid with the miniature microphone's opening 1–2 mm from that of the hearing aid's microphone. During measurements in the OTE condition, the putty used to simulate the ITE hearing aid was placed in the subject's concha to simulate an earmold.

Measurements were made in a sound-treated audiometric room. The signal was a broad-band thermal noise delivered from a loudspeaker located at a 0-degree azimuth, 1 m from the subject. The signals received at each microphone location (ITE and OTE) were spectrally analyzed and stored using a Wavetek Rockland 400-line analyzer, Model 5820A, set to the 10-kHz bandwidth. The spectrum measured at the OTE microphone was then subtracted from the spectrum measured at the ITE microphone location. This resulted in a difference curve showing the sound received at the ITE microphone location relative to the sound received at the OTE microphone location.

RESULTS

Figure 5 shows the mean difference curve obtained for the 10 ears. The ITE data are plotted relative to the OTE data. Hence, a positive difference indicates that the level entering the microphone of the ITE instrument was greater than the level entering the microphone of the OTE instrument.

Throughout the measured frequency range, the signal at the ITE microphone location was greater than the same signal measured at the OTE microphone location. However, the mean difference in input to the two hearing aid types was only about 1 dB at frequencies less than 1600 Hz. At 2500 Hz the mean level at the ITE microphone was 4.5 dB greater than the corresponding level at the OTE microphone. This advantage increased to a maximum of 6 dB at 4000 Hz. These measurements indicate that the high-frequency emphasis associated with a partially filled concha is less than that reported for an unfilled concha (Shaw & Teranishi, 1968). Nevertheless, ITE microphone placement clearly facilitates reception of high-frequency signals.

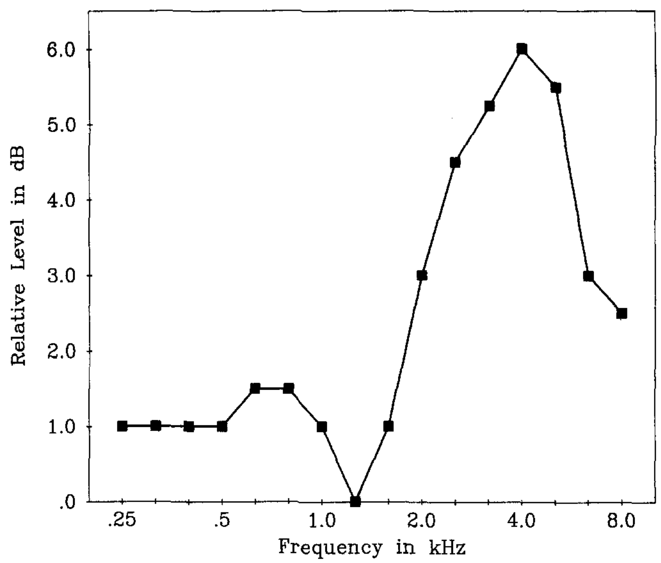

FIGURE 5. Main difference in input to ITE hearing aid microphone and OTE hearing aid microphone when both were exposed to the same broad-band sound field signal. The ITE data are plotted relative to the OTE data. $N = 10$ independent ears.

GENERAL DISCUSSION

The differences between sound field thresholds measured with preferred OTE and ITE fittings (Figure 2) indicate that amplification obtained with the two hearing aid types was, in the main, very similar. However, these data, in combination with the mean thresholds shown in Figure 4, also reveal that the ITE hearing aids consistently yielded somewhat lower sound field thresholds in the high frequencies than did their OTE counterparts. In spite of attempts to equate the ITE and OTE fittings, the high-frequency real-ear gain obtained with the ITE instrument was typically a few decibels greater than that obtained with the OTE instrument even when high-frequency emphasis earmolds were used in the OTE fittings. As a result, the ITE hearing aids did not match the aided threshold goals provided by the MSU prescription quite as well as did the preferred OTE hearing aids.

The results of the SIR test (Table 1) indicate that there was no evidence of a difference between the ITE instrument and the preferred OTE instrument in terms of speech intelligibility. This outcome suggests that, at least for subjects with mild to moderately severe hearing losses, the speech intelligibility obtained from an appropriately adjusted custom ITE fitting is typically no poorer than would be obtained from the best OTE hearing aid identified in a comparative hearing aid evaluation procedure.

The relationship between functional gain and coupler gain was found to be significantly different for the OTE and ITE hearing aid types at frequencies above 1600 Hz. This outcome is consistent with the suggestion that placement of the ITE microphone in the partially filled concha results in a significant high-frequency emphasis of incident sounds, whereas a microphone placed above the pinna (the position for OTE hearing aids) does not benefit from high-frequency emphasis of incident sounds.

It was of interest to compare the average acoustically measured high-frequency advantage of in-the-concha microphone placement, shown in Figure 5, with the average psychoacoustically measured functional gain advantage seen in Figure 3. Comparison of these two sets of data revealed that the acoustically measured differences in input to ITE and OTE hearing aid microphones were large enough to account for most of the high-frequency functional gain differences observed psychoacoustically. It should be kept in mind that the data shown in Figure 3 and those shown in Figure 5 were measured on different subject groups; hence, it is unlikely that they would correspond perfectly. When the acoustic differences are subtracted from the functional gain differences, there is a remaining high-frequency discrepancy of 2–4 dB between ITE and OTE functional gain. Some of this discrepancy probably was due to the use of the HA-2 earmold instead of the subject's own earmold in the HA-2 coupler measurements (the HA-2 coupler was used to facilitate comparisons with previous investigations). Overall, these data suggest that the functional gain difference between ITE and OTE hearing aids is attributable to the different input spectra they receive because of their differing microphone locations.

CONCLUSION

The results of this investigation suggest that custom in-the-ear hearing aids and over-the-ear hearing aids are equally beneficial for persons with mild to moderately severe hearing losses. On the whole, the speech intelligibility achieved with an appropriately adjusted ITE instrument was equal to that obtained with an appropriately adjusted, comparatively selected, OTE instrument. Furthermore, it was possible to adjust the frequency/gain function of the custom ITE instrument to achieve reasonable correspondence with the type of gain prescription used in this investigation. Because most prescription schemes result in rather similar gain prescriptions, it seems reasonable to suggest that this outcome can be generalized to other prescriptive methods.

In addition, the results of this investigation indicate that gain prescriptions for ITE hearing aids should be adjusted to account for the high-frequency emphasis of incident sounds that is inherent in the in-the-concha microphone placement. Values derived from Figure 5 could be used for this purpose.

ACKNOWLEDGMENTS

Part of this work was presented at the Annual Convention of the American Speech-Language-Hearing Association, Washington, DC, 1985.

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Received March 12, 1986
Accepted June 17, 1986

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APPENDIX A

Earmold Prescription Guide

Acoustically appropriate earmolds were ordered for use in the OTE hearing aid fittings. To determine the appropriate specifications for these earmolds, the procedure outlined below was used.

First, the subject's audiogram was categorized according to both high-frequency sensitivity and low-frequency sensitivity. A transparent overlay, shaded and divided as shown in Figure A-1 was aligned over the pure tone audiogram for the ear to be aided.

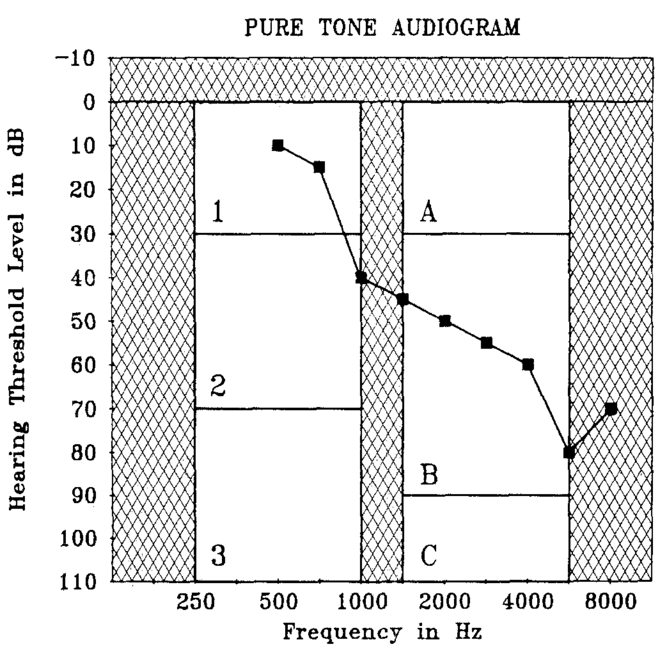

Figure A-1. Audiogram overlay for categorizing hearing loss configurations. A hearing loss is categorized according to the low-frequency area and the high-frequency area within which most of the visible thresholds fall. A Type 1B hearing loss is shown for illustration.

The hearing loss was categorized according to the areas within which most of the visible threshold measurements fell. For example, Figure A-1 illustrates an audiogram that would be categorized as "1B."

After the hearing loss was categorized, the earmold was ordered according to the following specifications.

Low-frequency area:

1. Large parallel vent with inserts.
2. Small parallel vent.
3. No vent.

High-frequency area:

A. Maximum high-frequency cut—#16 tubing completely through bore.
B. High-frequency emphasis—maximum horn effect.
C. Moderate low-frequency emphasis—#13 tubing completely through bore.

Hence, a 1B earmold would be ordered with a large parallel vent with inserts and a maximum horn effect (the maximum horn effect available for a given earmold impression is determined using precise measurements of the narrowest portion of the ear canal impression). The subjects who served in this investigation all obtained 1B or 2B earmolds for use in the OTE hearing aid fittings.

This earmold prescription guide has been in use in a clinical setting for several years. The guidelines for venting are based on the report by Cox and Alexander (1983) that vented earmold fittings are clearly preferred over unvented fittings by individuals with good low-frequency sensitivity. The guidelines for high-frequency specifications are based on the assumption that it is possible to predict amplification needs, in broad outline, on the basis of the audiogram—before a specific amplification prescription has been developed for the individual. It should be noted that a 1C classification produces an illogical earmold recommendation; a 1C audiogram cannot be accommodated within these guidelines.

APPENDIX B

Threshold and Functional Gain Data for Individual Subjects

TABLE B-1. Unaided sound field thresholds (dB SPL) for each subject for warble tones from a 0-degree azimuth.

	Frequency (kHz)					
Subject	*0.5*	*0.8*	*1.0*	*1.6*	*2.5*	*4.0*
1	35	55	55	55	45	40
2	35	30	35	70	60	55
3	45	50	45	45	25	35
4	40	45	40	50	30	40
5	60	70	65	75	65	70
6	45	50	45	50	55	40
7	55	60	55	70	60	55
8	55	60	55	55	45	50
9	70	70	60	50	50	40

TABLE B-2. Functional gain (dB) measured for each subject's in-the-ear hearing aid.

	Frequency (kHz)					
Subject	*0.5*	*0.8*	*1.0*	*1.6*	*2.5*	*4.0*
1	0	10	15	15	20	15
2	5	−5	0	15	35	25
3	0	10	15	20	10	10
4	0	5	10	20	10	20
5	15	25	20	30	25	30
6	20	25	25	35	30	30
7	20	30	30	45	35	35
8	15	15	15	30	20	20
9	10	20	30	30	25	20

TABLE B-3. Functional gain (dB) measured for each subject's preferred over-the-ear hearing aid.

	Frequency (kHz)					
Subject	*0.5*	*0.8*	*1.0*	*1.6*	*2.5*	*4.0*
1	0	10	15	15	10	0
2	5	0	0	15	25	20
3	5	15	15	20	15	10
4	5	10	10	20	0	10
5	10	20	15	20	10	15
6	20	20	30	30	40	20
7	10	15	20	35	30	25
8	20	20	15	20	25	25
9	5	25	25	25	25	20