Proceedings of The Institute of Acoustics

HEARING AID PERFORMANCE MEASURED ON REAL EARS, THE 2 cc ACOUSTIC COUPLER AND THE ZWISLOCKI ARTIFICIAL EAR

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Introduction

Hearing aids are prescribed or fitted in order to best compensate for the particular audiological patterns of an impaired ear with appropriate electro-acoustic characteristics of the aid. The characteristics of a hearing aid, in particular the frequency-gain response, are determined according to national and international standards (1,2,3). The standard methods call for the use of the 2 cc acoustic coupler as an acoustic load for the aid under test. Measurements made using this simple,easily manufactured electro-acoustic device may be used for repeatable specification and information transfer, but not necessarily to simulate the performance of an aid on a real ear. The Zwislocki artificial ear (4), on the other hand, was designed to closely approximate the physical dimensions and acoustic properties of the human ear. Each of these electro-acoustic devices has attractive qualities, but which is more useful for accurately estimating hearing aid performance in actual use?

Experimental Method

In the course of an experiment concerning the effects of hearing aid frequency response modification upon speech reception (5), transmission gain and frequency response measurements were performed on a large number of behind-the-ear hearing aids, both *in situ* on impaired ears and in a hearing aid test box. For the *in situ* measurements, a wide-band noise of 70 dB S.P.L. was presented as a free field input to the hearing aids in place on the heads of hearing-impaired experimental subjects. The input to each aid was monitored by a wide-band flat-response subminiature microphone mounted on the aid within 8 mm of the inlet port, as shown in Figure 1. The output of each aid into the closed ear canal was monitored using a duplicate subminiature microphone and probe tube penetrating 5 mm through the plastic foam temporary earmould. The input and output signals were tape recorded for later narrow band frequency analysis.

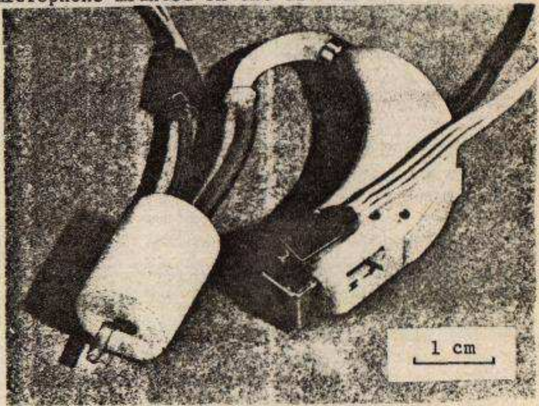

Fig.1 - Experimental aid with subminiature microphones for *in situ* measurements.

In addition, the transmission gain and frequency response of each aid and sound tube were measured in a hearing aid test box using the British Standard method. In the box, a sound field of constant 60 dB S.P.L., with pure tone frequency swept slowly between 100 Hz and 8 kHz was presented as input to each aid. The aid output was measured using both the 2 cc acoustic coupler (as required by the British Standard) and the Zwislocki artificial ear, both specially adapted to receive the sound tube used for the in situ measurements. Thus it was possible to directly compare the performance of the individual hearing aids measured in actual use in human ears and into the two electro-acoustic devices .

Analysis and Results

During the speech reception experiment, each of 28 hearing-impaired subjects adjusted 4 hearing aids to suit his individual requirements. Of these 112 hearing aid treatments, a sample of 54 aids (over 22 ears) was subjected to detailed analysis of gain-frequency response. At a number of frequencies, the transmission gain was calculated from the data obtained using the 2 cc coupler and Zwislocki ear, and from 3% bandwidth frequency analysis of the in situ noise recordings. These transmission gain data were formed into differences:

$$\text{(2 cc gain)} - (\underline{\text{in situ}}\ \text{gain}) = \Delta\ \text{2 cc}$$
$$\text{(Zwis.gain)} - (\underline{\text{in situ}}\ \text{gain}) = \Delta\ \text{Zwis.}$$

These differences indicate how closely the elctro-acoustic device measurements estimate the real ear performance of the aids at each frequency chosen.

The mean and standard deviation of the 2 cc differences and Zwislocki differences are shown as a function of frequency in Figures 2 and 3 respectively. A positive gain difference indicates that the coupler or artificial ear over-estimated the real ear performance of the sample of hearing aids; a negative difference indicates under-estimation. From Figure 2, the mean differences indicate that the 2 cc acoustic coupler consistently under-estimated the hearing aid output into the sample of real ears. Furthermore, this error was frequency dependent, being greatest for the frequencies greater than 1 kHz. Figure 3, on the other hand, shows that the Zwislocki artificial ear gave a relatively smaller positive error when compared to the aid output into the sample of real ears. This over-estimation was essentially flat for frequencies below 4 kHz.

The differences found for both the 2 cc coupler and the Zwislocki ear were tested statistically to determine if one device was superior in estimating the performance of hearing aids in actual use. At each frequency, a two-tailed t test was performed in an attempt to disprove the hypothesis that the device gain minus in situ gain equalled zero. In the case of the 2 cc acoustic coupler, this hypothesis was rejected (at the 0.01 significance level) for all frequencies.

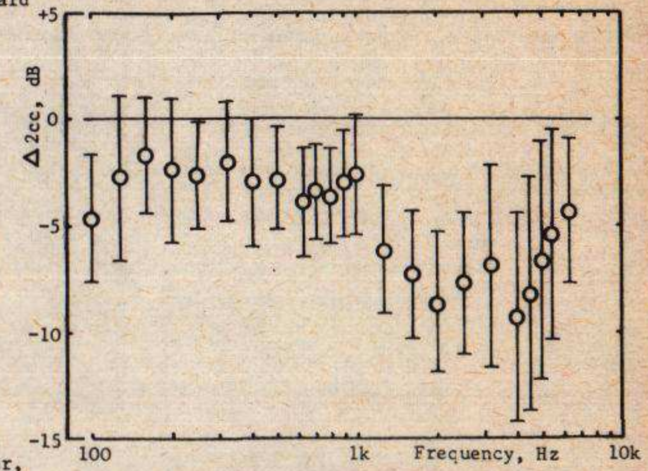

Fig.2 - Means and standard deviations (bars) of 2cc gain minus in situ gain.

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Thus, the 2 cc coupler gave consistently erroneous estimates of the transmission gain of the sample of hearing aids on real ears. For the Zwislocki ear, the t tests failed to reject (0.01 level) the hypothesis of zero error or zero gain difference at a number of frequencies. These insignificant errors, shown in Figure 3 as the solid symbols, ranged in frequency between 160 Hz and 4 kHz. Thus on the basis of the sample of 54 hearing aids, one may conclude that hearing aid performance measured using the Zwislocki artificial ear gives a close approximation to the performance of that aid on a human ear.

Discussion

The results reported here are in good general agreement with similar research performed by a variety of methods. For the 2 cc acoustic coupler, other experiments (6,7,8) have demonstrated a frequency dependent under-estimation of the frequency-gain characteristics of aids on real ears, regardless of whether the coupler data was taken at the bottom of the cavity or at the end of the earmould placed in the coupler. These pressure differences ranged between 2 and 6 dB for frequencies less than 1 kHz. For frequencies greater than 1 kHz, the 2 cc coupler error rose smoothly to between 8 and 20 dB, sometimes with maximum under-estimation around 5 kHz. The small number of ears and/or aids tested, usually about 10, have precluded any firm conclusion about the absolute differences between data from real ears and using the 2 cc coupler. However, there is general feeling confirming the disclaimer written in various standards, that results obtained using the 2 cc acoustic coupler should not be used to represent the performance of a hearing aid on an individual ear. In contrast, the research reported here and elsewhere (8) has shown that the Zwislocki ear gives an accurate simulation of real ear response at least up to 4 kHz, possibly up to 7.5 kHz if the data are corrected for S.P.L. differences between measurement points in the ear canal (beyond the earmould vs. at the eardrum).

On the basis of such results, many authorities feel that, although the Zwislocki artificial ear is a valuable research tool, the 2 cc coupler should be retained for aid specification purposes due to the simple structure and well understood acoustic properties of the coupler. However, users of the 2 cc acoustic coupler should keep in mind the drawbacks in application of results. The situation is reversed for the Zwislocki ear. Evidence is accumulating that the device is an accurate simulation of the human ear, good enough for specification of hearing aid transmission performance in parallel with the

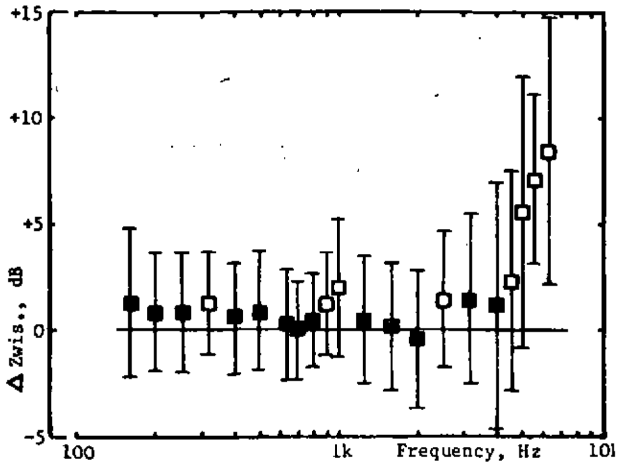

Fig.3 - Means and standard deviations (bars) of Zwislocki gain minus in situ gain (solid symbols indicate not significantly different from zero).

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2 cc coupler. However, the variable materials used in the complicated construction of the 4-branch Zwislocki ear are drawbacks for the adoption of this device as a specified standard acoustic load for aids. (There are considerably simpler electro-acoustic devices, the I.R.P.I. 2-branch occluded ear simulator (9) for example, which mirror the acoustic properties of the human ear).

The transmission characteristics of a hearing aid, determined using any coupler or artificial ear, do not tell the whole story. It is necessary to consider instead the insertion gain of an aid to obtain the amplification as heard by the user. An aid of known transmission characteristics is positioned on the user's head or body, which diffracts and reflects the sound field in a complicated manner. One must consider the pressure transformation between free-field and aid microphone location, and between free-field and unoccluded eardrum. It is then possible to estimate the aid gain as heard by the user. The necessary transformations are reported in the literature, but are derived from measurements made on samples of human subjects and thus have great variability. So, in order to determine what benefit an individual aid user is receiving from his instrument, one may either estimate the insertion gain, with associated variability, or measure directly the insertion gain of the aid on the individual client or patient.

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