Proceedings of The Institute of Acoustics

A SURVEY OF THE SOUND FIELD WITHIN THE OCCLUDED EAR CANAL

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Introduction

Much hearing aid research effort has been concentrated on formulating relationships between various acoustic characteristics of aids and the benefit which the hearing impaired may derived from these characteristics. Such research requires accurate specification of hearing aid output, the independent variable. For this purpose, a number of artificial ears and acoustic couplers have been developed which variously reproduce the dimensions and acoustic properties of a mean or median human ear. However, such electro-acoustic ear simulators are of very limited value in predicting aid performance into any individual real ear.

Obviously, the most direct way to determine hearing aid output into a real ear is to measure the sound pressure level in the occluded ear canal. Such probe microphone measurements are, for safety reasons, usually made at the earmould end of the canal. However, research has shown that these sound pressure measurements vary, depending on the location of the probe in unoccluded ears (1,2), artificial ears (3,4,5) and occluded ears (5,6). Sound level at or near the earmould or similar occluding device has been found to be lower than that measured at the eardrum, with large differences as low as 3 kHz. In the higher frequencies, the most desirable measurement location (for safety) can show differences up to 15 dB from the equivalent eardrum pressures.

The purpose of the research reported here was to survey the sound field from an aid-like source, along the length of the occluded external ear canal from the tympanic membrane to the tip of the earmould. It was desired to know the sound level differences at various measurement locations, compared to the eardrum, and also the variation to be expected at any one location.

Experimental Method

Ten adults, with mean age 25.5 years (range 18-37 years), were accepted to participate in the experiment. The ear canals used were free of any large accumulations of wax and had no abnormal signs in the external canal or eardrum. Impedance testing indicated middle ear function within normal limits.

The ear canals tested were occluded in one of two ways. For larger canals, an acrylic "shell" earmould was prepared; for canals of relatively normal size, a malleable plastic foam earplug was inserted 4 to 7 mm into the canal. The two methods of occlusion gave similar lengths of enclosed ear canal volume. In both cases, the plug/mould was penetrated by a large bore sound tube and a probe tube, of 1 mm bore, with a wide-band, flat- response subminiature microphone attached on the outside end. The probe tube was not fixed in the plug/mould, but could be moved along the length of the enclosed canal volume. The inside end of the probe tube had tufts of very fine nylon fibres protruding 2 mm beyond the tip.

When the plug/mould was placed in the ear canal, a fibre-optic medical endoscope (2.2 mm external diameter) was advanced along the sound tube a few mm into the enclosed volume. Thus, the probe microphone tube could be placed near the eardrum

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under visual observation. When the probe tip was within 2 mm of the eardrum, the nylon fibres were observed to deflect against the drum, and the subject reported a "scraping/hissing" noise. The endoscope was then withdrawn from the sound tube, and replaced by a dummy hearing aid containing a receiver driven by a constant voltage sine wave source, swept slowly from 200 Hz to 10 kHz.

The sound pressure produced by the dummy aid was measured near the eardrum by means of the probe tube and subminiature microphone. A number of constant input sine sweeps were recorded, with the probe tip withdrawn 2 mm each time. Thus, the sound field in the enclosed canal volume was measured and recorded over frequency, from 200 Hz to 10 kHz, at locations from within 2 mm of the eardrum outwards to the mould tip.

Results and Discussion

Fourteen observations were made over the ten subjects, each observation being constant input sine sweeps repeated for pressure measurements at 2 mm intervals from the drum outwards. For each ear canal, all sound pressure measurements over frequency and location were normalized to those recorded 2 mm from the eardrum. The means and standard deviations of the sound pressure measurements are shown in Fig. 1. Here, the drum-normalized pressure values are presented to show the change with distance from the tympanic membrane for specific frequencies.

Note that for the lowest frequencies, there is very little pressure change along the length of the enclosed volume. However, as the frequency increases, the length of the occluded ear canal becomes a significant fraction of the wavelength and interference patterns develop. Pressure minima develop which are 1/4 wavelength resonances, seen especially well in the highest frequencies 7-9 kHz. The dimensions involved are approximately correct to set up such destructive interference between the incident and reflected sound waves.

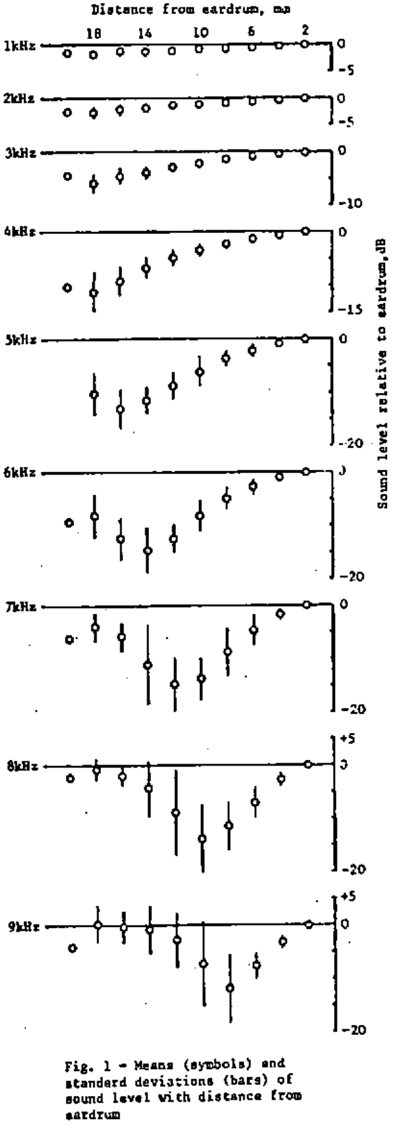

Fig. 1 - Means (symbols) and standard deviations (bars) of sound level with distance from eardrum

Also note that the standard deviations become larger in the pressure minimum

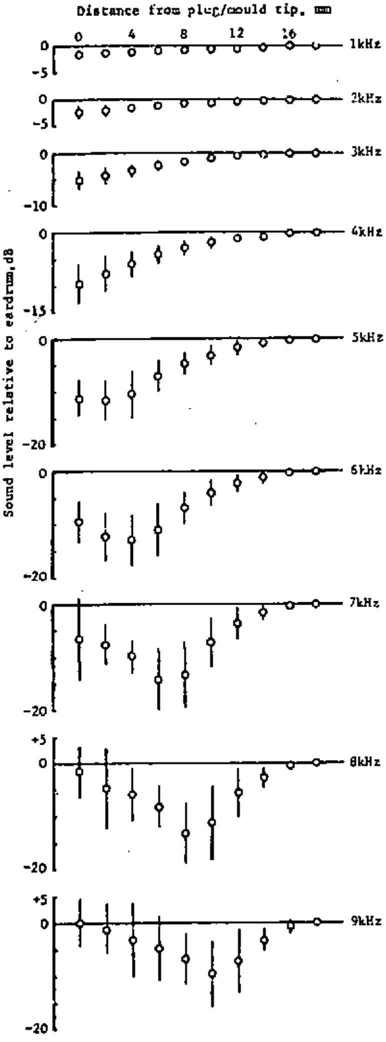

Fig. 2 – Means (symbols) and standard deviations (bars) of sound level with distance from plug/mould tip

troughs. This is due to a combination of random distance errors. Firstly, between-subject differences of 1-2 mm insertion depth may be expected in placing the probe tip near the complicated, inclined surface of the ear-drum. Secondly, errors of ±0.2 mm in with-drawal distance may be expected using manual manipulation of the probe tube. These two random distance errors combine to produce sometimes quite large between-subject variation in the placement and depth of the pressure minima.

The fourteen sound pressure observations along the length of the enclosed ear canal volume were also used to show changes in eardrum-normalized pressure with distance from the plug/mould tip. These means and standard deviations, given in Fig. 2, exhibit patterns similar to the drum-distance plots. Note however, that the pressure minimum troughs are broader, with larger standard deviations of sound pressure. This is due to the relatively large between-subject variation in the length of enclosed canal volume. The distance from the eardrum to plug/mould tip may vary nearly 10 mm between subjects, whereas the placement of the pressure minimum is considerably more stable when measured from the eardrum.

Implications

The research reported here, and in the literature, indicates considerable variation in sound pressure depending upon the location of the probe microphone tube in the ear canal. Generally, sound level measured at or near the earmould tip is lower than that observed at the eardrum. This difference is greatest in the higher frequencies, 4-10 kHz, where differences in hearing aid output can have significant effects upon benefit and subjective impression. Thus, in order to accurately measure aid output into real ears, it is worthwhile to consider the errors to be expected at common measurement locations in the occluded canal.

Using the means and standard deviations for each frequency, a lower 95% probability limit was calculated. By this, it is meant that 95% of the data had a minus difference from drum sound level no greater than the calculated value. These lower 95% limits are shown in Fig. 3 for three measurement

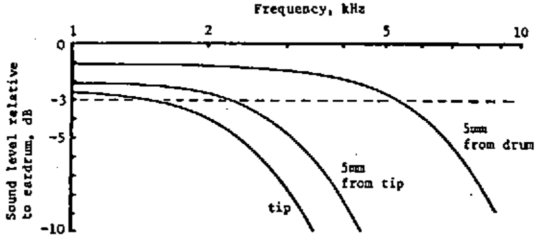

Fig. 3 – Lower 95% probability limit of sound level difference from eardrum, for different measurement locations

locations: 0 mm and 5 mm beyond the earmould tip; and 5 mm from the eardrum. For measurement locations near the tip, the differences from drum sound level increase rapidly. If it is desired to estimate sound pressure level at the eardrum with an error no greater than -3 dB, measurements made near the earmould tip are useful only up to certain frequencies (tip, less than 1.5 kHz; 5 mm beyond tip, less than 2.5 kHz). For measurements made 5 mm from the drum, the lower 95% limit intersects the -3 dB maximum permitted difference at approximately 5.3 kHz, a more useful upper frequency limit considering the typical hearing aid frequency range.

Use of probe microphone techniques to measure or estimate in-the-ear performance of hearing aids requires careful balance between the safety of the experimental subject and the quality of the data to be obtained. Sound level measurements made at or near the earmould tip carry little risk to the aid user, but are of limited value in dètermining the aid output heard by the user. The usefulness of real-ear aid output measurements increases, in terms of upper cut-off frequency for acceptable accuracy, with the distance from earmould tip to measurement location. By careful measurement of sound level inside the human ear canal, within a few mm of the eardrum, it is possible to avoid interference patterns(and the associated variability) throughout the frequency range of interest. Such measurements close to the tympanic membrane are necessary because the modern hearing aid, coupled with a specially designed and carefully executed earmould, may have a useful frequency range extending up to 7-8 kHz.

References

1. Francis M.WIENER and Douglas A. ROSS 1946 J. acoust.Soc.Am.18,401-408. The Pressure Distribution in the Auditory Canal in a Progressive Sound Field.
2. D.DJUPESLAND and J.J. ZWISLOCKI 1972 Scand. Audiol. 1,197-203. Sound Pressure Distribution in the Outer Ear.
3. Richard M. SACHS and Mahlon D.BURKHARD 1972 J.acoust.Soc.Am. 51,140(A). Making Pressure Measurements in Insert Earphone Couplers and Real Ears. (Full text as an Industrial Research Products, Inc. report)
4. R.M. SACHS and M.D. BURKHARD 1972 J.acoust.Soc.Am. 52, 183(A).Insert Earphone Pressure Response in Real Ears and Couplers. (Full text as Industrial Research Products, Inc. Report No. 20021-2)
5. Vernon D. LARSON, Gerald A. STUDEBAKER and Robyn M.COX 1977 J.Am.Audiol.Soc. 3,63-70. Sound Levels in a 2-cc Cavity, a Zwislocki Coupler, and Occluded Ear Canals.
6. G.A. STUDEBAKER 1974 paper presented at Ann.Conv., Am.Speech Hearing Assoc. Sound Levels Measured at Three Positions in Ear Canals Occluded by an Earmold.