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RESPONSE MEASUREMENTS ON HEARING AIDS BY PSYCHO-ACOUSTIC AND OTHER REAL EAR TECHNIQUES.

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1. Introduction.

The insertion response of a hearing aid on an average person is not readily predictable from a transmission response on a coupler or ear simulator. Furthermore, the insertion response of a behind-the-ear (BTE) aid can differ, perhaps by as much as 20 dB from wearer to wearer even at frequencies as low as 2 kHz [1]. Thus even a manikin or average real ear response may not fully characterise an aid's response on an individual. If the response of an aid as experienced by a given wearer need be known, for example in research to correlate with some measured 'benefit', or perhaps when prescribing an aid [cf.2], then the response must be measured on that person.

There are various ways of doing this, but one method, a loudness balance, has been found to give unexpectedly low gain values [3]. It was therefore decided to compare directly methods of measuring aid insertion responses to establish their equivalence and validity or otherwise. The methods compared were (i) a balance of aided and unaided loudness, (ii) a comparison of sound pressure levels (SPLs) in aided and unaided ears with a probe-tube microphone, and (iii) an acoustic reflex threshold shift.

2. Experimental methods.

The gain control of a National Health BE-11 BTE aid was sealed and the gain was measured by each method at 500 Hz, 1 kHz, 2 kHz and 4 kHz on the left ears of four otologically and audiometrically normal subjects (hearing levels ≤ 20 dB re. ISO R389). Normal subjects were employed to enable fair comparisons to be made with manikin and ear simulator measurements,and for intersubject consistency.

Loudness balance and probe microphone measurements.

The loudness balance and probe microphone measurements were made simultaneously. Each subject sat in an anechoic room and a pulsed pure-tone reference signal at the particular test frequency was presented to his right ear from a hearing aid receiver mounted in an aid shell via an earmould. The reference signal level was 75 dB SPL measured in a Zwislocki ear simulator, pulses were 500 ms long with an exponential rise and fall. A second signal, of similar pulses alternating with the reference pulses, was presented from a loudspeaker 1m in front of the subject at mouth height. The level of this signal was directly controlled by the subject. Since his right ear was occluded he heard the loudspeaker monaurally either directly in his unaided left ear or via the BE11 aid worn on that ear, in either case adjusting the level of the pulses in his left ear to match in loudness the reference pulses in his right. The loudspeaker driving voltage was then noted. The 'subjective gain' of the aid was defined as the decibel difference between the loudspeaker voltage for unaided equal loudness and that for aided equal loudness. Each subject made one aided and one unaided balance at each frequency in a fully counterbalanced experimental design.

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Sound pressure levels at equal loudness were measured in the subjects' earcanals using a calibrated Knowles XL-9073 microphone [4] with 1.3 mm bore polythene probe tubes. Measurements were at 5mm beyond the earmould in the aided ear, the probe tube passing through the mould, and at the same depth in the unaided ear. Previous measurements of SPL variation along a Kemar manikin's ear and to a limited depth in real ears suggest that errors due to not measuring SPL at the eardrum would roughly cancel, to within about 2-3 dB, between aided and unaided ears in the gain calculations, provided that measurements were at this same depth in each case. The 'pressure insertion gain' of the aid at each frequency was calculated as the difference in SPL between aided and unaided ears corrected to the same loudspeaker output.

Acoustic reflex threshold shift method.

Tone pulses at each frequency were presented from the loudspeaker to the aided and unaided left ear of each subject. The loudspeaker output was increased until an acoustic reflex was detected by monitoring on an oscilloscope the output of an otoadmittance meter connected to an impedance probe in the subject's right ear. The aid gain by this method is the decibel difference between the minimum loudspeaker voltage required to elicit a reflex in the unaided and aided ear respectively.

3. Results and Discussion.

Results are shown in Figures 1 - 3. The acoustic reflex threshold shift, if a reflex were present, gave gains very similar to the pressure insertion gains, both for individuals and on average. The slight differences between methods were most probably due to not measuring SPL at the eardrum. This implies the acoustic reflex is at about the same SPL whether an ear is aided or unaided. The loudness balance, however, gave average measured gains up to 17dB lower than the other two methods, the average SPL in aided ears being up to 17 dB than in unaided ears for the same loudness. With the acoustic reflex threshold at the same SPL in aided and unaided ears this 17 dB discrepancy must be psycho-acoustic rather than physical, arising in the brain above the level of the acoustic reflex arc.

This discrepancy is not a constant 17 dB. Subsequent experiments have shown that (i) increasing the gain of an aid increases the SPL required in the ear for a given loudness, and, (ii) occluding the ear with a full earmould, as opposed to merely using a sound tube into the unoccluded ear from an aid, increases the SPL required for a given loudness by 5-7 dB - an effect reminiscent of the "Missing 6 dB"[5,6] though here not confined to low frequencies. Both effects are considered to be due to circuit noise generated within the aids partially masking the tone pulses. Increasing aid gain and sealing the ear both increase the level of circuit noise within the ear and consequently the degree of any partial masking. Figure 4 shows how the SPL in the ear for a given loudness depends on the circuit noise level. The degree of partial masking found is in good quantitative agreement with published data for wide-band noise [7,8].

Circuit noise in modern aids arises mainly in the microphone unit and is typically equivalent to a 26 - 28 dB(A) sound input. Such levels would normally be masked in use by ambient acoustic noise, but amplified circuit noise in the ear may, at typical use-gains, be above or comparable to auditory thresholds of persons with

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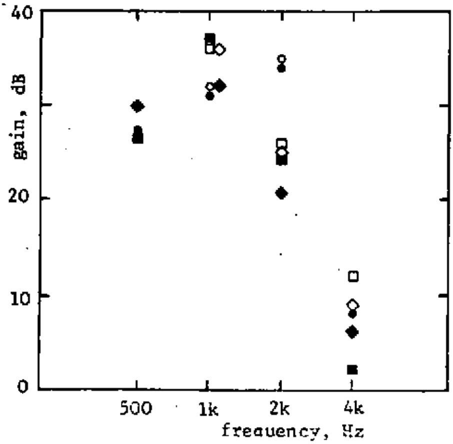

Fig.1 Gain of the BE11 aid on 3 subjects by acoustic reflex (open symbols) and probe mic. (filled symbols). Subject 4's reflex was not detected.

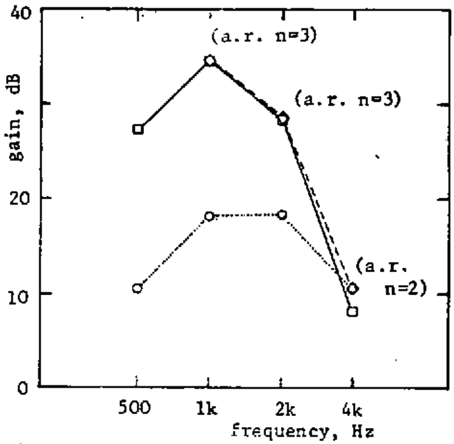

Fig.2 Gain of the BE11 aid; means of all results. (n=number in mean)
◇------◇ acoustic reflex method.
□———□ probe mic. method (n=4).
○·········○ loudness balance method (n=4)

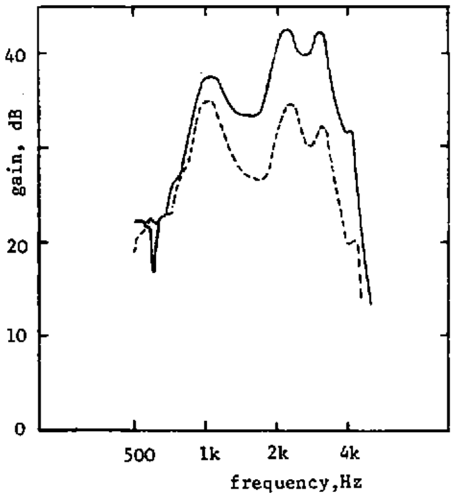

Fig. 3 Response of the aid on the 2cc coupler (broken line) and a Zwislocki-type ear simulator (continuous line)

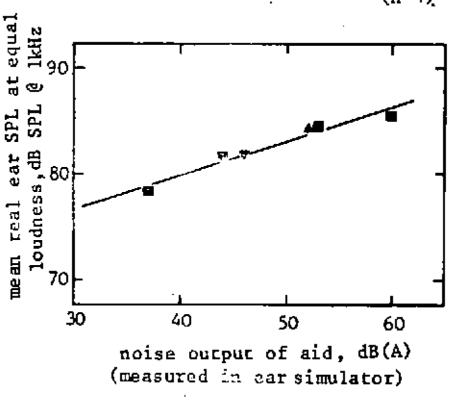

Fig.4 Variation in SPL in the aided ear for a given loudness with circuit noise output levels of hearing aids. Means of six subjects.
■ four BE11's, different gains
▲ Widex 691
▼ Alto "Focus"

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hearing levels below 40-50 dB at 1 kHz. Discrimination of speech at normal levels will not be impaired by circuit noise, but a loudness balance is likely to give erroneously low gain values on these as well as on normally-hearing subjects. An auditory threshold shift method of gain measurement would have these limitations too. The loudness balance method should be reliable when aid circuit noise is completely inaudible to the aid wearer, but this is not proven. The probe microphone and acoustic reflex methods, being unaffected by the noise and both giving essentially the same results are considered reliable. But not everyone will have a detectable reflex and a probe mic. will not fit all earcanals, so neither method will be universally applicable.

An incidental finding of these experiments is that wide-band noise at levels even slightly above threshold, e.g. 10-20 dB(A), may detectably reduce the loudness of 1 kHz tones at 75 or 85 dB SPL. Many reported instances of "Missing 6dB"-type effects may be due to equipment generated noise, therefore. Since it is not widely realised how far-reaching the effect of a little circuit noise can be attention is drawn to this. There was no evidence of any "Missing 6dB" effect here other than that explicable by partial masking.

4. Conclusions.

Measurements of the real ear insertion gain of a hearing aid show that an acoustic reflex method and a probe microphone method give essentially the same results. A loudness balance method can give erroneously low results because of partial masking by hearing aid circuit noise.

5. References.

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Acknowledgement.

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