The use of post-auricular muscle responses

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There are at least three types of sonomotor responses which have received detailed study. The inion response (Bickford *et al.*, 1964; Cody *et al.*, 1964), the short latency vertex and parietal response (Mast, 1963; Goldstein, 1965), and the post-auricular response first reported by Kiang *et al.* (1963), who described it as a variable low-threshold response. Jacobson *et al.* (1964) described some of the basic response properties, and since then various studies have been made to assess the clinical audiometric information which can be obtained from these myogenic potentials.

Yoshie and Okudaira (1969) regarded the use of these responses in the estimation of audiometric threshold to be most promising. They also mentioned the possible application in the diagnosis of audiological and vestibular disorders of the brainstem, but pointed out that a more detailed knowledge of the anatomical pathways involved and the physiological function of the response is required to enable useful clinical application.

Mast (1965) regarded these responses as a combination of both neurogenic and myogenic activity, and Douek *et al.* (1973) raised the question as to whether abnormal results reflect a separation of the neurogenic and myogenic elements. Douek *et al.* (1973) also stressed the importance of recording from both sides simultaneously as the response has a bilateral representation. For this reason they called it the Crossed Acoustic Response (CAR), but with the recording technique used by the present author, the neurogenic brainstem potentials as well as the post-auricular responses are routinely recorded from each side; this results in four additional responses which can have bilateral representation, and so the term post-auricular muscle (PAM) responses will be used as the descriptor of the myogenic component.

Picton *et al.* (1974) reported that the PAM response was highly variable both within and between subjects. Although they presented data recorded from each side separately, it is not clear whether their conclusions are based upon a consideration of the records obtained from one side alone or from a simultaneous assessment of both records.

In this paper the techniques used to obtain the PAM responses are discussed, and data are presented on the use of these responses in the estimation of audiometric thresholds of patients with a wide range of hearing losses.

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Method

Silver-chlorided E.E.G. disc electrodes were used and the active electrodes for the two recording channels were placed at each mastoid process (M_1, M_2) a common reference electrode was placed close to the hairline at the temple—forehead region (F_4) and a forehead electrode (F_z) provided the ground connection. Once the electrodes had been positioned, the patient lay on a bed with his head supported by two pillows in an electromagnetically screened anechoic room. Very young children generally sat on the bed or were held by a parent. No sedation was used and the test procedure was well tolerated by nearly all patients. Click stimuli were delivered by a loudspeaker mounted above the bed, and were presented at a rate of 10 per second. Monaural stimulation was achieved by masking the non-test ear using an insert receiver. A standard subjective threshold for these clicks had previously been determined using normally hearing subjects. Figure 1 shows a general view of the patient and the recording system.

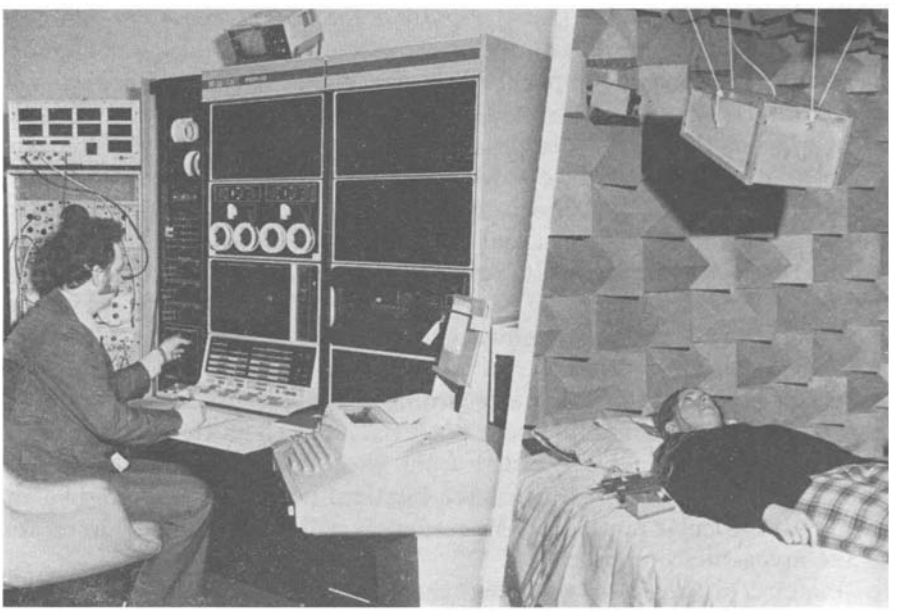


FIG. 1.
General view of the patient and computer recording and analysis system.

In order to derive a clear response waveform from the background electrical activity the usual digital averaging technique, already applied in Electric Response Audiometry (ERA) and Electrocochleography (ECoG), has to be used. If the PAM response alone is being measured, then 200 to 300 stimulus presentations are normally sufficient to obtain

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a clear response. However, the diagnostic inferences which may be derived from the cochlear and brainstem nuclei responses (Thornton, 1975*a* and 1975*b*), make the recording of these potentials of considerable importance. In the clinical situation it is not generally possible to take a series of records derived from the 1000 to 2000 stimulus presentation which are required to obtain clear brainstem response waveforms, and then to repeat the measures using 200 to 300 presentations to obtain the PAM responses. Thus, several of the PAM responses are obtained from the averages of up to 2000 sweeps where both the PAM and brainstem responses have been recorded together. This method, made necessary by the demands of clinical testing, is probably not optimally efficient for the PAM response as the author has some evidence that there is appreciable adaptation of the response over this number of sweeps. In addition, the electrode derivation, used to enable the brainstem responses to be recorded, is not the best possible for the PAM response. This is reflected in the fact that the response amplitudes are less than those reported elsewhere.

Instrumentation

A block diagram of the system is shown in Figure 2. The electrodes are connected to the two preamplifiers which are placed next to the patient. The signals are then passed to the main amplifiers and filters in the control room. Audible monitors produce a warning signal if the input voltage exceeds the maximum level permitted by the computer, and this allows the operator to suspend the averaging process until the waveform has returned to its normal state. The recording bandwidth is from 100 Hz.

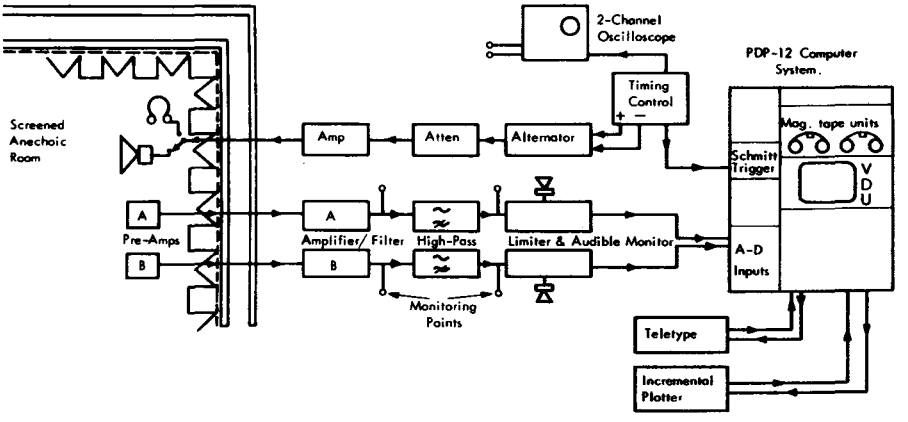


FIG. 2.
Block diagram of the system used for electrocochleography and PAM response measurement.

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to 4 kHz. The signals then pass to the PDP-12 computer which averages a 30 ms. section of each channel separately. When the averaging operation is completed the data, together with information about the acquisition parameters and the patient's identification number, are stored on digital magnetic tape for subsequent measurement and analysis.

A specially designed timing unit controls the computer and produces the electrical pulses for the click stimuli. These are passed to an attenuator and amplifier and finally drive the loudspeaker in the anechoic room. The acoustical click stimulus that arrives at the patient's ear has a main spectral peak, and hence most energy at approximately 2 kHz. Therefore, where audiometric thresholds are compared with PAM estimates of threshold, the audiometric threshold at 2 kHz is used. A microphone, placed at the pinna and in line with the external auditory meatus, was used to record the stimulus, and the response latency was calculated from the time of arrival of the stimulus at the microphone.

Response measurement

Figure 3 shows the PAM response in relation to the VIIIth nerve (N_1) and brainstem nuclei responses (N_2–N_5). This record was obtained with the patient lying relaxed on the bed with his head well back so that there was very little muscle tension, and hence a very small PAM response was

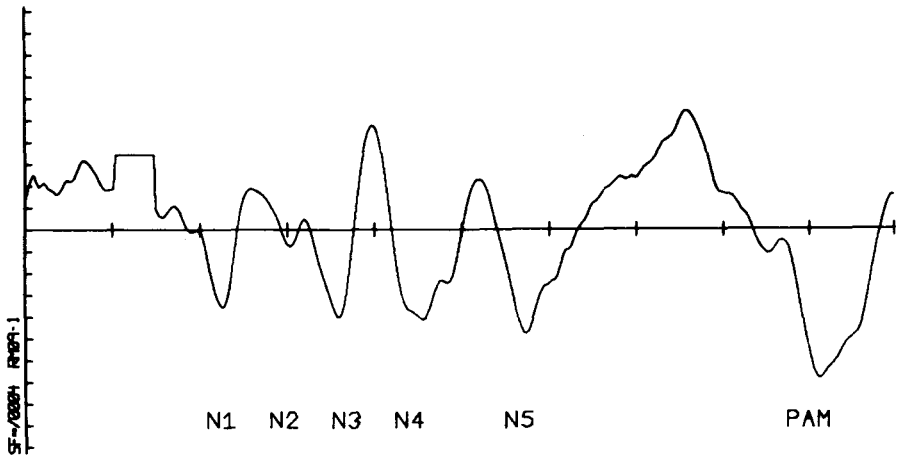


FIG. 3.

The PAM response together with the cochlear (N_1) and brainstem responses (N_2–N_5). The later edge of the inset pulse marks the stimulus position.

generated. When the patient's head is propped forward with pillows, or when the patient is sitting, the PAM response is very much larger than the brainstem responses (Yoshie and Okudaira, 1969). Such a case is illustrated in Figure 4 where, when the data are scaled to suit the PAM

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response, the brainstem potentials cannot be detected. With the recording technique described above a response complex of five peaks is obtained (P_1–P_3). The largest response measure is the N_1–P_2 peak-to-peak amplitude and the response polarity is referred to the mastoid electrode; that is, P_2 reflects a positive potential at the mastoid with respect to the reference electrode. In the data presented by Picton *et al.*, (1974) the polarity is referred to the vertex electrode, and so a positive peak reflects a negative voltage at the mastoid with respect to the vertex electrode, and would

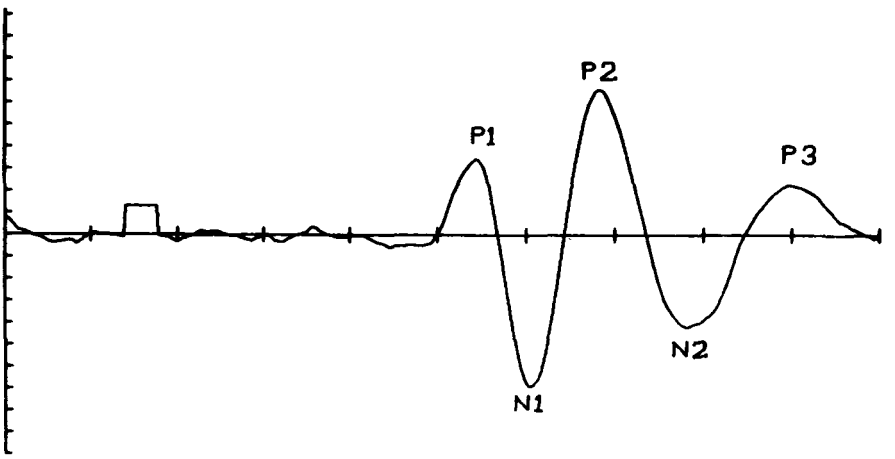


FIG. 4.

A typical PAM response showing the 5 peaks P_1, N_1, P_2, N_2 and P_3. The peak-to-peak amplitude is measured from the N_1–P_2 peaks.

correspond to a negative peak as shown in Figure 4. The P_1 peak of Figure 4 has a latency of approximately 11 ms. and corresponds to the 9 ms. N_0 peak of Picton. The N_1 peak at 12·5 ms. agrees with the 12 ms. component of Picton and with the findings of nearly all published data. The P_2 peak at 15 ms. latency corresponds to Picton's N_a peak at 16 ms., but the N_2 and P_3 components arrive before the next peak reported by Picton which occurs at 25 ms. Taking into account the difference in electrode derivations and stimulus intensities, the P_1, N_1, and P_2 peaks are in reasonable agreement with Picton's data. Other authors (Mendel and Goldstein, 1969; Douek *et al.*, 1973) have reported only a negative peak at about 13 ms. followed by a positive peak at 24 ms., and Yoshie and Okudaira (1969) obtained negative peaks at about 12 ms. and 21 ms. with a positive peak at 16 ms. These discrepancies seem too large to be accounted for by differences in electrode derivation and stimulus level, but may well be due to the different recording bandwidths used. Table I summarizes the latencies of the different components obtained with different bandwidths. There is good agreement on the latency of the first

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TABLE I

PAM COMPONENTS OBTAINED WITH DIFFERENT BANDWIDTHS

Author	Bandwidth Hz.	Latency ms.			
		N_1	P_2	N_2	P_3
Mendel and Goldstein (1969)	100	13	–	–	23
Douek *et al.* (1974)	200	14	–	–	25
Yoshie and Okudaira (1969)	500	12	16	21	–
Picton *et al.* (1974)	2,500	12	16	25	36
Thornton (this study)	3,900	12·5	15	18	22

negative wave, and for bandwidths less than 500 Hz., the next positive peak occurs at 23 to 25 ms. Where the bandwidth is 500 Hz. or greater there is again good agreement that the next positive wave occurs at 15 to 16 ms. with a second negative wave at 18 to 25 ms.

The effect of different bandwidths is illustrated in Figure 5 where the PAM waveform has been digitally filtered at various cut-off frequencies. Digital filtering can be performed by taking the Fourier transform of a waveform, removing from the transform all frequency components above the desired cut-off frequency, and then resynthesizing a new waveform from the modified Fourier transform. In Figure 5 trace (A) shows a PAM waveform obtained in this study, trace (B) is the resynthesis of that waveform without any filtering applied, and serves to illustrate the accuracy of the procedure. The main positive peak in trace (B) is at 15 ms. latency. Traces (C) and (D) are the waveforms obtained by low-pass filtering at 500 Hz. and 300 Hz. respectively, and the latency of the main positive peak is now 22 ms. (Trace C) or 24·5 ms. (Trace D).

Thus it would appear that the bandwidth of the recording system will determine, to a great extent, the exact waveform of the response. With the wider bandwidths five peaks are present in the response, whereas two peaks are recorded with the narrower bandwidths. The data presented in the following sections were all obtained with a passband from 100 Hz. to 4,000 Hz., and the peak-to-peak amplitude measures were derived from the N_1–P_2 peaks.

As a reference electrode which is close to the temporalis muscle had been used, there is the possibility that the response waveform is comprised of a PAM response with negative and positive peaks at 12 ms. and 16 ms. respectively (Picton *et al.*, 1974), and a temporalis muscle response with negative and positive peaks at 17 ms. and 23 ms. (Picton *et al.*, 1974). To test this possibility several recordings were made using a reference electrode at the vertex. No differences were found in the wave-

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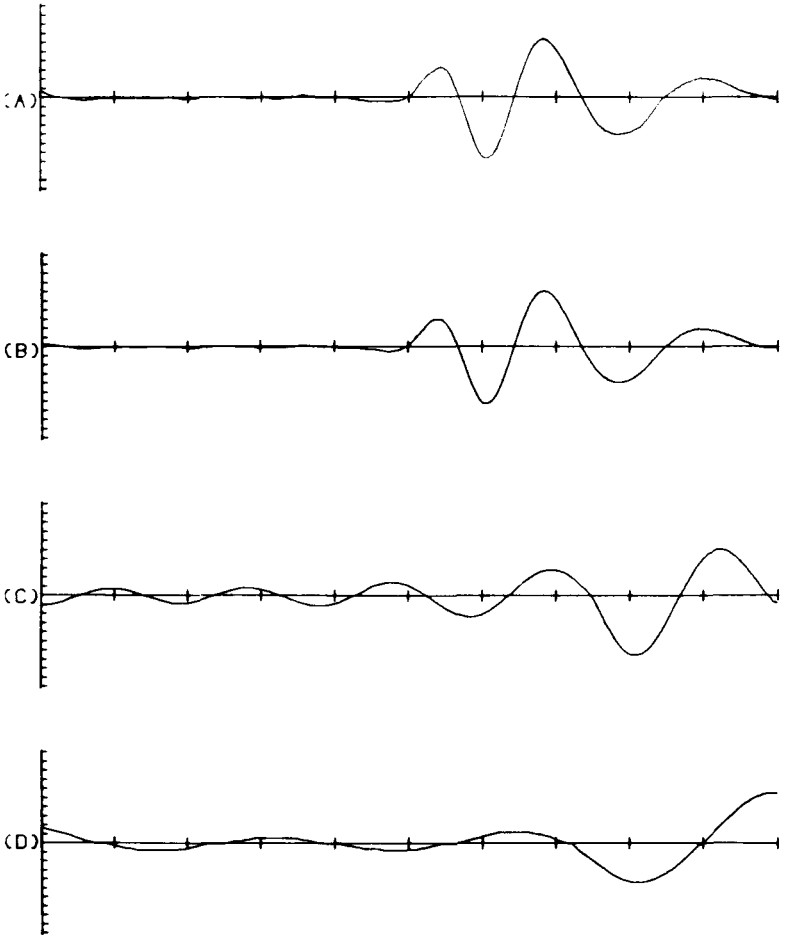


FIG. 5.

The effects of digitally filtering a PAM response.
(A) Original response waveform.
(B) Obtained by resynthesis without filtering.
(C) Obtained by resynthesis after using a 500 Hz. cut-off.
(D) Obtained by resynthesis after using a 300 Hz. cut-off.

shape, the latencies of the peaks, nor in the relative amplitudes of the first and second pair of peaks, and so this possibility was discounted.

Because the response amplitude is dependent upon muscle tension which may vary if the patient moves his head, and as the response has a bilateral representation, it is important to record from both mastoids simultaneously. Further, if the average of these two responses is used to provide the measured values, there will be a degree of protection against the effects of head movement. This procedure was used to obtain the data values presented here.

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Results

Twenty sets of records were obtained from patients with hearing levels ranging from *−10 dB. to 75* dB., for whom there were reliable audiometric measurements of threshold. These patients had cochlear lesions (generally with greater hearing losses) and central lesions (generally with normal hearing or small losses). The PAM responses were normally recorded for 10 dB. steps of stimuli level, and four responses, taken from a set of records, are shown in Figure 6. In order to cover the range 10 to

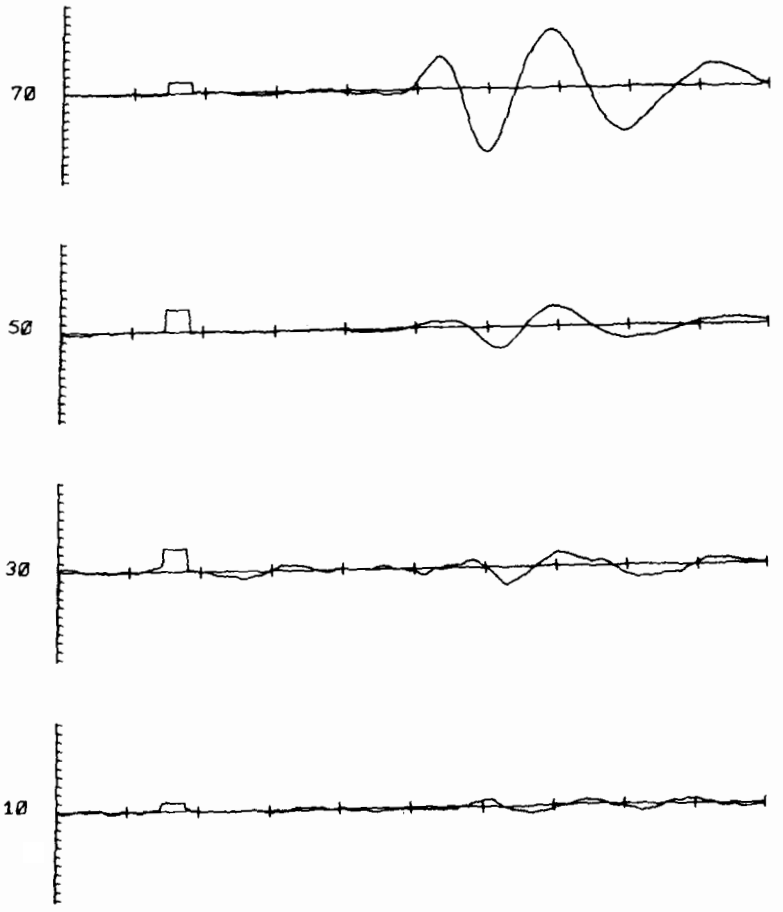


FIG. 6.
Changes in the PAM response with stimulus level.

70 dB. these records are shown at 20 dB. steps. As the stimulus level is decreased the classical pattern of increasing latency and decreasing response amplitude can be clearly seen. A complete amplitude input-

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output function of response amplitude by stimulus level is shown in Figure 7. The stimulus level is in dB. above the threshold for normally hearing subjects for the click signal. The patient's audiometric threshold at 2 kHz. is also marked for comparison. At stimulus levels which are near threshold the function has a section of small slope which changes to a much steeper section as the stimulus level is increased. The input-output functions for a patient with a more severe hearing loss are shown

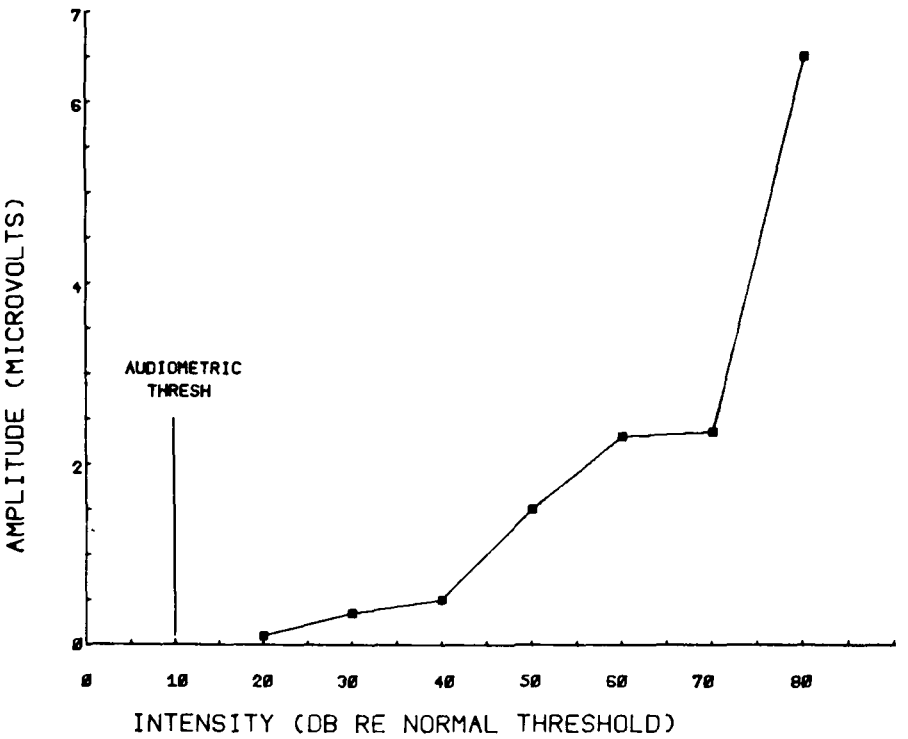


FIG. 7.

The PAM input-output function for a patient with a 10 dB. hearing loss at 2 kHz. The intensity axis is in dB. re normal threshold for the click stimulus.

in Figure 8. Again the audiometric thresholds for left and right ears have been compared with the appropriate response functions. Here the curves are very much steeper and do not show the distinct low and high slope sections shown in Figure 7. It was generally found that the input-output functions obtained from patients with hearing losses that were less than 50 dB. showed the two low and high slope sections, whereas those obtained from patients with greater losses tended to be composed only of a steeply sloping curve.

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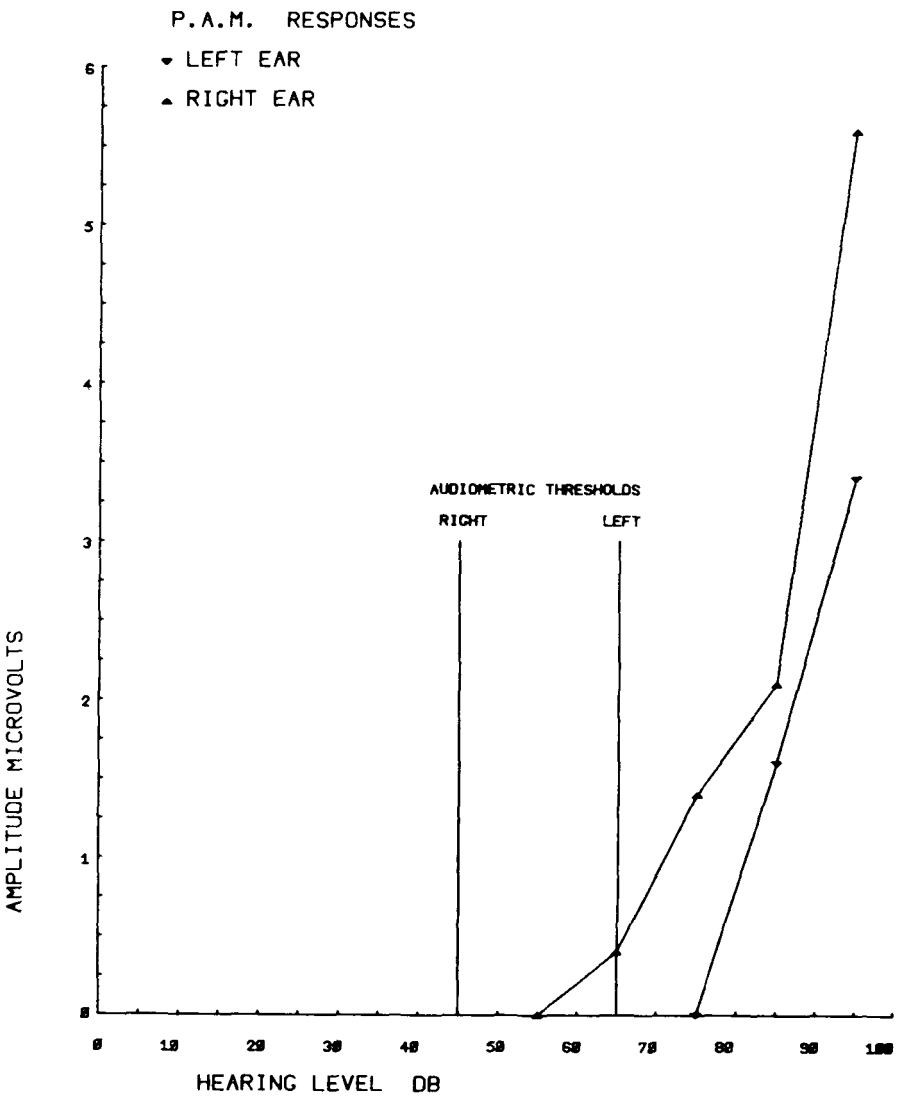


FIG. 8.

The PAM input-output functions for a patient with a loss at 2 kHz. of 45 dB. on the right side and 65 dB. on the left side. The intensity axis is in dB. re normal threshold for the click stimulus.

From comparisons of the results for patients with similar hearing losses and pathologies the observation of Picton *et al.* (1974) that there is large variability between subjects in the response amplitude appears to be confirmed.

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Threshold estimation

The PAM threshold was defined as the lowest level at which a response could be measured. The PAM threshold estimates are plotted against the audiometric 2 kHz. threshold measurements in Figure 9. The relationship between PAM and audiometric thresholds appears to be reasonably

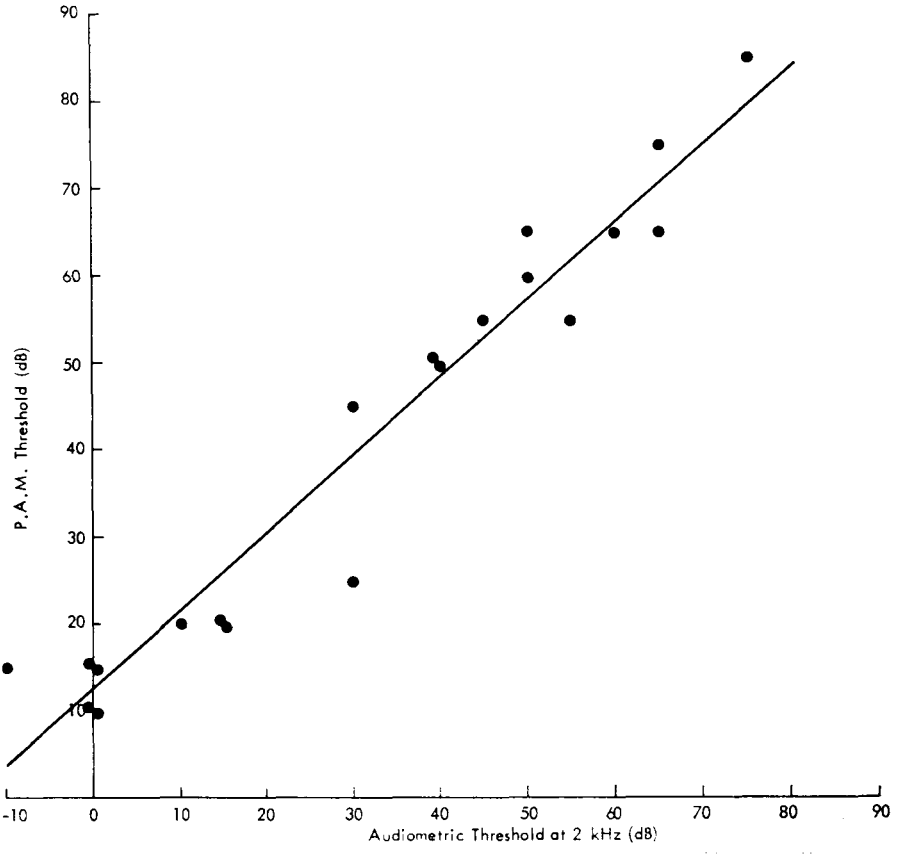


FIG. 9.

PAM threshold estimates by audiometric thresholds, together with the fitted regression line.

linear, and to quantify this a regression line was calculated and is also shown in Figure 9. The line was a very good fit to the data points and accounted for 94 per cent of the measured variance. The slope of the line was 0·9 (42 °). The accuracy of PAM threshold estimates may be evaluated by computing the histogram of the difference between the PAM threshold and the audiometric threshold. This histogram is shown in Figure 10, and the mean difference between the two thresholds was 9 dB. with a 7 dB. standard deviation. The accuracy of the PAM estimate may, of course,

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depend upon the amount of hearing loss involved. Thus, the PAM-audiometric differences were plotted by the audiometric value of hearing loss, and these data are shown in Figure 11. With the results available there is no indication of any trend and the accuracy of the PAM threshold estimate appears to be independent of the amount of hearing loss.

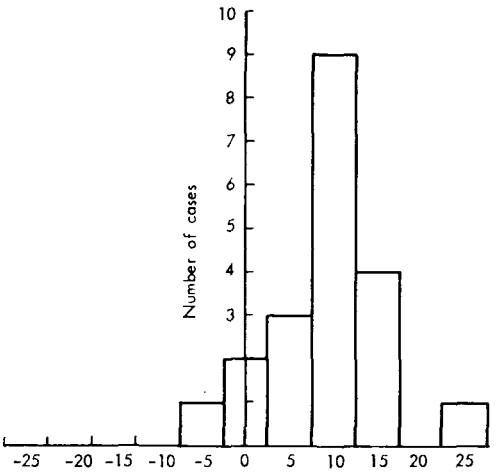


FIG. 10.
Histogram of the distribution of PAM threshold estimates minus the corresponding audiometric thresholds. The mean difference is 9 dB. with a 7 dB. standard deviation.

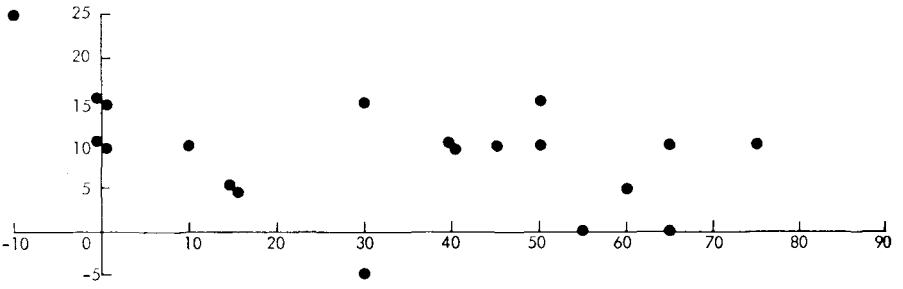


FIG. 11.
PAM-audiometric threshold differences plotted against the audiometric thresholds.

Conclusions

With the technique described here the PAM response can be obtained without difficulty. The exact measurement technique, and in particular the recording bandwidth used, is obviously a major factor in the determination of the response waveform. It would appear that, in order to obtain the full set of response peaks, a bandwidth greater than 1,000 Hz.

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should be used. Although the use of the PAM response in threshold estimation has been discussed since 1967, there have been very few quantitative data about the accuracy and properties of such an estimation. Although the data given here comprise only 20 results, nevertheless some preliminary conclusions may be made.

The response amplitude is very variable between subjects, but the threshold estimates taken from the input-output function curves give results which are reasonably consistent. The mean PAM threshold-audiometric threshold difference was 9 dB. with only a 7 dB. standard deviation. This accuracy is comparable with that achieved by conventional audiometry and by cortical evoked response audiometry.

However, it should be noted that the PAM estimates were derived using 10 dB. steps and the audiometric thresholds used 5 dB. steps, and that a sample of twenty results may not adequately predict the accuracy that would be obtained with a larger sample. The comparatively large variability of response amplitudes at supra-threshold levels contrasts with the low variability of the threshold estimates. It has already been postulated that the response might comprise myogenic and neurogenic elements. The neurogenic element could be the end-plate potential or the electrotonic spread of the end-plate potential over the muscle surface at a level that is too low to elicit a contraction. Thus, at high levels of stimulation a predominantly myogenic and variable response may be recorded, whereas, at levels close to threshold, a predominantly neurogenic and more stable response could be obtained.

Further, it would appear that there is a good linear relationship between the PAM and audiometric thresholds, and that the accuracy of the PAM estimate does not depend upon the amount of hearing loss present.

Thus, these results provide sufficient reason, at this time, for a guarded clinical application of the PAM responses as a threshold estimator.

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