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(*Founded in* 1887 *by* MORELL MACKENZIE *and* NORRIS WOLFENDEN)

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Electrocochleography

By ROBIN HOOPER (New York)

RECENT advances in electronic instrumentation and computer technology now enable us to measure relatively easily cochlear potentials to acoustic stimuli. These potentials are made up of cochlear and neural responses. The cochlear microphonic (CM), a potential originating in the hair cells of the organ of Corti, closely follows the characteristics of the stimulus. The eighth nerve action potential (AP) represents the sum of all the units of the cochlear division of the eighth nerve. (The summating potential, a DC response, which is thought to arise from the inner hair cells is not recorded by the technique to be described.)

Determination of the threshold response of these peripheral electrical potentials to acoustic stimulation will, therefore, give us an objective audiometric threshold.

This is a preliminary report in which an attempt is made to establish a baseline of the threshold response of the action potential to acoustic clicks in volunteers with normal hearing and in subjects with sensorineural deafness.

Background

There are two main components recordable from the round window of the inner ear. They are the cochlear microphonic originally recorded by Wever and Bray in 1930 and the action potential of the eighth nerve reported by Derbyshire and Davis in 1935. The cochlear potential in man was first detected with the aid of headphones by Fromm, Nylén and Zotterman in 1935. Andreev, Arapova and Gersuni, in 1939 measured and

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observed human cochlear microphonics on the oscilloscope in man. Lempert, Meltzer, Wever and Lawrence were able to obtain responses to sound in about one-half of patients in whom they attempted to record cochlear potentials.

Cochlear microphonics were studied in much greater detail by Ruben *et al.* (1959, 1960, 1962, 1969) using a wave analyzer. They were performed by measuring the potentials received by an electrode placed on the round window membrane. These studies were performed in the operating room when the electrode was placed on the round window via permeatal tympanotomy. The emphasis was on the diagnostic potential of these recordings. Ronis (1966), using an average response computer which enabled him to look at the summed response to repetitive acoustic stimuli, reported how human cochlear potentials could be used as an indication for surgical success in patients undergoing stapes surgery for otosclerosis. Finck, Ronis and Rosenberg (1969) also stated that the cochlear microphonic response taken in the operating room favourably predicated the audiogram taken in the clinic.

Yoshie and Yamaura (1969) developed a non-surgical method of recording the cochlear microphonic (CM) by placing a needle electrode in the external auditory canal using both continuous pure tones or short bursts of pure tone. Abnormal patterns were obtained in patients with severe sensorineural loss: they showed (1) a reduction in the magnitude of the cochlear microphonic response; (2) distortion in the form of the intensity function (non-linear relation); and (3) a parallel shift of intensity function to the right side (reduced sensitivity). They stated that the sensitivity of the cochlear microphonic seemed to have some relation to the degree of hearing loss in the audiogram. Yoshie *et al.* (1967, 1968) also demonstrated that the changes in amplitude and latency of the first peak (N_1) of the action potential (AP) was a function of click intensity. The latency increases with decreasing sensation levels of the click, whereas the amplitude of the N_1 response decreases. Sohmer and Feinmesser (1967) and Salomon and Elberling (1971) also measured amplitude and latency to repetitive acoustic clicks from an electrode placed on the ear lobe and in the external auditory canal respectively.

We have been recording the electrical activity of the peripheral response by placement of an electrode transtympanically onto the promontory (Aran *et al*, 1968). Responses obtained from elsewhere such as the external auditory canal have only about one-tenth the amplitude. The more distal electrode placement may be satisfactory in patients with near normal hearing or in the conductively deaf. However, we agree with Aran that in very deaf patients, even with averaging techniques, it is necessary to be as near as possible to the generator of the potential as the aim of this research is to develop a technique which can be used clinically to assess objectively a patient's peripheral hearing.

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One of the most important aspects of this procedure will be the application of this technique as a routine clinical investigation to assess the hearing in young children with communicative disorders. Aran (1971) reported results in twenty-nine children (from 1 month to 6 years of age) who had specific hearing impairments or more general disorders in which a hearing deficit was suspected. Twenty cases showed thresholds at varying levels ranging from 0–90 dB (HL). In nine cases no response could be obtained even to a click of 100 dB. All these children had shown absolute or near absolute deafness by classical audiometry. Sohmer *et al.* (1972) tested thirty-one children of ages ranging from 4 months to 31 months using an ear lobe-vertex electrode placement. He described one case of a child who had profound behavioural hearing losses who had apparently normal neural responses on electrocochleography. It was thought that the absence of behavioural response was due to the child's retardation and not to any peripheral auditory lesion.

Procedure

The patient lies on a bed in a sound-proof room. Cotton-wool impregnated with xylocaine jelly is placed, with small forceps, on the tympanic membrane of the ear which is to be tested. Skin electrodes, similar to those used in electroencephalography, are placed on the centre of the forehead (earth) and on the lobe of the ear which is to be tested (indifferent). The resistance of the skin electrodes is checked so that the resistance between the skin electrodes is less than 10,000 ohms.

A 'donut' (Fig. 1) is placed around the pinna of the ear and a plastic aural speculum is inserted into the external auditory canal. The xylocaine-soaked cotton-wool is removed. A fine teflon-coated electrode, 4 inches long and insulated to within 0·5 mm. of the tip, is inserted through the tympanic membrane between the umbo and the annulus at 7 o'clock. It is held in place by a taut rubber band which passes over its forked distal end and is attached to the 'donut'. This ensures that the end of the electrode sits firmly on the promontory with an even pressure.

The electrode leads are plugged into an FET differential probe which leads through two Tektronix 122 pre-amplifiers (bandpass setting set at 8 Hz to 10k. Hz. Total gain of recording system 100,000) and then into a CAT 1000 computer (Fig. 2). The analysis time was 32 m./sec., sample interval 0·03125 m./sec.

The acoustic click comes from a Tektronix 161 pulse generator which is fired by a Tektronix 162 wave form generator which also triggers the computer. The usual width of the click is 0·1 m./sec. or 0·5 m./sec. and the rate of stimulation is most frequently 10 per second. Stimulus pulses are taken from the function generator and fed into a Macintosh 75 audio amplifier through a Hewlett Packard 350D attenuator and then into an

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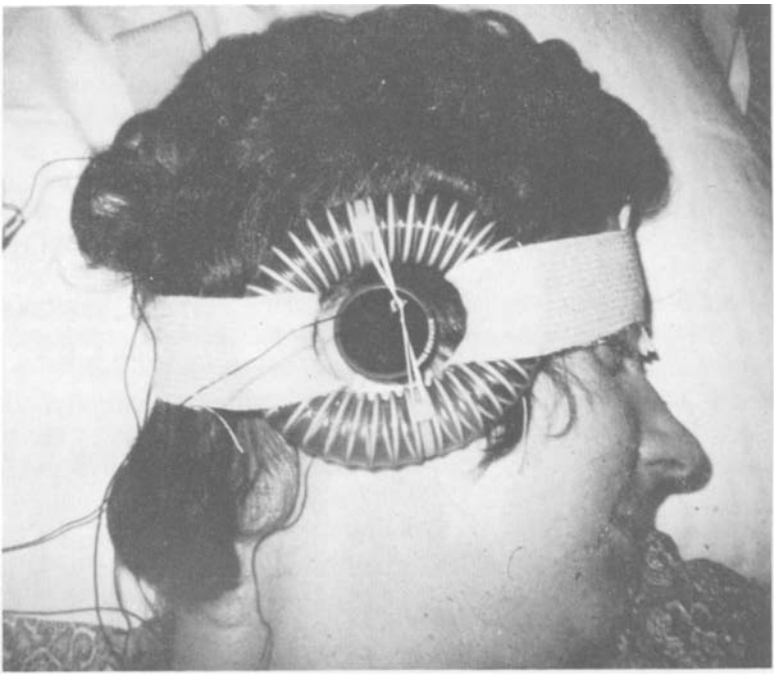


FIG. 1.
'Donut' and rubber band holding electrode in position.

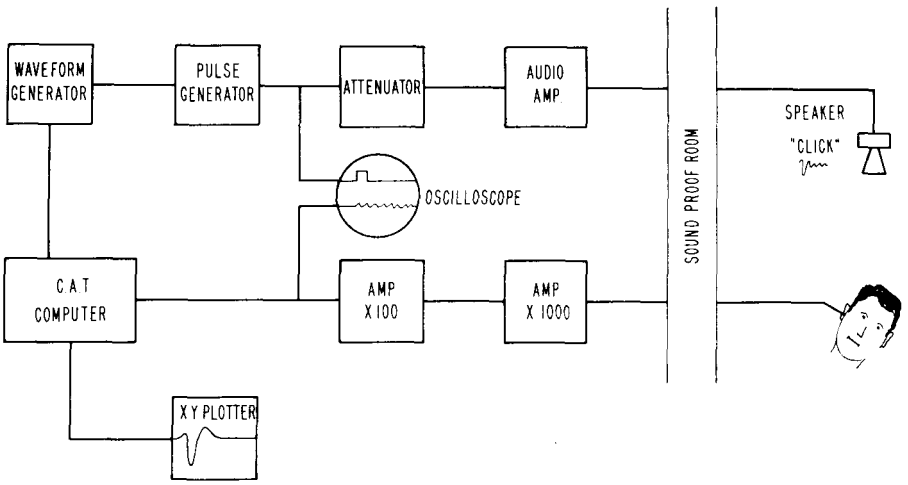


FIG. 2.
Schematic diagram of apparatus.

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IAC sound treated chamber to a University Sound 1D-60 driver speaker which is placed 60 cm. from the pinna of the ear being tested.

The clicks are calibrated with a Bruel & Kjaer 4132 condenser microphone which is placed at a distance of 60 cm. Sound pressure levels are read in dB (above 0·0002 dyne cm^2) using a Bruel & Kjaer microphone amplifier.

The subject is stimulated with 1000 clicks of 0·1 m./sec. or 0·5 m./sec. duration at 10 per second, made up of 500 rarefaction and 500 condensation clicks. The resulting summed response from these clicks cancels the microphonic response so that only the summed action potential is recorded. This response is written out on an XY recorder. This procedure is repeated at decreasing increments of 10–15 dB from a maximum of 90 dB down to a minimum measurable threshold (Fig. 3). The threshold is compared to the average pure tone threshold (i.e. the average of the 500, 1000 and 2000 Hz thresholds re 1 SO norms), the average of the 2000, 4000 and 8000 Hz pure tone thresholds and the speech reception threshold.

The latency of the response and the amplitude of the response is measured and charted as in Figure 4. The amplitude of the response is expressed as a percentage of the maximum amplitude.

Results

Comparison of AP threshold response with clinical audiometry

1. Six normal ears
   All six subjects in this category had a pure tone average of 25 dB or less, and a speech reception threshold of 25 dB or less. All had nearly 100 per cent speech discrimination. The minimum measurable AP to the acoustic stimulus occurred at 25, 30, 25, 30, 25 and 30 dB SPL. The average threshold response for the AP therefore was 27·5 dB compared to 6 dB for the average pure tone threshold of 500 Hz, 1000 Hz and 2000 Hz; 6·5 dB for the average of the 2000 Hz, 4000 Hz and 8000 Hz pure tone thresholds; and 12·5 dB for the average speech reception threshold. A more detailed tabulation of results can be seen in Table I.

2. Six abnormal ears
   The six subjects in this category had hearing deficits ranging from 15 to 40 dB on pure tone audiometry and speech reception thresholds ranging from 15 to 45 dB. Their threshold AP responses were obtained at 40, 60, 50, 50, 50 and 45 dB SPL. The average pure tone threshold of 500 Hz, 1000 Hz and 2000 Hz was 35 dB; the average pure tone threshold of the 2000 Hz, 4000 Hz and 8000 Hz was 52 dB; and the speech reception threshold was 35 dB. More detailed analysis of the results can be seen in Table I.

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The minimum measurable AP responses in all twelve ears (both normal and abnormal) were, therefore, obtained at an average of 18 dB

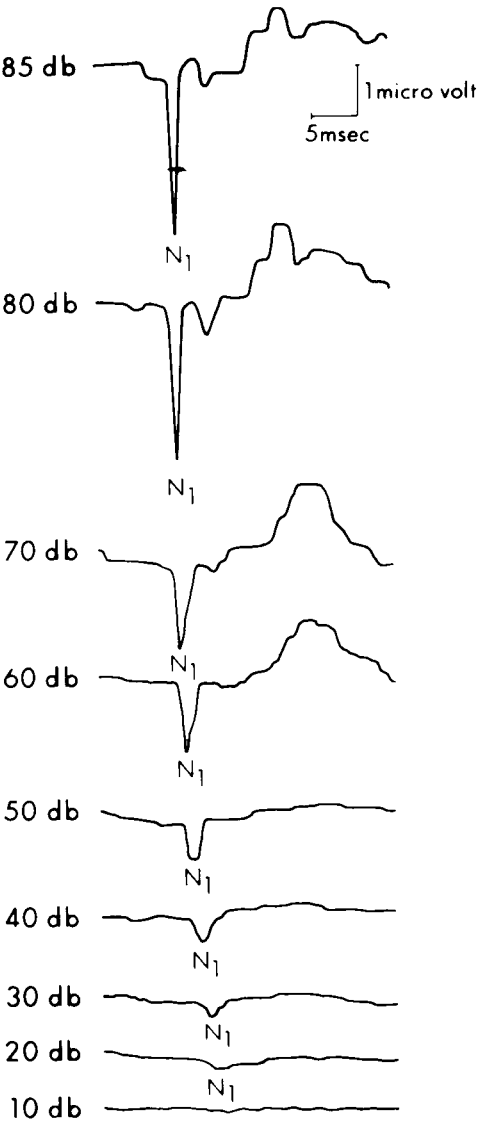


FIG. 3.
Tracings of Action Potential (AP) in a normal subject.

above the average pure tone threshold (500 Hz, 1000 Hz and 2000 Hz); 9 dB above average of the 2000 Hz, 4000 Hz and 8000 Hz pure tone thresholds; and 14 dB above the speech reception threshold.

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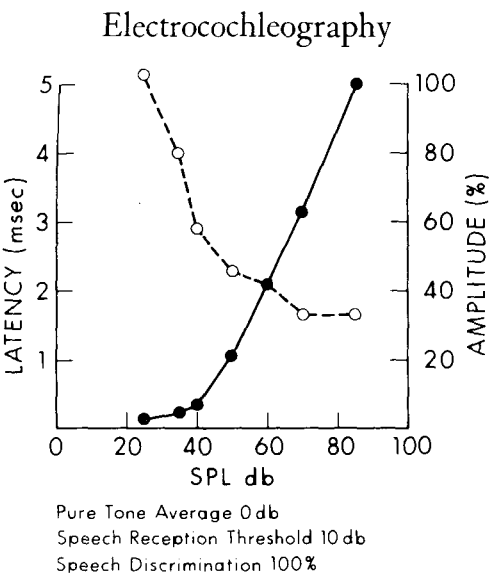


FIG. 4.
Chart of intensity-amplitude of response and latency in a normal subject.

TABLE I.
TABLE SHOWING COMPARISON OF THRESHOLDS

	Threshold for AP response (dB SPL)	Pure tone average of 500 Hz, 1000 Hz and 2000 Hz thresholds (dB HL)	Pure tone average of 2000 Hz, 4000 Hz and 8000 Hz thresholds (dB HL)	Speech reception threshold (dB HL)
Normal ears ..	25	0	5	10
	30	5	5	10
	25	5	5	10
	30	5	5	10
	25	5	5	10
	30	15	25	25
Abnormal ears ..	50	40	60	40
	50	40	55	40
	45	15	50	15
	50	45	50	45
	60	40	40	40
	40	30	60	30

Latency of AP responses

The latency of the AP response was measured from the time of the stimulus reaching the external auditory canal to the point of maximum deflection of the N_1 (Fig. 5). The point of maximum deflection was chosen rather than the beginning of the response because at low stimulus intensities it is difficult to pin-point accurately the start of the AP because of the broadness of the response.

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The average latency at maximum stimulus intensity for normal and abnormal ears was 1·3 and 1·5 m./sec. respectively. The average latency in normals at threshold SPL was much longer (5·3 m./sec.) compared to the abnormals (3·2 m./sec.).

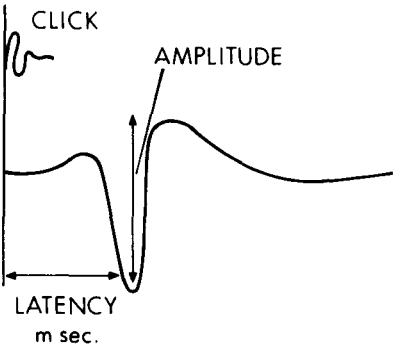


FIG. 5.
Measurement of latency.

Discussion

These results show that the thresholds of these potentials is higher in patients with hearing loss than in subjects with normal hearing. The expected prolonged latency of the threshold response in the normal hearing population was confirmed. The purpose of this pilot study, however, was to try to establish a baseline for our technique by comparing the threshold responses with known clinical audiometric thresholds. These comparisons have been referred to by several writers but not documented as far as we can establish on review of the literature to date. If this technique is to be of value in establishing the hearing level in non-communicative patients, the sensitivity and consistency of the threshold response should be determined. We would hope when we have more patients to determine the standard deviation of the threshold responses from the clinical audiometric thresholds.

We do recognize that there is a theoretical difficulty in relating the action potential (AP) response to 'a click', to specific tonotopic areas on the basilar membrane of the cochlea. Even filtered clicks representing different frequency bands may still represent only the gross response of the eighth nerve to an acoustic stimulus. The maximum power of our gross click was around 2000 Hz.

Summary

The physiological action potential (AP) thresholds were compared to the behavioural pure tone thresholds. These physiological thresholds measured by the technique described were 10–20 dB higher than the

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behavioural thresholds. The physiological (AP) thresholds were closer to the average thresholds of 2000 Hz, 4000 Hz and 8000 Hz than to the average of 500 Hz, 1000 Hz and 2000 Hz. This is consistent with the generally accepted view that the bulk of the fibres making up the gross click AP come from the basal portion of the basilar membrane (i.e. that part of the basilar membrane subserving perception of frequencies above 3000 Hz).

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Department of Otorhinolaryngology,
The Albert Einstein College of Medicine,
1300 Morris Park Avenue,
Bronx, New York 10461.

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