Electrocochleography

By Michel Portmann (Bordeaux)

Electrophysiological techniques have assumed considerable importance in clinical audiology during the last ten years.

It is now feasible in man to record the different electrical potentials produced by activity of the auditory sensorineural pathways, from the organ of Corti peripherally to the auditory cortex centrally.

When the ear is stimulated by a sound of very brief duration, such as a click, a succession of electrical phenomena is produced representing the activation of the cochlea and the conduction of the message right to the temporal cortex. These phenomena are:

— at the instant of the stimulus, the microphonic and summation potential originating from the cochlea itself;

— from 1 to 6 millisecs later the action potential of the nerve indicates the activity of the auditory nerve itself (VIIIth cranial nerve);

— from 2 to 10 millisecs a series of potentials signalling the arrival of the message at the pons and its passage along the brain stem;

— from 30 to 100 or more millisecs the wave pattern represents the activity of the higher centres and of the cortex.

All the techniques suitable for recording these various potentials are based on the same principles:

— *Synchronization* of the nervous activity of the various units making up the auditory pathways by the use of the shortest possible stimulus.

— *Recording* of the electrical activity of these units by means of appropriately placed electrodes.

— *Elimination* of the electrical and bio-electrical background noise, which obscures the response specific to each stimulus, by the summation of the responses produced by a series of repeated identical stimuli. This process is made possible by the ability of averagers and computers to memorize and average the electrical messages received. The first step in all levels of research is the recording, measuring, analysis and clinical interpretation of the response received.

Unfortunately it is not yet possible to study clinically these electrical events along the auditory nervous pathways for a single stimulus. The necessary equipment is too complex and its various parts are too different

https://doi.org/10.1017/S0022215100084218 Published online by Cambridge University Press

from each other, mainly because of the great time span involved. This must extend from only a few milliseconds to record the electrocochleogram, to several hundred milliseconds to study the central phenomena.

At the present time, the following techniques are in use in electrophysiology:

— *Electrocochleography* (from 0 to 5 millisecs) recorded by a transtympanic electrode (the technique of J. M. Aran) in contact with the cochlea.

— *Early electrical phenomena* (from 0 to 15 millisecs) studied by means of surface electrodes and arising not only from the periphery, but also from the brain stem.

— *Evoked response audiometry* (ERA) recorded from the brain from 30 to 100 or even 150 and more milliseconds.

— Lastly, study of the expectance waves produced centrally ('D.C. Responses', 'continuous polarization' or 'contingent negative variation').

In our own clinic for the last ten years we have been studying the electrocochleogram using the technique of J. M. Aran. In human clinical work the best method is the one which is most practical. In the case of electrocochleography, the method fulfils these criteria, because the active electrode, being placed on the promontory, is as close as possible to the sensori-neural structures which are under study.

I. Examination procedure

Electrocochleography is a test which notes, records, and measures the averaged electrical responses which are set up between the bony promontory of the cochlea and the lobe of the ear in response to very short acoustic stimuli (clicks, filtered clicks, and tone bursts).

The examination is carried out in a cubicle insulated for sound and electrical activity.

The stimulus

The sound-producing equipment comprises an impulse generator; an inverter (which converts the positive impulses from the generator into alternating positive and negative impulses); a filter (for the filtered clicks); an attenuator; and an amplifier.

The signal is then sent to the loudspeaker in the insulated cubicle. The click is produced by a rectangular impulse of 0·1 ms duration, and alternately of positive and negative phase.

The filtered clicks are obtained by filtering this rectangular impulse in the passive filter, which is adjusted to the following frequencies: 300, 600, 1,200, 2,400, 4,800 and 9,600 Hz.

https://doi.org/10.1017/S0022215100084218 Published online by Cambridge University Press

The sound levels are measured in turn for each stimulus (clicks and filtered clicks) in decibels above the level which corresponds to the average threshold for these different sounds in normal subjects, the loudspeaker being placed laterally at 70 cm from the ear (dB H.L.: Hearing level) (0 dB H.L. corresponds, for the click, to a peak sound pressure level of 25 dB above 0·0002 dynes/cm²).

Electrodes and accessories

We use a system with three electrodes: *the active electrode* is a fine stainless steel needle 5 cm long and 0·2 mm in diameter, whose point has been sharpened by electrolysis in acid. It is varnished along its whole length except for the two ends: at the point it is unvarnished for $\frac{1}{2}$ mm, while the other end, which is broadened, is unvarnished over 1 cm. This end is plugged into the electrode-holder, which in turn connects it to the preamplifier; and the indifferent and earth electrodes are discs of silver chloride (as used in the EEG). The indifferent electrode is placed in contact with the lobe of the ear, while the earth is connected to the forehead. Electrode jelly is used to make the connection between the electrode and the skin.

Accessories. In order to hold the active electrode and to keep it in place, we use a plastic ring, 10 cm in diameter, which is maintained in position around the ear by a strap. The speculum can be attached to this plastic ring by adhesive tape; by means of its hooks, the ring also holds an elastic band which maintains tension on the electrode-holder.

The electrode-holder is a tube 3 cm long, and of an internal diameter slightly greater than that of the tip of the electrode which can then be passed through it. It is provided with a terminal, and ends in a neck through which passes the elastic band, which thus maintains light pressure on the electrode and keeps it in contact with the promontory.

Amplification

The signal picked up by the electrodes is amplified in a preamplifier with a gain of 1,000 (50 MΩ impedance, band width 1 Hz to 30 Hz) placed near the patient. Then it is amplified again in a second amplifier ($\times$ 10), visualized on an oscilloscope (double tracing), and then recorded into the averaging computer.

The averaging computer

The averaging computer we use is a 'wave form eductor' model TDH 9, from Princeton Applied Research. This is an analogical computer comprising 100 memory points on condensers. The analysis time can be preset between 100 milliseconds (1 point per microsecond) and 10 seconds (1 point per 0·1 second). It is thus equally suited to recording rapid changes and slow changes (like the cortical responses). The length of analysis

https://doi.org/10.1017/S0022215100084218 Published online by Cambridge University Press

chosen is 10 milliseconds (1 point per 0·1 ms). The analysis is set in motion one millisecond before the acoustic stimulus reaches the ear (allowance must be made for the interval between the arrival of the impulse at the loudspeaker and the arrival of the click at the ear; as the distance is 70 cm, this means an interval of the order of 2 milliseconds due to the time taken by the sound wave).

The computer and the (sweeping) oscilloscope are regulated by a synchronizing impulse from the impulse generator.

The output of the computer is monitored on the second oscillograph tracing. In this way the signal entering the computer (as it leaves the amplifiers) and the averaged signal as it leaves the computer can be observed simultaneously. The averaged response can be equally well recorded on a slow-speed tracing on paper.

Technique of examination

The patient lies on an examining couch in the sound-insulated cubicle.

Positioning the electrodes

In the adult and the child over eight years of age, the tympanic membrane is anesthetized locally with xylocaine gel, which is left in place for 10 minutes. The tympanic membrane has a frosted appearance following this. The electrode is held in angled forceps and, under binocular control, is lowered and made to pierce the tympanic membrane at a point half-way along a line joining the umbo to the sulcus at eight o'clock (in a right ear). The elastic band is then positioned on the electrode-carrier.

In the infant—general anaesthesia

In the infant and baby, the test is carried out under light general anaesthesia. The anaesthetic agent which we use can be given by the intramuscular or intravenous routes, and is called Ketamine. This promotes a subcortical dissociation with analgesic effects, and results in narcosis with analgesia which comes on in three to five minutes when given by intramuscular injection. Premedication with an atropine-like drug is required, as some non-premedicated children have been shown to have had cholinergic reactions.

This anaesthetic agent has the advantage of not depressing the cardiovascular or respiratory centres; it is, therefore, easily administered, and the child does not need to be intubated. As soon as the anaesthetic allows, the electrodes are positioned; the obliquity of the tympanic membrane in the very young child does not give rise to any difficulty.

The method of recording

Having placed the loudspeaker at 70 cm from the ear, and connected up the electrodes, the operator can see the signal on the oscilloscope. If

https://doi.org/10.1017/S0022215100084218 Published online by Cambridge University Press

the background noise is steady, of 20 μV amplitude (which corresponds to a level on the oscilloscope of 200 mV, a total gain of 10,000), without mains interference, and free from sudden fluctuations, the electrode contact is then satisfactory, and recording can commence. The clicks are produced at the rate of 10 per second for one and a half minutes (a total of 900 recorded responses). First, a click of sufficient intensity must be used in order to elicit a definite response. Once the response has been obtained, it is recorded on paper (the information in the memory is read at a slower speed), then the threshold is found by progressively decreasing the intensity in 10 dB steps. As the intensity is diminished, the amplitude of the response can be seen to decrease, while the latent interval is increased. Usually it is very easy to determine the threshold as lying on one of these 10 dB increments, since the level at which there is no response, but 10 dB above which there is a definite response, is not difficult to find. Then a recording is made of the responses to click stimuli from threshold up to 80 or 100 dB (according to the case) in increments of 10 dB. In practice we have found that the fact of observing the responses at all levels, as well as determining just the threshold, allows us to study very precisely the dynamic function of the inner ear, and thus to obtain a great deal of valuable additional information.

If, in addition, an audiometric curve is required, the thresholds for filtered clicks can be determined; but whereas it is easy to record the responses to filtered clicks in the high frequencies, it is much more difficult for the low frequencies (from 1,200 to 3,000 Hz). For this reason it is usually sufficient to find the threshold for a filtered click at a high frequency (9,600 to 4,800 Hz) and to compare this with the threshold which has been determined for the click itself; this comparison allows the shape of the audiometric curve for the tested ear to be predicted approximately.

The measurements

For each of the responses which have been recorded, from the threshold to the maximum, the two essential characteristics of the nervous response are measured: the amplitude, from peak to trough; and the latent interval, which is the time interval between the arrival of the click at the ear and the first negative trough of the action potential. Then these readings are recorded on the same graph, the abscissae being graduated in dB for the click intensity, and the ordinates recording the values of the two characteristics mentioned above: the amplitude on the left, and the latent interval on the right.

For the amplitude, a linear scale is used; it is not expressed directly in microvolts, but as a percentage of the maximum amplitude obtained during the test. This value is indicated in the top left-hand corner of the graph. This system of tabulation has been chosen as the figure obtained for the amplitude varies between wide limits in different subjects, and would,

https://doi.org/10.1017/S0022215100084218 Published online by Cambridge University Press

therefore, be difficult to represent on a simple scale graduated directly in microvolts.

An example is given in Figure 1 for the two ears of the same subject.

II. Results

Out of all the information obtained in routine clinical examination, we retain the following:

1. The threshold of the response to the click.
2. The value of the maximum amplitude.
3. The shape of the response, which is of great significance.
4. The shape of the curve showing the values of amplitude and latent interval corresponding to the different click intensities.
5. The threshold for the high tone filtered clicks and the shape of the responses for the different filtered clicks.

We must make it clear that the information obtained from one ear is independent of the state of function of the opposite ear. The stimuli are delivered in a free field; therefore, the contralateral ear does not have to be masked.

Working from these data the electrocochleographic features of certain clinical conditions can be described:

(1) *Conductive deafness*

Pure conductive deafness gives a very characteristic picture on the electrocochleogram (Fig. 2). Naturally the threshold of the responses is

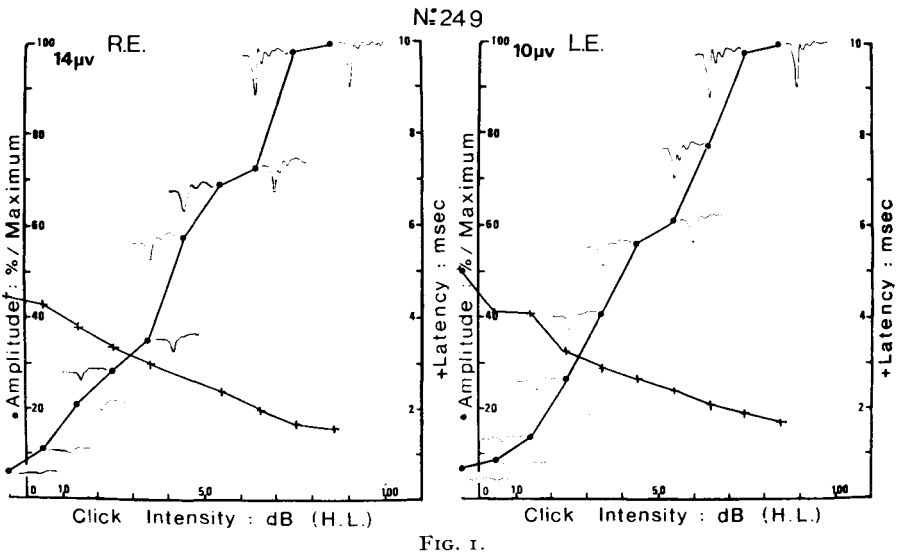


FIG. 1.
Input–Output curve: Normal.

https://doi.org/10.1017/S0022215100084218 Published online by Cambridge University Press

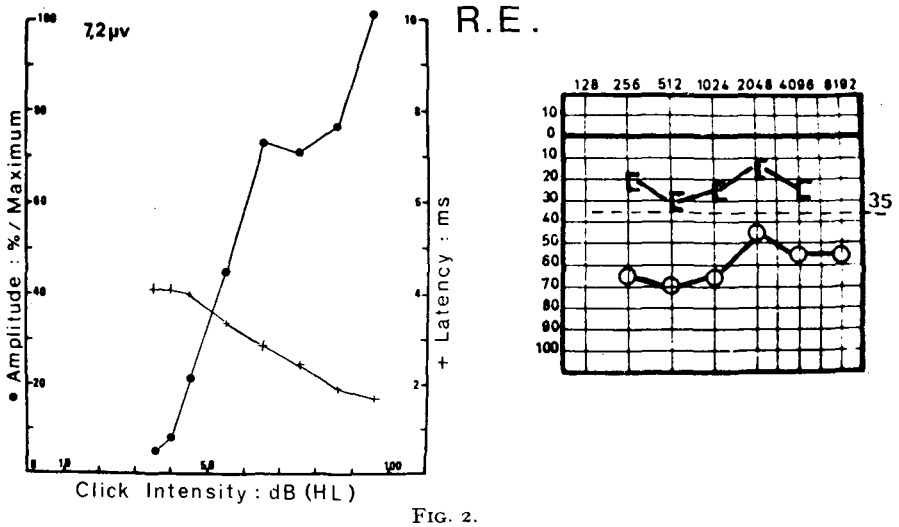


FIG. 2.
Conductive deafness.

raised, but the latent interval at threshold is the same as that found at 0 dB in the normal subject (4 to 5 milliseconds), and it changes progressively in exactly the same way. The plateau in the tracing of amplitude is shifted towards the high intensities by the same number of dB. In effect, all the curves are shifted toward the higher intensities, and the degree of this shift is an indication of the degree of conductive loss.

(2) *Sensorineural deafness involving all frequencies equally and showing recruitment*

Here is a varied aetiology, but nevertheless one which is strictly peripheral, as in Menière's disease which has become stabilized, some traumatic deafness, presbyacusis, etc. (Fig. 3).

(a) The threshold is raised (60 dB, for example).

(b) A short latent interval at threshold, whose value is usually of the same order as the latent interval corresponding to that hearing level in the normal subject (2 ms at 60 dB in the example).

(c) A diphasic response, even in the high intensities.

(d) A high reading for maximum amplitude.

(e) No plateau on the amplitude curve, and often a very rapid increase in amplitude with increasing click intensity.

Many cases show recruitment; this is as though the sensory and/or nervous receptors, which are responsible for hearing at low intensities (the outer hair-cells), are absent, while those which respond to high intensities (the inner hair-cells) are normal.

https://doi.org/10.1017/S0022215100084218 Published online by Cambridge University Press

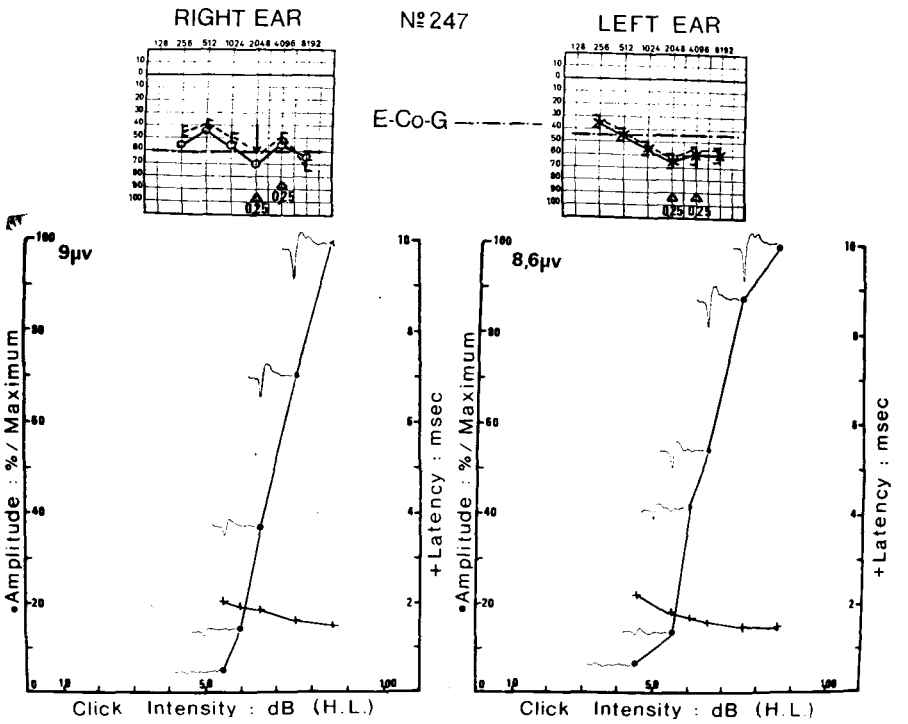


FIG. 3.
Recruiting neuro sensory deafness involving all frequencies.

(3) *Sensorineural deafness affecting the high frequencies with recruitment*

In this type of case the following responses are obtained (Fig. 4):

Unfiltered click: Dissociated input-output curve. The first part occurs at the normal threshold with a long latency (this corresponds to the response of the low tones which have remained normal in the apical part of the cochlea).

Then, at a level which corresponds to the abnormal threshold of the high tones a short latency response dissociated from the first one appears. The global response curve then follows; this consists of a rapid negative peak (the response from the first turn inner hair-cells of the cochlea, high tones) followed by a second later negative peak of lesser amplitude (the response from the last turn of the cochlea, low tones).

The whole response gives an input-output (intensity-amplitude) curve with a slow take-off but rapid acceleration of the final slope, and disappearance of the normal plateau.

Filtered click (6,000 Hz): By contrast this reproduces the responses already encountered, with their characteristics of recruitment, from a non-filtered click in cases of sensorineural deafness affecting all frequencies equally.

https://doi.org/10.1017/S0022215100084218 Published online by Cambridge University Press

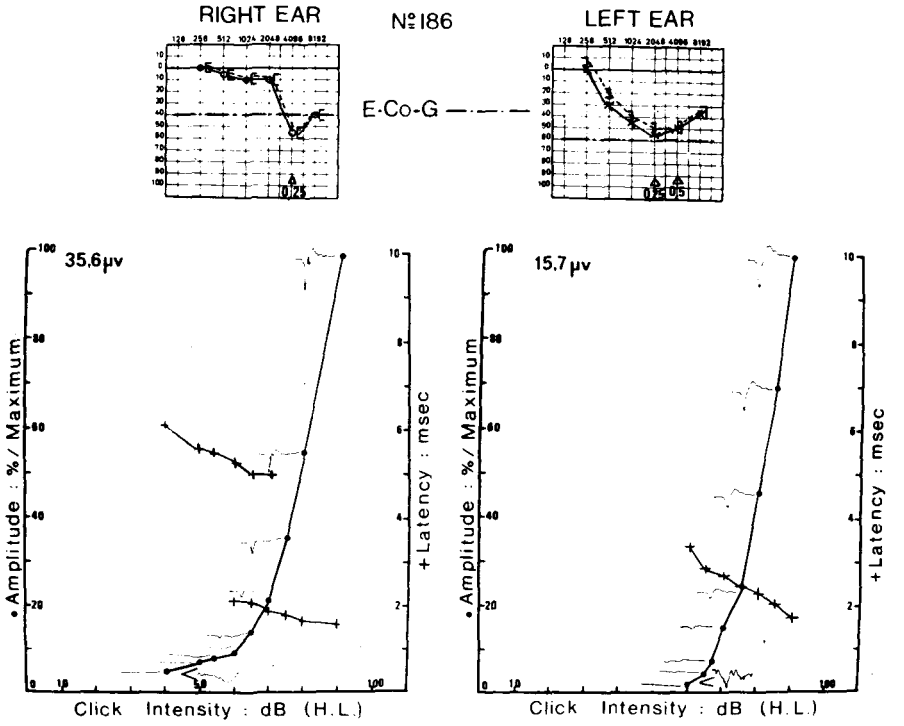


FIG. 4.

Input–Output curve with unfiltered click, showing dissociation with filtered click showing recruitment.

(4) *Deafness in Menière's disease*

All the frequencies tend to be equally affected. The non-filtered click gives an input-output curve of the recruiting type, i.e. disappearance of the plateau, narrowed amplitude and short latency. However, the form of the response is not diphasic but broad. Dixon has shown that if the part caused by the variation in the summating potential can be subtracted from the response, a diphasic form typical of a recruiting ear is obtained. Typical results are shown in Figure 5.

The width of the response would then be due to the combination of an abnormal summating potential (caused perhaps by a change in the position of the basilar membrane due to the hydrops) with the action potential of the nerve.

(5) *Retrolabyrinthine lesions*

Finally, in certain cases, very abnormal responses may be found, but these all have a similar pattern of response (VIII neuroma, nuclear icterus, complex neurological disturbance, vertebral artery compression). This response has a very early positive peak (the sensory response) followed by

https://doi.org/10.1017/S0022215100084218 Published online by Cambridge University Press

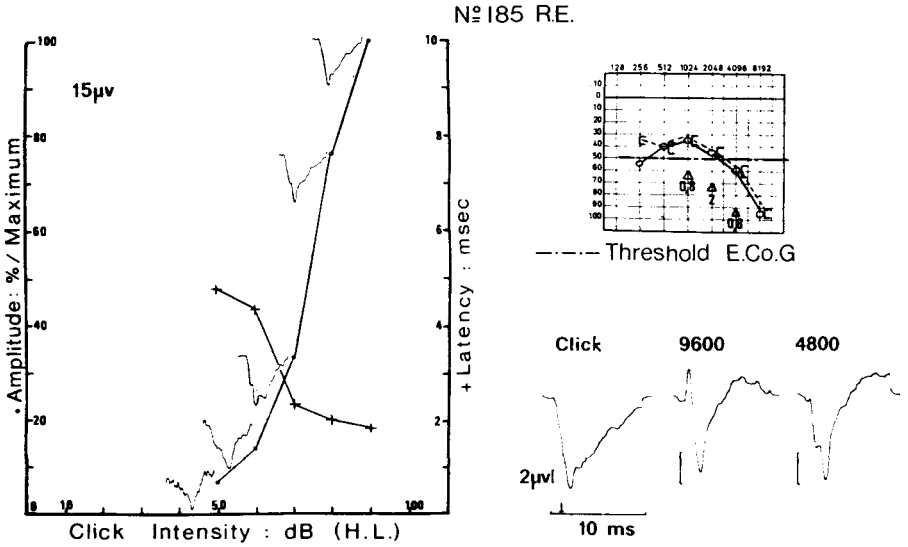


FIG. 5.
Menière's disease.

a slow negative wave (or the distorted action potential) or the combination of an abnormal summating potential and very small action potential or no action potential at all. This type of responses is presented in Figure 6.

J. M. Aran, in carrying out research to explain these findings, has been able to reproduce these particular patterns in the guinea-pig by injecting a diuretic toxic to the internal ear, etacrynic acid.

After the injection, the ECochG response to a click disappears suddenly and then gradually returns. As it recovers, the form of the response is of the 'abnormal' type encountered in vascular and retrocochlear disorders. During this experiment, if a sound of short duration (a tone burst at 16,000 Hz for a duration of 10 ms, rising in 3 waves) is used, a rapid change in the polarity of the summation potential is observed. At the beginning of the recovery period, *the action potential is very weak but retains its normal* form, whereas *the summating potential is very strong*.

This summating potential can be subtracted from the overall response by combining this use of a high frequency tone burst with various repetition rates. Fast repetition rates induce an important decrease of the neural response whereas the sensory potential remains the same. With the use of a computer the two responses can be subtracted leaving a purely neural response. An example is given in Figure 7.

It would seem therefore that the 'abnormal' response to a click consists of a strong summating potential related to a very weak action potential. This means that the hair-cells are responding, whereas the response from the nerve remains very weak. This could be the situation

https://doi.org/10.1017/S0022215100084218 Published online by Cambridge University Press

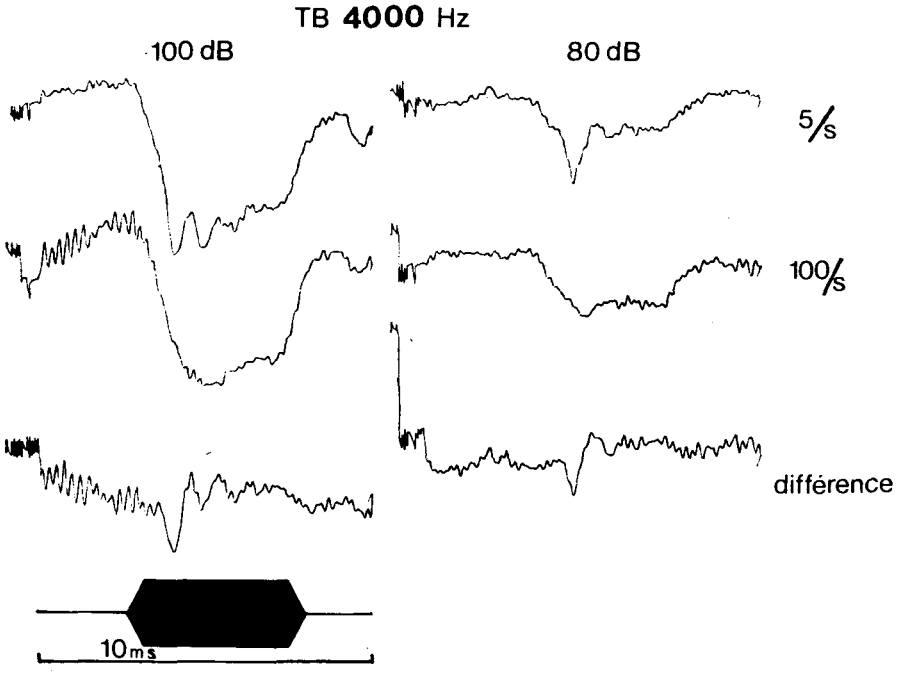


FIG. 6.
Abnormal response with retrolabyrinthine disease.

in retrolabyrinthine lesions in man. Thus the abnormal forms appearing in certain cases could be due to the combination of a still normal cochlear function (summating potential of good amplitude) with a marked decrease in the activity of the auditory nerve neurone (very weak action potential).

In retrolabyrinthine tumours, there is often an ECochG threshold which is better (and which may even be normal), with an input-output curve and a response of normal form, than the subjective threshold, which may be very poor or even absent (total deafness). This would be due to satisfactory peripheral function, but with nervous conduction cut-off partially or completely, between the ear peripherally and the higher centres centrally by a lesion situated in the internal auditory meatus or at the cerebellopontine angle.

III. Clinical statistics

The Audiology Laboratory in the Bordeaux School has carried out over 2,000 ECochG tests up to the present time. Today we present the results of this work.

Between 1969 and 1973, 800 ECochG were examined. The percentages obtained over that period are substantially the same as those which we are obtaining at present. These are:

https://doi.org/10.1017/S0022215100084218 Published online by Cambridge University Press

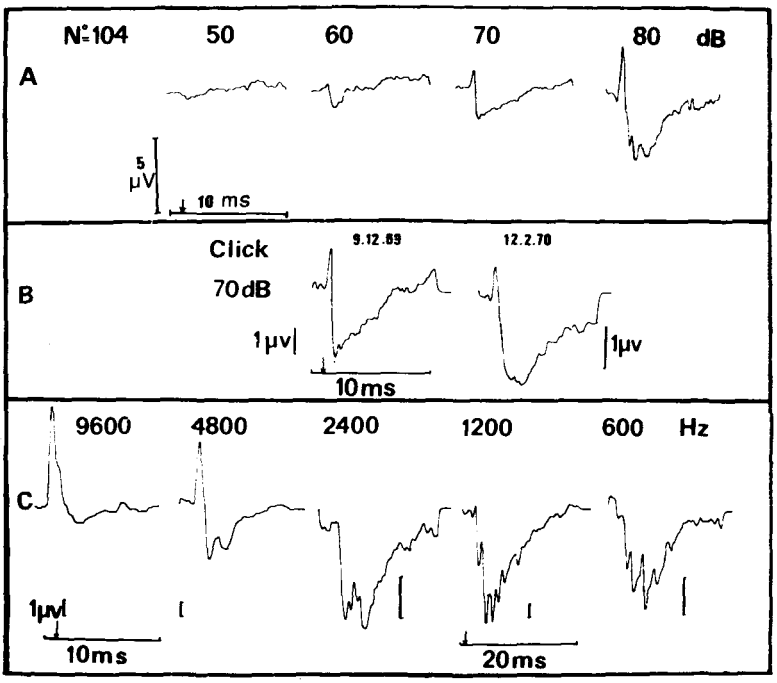


FIG. 7.

Demonstration of the combination of an abnormal summating potential and very small action potential.

ECochG were carried out on 1·5% of all the adults tested audiometrically and on 12% of the children. This is a small percentage in view of the fact that our centre receives many children who are difficult to test.

The age distribution of the children on whom ECochG was done was:

59% under the age of 3 years,

10% between 3 and 5 years,

25% older than 5 years.

In the youngest age group (under 3) this examination is needed to establish the thresholds, especially in the very young children; the youngest baby tested was 20 days old.

Above the age of 5, most of the tests are done in cases affected by major diseases, such as autism and other neurological disorders.

Some of the indications for ECochG in children are as follows:

(a) in 8% of the cases the diagnosis has already been made, but the ECochG was able to give additional information such as the presence of recruitment, the individual form of the curves and also the presence of any of the abnormal forms of the response.

https://doi.org/10.1017/S0022215100084218 Published online by Cambridge University Press

(b) in 50% of the cases the ECochG was used to confirm a diagnosis made doubtful by features such as masking problems (phantom curves, congenital atresias), very young children or behaviour problems (threshold for high tones, recruitment, the better ear for a hearing aid).

(c) in 6% of the cases, the ECochG was indispensable because the classical methods of subjective audiometry could not be used:

— serious behaviour problems (psychotics, autistic children);

— motor disorders (cerebral palsy);

— children with associated defects (deaf-blind, etc.).

Conclusion

In conclusion, it can be said that ECochG enables the site of the lesion to be defined accurately, especially in cases of Menière's disease and in neuromas, by means of the classical technique, mentioned earlier. In addition the studies of the summating potential associated with the act on potential (GIBSON), the difference in the responses obtained from certain types of stimuli (clicks, tone bursts and tone pips of various frequency bands, EGGERMONT) and lastly the surface electrode techniques for seeking the potentials from the brain stem, have all contributed to defining the site of the lesion.

In children, ECochG is useful in special cases, because by using the standard techniques, a good paediatric audiometrist can get a very good idea of the hearing levels even under the age of 1 year.

However, in very young infants, in children showing abnormal behaviour and associated problems, this test becomes indispensable and irreplacable. Also, in other children, its permits the confirmation of doubtful results, and gives further information on auditory function at that age (such as recruitment or disordered quality of the message—broad and abnormal forms).

Finally it is the only technique available which can investigate the function of each ear separately from the earliest days of life.

86 Cours d'Albret,
33 Bordeaux,
France.

https://doi.org/10.1017/S0022215100084218 Published online by Cambridge University Press

https://doi.org/10.1017/S0022215100084218 Published online by Cambridge University Press