Recent Advances in

# OTOLARYNGOLOGY

EDITED BY

**T. R. BULL**

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# Preface

The early editions of *Recent Advances* aimed to cover the entire specialty of otolaryngology. In the last edition, published 5 years ago, only aspects of the specialty in which there was definite or likely advance were selected: this pattern is followed in the present edition. It does not, however, supersede that of 1973 in which much of the material is still current.

Advances in otology were particularly dramatic between 1960 and 1970 in middle ear surgery. Today, while there is still some controversy over middle ear surgical techniques the tempo of advance has slowed: the emphasis has moved towards the innovative inner ear surgery, with associated refinements in audiometric investigation. In head and neck surgery, interest and expertise in the plastic and reconstructive aspects has increased in the specialty, particularly in North America. Advances in subjects closely related to otolaryngology, such as radiotherapy and chemotherapy, are again included in this edition.

We would like to thank the contributors for their work for this edition. We are particularly grateful to the authors from overseas including those from America and Germany from whose countries such immense advances in otolaryngology have been made.

London, 1978 T.R.B.

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# Contents

# 1. Electric response audiometry

*John Graham*   *H. A. Beagley*

## INTRODUCTION

One or two milliseconds after a sound reaches the ear, electrical action potentials travel along the cochlear nerve, carrying information to the brainstem and cerebral cortex. Using Electric Response Audiometry (ERA) it is possible to detect these electrical changes and use them to find not only a patient's threshold of hearing but also the site and probable cause of his hearing loss. ERA can also be used as a neurological tool to investigate dysfunction of the central nervous system.

This review will briefly explain the principles of ERA, how the various tests work and what they measure. In particular we shall point out the occasions when ERA gives unique information that can be obtained in no other way. In some cases, especially in threshold detection, two or more different electrophysiological tests can supply similar information. The choice of test will then depend on the equipment available and the personal preference and experience of the tester. Many of the tests used in ERA are still at the research stage. Only those suitable for routine clinical use will be discussed here.

*Objective audiometry*. Electric Response Audiometry is said to be objective. This is certainly true for the person being tested since sounds are used to evoke from his central nervous system electrical responses of which he is not conscious and which he cannot control. The gain in objectivity, however, is accompanied by a potential loss when it comes to the person doing the testing, since at present the identification and analysis of these electrical responses is by a clinician who has to make a value judgement on the results obtained.

## SOME BASIC PRINCIPLES

### Evoked potentials

A simple example of an evoked potential which will be familiar to most readers from their early training in physiology is the electrical potential evoked in a frog's nerve by some stimulus and measured using two wire electrodes placed on the nerve. It is easier to record such an evoked potential rather than spontaneous activity since the stimulus produces a synchronous discharge from most of the fibres in the nerve.

In ERA the stimulus is an auditory one. Compared with direct recording from a frog's nerve the detection of evoked auditory potentials in humans is more difficult because the responses are very small and are largely swamped by other electrical events, since:

1. The recording electrodes are further away from the region where the electrical signals are generated.
2. There is superimposed electrical activity from the scalp muscles, EEG waves, and possibly from electric cables and appliances in the vicinity as well.

Although these problems had been solved, to a limited extent, by physiologists it was the use of electronic averaging devices (Dawson 1954) that improved the situation and has brought the techniques of ERA into routine clinic use.

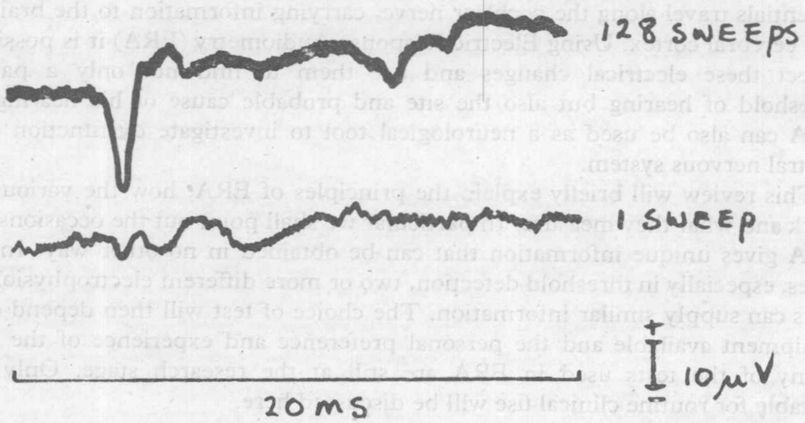


**Fig. 1.1** Lower trace shows the AP from a single acoustic click buried in background physiological 'noise'.
Upper trace shows the average of 128 such responses. This has resulted in a clearly visible AP while the background noise has been relatively reduced.

## Averaging

A nerve's response to a stimulus has a latency and electrical polarity that remain the same if the stimulus is repeated a second or so later. For example in response to a click at 100 dB hearing level (HL) the compound action potential of the cochlear nerve would be as shown in Figure 1.1 when recorded from a needle electrode placed on the bony promontory of the middle ear. (Fig. 1.1.)

In the context of the living head the individual action potential is hidden in a forest of unrelated electrical activity as Figure 1.1 shows. Averaging, however, can extract a repetitive response from the unwanted electrical noise. When the response is small in relation to the noise, a large number of stimuli and responses are needed for the averager to do its work. When the signal-to-noise ratio is better, a smaller number of stimuli will suffice to give a clearly visible response.

## Far-field and near-field recording

At this stage the concept of far-field and near-field recording should be mentioned. The best example of near-field recording is when electrodes are placed directly on the nerve itself. The size of the response will then be very large compared with the background electrical activity; i.e. there is an extremely good signal-to-noise ratio. Only events which are quite close to the electrodes are seen but these are very clear. It is rather like looking through a powerful magnifying glass—the depth of focus is small but what is seen is very clear against a blurred background. To continue the analogy, far-field recording is like looking through a lens with a great depth of focus—everything at whatever distance looks equally clear but no particular object stands out from the rest. In far-field recording the electrodes are at a greater distance both from each other and from the events they record. Averaging is therefore vital to detect all but the greatest electrical changes. Near-field recording is used for electrocochleography and the post-auricular muscle responses; far-field for the brainstem electrical responses. Cortical ERA represents a compromise between the two.

## NOMENCLATURE

It seems sensible at this point to give a list of the most commonly used tests with their synonyms and abbreviations. The list begins at the ear and works centrally. Those techniques which have no immediate application in current audiological practice will be listed but not discussed further.

1. *Electrocochleography (ECochG)*

| | | |
|---|---|---|
| a. Cochlear potentials from hair cells: | Cochlear microphonic | (CM) |
| | Summating potential | (SP) |
| b. Compound action potential of the auditory (cochlear) nerve: | Action potential | (AP) |

2. *Brainstem responses*

Brainstem electrical responses (BSER); these are neurogenic potentials from five different sites:

a. Cochlear nerve (ipsilateral).
b. Cochlear nucleus (ipsilateral).
c. Superior olivary complex (bilateral).
d. Ventral nucleus of lateral lemniscus (bilateral).
e. Inferior colliculus (bilateral).

Sonomotor Reflexes:

a. Intra-tympanic muscle reflexes (not dealt with here).
b. Post-auricular myogenic response (PAR or PAMR) (Synonym:— Crossed acoustic reflex (CAR)).
c. Inion response from the nuchal and other muscles in the head region (not dealt with here).

3. *Cortical responses*

a. Middle responses originating from somewhere between the medial geniculate body and the primary auditory projection area (not discussed here).

b. Vertex responses, from the primary and secondary auditory areas, used in cortical electrical response audiometry (CERA or ERA).
(Synonyms: slow cortex response, vertex potential, V-potential).

c. DC responses including:
 i Contingent negative variation (CNV) (not discussed here).
 ii Sustained DC potentials (not discussed here).

## DESCRIPTION OF TESTS USED IN ERA

### 1. ELECTROCOCHLEOGRAPHY (ECochG)

**Applications**

ECochG is used for threshold audiometry in children and to investigate the site and cause of hearing loss in both adults and children.

In children electrocochleography has several great advantages when used for finding a child's hearing threshold. The responses obtained are large, easily seen, and can usually be followed to within 5 dB of the behavioural threshold. It is also possible to obtain information about a child's residual hearing (e.g. whether recruitment is present or whether the deafness is mainly retrocochlear). This should help the future management of the child.

In adults one of the main purposes of audiometry in sensorineural deafness is to separate cochlear from retrocochlear lesions. Electrocochleography is especially useful for this task when conventional audiometric tests give conflicting results or are impossible because of the severity of the deafness. As the AP recorded in ECochG is derived only from the cochlea and cochlear nerve being tested, it is unnecessary to use masking of the contralateral ear as cross-over effects cannot occur. Masking of the *test* ear with filtered noise bands may be used however, as Eggermont (1976) has done in order to carry out a narrowband analysis of the AP.

**Technique**

*Anaesthesia*. For most children a general anaesthetic is necessary. Hutton (1976) gives a full account of the anaesthetic techniques used in electrocochleography. For children under three years old a single intramuscular dose of Ketamine produces a satisfactory level of anaesthesia, with retention of the swallow and cough reflexes. No endotracheal intubation is necessary. For children over three years old nitrous oxide and halothane inhalation anaesthesia, with endotracheal intubation, is quick and safe, but the expired halothane vapour should be discharged to the outside of the building. If electrocochleography is performed in the morning, breakfast is the only meal missed. Between three and five children may be tested in a morning and most of them can go home by lunch time. The younger children should be tested first, since Ketamine anaesthesia takes up to four hours to wear off. The youngest child we have tested so far was eleven weeks old. The parents can usually be given the result of the test at once. It is therefore convenient to have someone standing by to talk to the parents sympathetically and at some length, especially if the result shows deafness which is unexpected or which the parents may be unwilling to accept. We have found it very useful to have a teacher of the deaf available for this.

Adults present fewer problems as local anaesthesia can be used. The transtympanic needle electrode is smaller in diameter than a venepuncture needle and although the idea of having a wire pushed through their tympanic membrane may worry some people, it is actually less painful than venepuncture in experienced hands. In the authors' experience patients are unanimous in preferring it to caloric tests. Nevertheless the patient's discomfort should be kept to a minimum

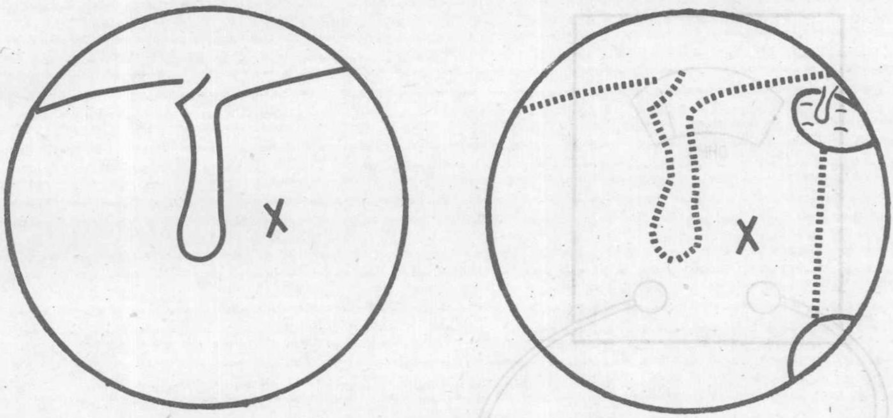

**Fig. 1.2** Left—this is a diagram of the left ear drum showing the position on the drum where the needle electrode is inserted. Right—this shows the position, relative to the oval and round windows, on the promontory where the tip of the electrode rests.

and the technique of iontophoretic anaesthesia of the external auditory meatus and lateral surface of the tympanic membrane makes most of the procedure almost entirely pain-free. Alternatively, simply spraying the tympanic membrane lightly with Benzocaine is usually adequate. The mucosa over the promontory in the middle ear cannot, of course, be anaesthetised so the patient is bound to feel some sensation, often referred to the throat. Extremely nervous adults can also be sedated with intravenous Valium (diezapam) but this is rarely necessary.

*Recording technique*. The transtympanic technique was first described by Aran and Le Bert (1968) and by Yoshie (1968) and is simple to perform by anyone with a knowledge of otology. The tympanic membrane is identified using a binocular operating microscope. The electrode, a fine steel needle, electrically insulated by varnish or teflon except at the tip, is passed through the posterior part of the tympanic membrane at a point half way between the tip of the malleus handle and the annulus. The tip of the electrode makes contact with the mucosa on the bony promontory and is held in position by a fine band of elastic. Figure 1.2 shows the final position of the electrode tip on the promontory over the basal part of the cochlea, a few millimeters in front of an imaginary line between the oval and round windows. Occasionally the electrode may tend to skid on the tympanic membrane and pass through the periosteum of the malleus handle. This situation should be avoided since it will tend to tether the tympanic membrane and can produce a significant conductive deafness, while the electrode is in place.

The reference and earth electrodes are silver discs placed on the ear lobe and forehead respectively. The skin is cleaned with spirit and the electrodes are attached with double-sided adhesive discs. Electrode jelly is injected through a hole in the disc electrode into the space between the electrode and the skin using a needle with a slightly roughened end (e.g. a wide bore hypodermic needle, shortened and with its bevelled tip ground off). The needle is rotated to scrape the skin gently and so give good electrical contact. The resistance between

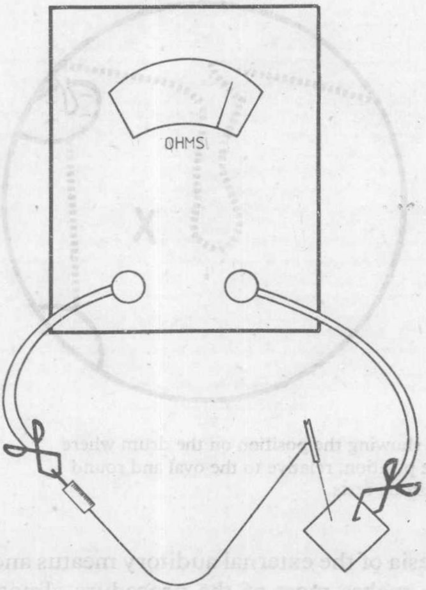


**Fig. 1.3** This shows how the electrical continuity of the electrode and its lead is verified prior to being used for ECochG. When the tip of the electrode makes contact with the piece of sterile aluminium foil, electrical continuity shows as a short circuit on the meter (i.e. zero ohms). The electrode is then ready to be used.

the earth and reference electrodes is tested and should be between 2 and 3 kilohms.

An essential step is to measure the resistance along the needle electrode and its wire flex before it is placed on the promontory, to make sure that there are no breaks in the circuit. To do this the tip of the needle electrode, which is connected with its lead to a resistance meter, is placed in contact with a piece of sterile aluminium foil which is also connected to the resistance meter. If there is electrical continuity the meter will show a short circuit, and the electrode and its lead can be used with confidence (Fig. 1.3).

For *extratympanic*, as opposed to transtympanic, recordings a metal ball or foil electrode is placed near the tympanic membrane, or a needle is inserted into the meatal skin. The earth and reference electrodes are the same as for the transtympanic technique.

The main advantage of transtympanic electrocochleography is that the signal-to-noise ratio is extremely good. Large action potentials are recorded using relatively few stimuli. The cochlear microphonic is easily visible; in fact it is difficult to detect the cochlear microphonic at all using the extratympanic technique. Transtympanic electrocochleography has been established as a safe procedure (Crowley et al 1975) and is certainly innocuous even when compared with the operation of myringotomy and insertion of grommets.

*Stimuli*. The most effective stimulus for ECochG has an abrupt rise time. The simplest stimulus of this kind is a wide band click, but short tone bursts with very short rise times can also be used. In fact, a whole variety of clicks, filtered clicks, short tone bursts, half sine waves and other stimuli have been used and all are effective if the onset is sufficiently sudden.

Wide band clicks affect the whole of the basilar membrane and therefore stimulate all the fibres of the cochlear nerve, but only the more basally situated fibres are sufficiently synchronized when they fire to produce a coherent compound AP. The fibres from the more apical regions, being less synchronized, give no coherent AP in ECochG. Thus, filtered clicks and short tone bursts are useful only if they are in the high frequency range, 2 kHz. or above. Below this frequency it is not possible to get reliable AP responses by ECochG, although researchers are active in attempting to solve this problem using such techniques as deconvolution, or digital filtering combined with high-pass masking. However, despite some loss of frequency selectivity considerable information can be obtained using only wide-band clicks. The usual repetition rate is 10 per second through loud-speakers or headphones and alternate stimuli are usually reversed in polarity to remove the CM from the record.

*Cochlear Microphonic (CM)*. This potential is produced by the hair cells, the outer cells providing the larger contribution. The longer cilia of the outer hair cells are in contact with the tectorial membrane and as the basilar membrane moves up and down in response to vibrations entering the cochlea there is a shearing motion between the basilar and tectorial membranes and the cilia are bent back and forth. This ciliary movement produces an alternate depolarization and repolarization of the hair cells which can be recorded as an alternating current as if the inner ear were functioning as a simple microphone. Wever and Bray (1930) were able to use the cat's ear as a microphone by recording from the cochlear nerve. They thought that the electrical discharges they had detected were a volley of nerve action potentials but Adrian suggested that the cochlea was the source of these potentials, and the CM was identified as a separate entity by Saul and Davis in 1932. In humans, because of the site of the transtympanic electrode on the promontory, the CM is only recorded from the basal few millimeters of the cochlea. It is a reasonably faithful copy of the sound waves entering the cochlea and reflects the wave motion of the basilar. membrane. It therefore continues as long as the stimulus persists.

The CM varies in amplitude with the stimulus but in clinical electrocochleography it can only very rarely be detected using stimuli of under 50 dB HL. It must be stressed that this is only a threshold of detectability and not a true threshold in the physiological sense. It is important to distinguish between the true cochlear microphonic and artefacts produced by the stimulus itself or by vibrations of the recording electrode although Beagley and Gibson (1976) showed that the latter are relatively insignificant and unlikely to cause confusion in clinical use.

*Summating potential (SP).* The summating potential, like the cochlear microphonic, is produced by hair cells. It is a direct current potential which persists as long as the stimulus continues. The SP is made up of several components but probably the most important one is produced by a mechanical bias of the basilar membrane which affects the cochlear microphonic. A simple illustration of this effect is a trampoline with some small children marching across it in single file. The dents made by the children's feet are equivalent to the oscillations of the cochlear microphonic while the SP is like the sagging of the trampoline produced by their total weight. (Fig. 1.4.)

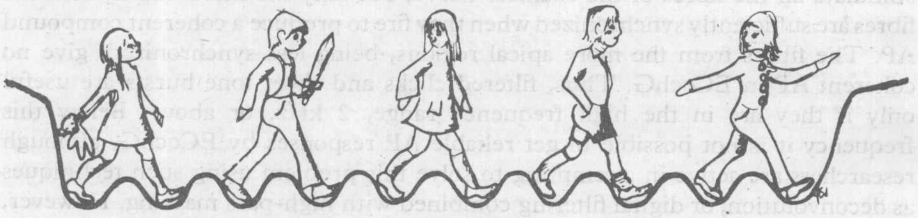

**Fig. 1.4** Sagging of the trampoline under the weight of the line of children is analogous to the biassing of the basilar membrane under high intensity sound stimulation. By the same analogy the children's feet produce indentations which would correspond to the oscillation of the cochlear microphonic.

Like the cochlear microphonic the summating potential recorded by electrocochleography arises mainly from the basal few millimeters of the cochlea, and because of this it is fairly small and is usually negative in polarity. A more marked negative summating potential does appear, however, in some abnormalities of cochlear function, particularly when there is mechanical loading of the basilar membrane, such as that produced by endolymphatic hydrops in Ménière's disease and in syphilis.

*Action potential (AP).* Of all the auditory potentials the action potential is the most useful as a clinical tool. It is a direct current potential which comes 1 to 2 milliseconds after the arrival of sound waves at the cochlea. It is compounded of numerous single potentials resulting from the progressive firing of the fibres of the cochlear nerve as the travelling wave passes along the basilar membrane. For this reason the AP measured is referred to as the *compound* action potential of the cochlear nerve.

Its size and latency vary with the intensity of the stimulus. In a normal subject using a transtympanic electrode the amplitude is between 5 and 20 microvolts. Figure 1.7 is a graph of input/output function showing that an action potential increases in size with the increase in intensity of a stimulus. Unlike the CM, the AP can be traced to within about 5 dB of the patient's subjective threshold. Figure 1.7 also shows the relation between the latency of the action potential and the intensity of the stimulus.

*Technique for separating CM from AP.* Figure 1.5 shows the CM and AP recorded together. These two potentials can more easily be assessed if they are

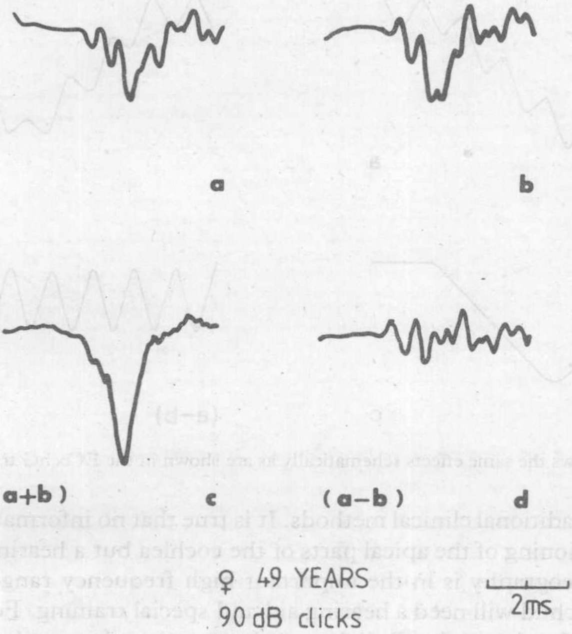


**Fig. 1.5** (a) This shows the CM and the AP in response to a series of clicks in one polarity while (b) shows the same in response to clicks of the opposite polarity. This results in reversal of polarity of the CM and (c) shows the result of adding (a) to (b)—the AP is preserved, but the CM is suppressed. (d) shows the effect of subtracting (b) from (a)—in this case the AP is suppressed but the CM is preserved.

separated, and an ingenious technique is available for this. The loud-speaker of headphone producing a click can be excited in two ways. The initial movement of its cone may be towards the patient, producing a *compression* click or away from the patient, producing a *rarefaction* click. This initial movement of the loud-speaker is reflected in the movement of the tympanic membrane, ossicles and basilar membrane. Thus a compression click will produce an inward movement of the stapes footplate and an initial 'downward' shift of the basilar membrane in the direction of the scala tympani, while a rarefaction click has the opposite effect. So, for the two different kinds of click, the resulting waves of the CM will be of opposite polarity. Figures 1.5a & b and 1.6a & b show these possibilities. If these two different kinds of click are presented *alternately* then the two different responses can be stored separately in each half (a or b) of the divided memory of the averager, then added together producing cancellation of the CM. Figures 1.5 and 1.6. The AP, however, is not cancelled because its polarity is not changed by reversing the clicks. Instead of adding (a) and (b) together, (b) can be subtracted from (a). In effect this means turning one of the traces upside-down and adding the two traces together. The CM will then be enhanced while the AP disappears.

**Threshold detection.** Electrocochleography has the advantage of giving a rapid and accurate estimate of the hearing threshold in children who may be completely