METHODS OF OBJECTIVE AUDIOMETRY

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TRADITIONALLY all hearing tests whether qualitative or quantitative are subjective. This means that the subject being tested is obliged to make a conscious judgment as to whether or not he actually hears the test sound. The response he makes on hearing the sound varies—he may answer a question or repeat a word, or in pure tone audiometry he may be required to press a button or raise his finger as a signal. In every case recognition must occur and the behavioural activity follows. It is clear that co-operation and adequate motivation must be present if reliable subjective tests of hearing are to be applied.

Such co-operation and motivation may not always be forthcoming, in which case an objective method of testing would be valuable, for example, in testing the hearing of young children and infants. In practice simple subjective "screening" tests are used and, while valuable, they are qualitative rather than quantitative and are not always entirely reliable. To overcome this difficulty various expedients have been adopted. At this point we can define an objective test as one in which the *tester* determines whether or not the patient hears in contra-distinction to the subjective method where the subject indicates that he hears by making some conscious action or movement.

1. *Psychogalvanic skin reaction*

This technique takes advantage of the fact that sweating reduces the electrical resistance of the skin. Such a sweating reaction can be induced in children by means of an electric shock. A burst of pure tone is presented to the subject followed shortly by an electric shock until he becomes conditioned to expect a shock after every such tone. If presentation of a tone brings about a measurable resistance change in the skin this is taken as evidence of hearing and the method has been used to establish the auditory threshold of children.

There are, however, a number of disadvantages with such a technique. Not every child, when shocked, does sweat and lower his skin resistance, whereas others rapidly adapt and so fail to respond. Others again react unduly to the shock so that reliable results become unlikely. In fact this can be regarded as a form of conditioned rather than *objective* audiometry. Bordley and Hardy (1949) and Barr (1955) have been distinguished

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proponents of this method but it is fair to say that it does not enjoy widespread popularity today. Despons, Portmann, Lafon and Morgon (1965), have referred to it with some perspicacity under the heading of "l'audiometrie dite objective". The next two techniques do, however, satisfy the criteria of objectivity.

2. *Acoustic impedance measurement*

Contraction of the middle-ear muscles in response to a sufficiently intense sound stimulus brings about an increase in the acoustic impedance of the middle ear, due to increased rigidity of the ossicular chain. By means of an acoustic impedance bridge it is possible to detect and measure such impedance changes and, if one were to elicit such a change following a sound stimulus on the homolateral or contralateral side, this is evidence that the cochlea so stimulated is indeed active and able to play its part in activating the reflex. In these circumstances the production of such an impedance change indicates an active cochlea. As a test it is certainly objective, not being in any way dependent on conscious action of the patient.

As a result of the work of Moller (1958), Terkildsen and Nielsen (1960), Zwislocki (1961), Klockhoff (1961), and others, acoustic impedance measurement presents unique potentialities in otological investigation, especially in such conditions as stapedial ankylosis, ossicular discontinuity, facial paralysis and possibly noise susceptibility.

As a test of hearing, however, it falls short as the stapedial reflex is mediated at the brainstem level and can even be studied in decerebrate animals as Wersäll (1958) and others have shown. Thus there is no assurance that a positive stapedial reflex indicates that auditory information has reached the higher centres.

3. *Evoked response audiometry*

Recordings from the exposed cerebral cortex of experimental animals at the end of the last century have shown that centrally directed nervous impulses from peripheral sensory stimulation can reach the cortex where they are detected as a change in electrical potential.

Recordings from the scalp, however, give little evidence of the arrival of sensory impulses as the recordings contain large and complex signals from the brain itself, the electroencephalogram, (Burger's waves), and the small sensory evoked potential is usually completely submerged in the larger waves and is thus unrecognizable. In the case of hearing, an electrical disturbance known as the K-complex described by Davis *et al.* (1939), could in many cases be elicited from the scalp of the sleeping subject when stimulated by sound. This has been investigated as a test of hearing, but has proved rather difficult to recognize and interpret, and

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methods based on recognition of the K-complex have been largely discarded.

A fairly recent technical innovation known as "on line averaging" has been applied to the problem of extracting the evoked cortical response from the background electrical activity of the brain. The method is actually a process of repeated summation of the signal and the accompanying electrical noise in a storage device such as the memory of a digital computer. The term "on line" simply means that the data is processed immediately whereas "off line" indicates that the signals are tape-recorded and fed into a computer later.

If the same stimulus, such as a tone burst, is applied to the patient's ear repeatedly—say fifty times—and the computer is triggered so as to collect and store the resultant electrical activity of the brain, by way of scalp electrodes, two things will happen. First the auditory evoked cortical potential will grow in amplitude in the computer memory by summation as successive similar signals are applied. Secondly, the accompanying E.E.G. activity being in the form of irregular positive and negative waves occurring at random times with respect to the acoustic stimulus, tends to cancel and approach zero as successive samples are added. The cancellation of the background activity which occurs simultaneously with summation of the evoked potential, results in a marked enhancement of the signal-to-noise ratio. In this way the summated evoked response is readily identified and can be observed on the "read out" and "write out" devices that are used in conjunction with the computer.

Historically, on line averaging of evoked potentials was pioneered in this country by Dawson (1954) and applied by Geisler, Frishkopf and Rosenblith (1958), to the detection of auditory evoked potentials. Since then extensive research has been carried out by several investigators, e.g. Davis and Yoshie (1963), Grey Walter *et al.* (1964), Bickford *et al* (1964), Davis (1965), Rapin (1965), and others. Davis in particular as a neurophysiologist has been interested in the properties of the evoked response as such, as well as being active in employing it practically as a test of hearing.

Fig. 1 shows the block diagram of the equipment used by the authors of the study now to be presented. An audio-oscillator produces a sinusoidal waveform and passes it to a Grason-Stadler electronic switch, type 829E. This device converts the electrical wave into a succession of bursts, in this case one every 2·5 seconds, each with a duration of 0·25 seconds and a rise and decay time of 100 milliseconds. The intensity of the acoustic signal so produced in the loudspeaker or headphones is controlled by a step attenuator calibrated in decibels.

In this study silver disc electrodes applied to vertex and earlobe collect the E.E.G. potentials which are fed to the E.E.G. amplifiers

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(Offner R. Type Dynograph) and thence to the computer (Enhancetron ND-800). A triggering pulse emitted by the electronic switch at the start of the tone burst triggers the computer which samples the incoming complex potentials 1,024 times in 0·5 seconds (in this instance). After a certain number of stimuli, say fifty, have been applied to the patient and their response analysed by the computer, the summated

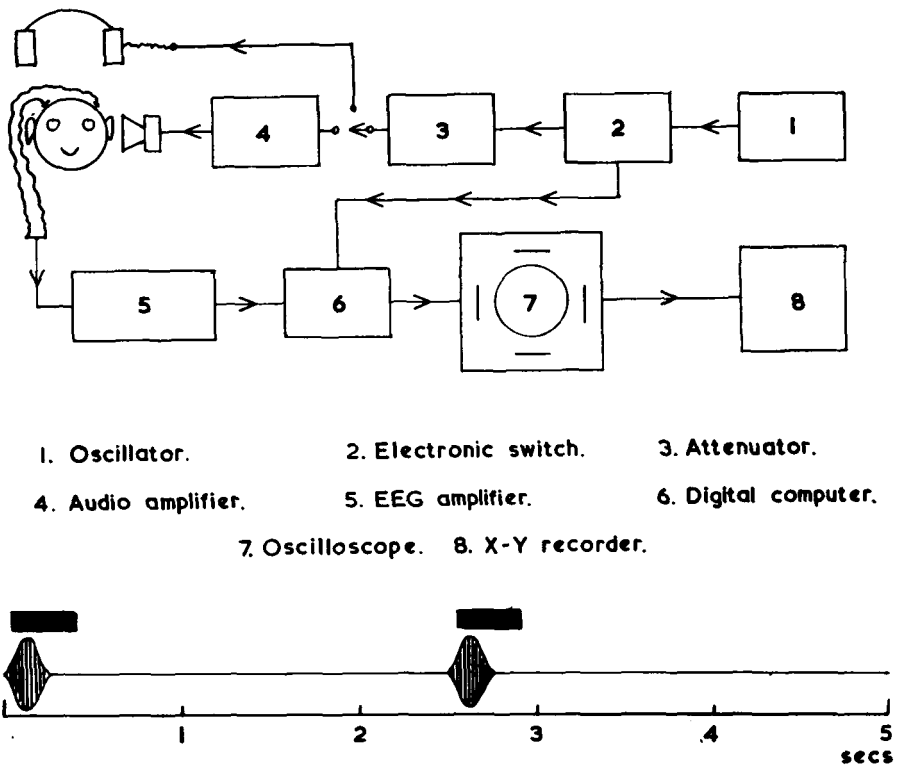


FIG. 1.

Top: block diagram of the equipment used in evoked response audiometry.
Bottom: time relations between the stimulus (vertical hatching) and the evoked response (solid rectangle).

evoked response is displayed on a Tektronix type 503 oscilloscope and traced on paper by an Advance type HR 96 X-Y recorder. Thus the auditory evoked cortical potential can be seen immediately and recorded for study.

The evoked response has a number of features which makes the waveform relatively easy to identify. As can be seen in Fig. 2 it consists of two positive peaks and one negative peak. The duration of the response is about 350 milliseconds. The first 50 milliseconds is discarded as it consists

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mainly of scalp muscle response and, as shown by Bickford, is not directly related to hearing. The typical waveform consists of a small positive peak (P1) with a latency of about 100 milliseconds and is often reduplicated.* Next follows the most conspicuous and constant element of the waveform, a large negative peak (N1) at 150–200 milliseconds followed by a second positive peak (P2) at about 250 milliseconds. In practice the inspection of the waveform has been curtailed after the end of P2 some 350 milliseconds after the onset of the acoustic stimulus. The undulations that follow P2 have not been analysed in any detail so far as they are not particularly consistent, but observations are being continued.

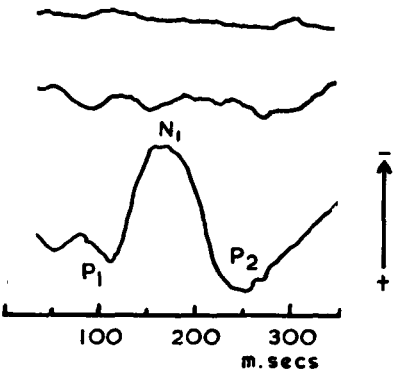


FIG. 2.

Bottom trace: a typical auditory evoked response recorded from the vertex in a young adult using a train of fifty tone bursts at 50 db. re normal threshold. Note the typical positive and negative waves, especially the prominent N1–P2 component.
Middle trace: again fifty tone bursts were given at 50 db. re normal threshold, this time with sufficient white noise to bring about complete subjective masking.
Top trace: no auditory stimulus has been used in this case—notice that this trace is virtually a straight line, the E.E.G. waves having been averaged towards zero.

When a 1,000 c.p.s. tone burst is given repeatedly well above threshold, say at 50 db. re normal threshold a typical waveform is seen as in Fig. 2. As the sequence is repeated at lower intensities two things are observed.

1. The amplitude of the evoked response diminishes.

2. The latency of the component parts of the waveform, in particular N1, is often, but not always, increased as in Fig. 3. In a typical young adult the waveform can often be identified within 10 db. of threshold whereas in a child the waveform can generally be perceived right down to threshold. (See Fig. 4.)

* Technical refinements giving shorter tone pulses with shorter rise times have resulted in latencies for P1 of 50–60 milliseconds, N1 of 100 milliseconds and P2 of 175 milliseconds. See Fig. 3.

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Fig. 2 also shows how the waveform of the evoked response can be obliterated by masking noise, while the top trace in the same figure shows the absence of the waveform when no acoustic stimulus is employed.

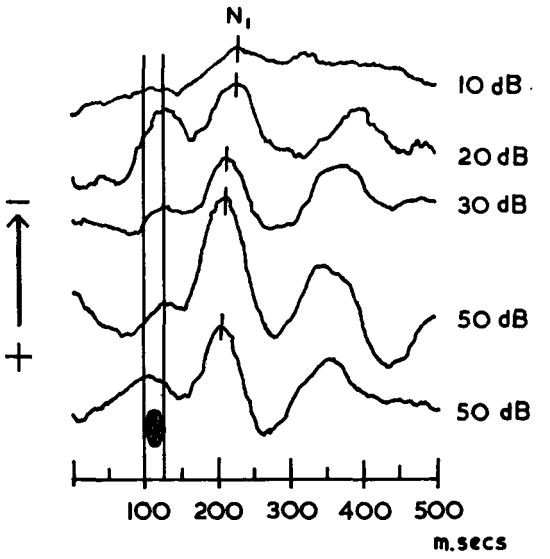


FIG. 3.

Fig. 3 indicates how the latency of the N1 peak is increased as the intensity of the stimulus is decreased. The subject was a normally hearing young adult. In this figure the stimulus follows 100 milliseconds after the beginning of the sweep. The two traces at 50 db. indicate the order of repeatability.
Stimulus: 1 K.c/s. tone, 25 milliseconds duration, 2·5 milliseconds rise and decay. 90 sweeps.

Discussion

While this is very much a preliminary report, it shows quite clearly what can be expected of the auditory evoked cortical potential as a test of hearing. The correlation between the threshold as determined by this method agrees with the known threshold at least within about 10 db. in the case of adults, and much more closely in the case of children. Davis (1964) has also commented on this. In addition to giving a good estimate of the patient's hearing it has the great advantage of being entirely objective; interpretation of the results does not appear to be unduly difficult, and is likely to be of value diagnostically when dealing with young children. Goodman *et al.* (1964) have even carried out successful evaluation of the hearing of babies in the neonatal period by this method.

Naturally much research and evaluation remains to be done, especially in the matter of determining the most suitable form of acoustic stimulus, and in checking the interaction of the various sense modalities. It is entirely possible that a conditioning sequence as used by Grey Walter and

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co-workers which has resulted in the discovery of the "expectancy potential" or contingent negative variation, may give a more realistic idea of the patient's capacity to hear, in the cognitive sense. But for the clinical otologist there is the satisfaction that there now appears to be available a reliable objective test of hearing which can be used where subjective methods are not appropriate.

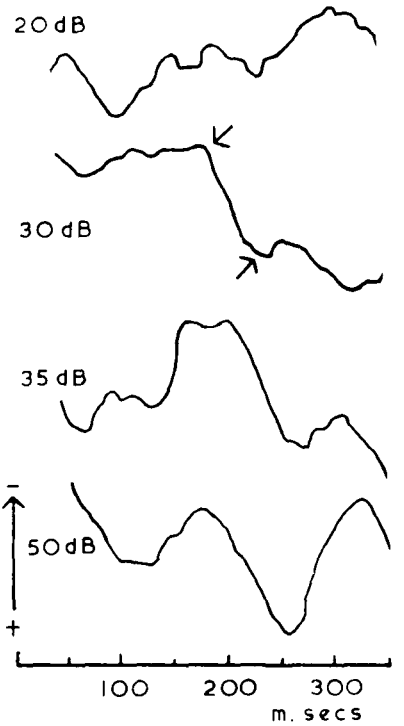


FIG. 4.

Traces from a 5½-year-old child with conductive hearing loss. Note that the N1–P2 component (pointers) is still recognizable at 30 db. re normal threshold, which agrees within 5 db. with his subjective threshold. Below this level no recognizable response is elicited. 50 sweeps.

Conclusions

1. The psychogalvanic skin reaction is not considered entirely satisfactory as an objective method of measuring hearing.

2. Measurement of the acoustic impedance of the ear has a very real place in otology but with the use of the acoustic reflex as a positive index of hearing, assurances are always lacking that the acoustic stimulus has reached the higher centres due to the fact that it is based on a brainstem reflex.

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3. Some of the advantages of evoked response audiometry in the light of this preliminary study are adduced in the text and illustrated by a number of normally hearing and deaf subjects.

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