Can present day audiology really help in diagnosis?

The reason for including electro-nystagmography (E.N.G.) as part of a comprehensive investigation by audiological staff in support of the otologist has already been explained. What therefore can it offer, supplementary to the ordinary clinical techniques of vestibular investigation? The advantages are threefold: (i) it provides a more satisfactory means than by Frenzel's glasses of comparing the effect of presence or absence of visual fixation on spontaneous and/or induced nystagmus, (ii) by testing with eyes closed or, better, with eyes open in darkness, much of the normal visual-fixation inhibition of nystagmus is removed and the test consequently gains in sensitivity, and (iii) it is more easily quantified and allows measurement of the velocity of the slow phase of nystagmus, which is more directly related to the response of the vestibular system to a nystagmus-inducing stimulus or tonal imbalance than is the case with measurement of duration of nystagmus. Moreover, it is considered that a suitably trained audiologist can perform all the tests, including calorics, provided the ears are medically certified beforehand as fit for irrigation and medical advice is immediately available should any problem arise—similar qualifications to those applying to a nurse in syringing an ear for removal of wax.

Spontaneous nystagmus may be enhanced or revealed for the first time when visual fixation is removed; this is characteristic of the nystagmus produced by a fairly recent or rapid change in the resting tone of the peripheral vestibular activity, i.e. due to a disturbance of the sensory or peripheral neural part of the system. It has to be fairly recent and/or sizeable because long-term adaptation abates the signs and symptoms even from a severe vestibular imbalance; and it has to have occurred fairly rapidly, otherwise adaptation keeps pace with the development of imbalance, as in the case of the slowly increasing pressure effects of an acoustic neuroma.

On the other hand, if the spontaneous nystagmus recorded by E.N.G. is reduced in slow-phase velocity or abolished by removal of visual fixation, then the disturbance is of the central neural type, probably with an anatomical locus at or a little above the vestibular nuclei (Dix and Hallpike, 1966).

We have not found much additional benefit from using E.N.G. in performing positional nystagmus tests. Without visual fixation there is some gain in sensitivity, but small degrees of vertical, oblique or rotatory nystagmus visible by direct observation are apt to be missed in the recordings. On the other hand, we have recently started doing a neck position test; with the eyes closed, the patient turns his neck as far as possible to one side and holds it there for 20 seconds, then to the other side, then fully extended, and finally fully flexed. It is surprising and gratifying to find how often patients with somewhat vague and atypical symptoms of vertigo, sometimes even suspected of being psychogenic,

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may then produce a typical labyrinthine type of nystagmus. Presumably this can arise from disordered neck reflexes as from cervical spondylosis or trauma, or from a deficiency in the vertebro-basilar arterial supply of the hind-brain and/or internal ear. Another possibility is that, even if the neck and arteries are normal, these manœuvres may result in a reduction of blood supply; in normal persons this would presumably have no effect, but where there is already an abnormality of either the peripheral or the central parts of the labyrinthine systems the reduced blood supply might cause symptoms or recordable nystagmus. More work needs doing on this, but it does at least provide useful evidence that the patient's symptoms are based on some organic disorder and this is often supported further by radiological findings of abnormality in the cervical spine. It also helps to sort out those cases of positional nystagmus which are induced not so much by labyrinth orientation as by neck position.

In caloric tests, E.N.G. is a help whenever there is a spontaneous nystagmus and the end-point or duration of induced nystagmus cannot be recorded. More important though, it is a great help where conventional caloric tests, with visual fixation and direct observation of the nystagmus, have failed to reveal any response to caloric stimulation. Such a lack of response in the presence of an active vestibular system may occur under two circumstances.

Firstly, the irrigation may have been inadequate; that is, it may not have reached the deep part of the external meatus. Because of this frequently-encountered difficulty and uncertainty, rotational tests are preferred by some investigators as a more certain means of delivering a stimulus of precisely known magnitude—unfortunately to both ears simultaneously though, which drastically reduces its diagnostic usefulness. A technique which we have found extremely valuable in ensuring the adequacy of caloric irrigation is, as soon as possible after the hot (44 °C) irrigation, to inspect the tympanic membrane. In the vast majority of cases, a marked hyperaemic flush down the handle of the malleus, of the tympanic membrane, and/or of the wall of the deepest part of the bony meatus is visible immediately after an adequate irrigation, becomes maximal after 60–90 seconds from the start of irrigation and in most cases persists for five minutes or longer. This is much less obvious and slower to develop after the cold (30 °C) irrigation, though after very cold (20 °C) tests a marked flush is sometimes seen, possibly due to a reactive hyperaemia. For this, and other reasons, we always perform the hot tests first; and if, with the eyes open in darkness, no recordable nystagmus is induced and there is no visible flush in the ear, then the irrigation is repeated with the greatest possible care to ensure as far as possible that the flow of water penetrates to the depths of the meatus. In many instances a nystagmus previously absent then becomes evident; but, as a corollary, we are very guarded about an apparent absence of caloric

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nystagmus in the occasional instances in which he had been unable to demonstrate the adequacy of stimulus by this 'tympanic flush sign.'

Secondly, the caloric nystagmus may have been inhibited in the usual tests performed with the eyes open in the light, i.e. with visual fixation. Such strong inhibitions occur either occupationally, classically in ballet dancers (Dix and Hood, 1969) and figure skaters, but also in sailors and other persons with frequent occupational exposure to high level or prolonged vestibular stimulation, or as a result of pathological processes resulting in severe vertigo, for example, following vestibular neuronitis (Dix and Hood, 1970). Some degree of inhibition is normal and indeed an optic fixation index for caloric-induced nystagmus,

$$= \frac{\text{slow phase velocity with visual fixation}}{\text{slow phase velocity without visual fixation}},$$

that is below about 0·5 is found in normal persons and those with peripheral vestibular lesions (Ledoux and Demanez, 1970).

Most of these tests help to distinguish between central and peripheral sites of lesion but not between one peripheral site and another, i.e. between sensory and peripheral neural. For instance, our Mrs. N. P. had a right canal paresis, and this could just as well have been due to a hair-cell as a nerve lesion. However, there is one technique recently described by which information can be gained that may help in differentiation of sensory from neural types of disordered function. This is known as thermal vestibulometry (Litton and McCabe, 1967). In essence, it is an extension of the caloric test carried out in absence of visual fixation and with E.N.G. recording. Progressively stronger stimuli are given and the response to each is measured; we use water at 25°, 20° and 15 °C, and measure the maximum velocity of the slow component of the induced nystagmus. The results, together with the conventional 44° and 30 °C caloric test responses, are then graphed in the manner shown in Fig. 7.

Utilizing our own experience, in 31 such cases up to the time of writing, and the published data of Litton and McCabe, examples are shown of the various patterns of response that can result. In both normal persons and in those with sensory disorders there is a fairly linear growth of response as the strength of stimulus grows, although where there is a severe canal paresis as in example 'A' the growth rate is small. The slight deceleration of growth of response is presumably the result of adaptation or habituation, though by spacing out successive tests by intervals of not less than ten minutes habituation is minimized. The opposite, an acceleration of the growth of response, which would correspond to a form of vestibular recruitment, does not seem to occur though. The deceleration of response growth becomes marked in cases of neural site of disordered function, presumably due to the abnormal adaptation so often found of nerve lesions; this is termed 'vestibular

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fatigue' by Litton and McCabe. In some instances, example 'B', the curve merely flattens off, but in others ('C', 'D' and 'E') the response eventually decreases with increasing strengths of stimulus; these patterns have been found in central vestibular lesions, but, we feel, are due to a disturbance

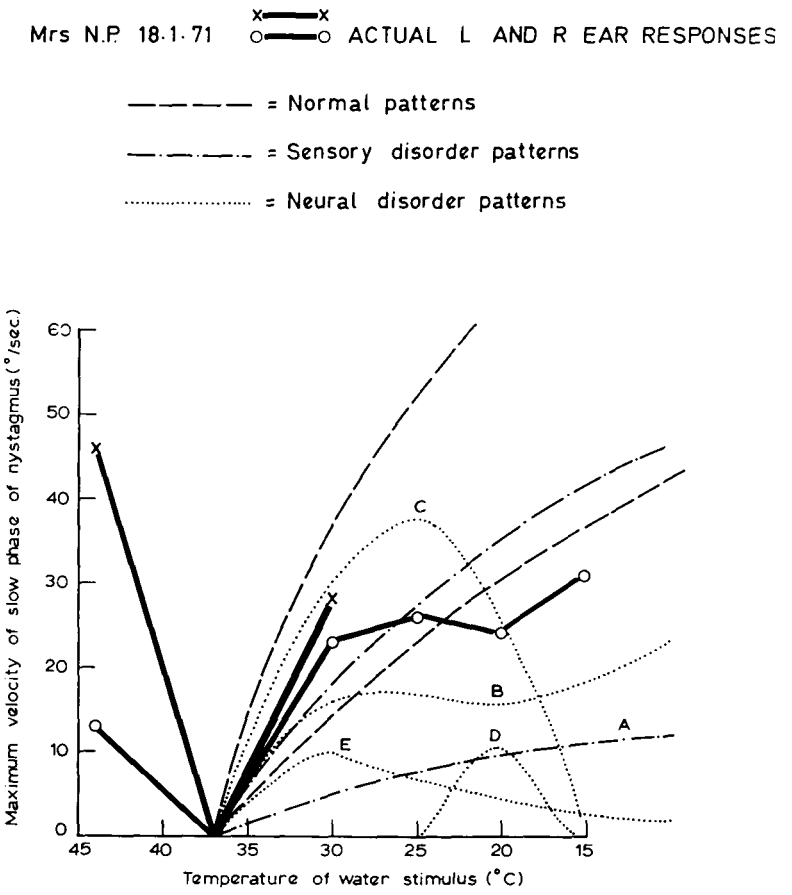


FIG. 7.
Caloric tests and thermal vestibulometry.

of nerve fibre conduction generally rather than of the central nervous system specifically, and therefore the term 'neural' has been used to describe them.

Some cases of primarily neural pathology, e.g. an VIIIth nerve neurofibroma, appear to masquerade as a sensory disorder however, as may also occur in disturbances of auditory function, presumably because a secondary disturbance of labyrinthine blood supply or a direct extension of the pathological process to the labyrinth produces damage to the

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sensor of a degree which is sufficiently more severe as to dominate the pattern of response to tests. But a dominance of sensory signs in a primarily neural case does not necessarily affect both parts of the auditory/vestibular system; in one case of acoustic neuroma seen recently the auditory signs were of neural type of disorder but the vestibular signs were more suggestive of a sensory lesion. In general though, and in the case of Mrs. N. P. illustrated here, our experience is that at least some cases with peripheral neural lesions show the diagnostically highly significant neural pattern of response. More work needs doing on this technique before its clinical usefulness can be assured. The obvious snag is the inordinate amount of time needed for it, but for selected cases meriting the time needed it seems to us to be most promising.

Electrophysiological and other forms of objective audiometry

There are various electrophysiological measurement techniques which are, or are liable to be, within the scope of audiological practice. When used, they often provide great diagnostic benefits either in differential diagnosis of site of disorder or in objective measurement (i.e. not dependent on a voluntary response by the patient) of the function of certain components, or series of components, in the auditory system. Their scope is limited, however, to components in the range from middle ear to cerebral cortex and none of them provides a complete measurement of hearing.

Thus, they may not indicate any abnormality in the pathways from ear to brain, yet this does not necessarily imply that the auditory signals, transduced to neural events and then transmitted to the brain, result in a consciously perceived sensation. For instance, in hysterical, autistic or aphasic patients the auditory signals may evoke an electrical response in the cerebral cortex but the patient may still be 'deaf' in the ordinary sense of the word, in that he appears not to hear auditory signals in circumstances that normal persons of the same age and development could be expected to hear. But what does 'hearing' and 'deafness' really mean? Most medical and audiological definitions, and the ones used in our own clinical work are more restricted than the everyday usage of these words and stop after the level of consciously perceived auditory sensation. Thus, a hysteric with a loss of conscious auditory sensation could correctly be described as having a hysterical deafness; on the other hand an autistic or aphasic, who was thought to perceive sounds consciously at normal intensities but whose disability was a failure to recognize and understand sounds, would appear not to hear sounds yet would not be truly deaf according to the definition given above. The problems of semantics as well as the limitations of the tests themselves complicate the task of accurate and understandable reporting of the results of objective audiometry. One is forced to such long-winded expressions as 'whilst the clinical appearance was one of deafness, the evoked response audiometric thresholds were

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normal; it seems likely that the disorder is either a functional deafness or an impairment of recognition and/or understanding of sounds.'

In clinical interpretation, and especially in medico-legal interpretation of objective audiometric tests, one must therefore exercise great care in choice of words used to describe what these tests have revealed. This, in turn, depends on careful consideration of what parts of the auditory system each objective test procedure has in fact tested. A useful schematic diagram to aid this is shown in Fig. 8. This is a modification of the

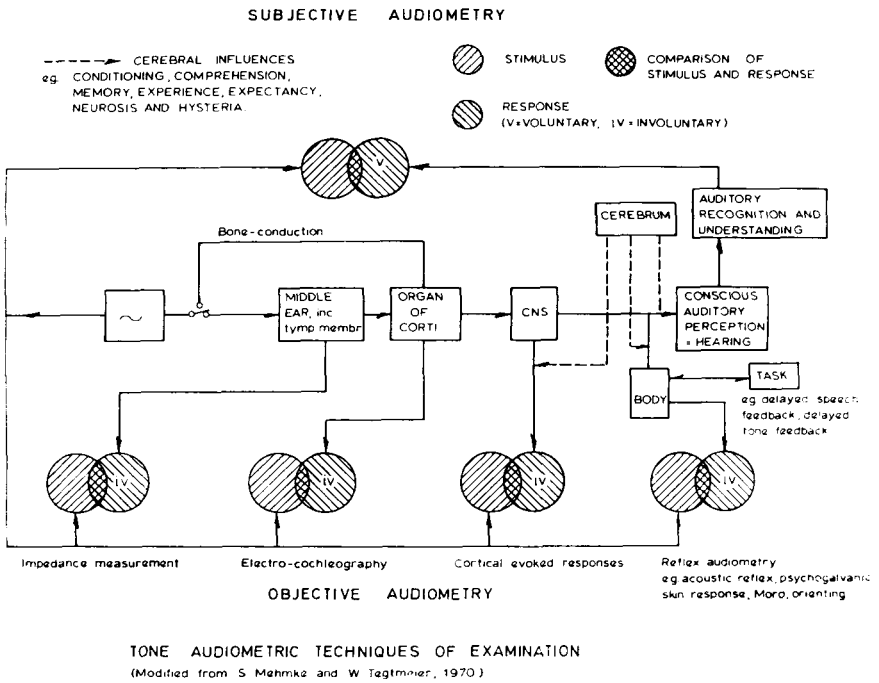


FIG. 8.

Objective and subjective audiometric tests in relation to components of the hearing mechanism (modified from Mehmke and Tegtmeier, 1970).

scheme published recently by Mehmke and Tegtmeier (1970) and embodies most of the objective tests applicable to clinical audiology.

Much has been written and spoken about evoked (or electrical) response audiometry (E.R.A.) in recent years, and as this has not already been described in this paper, it is relevant to expand on it slightly now. Strictly the term should have 'cortical' preceding it as there are a whole range of auditorily evoked responses which can be utilized for audiometric purposes, e.g. an involuntary movement, a change in skin resistance, an acoustic reflex, an VIIIth nerve action potential. Others have used more precise terminology such as electroencephalographic (E.E.G.) audiometry

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or evoked vertex response audiometry, but for the purposes of this paper the procedure will be referred to simply as E.R.A.

The principal clinical uses of E.R.A. can be summarized as providing an objective audiometric measurement in those who cannot or who will not respond voluntarily to conventional audiometric procedures. The 'cannot' variety is comprised mainly of infants and young children, and the 'will-not' category mainly of older children or adults with non-organic hearing loss. Whilst the test is nearly always successful in the latter, it has provided many disappointments in the former.

There are three main problems with E.R.A. in children. The first two affect all types of children; their E.R.A. patterns have greater inter- and intra-subject variability, and the children tend quickly to become bored and either go to sleep or start to fidget. This alters the E.E.G. pattern which, respectively, may upset the quantitative value of the E.R.A. or provide so many transients in the E.E.G. and artifacts in the summed evoked responses as to render them difficult or impossible to interpret. The third problem is that the kinds of child for whom E.R.A. has the greatest potential value, because of difficulty in testing by conventional paedo-audiological techniques, are those children with central nervous system disorders either causing their apparent deafness or complicating an auditory system lesion. Again these may be so hyper-kinetic or have such abnormal E.E.G.s anyway that E.R.A. provides little if any reliable additional information on them. In our experience, about one-third of the children referred for E.R.A. fall into this group. In another third, the tests provide rather limitedly useful information, sometimes little more than confirmatory to conventional assessments, In the last third, however, E.R.A. has provided information of the greatest value.

It is hoped that current research, in our laboratories and in many others in this country and overseas, will improve further the clinical value of E.R.A. in children. But one aspect is already quite clear and will not change. Whilst E.R.A. can be a most powerful and valuable technique for audiometry in children, it cannot and must not take the place of any of the more conventional methods of paedo-audiological assessment; it can usefully supplement them, not replace them.

The same usage, and limitations imposed by expense, time and skills, seem likely to apply to the still newer technique of electrocochleography (E.Co.G.). In this, electrodes in or around the ear pick up the VIIIth nerve action potentials resulting from auditory stimuli delivered to that ear. These are then amplified, analysed and displayed. With advanced computational analysis, the cochlear microphonics may also find clinical usage.

The type and siting of electrodes used in E.R.A. and E.Co.G. is shown diagrammatically in Fig. 9, and in the case of E.Co.G. the associated source of acoustic signal is also indicated. For E.R.A., the signal can be a tone burst of known frequency, intensity and duration, and can be

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given by loudspeaker, earphone or bone conductor; and masking of the non-test ear can be used where appropriate. Also, non-acoustic signals using other sensory modalities, such as by light-flash or tactile stimuli, often have great value in differential diagnosis between purely auditory system and more generalized central nervous system disorders. The procedure suffers however from the problems already described, which

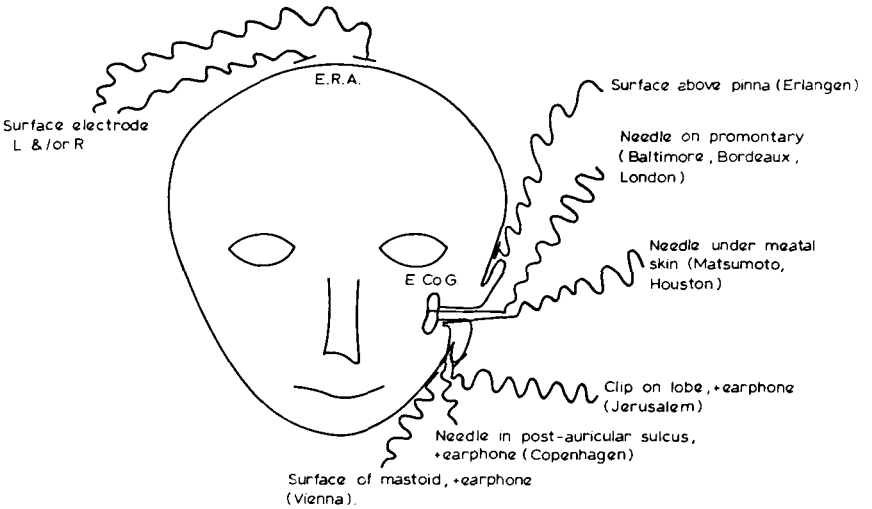


FIG. 9.

Site of active electrodes in cortical evoked response audiometry (E.R.A.) and electrocochleography (E.Co.G.).

are related to any factors influencing the E.E.G.; the latter include sedatives, anaesthetics, sleep, fidgeting, hyper-kinesia, and central nervous system disorders.

E.Co.G. on the contrary is more or less independent of these cerebral influences and there is no need for masking of the non-test ear. But as yet it is much less accurate quantitatively in relation to the intensity and frequency of the stimulus, and it is limited to the air-conduction route of stimulation. Stimuli are usually clicks, or at best frequency-filtered clicks. Bone-conduction stimuli may eventually become possible, but in the present state of the art the responses would be obscured due to the microphonic effects associated with the direct vibration of the electrodes. Nevertheless, E.Co.G. has great differential diagnostic potential, especially if the associated electrophysiological and computer technology develops to allow greater use of the clinically more acceptable surface electrodes, also of the bone-conduction route of stimulation, and possibly of the cochlear microphonic responses as well.

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Conclusion

I may be criticized, quite rightly, for complicating the ordinary clinical audiological test procedures which may have seemed up to now to be quite simple, reliable and sufficient. But I am quite unashamed of this because in fact all I have done is to illustrate that audiology, indeed quite often even the basic procedures, is complex. But audiology, and vestibulometry, have potential diagnostic advantages that reach far beyond their currently rather limited role in the majority of hospital clinics, the limitation being enforced by the present organization of audiology in the National Health Service.

The potential benefits consist not only of a general extension of diagnostic procedures which would appreciably reduce the proportion of patients in whom diagnosis is uncertain, but also of a much greater precision in application and interpretation of those techniques already in use. For the former, persons of scientific officer level and specialized facilities would be needed, perhaps on a regional basis. The latter involves provision of more staff generally in order to allow more time for a proper audiological investigation, which of itself means increases in space, equipment and remuneration, together with a drastic elevation of the minimal and/or inexpert training that many audiology technicians at present receive; it also includes introduction of advanced training courses for and posts of, at least, technical officer status.

I hope, therefore, that I have been successful in this lecture in so illustrating the diagnostic advantages to be gained that you will consider the complexity, additional staff, equipment and facilities to be more than justified. My hope for this success is because I am convinced that present-day, and future, audiology has a very worthwhile place in the clinical practice of otology. I am therefore most grateful for this opportunity of outlining the various fields in which modern audiology, including vestibulometry, really has a very great deal to offer you and your patients.

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Progress in objective audiometry

By H. A. Beagley (London)

Classically, audiometry is an application of psychophysics, where the patient's ability to respond to a measured stimulus is determined. This implies that the patient must be cooperative and that he participates actively in the test, making his own judgment as to the detectability of the stimulus (always a sound of known intensity in audiometry) and signifies this fact by making some conscious response. Tests of this type are generally referred to as being subjective, as the patient's subjective judgment is the critical factor. The subjectivity of classical audiometry implies no criticism of such methods. The reliability and repeatability of classical audiometry are beyond reproach in the great majority of instances.

However, in a small but important minority of clinical cases the necessary cooperation, participation and judgment of the subject under test cannot be ensured and the results are either unobtainable, or suspect on various counts. For this reason, methods have been sought which deal not with the subjective response of the patient, but with some other measurable criterion which the tester himself can evaluate. Such methods are often referred to as being 'objective', although the term is perhaps a little too naïve in some ways, as it suggests that subjective judgment is eliminated. This, of course, is not the case at all. It simply means that the measurement of the criterion selected is the task of the tester who must make the necessary judgment and this in itself is quite subjective. However, in dealing with unwilling or uncomprehending subjects, such a re-allocation of the task of judgment from the tested to tester has obvious attractions. It is not therefore surprising that efforts to devise suitable methods of 'objective' audiometry have continued for several years and this seems a good point at which to review progress in this direction.

In seeking to avoid the problems brought about by using psychophysical measures in certain difficult cases, it is apparent that the most likely area in which to seek suitable test criteria is the field of physiology. For this reason, audiometric tests depending upon conditioning procedures have been extensively investigated, despite the fact that the physiological phenomenon of classical or Pavlovian conditioning has a strong psychological content, while instrumental or operant conditions lie even more within the psychological domain. Nevertheless, such methods meet some of the requirements of 'objective' audiometry and should be included in such a general classification. In addition to this, they can be extremely useful methods.

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Classical or Pavlovian conditioning

Pavlov's investigation of the conditioned reflexes of animals is too well-known to require a detailed description here. Many of his experiments involved the measurement of salivary or gastric secretion in response to the placing of food in the animal's mouth. The animal was therefore entirely passive and the response measured was mediated through the autonomic nervous system over which the animal had no control at all, or only tenuous control. The interesting thing about these inborn reflexes was that the stimulus response could be 'generalized' by association with the original unconditioned stimulus (e.g. food), A bell, sounded when food was presented, came, with repetition, to be an effective stimulus in its own right, so that the autonomic response of salivation would occur when the 'conditioned stimulus' (ringing of a bell) was employed in the absence of food. Pavlov considered with some justification, that such conditioned reflexes were dependent upon the activity of the cerebral cortex, and certain mechanistic theories of human behaviour were erected on the basis of his findings. However, such theories proved untenable when it was discovered that decorticated animals can be conditioned, albeit with some difficulty.

The psychogalvanic skin response (P.G.S.R.) was the name of an audiometric technique devised to exploit Pavlovian principles as a hearing test. It used as its essential indicator an autonomic response (sudomotor activity in the skin) in response to a painful somatic stimulus (electric shock) with which an auditory stimulus was associated. The principle of stimulus generalization led to this becoming a conditioned stimulus which would produce the reflex independently. Thus we have the framework in which a patient can become conditioned to produce a physiological response to sound which resulted in increased skin conductivity that was easily demonstrated as a deflection on a meter.

Although fulfilling many of the criteria of an objective test, the P.G.S.R. very largely fell into disuse on account of the variability of the results it produced which severely limited its usefulness. It is, however, still retained in some audiological centres as a method for detecting malingerers claiming to be deaf.

Operant or instrumental conditioning

Although operant conditioning is a psychological rather than a physiological phenomenon, it has been applied to audiometric testing with some success although the tests employing such principles are not really objective. Operant conditioning is actually a form of 'behaviour shaping' where the overt response of the subject to a perceived stimulus results in a reward which further reinforces the responsiveness of the subject. The operant manœuvre, in experimental conditions using animals, is pressure

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on a bar which releases a pellet of food. In audiometry, the operant response to a sound is button-pressing which releases a reward either tangible (food) or social (approval, or the illumination of picture or the activation of a mechanical toy). This is the principle used in the well-known peepshow developed by Dix and Hallpike. Later, Lloyd and co-workers in Kansas, dealing with retardates employed a reward and 'punishment' method of reinforcement. Here the reward for a correct response is the release of a sweet when the response button is pressed. The mechanism of the instrument is arranged so that it will respond in this way for a fixed period after the cessation of the test tone. A subject who falsely responds, or simply presses the button continuously, is 'punished' by the fact that the whole mechanism becomes inoperative for a time which discourages such false-positive responses. The Kansas group got good results with severe retardates of up to about sixteen years of age. Proctor and Dempster employed an essentially similar, but simpler, arrangement for testing very young non-retarded infants, down to two years of age, also with very satisfactory results. Proctor and Dempster's method, described as Reinforced Response Audiometry, is in regular use in the Nuffield Hearing and Speech Centre, London.

Biophysical measurements

Measurements of the acoustic impedance of the middle ear have assumed an important place in otology and to a certain extent also in audiometry. The first investigator to measure the acoustic impedance of the ear clinically was Metz, but most of the subsequent progress in this field is due to Terkildsen and his associates. Mention must also be made of the very fine acoustic bridge designed by Zwislocki, but this has not proved particularly popular as a clinical tool and is used mainly for research purposes. On the other hand, the electro-acoustic bridge favoured by Terkildsen's group has now become an almost indispensable adjunct to clinical diagnosis in otology.

The electro-acoustic bridge most widely used today measures only one component of the acoustic impedance, namely the *stiffness*, which is analogous to the capacitative susceptance in electrical impedance (a pure tone is analogous to an alternating electrical current in this respect). Actually the reciprocal of the stiffness is measured and this is called the *compliance*. Thus, a middle ear with a high stiffness has a low compliance, and vice versa. Furthermore, the compliance of the middle ear can be plotted at various positive or negative meatal pressures, the meatal pressure being regulated by a pump which is an integral part of the bridge. As the compliance of the middle ear is at its maximum when the air pressure within it is equal to that in the meatus, this gives a method of measuring the intra-tympanic pressure. The typical peaked curve of the normal ear is shown in Fig. 2 where the compliance is plotted as the

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equivalent compliance of a certain volume of air, at various meatal pressures. Note that the peak of the normal compliance curve is at zero (middle ear and meatal pressures equal) or slightly negative. A blocked Eustachian tube causes the peak of the curve to be displaced in a negative direction as shown in Fig. 2, while a middle ear completely full of fluid (e.g. 'glue' ear) has little compliance and does not come to a peak. This

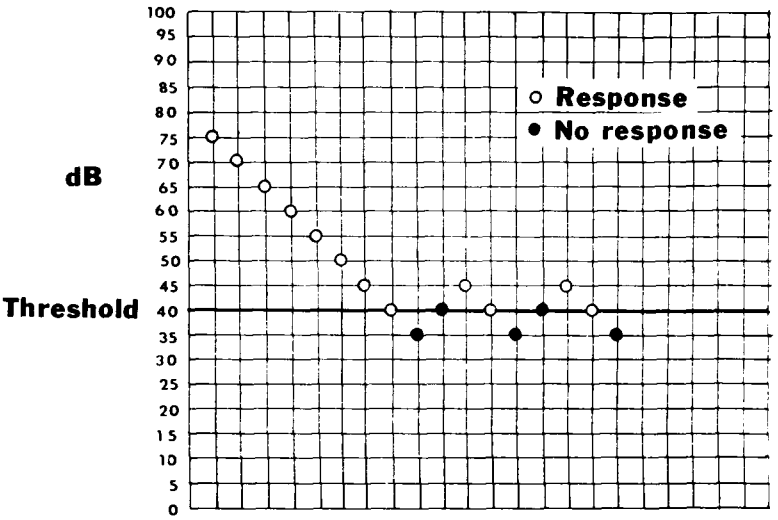


FIG. 1.

This graph shows how the auditory threshold is established by Reinforced Response Audiometry. The threshold, as shown by the heavy line, corresponds to the hearing level in decibels at which the patient gives a positive response as often as he gives a negative response. This patient was aged 2 years 11 months and the tone used in this test was 1,000 Hz.

is the most sensitive test to date for the presence of 'glue' ear and surveys in the Manchester region by Brooks have shown its usefulness in locating this common cause of conductive deafness in young school children, for which specific surgical treatment is available.

The intra-aural muscles can also be tested by means of the electro-acoustic bridge, and the stapedius reflex is of value in audiometry as well as in general otological diagnosis. The threshold of the reflex is about 80 dB H.L., 70–90 dB being the usual range. Conductive deafness, e.g. otosclerosis, or scarring due to healed otitis media, results in an absent stapedial reflex, as does an ossicular discontinuity, except in the case of fracture at the level of the stapedial crura. In the case where there is no conductive element to the hearing loss, the stapedial reflex can be used as an index of cochlear function and is of particular value in investigating a case suspected of having a non-organic hearing loss. One factor, however,

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must be considered, namely, that recruitment may result in a reflex at sensation levels much less than the expected 70–80 dB, in some cases.

Neurophysiological tests

The most promising of objective audiometric tests are those based on neurophysiological recordings, in particular the auditory evoked cortical

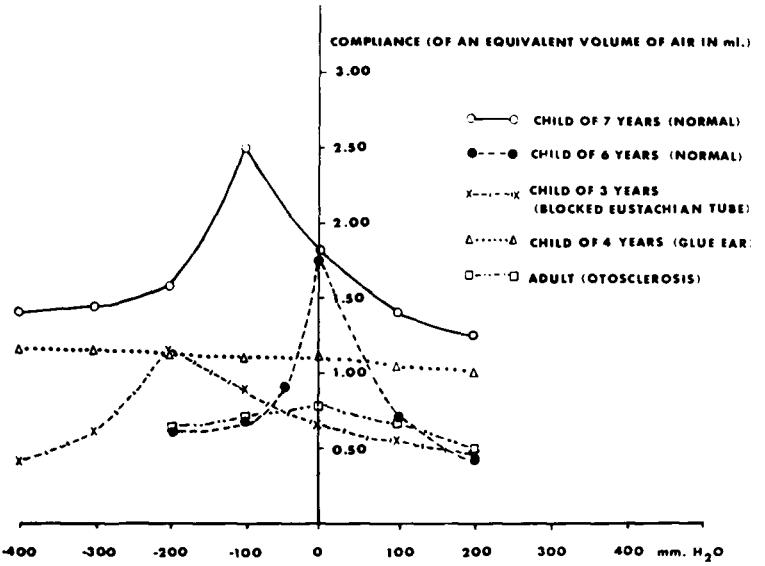


FIG. 2.
This shows compliance curves of a number of patients. Compliance of the middle ear expressed as equivalent millilitres of air was plotted against meatal pressure expressed in millimetres of water.

response. As several such tests are under development, the term 'Electric Response Audiometry' tends to be applied generically to this group.

These methods are subdivided as follows:

A. Central recordings
1. Auditory Evoked Cortical Response;
2. Contingent Negative Variations (of Grey Walter);
3. Acoustically Invoked d.c. Potential Shifts (Keidel and co-workers).

B. Peripheral Recordings
4. VIIIth Nerve Action Potentials (electrocochleography);
5. Cochlear Microphonics.

A. Central recordings

1. *Auditory evoked cortical response*

This method has proved of such interest to physiologists, otologists and audiologists over the last five or six years that an extensive biblio-

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graphy has already grown up around it. Basically the method consists of using a small averaging computer to summate the small cortical potentials which are otherwise too small to visualize directly in the electro-encephalogram. The method of electronic summation was introduced by Dawson in 1954 and was later applied to audiometric techniques, being associated at an early stage with the names of Williams *et al.* (1964), Davis (1964) and Keidel and Spreng (1965), and others.

The evoked response method is now becoming quite widely practised and accepted and results of validation experiments show that the test is almost as sensitive as pure tone audiometry in the case of adults and older children. The majority of adults show a loss of sensitivity of only 5–10 dB, or even less, when evoked response and pure tone thresholds are compared (Beagley and Kellogg, 1969). The method is useful in the case of adults who are unable to participate in conventional audiometric tests either because they are too confused or uncomprehending, or because they have a non-organic hearing loss (Beagley and Knight, 1968). In fact, the evaluation of non-organic hearing loss is one of the most important

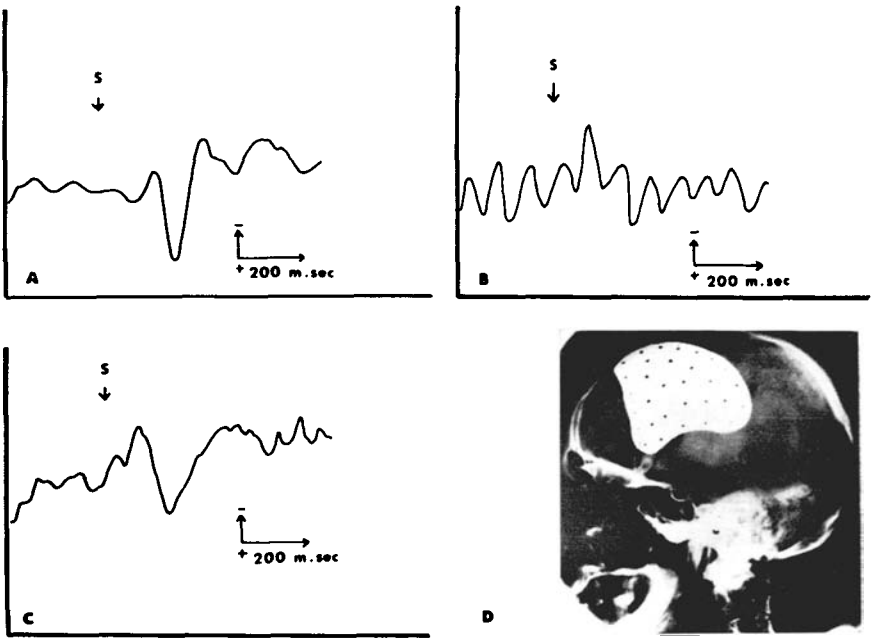


FIG. 3.

(A) This shows the auditory evoked response obtained from a boy of 6 years with cerebral palsy. His auditory threshold was established without difficulty.
(B) This trace was taken from an adult patient whose E.E.G. record was characterized by regular 'sinusoidal' wave-form suggestive of mu-rhythm. This caused some difficulty in establishing the precise threshold.
(C) This curve was obtained from an adult patient who had suffered a head injury and a skull fracture requiring repair by a large metallic plate, as shown in (D). No difficulty was encountered in establishing this patient's auditory threshold.

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uses of this technique in the case of adults and is likely to become more important if noise-induced hearing loss becomes prescribed as an industrial disease in this country (Coles and Priede, 1971). Passive cooperation is all that is needed to test adults. Epileptiform discharges may make the method inoperative during attacks, and in cases where there is a persistent alpha-like rhythm, or mu-rhythm, which is summated by the computer. Technical methods could be devised to overcome these problems, if they were considered as being of sufficient importance. In practical terms, retesting another day usually suffices. Cerebral palsy does not seem to impair the efficiency of the test and gross trauma to the skull and cortex may not impair it in many cases. One patient who suffered a severe head injury necessitating the insertion of a metallic plate of eight square inches in the fronto-parietal region of the skull was tested without difficulty (Beagley, 1970).

It is in testing very young children that much has been hoped for from the evoked response method—and it is fair to say that much has been achieved in this area, although there are still a number of problems to be solved. Children give larger and more variable responses which decrease the accuracy appreciably in many cases, leading to a gap in sensitivity of about 20 dB in children of two years and under, rising to about 40 dB in the neonatal period. Even passive cooperation cannot always be ensured with children, and in fact many of those in need of testing are extremely hyperactive. Fortunately, the evoked response can be elicited in the sleeping state, even under sedation. The latter introduces another very important variable into the test and one that has not yet been fully evaluated. Barbiturates are regarded with suspicion in this regard, but the writer has had encouraging results with intra-muscular Phenergan (Promethazine Hydrochloride) and studies are proceeding systematically.

In spite of some of the problems of testing these very young children, the disadvantages should not be over-emphasized, as no alternative method of constructing an audiogram exists in this age group. The 'sensitivity gap' which may be as high as 40 dB in the neonate, similarly does not invalidate the method. Even a relatively coarse measurement is far superior to mere subjective assessment based on observation and clinical impression in these extremely difficult children that one is sometimes called upon to examine. And while the sensitivity of the test may leave something to be desired in the very young infant, it is only rarely that an evoked response test gives a completely indeterminate result.

Further experience with sedation combined with refinements in the method of signal extraction, will probably do a great deal to minimize the above shortcomings. But if these methods are unavailing, it is possible that the electrocochleogram (see below) may provide a simpler and more

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direct test for the very young infant, allowing the measurement to be made under general anaesthesia.

2. *Contingent negative variations* (*C.N.V.*)

This phenomenon was described first in 1964 by Grey Walter and co-workers who elicited it during operant conditioning and in fact it seems to represent the physiological correlate of that procedure. It is shown as a d.c. variation (or 'expectancy wave') which develops as the subject is conditioned to respond to a particular stimulus. As it is related to the subjective significance of the signal, efforts have been made to use it as an objective test of the semantic content of a signal and it has been suggested as a method of 'objective' speech audiometry. The results at this stage, however, are as yet inconclusive, although there have been encouraging reports from Burian *et al.* (1969).

3. *Acoustically induced d.c. potential shifts*

Since Grey Walter described the contingent negative variations, Keidel and his group have demonstrated another phenomenon which is also in the form of a negative d.c. shift, similar to that described by Grey Walter, but whereas the C.N.V. occurred as a result of operant conditioning, Keidel's potential occurs and is co-extensive in time with a long pure tone stimulus of 1–1½ seconds duration. It appears to be related to attentiveness of the subject but unrelated to expectancy. Its significance at this stage as far as audiology is concerned is difficult to assess, but as it is clearly related to higher auditory functions, it could well have some practical application to the future.

B. Peripheral recordings

4. *VIIIth nerve action potentials* (*electrocochleogram*)

Recording from the round window of the middle ear during surgical operations has been attempted intermittently for many years, with variable results, mostly disappointing. The use of the averaging computer, however, has meant that extraction of the VIIIth nerve action potentials from the cochlear microphonic can now be undertaken with a much greater prospect of success. Yoshie in Japan, Sohmer and Feinmesser in Israel, and Portmann, Aran and Le Bert in Bordeaux are the three groups who have been very active in this field. Yoshie first recorded the action potential (A.P.) from the external auditory meatus, as did Feinmesser. But Aran and Portmann got greatly improved results from introducing a fine penetrating electrode through the tympanic membrane so that it makes contact with the promontory. Recently, Yoshie has also changed over to the use of a penetrating electrode (personal communication).

The stimulus generally used for electrocochleography is a sharp acoustic click. Pure tones are less suitable as stimuli. This means that,

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unlike the auditory evoked response test, it is impossible to obtain direct information in the frequency domain from such an acoustic stimulus. Aran has attempted to overcome this by indirect methods which are intended to indicate the probable slope of the audiogram (i.e. what the configuration of the audiogram would be if it were obtainable). He does this by using both a *click*, which stimulates the cochlea from base to apex, and a high frequency tone pip of about 8 kHZ., the effect of which is exerted solely in the basal region of the cochlea. From the data derived using these two stimuli the general configuration of the audiometric curve is postulated.

The outstanding problem with the electrocochleogram is that of getting accurate frequency information. Its great advantages are (1) that it can be carried out under general anaesthesia, and (2) as one records from only one ear at a time it is unnecessary to be concerned with masking in any form whatever, which is a unique advantage. In Fig. 4 (*a* and *b*) can be seen summated A.P. traces from both a human subject and from an experimental animal, while Fig. 4 (*c* and *d*), supplied by courtesy of MM. Aran and Portmann of Bordeaux, shows A.P. recordings from a three-year-old infant who was otherwise untestable on account of recurrent convulsions.

5. *Recording of cochlear microphonic*

This potential has been used as a physiological index of cochlear function in experimental animals for many years. Its use has been applied with varied success to the assessment of hearing in humans. Yoshie and Ohashi (1969) has succeeded in extracting this response in humans, using the averaging computer, but the level at which it is detectable was high, about 80 dB H.L., which made it of limited value. Recently, a method of signal extraction, somewhat similar to autocorrelation, using a 'lock-in' amplifier has been introduced, which allows the cochlear microphonic to be picked up from an electrode in the external auditory meatus. Keidel and co-workers (1971) are currently using similar methods in human subjects, recording from the earlobe and the hard palate. Methods such as this indicate the type of tests of cochlear function that may be evolved which could well be of assistance in audiometric assessment in the future. But at present the only neurophysiological tests that have come into practical clinical use are the evoked response test and the electrocochleogram. And it can be seen that these two tests used together in suitable cases will clarify the question as to whether or not there is a 'central' deafness present, as it is claimed from time to time, but which it is otherwise very difficult to prove.

This brief review of objective methods of hearing assessment, both in clinical use and in the process of development, will give some idea of how such methods can be applied to the elucidation of difficult audiological

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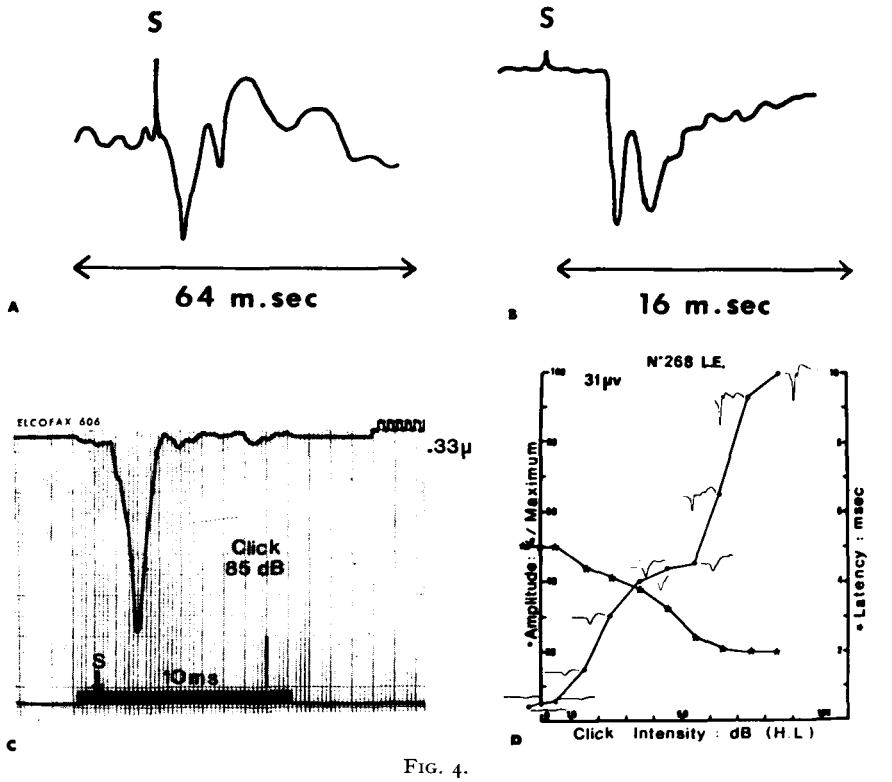


FIG. 4.

(A) This is an VIIIth nerve action potential obtained from an adult patient, who was suffering from a conductive hearing loss.

(B) This trace shows the action potential from a guinea-pig. In each instance acoustic clicks of 100 dB peak equivalent S.P.L. were used and the recording was taken from a trans-tympanic electrode which made contact with the medial wall of the middle ear overlying the basal turn of the cochlea.

(C) This shows an VIIIth nerve action potential on a 3-year-old child.

(D) This is an input/output curve of the VIIIth nerve action potential from the same child versus click intensity. The latency is also plotted on the same graph.

Traces (C) and (D) were kindly provided by MM. Aran and Portmann (Bordeaux). These unpublished data were taken from a child of 3 years who was otherwise untestable on account of recurring convulsions.

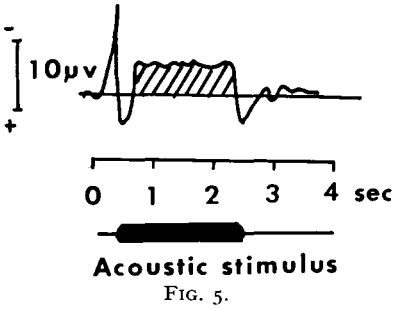


FIG. 5.

This is a sketch of D.C. potential shift demonstrated by David, Finkenzeller, Callert and Keidel (Erlangen, Germany). Note that the onset of the acoustic stimulus produced a typical evoked response as does the offset, but between the two there is a D.C. shift (shaded) which, unlike the evoked response, corresponds with the duration of the steady acoustic signal.

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and otological cases, and how they can be used in the development of appropriate therapeutic and rehabilitative measures.

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