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# The crossed acoustic response

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For many years important advances have been made in audiology, so that the volume of information known about the intricacies of the hearing mechanism is very great. The size and complexity of this information is itself responsible for obscuring the two main trends in the development of audiology and therefore the two main requirements sought by the clinician. No area has been darker than that of the evoked auditory responses and their place among these trends and clinical needs.

The first trend has been a response to the problem of discovering the anatomical site and nature of a hearing defect. It begins no doubt with the Rinne and Weber tuning fork tests. From early differentiation between conductive and perceptive deafness, many tests like loudness balance and tone decay have led to the separation of cochlear from retro-cochlear deafness. In the first of our papers, we postulate that electro-physiological tests based on evoked responses may be used to test the integrity of the auditory pathways in the brain substance. In this way the trend may be developed by the Crossed Acoustic Response to a further division of retro-cochlear deafness into neural and brain-stem causes.

The second requirement has been to measure the hearing acuity and the degree of hearing loss. The most valuable audiological test this trend has produced is pure tone audiometry. Its very simplicity, however, has made it necessary to introduce more sophisticated tests such as speech audiometry. As hearing is a subjective sensation there is no doubt that subjective tests will remain its main method of assessment. There can be no replacement for the intelligent and co-operative patient's description of what he hears. Many cases remain, principally in small children, where



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this co-operation is unavailable and an objective test becomes necessary. In our second paper we will show how the Crossed Acoustic Response offers a simple clinical test which is quick to perform and easy to interpret.

## I. Localization of lesions in the brain-stem

Measurements of the electrical responses evoked by auditory stimuli have been attempted for over forty years. Due to the minute voltages involved little progress was made until the advent of the computer averaging technique. Geisler (1958, 1960) was the first to apply such a method using sound stimuli. Various responses at different latencies from the stimulus have been recorded, some best measured from one place on the scalp, some from another.

The majority of workers turned to the development of the slow cortical evoked response which averages the electroencephalogram and they measured chiefly the V potential centred around the vertex and occurring with a latency of about 100 m.sec. This has been widely used as a measure of hearing threshold but certain problems in its nature as a test have led many workers to develop electrocochleography as an alternative. Both these techniques are discussed further in our second paper.

The response recorded by Geisler occurred within 30 m.sec. after the stimulus and was largest in the region of the inion. These responses with short latencies were shown to be essentially myogenic in nature (Bickford *et al.*, 1963, 1964). It was also shown that the occipital response only occurred if loud sounds were used at levels well above threshold and in some cases could be evoked via the vestibular apparatus. Slight interest had been revived in these early responses when the parietal and post-auricular regions were shown to give responses to low threshold levels in some subjects and when components of the early response were shown to be cortical (Rhum *et al.*, 1967). However, the small cortical response is swamped by the larger myogenic elements as the stimulus level is increased. Kiang (1963) obtained a response from the post-auricular region which was clearly acoustic in origin and was present at low sound levels. Many workers have studied this myogenic response as an objective test of hearing acuity (Lowell, 1965; Milner, 1970), but nowhere has it been found satisfactory, principally because the dependence of the amplitude of the response on muscle tone made it impossible to standardize.

### *The crossed acoustic response*

This response is obtained by first stimulating the cochlea with clicks filtered to various frequencies and then averaging the response obtained from behind each ear on a computer. The details of the equipment and the technique of measuring are described in paper II, but the response appears between 12–20 m.secs. after the stimulus (Fig. 1).



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## The crossed acoustic response

As we have mentioned before, there are many responses, at different latencies, which can be recorded from different parts of the head. In order to reduce the confusion and to place our response (C.A.R.) in its proper context we have produced Figure 2. This shows its relationship to the

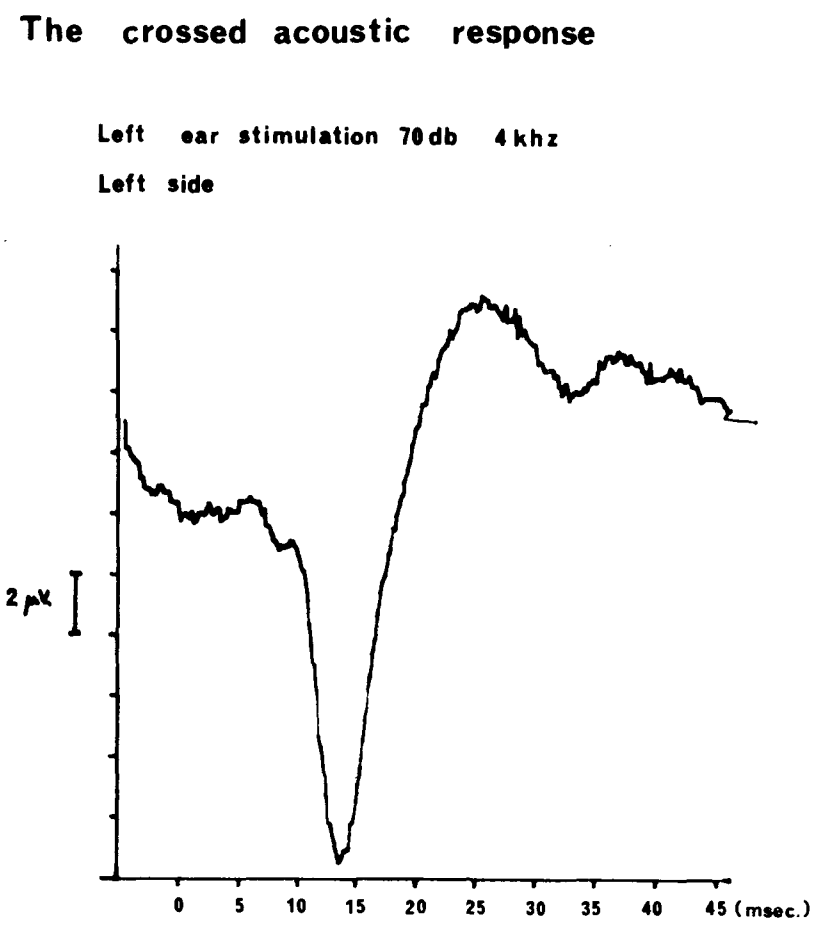



FIG. 1.

The Crossed Acoustic Response as recorded behind the stimulated ear only.

wider and more diffuse Evoked Cortical Response and to the Electrocochleograph (E.C.O.G.). The C.A.R. is therefore a response which can be recorded from behind the ear at a point chronologically in between the two better-known responses.

The origin of this response is still not clear. Our investigation suggests that we are dealing with a complex rather than a simple source. It is likely that at near-threshold levels of stimulus a neurogenic element is



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prominent. There is no doubt, however, that as the stimulus gets louder, the response is swamped by a powerful myogenic element originating in the post-auricular muscle fibres, supplied by the facial nerve and possibly associated with the Y-efferent system. We shall discuss our research on this question in the specialized journals.

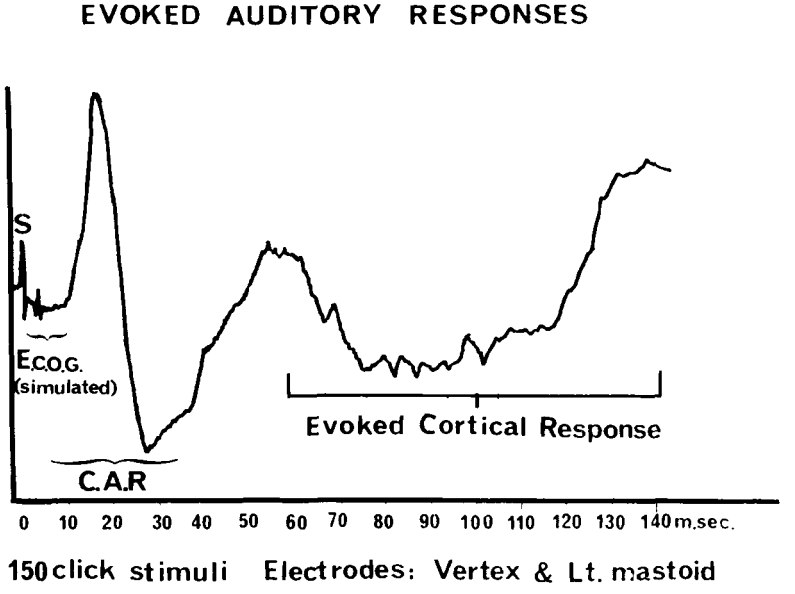



FIG. 2.

This shows the chronological position of the C.A.R. relative to two better-known responses as well as their shapes and frequency. Although the C.A.R. and Evoked Cortical Responses are true recordings from the same person, the ECOG is simulated.
S represents the stimulus.

A reflex arc involving the following pathway is therefore likely:
cochlear receptor — auditory nerve — undetermined brain-stem pathway — motor nucleus — facial nerve — post-auricular muscles.

The existence of such a reflex is no surprise when we consider that the muscles in question phylogenetically mobilize the pinna to locate the source of a sound. A similar reflex in the guinea-pig was described by Preyer (1881) and bears his name. But its latency is only 6 m.sec. and, therefore, must not be confused with the C.A.R. (12–20 m.sec.) as the latency is mainly dependent on the number of synapses in the pathway.

The most important feature of the C.A.R. and the one on which all our work is based has never received much attention in the past. It is the fact that like other central reflexes this one is bilateral and consensual. We have been able to record this response from behind the non-stimulated



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ear and the latency of the cross-over response is exactly the same in all but the occasional case (these may indeed deserve further study).

This equal latency in normal persons suggests that the impulses pass through an equal number of synapses and can be represented schematically in Figure 3. It is the crossed nature of this acoustic response together with

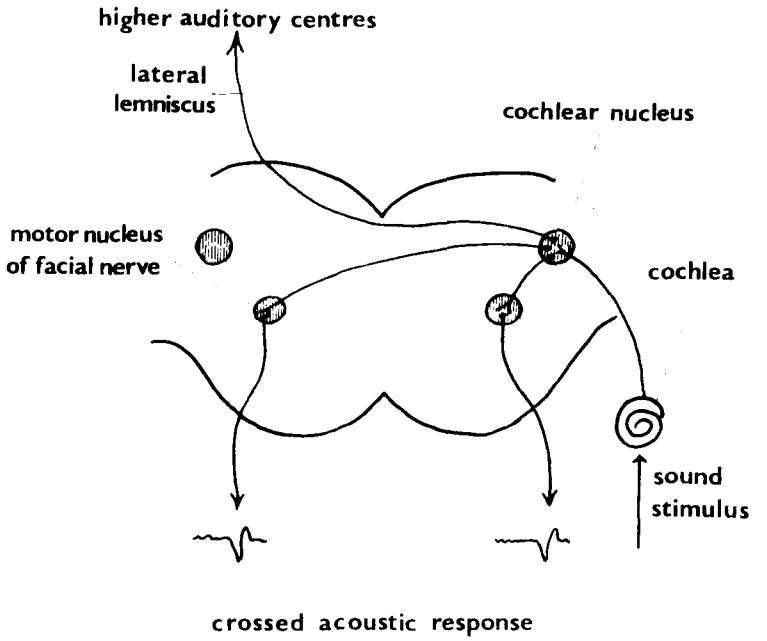



FIG. 3.
Schematic representation of the C.A.R. projection in the brain-stem.

other as yet not fully known aspects of its nature that has suggested the name Crossed Acoustic Response and has allowed us to test its clinical value.

*Theoretical clinical value of the C.A.R.*

Although Figure 3 takes no account of the nature of the cochlear nucleus, of the corpus trapezoideum and its nucleus or the superior olivary nucleus and the efferent pathway, it does stress the fact that the C.A.R. would have to cross the brain-stem.

The theory that we have tested is that a lesion in the brain-stem may interrupt the crossing fibres and thus abolish or alter the C.A.R. Following this central question, we may ask whether a large extra-cerebral lesion pressing on the brain-stem may also affect this response.

The answer to these questions, if positive, would then indicate that the C.A.R. may be a valuable clinical tool.



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*Results of testing for lesions of the C.A.R. pathway*

The subjects fall into three groups:

THOSE WITH NORMAL C.A.R. (Figure 4).

Normal subjects: Twelve people between the ages of 18 and 38 years have been tested. The C.A.R. was present on both sides when each ear was stimulated. There was a slight latency difference between the sides in three cases.

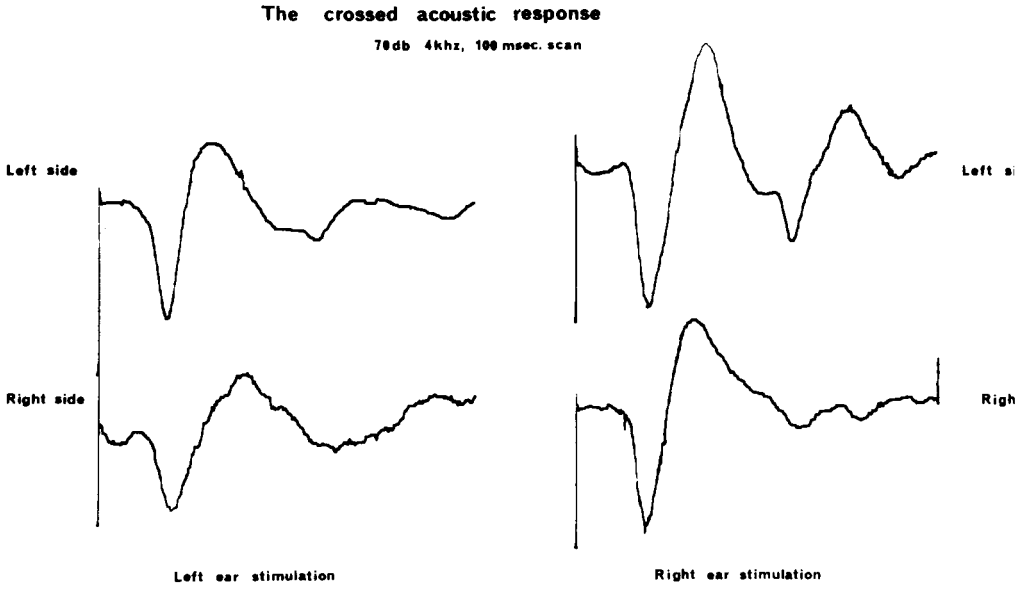



FIG. 4.
Normal responses showing good cross-over.

Patients with cochlear pathology: Twenty-two patients between the ages of 21 and 68 years have been tested. These cases included several known cases of Ménière's disease, acoustic trauma, presbyacusis, tinnitus, and others with unknown recruiting hearing losses. In all of these cases the cochlear nature of the pathology was decided by the history and the audiometric and vestibular tests at present in common use.

Again, in all cases the C.A.R. was present on both sides when each ear was stimulated but the slight latency difference was noticed in eleven cases. This may prove to be of significance in our further studies.

THOSE WITH ABNORMAL C.A.R.

In these patients there was evidence of interruption of the C.A.R. pathway. Seven cases have been studied and for ease of description they will be grouped in the following manner:



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1. *Those with proven lesions*

E.C. A man, aged 45, with pain right side of neck and face, diplopia and total hearing loss right ear.
C.A.R. No response from right ear.
Normal response from left but no cross-over.
He had an astrocytoma which had mushroomed out of the brain-stem to fill the right cerebello-pontine angle.

M.A. A woman, aged 60. Giddiness in 1964 with gradual perceptive hearing loss and tinnitus in right ear. Standard tests indicated retro-cochlear type of deafness.
C.A.R. Left ear normal and normal cross-over.
Right ear abnormal response and no cross-over.
Radiography showed a calcified round lesion the size of a golf ball in the posterior fossa, probably a meningioma.

2. *Diagnosis of brain-stem lesion made on neurological grounds*

A.R. A man, aged 58, unsteady for six months. Had a carcinoma of the bronchus and bladder. *No auditory abnormality other than slight bilateral lowering of thresholds.* Numerous neurological signs, a raised C.S.F. protein and an air-encephalogram suggesting cerebellar atrophy.
C.A.R. No responses from left ear.
Right ear normal response but no cross-over.
Carcinomatous atrophy of the brain or metastatic disease.

E.N. A woman, aged 66, with recurrence of breast cancer. Right-sided non-recruiting deafness tinnitus and vertigo. Nystagmus of central origin. Raised C.S.F. protein. X-ray shows probable metastatic deposits in parietal bone.
C.A.R. Left ear normal response and cross-over.
Right ear abnormal response and no cross-over.
Cerebral disease of carcinomatous origin.

M.B. A woman, aged 57, with advanced carcinoma of the breast not controlled by D.X.R., oophorectomy and hypophysectomy.
Also adenocarcinoma of the stomach.
Rapid onset of hearing loss and giddiness on head-turning.
*Audiogram showed a bilateral symmetrical perceptive deafness.*
C.A.R. Left ear normal response and cross-over.
Right ear normal response on sight but no cross-over.
Cerebral disease of carcinomatous origin.

L.L. A man, aged 49. Onset in 1967 of weakness of the right leg and arm, vertical nystagmus. Micturition difficulties and transient visual disturbance.



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*Normal pure tone audiogram.*

C.A.R. Right ear: broad response on right with normal cross-over.

Left ear: normal response on left but *no* cross-over.

Disseminated sclerosis.

3. *Unknown lesion*

W.A. A man, aged 62. Sudden 50 db right-sided hearing loss of one year's duration. Not deteriorating but non-recruiting. No vertigo. Electrogustometry normal. Recent onset of episodes of right facial spasms.

No other neurological signs.

C.A.R. Left ear: normal response and cross-over.

Right ear: abnormal response and no cross-over.

Extensive radiographic procedure have shown no abnormality. However, the combination of deafness and facial spasm suggest that there is an intra-cranial lesion and the C.A.R. may as a result be a more sensitive test than the procedures used at present.

*Discussion*

It would be premature to try and draw too many conclusions from these early cases. This is not only a new test but a new system of investigation and we suggest that more questions are asked than answered. What does a latency difference represent? Is it associated with a peripheral abnormality? Do the 'abnormal' responses represent a separation of neurogenic from myogenic elements and, if so, what is their significance? Can a crossing cortical evoked response also be used as a test of the integrity of nervous pathways rather than a threshold measure? These questions may take a long time to be answered.

We have, however, found enough evidence to answer the question which initiated this study. A lesion of the brain-stem does indeed interrupt the response and in the Crossed Acoustic Response we have taken a step forward in the assessment of the intra-cerebral auditory pathways. We can offer, therefore, the C.A.R. as a simple, quick and painless test of brain-stem function.

## II. The crossed acoustic response as a method of objective audiometry in children

The needs for objective hearing assessment are obvious. Apart from its use in the diagnosis of feigned or hysterical hearing problems, its most urgent place is in the assessment of young children. Usually the need for such a test first becomes apparent between one and three years after birth, when the child fails to respond to sounds. Often these children have other mental or physical handicaps and their co-operation during any subjective



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test is almost impossible to obtain. Despite the fact that this group urgently requires diagnosis, so far no test has been devised which can give objective information about their hearing acuity without recourse to prolonged testing under heavy sedation or general anaesthesia. The earliest methods of objective audiometry involved various studies such as the measurement of respiration and the psychogalvanic skin response. None of these was found to be of much clinical value in practice and they were abandoned.

Electro-encephalography was the most promising early method. When computer averaging techniques became available the response could be time-locked to the stimulus and the results of many stimuli accumulated and allowed to grow larger whilst the random background 'noise' cancelled itself out. Many potentials of different latency were studied but eventually it was the (70–200 m.sec.) 'V' potential that became the standard method of evoked response audiometry (E.R.A.). There is no doubt of the clinical value of this new tool and it has been widely used. However, in young children and babies there are several difficulties. Firstly, the test takes a long time so the children may grow bored. Sudden movements will obscure the response which may also be difficult to distinguish. These problems can be prevented by sedating the child, but this procedure will then exclude the test from being used actually during the clinic.

Recently electrocochleography has been put on a clinical footing by Portmann and Aran (1971). Recordings are made from the eighth nerve via the fluids of the basal turn of the cochlea by using a needle electrode which pierces the drum to lie on the promontory of the cochlea near the round window. In this way excellent responses near the threshold of hearing can be obtained. As general anaesthesia is required to carry this out in young children it cannot be used as a routine screening test for deafness.

*The aims of an objective test*

Because of the difficulties involved in the techniques mentioned above, we have set ourselves the aim of finding an objective test of hearing which is simple and easy to carry out. Such a test must be painless and acceptable to children without sedation. The results should not be difficult to interpret in subjects of all ages and should give us a good measure of the hearing acuity.

Finally, it should be applicable in a clinical situation and therefore be quick enough for use in a routine clinic, require no elaborate environmental conditions such as electrical screening, or more sound-proofing than necessary for routine audiometry.

*Use of the C.A.R. as an objective test*

Previous attempts to use a post-aural response had been abandoned as being unreliable. This was because the response is dependent on muscle



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tone which may alter and therefore modify the response according to head movements or even tension (Fig. 5). If it is realized, however, that it is indeed a 'crossed' response and recordings from behind *both* ears are made simultaneously on separate channels of an averaging computer, the situation is altered. If the response is damped down on one side by a head

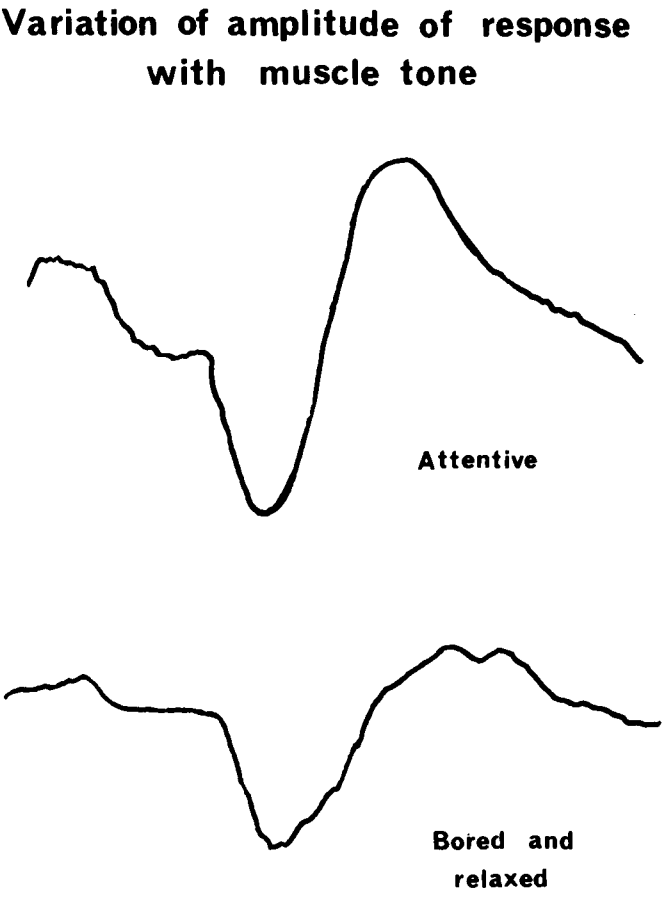



FIG. 5.

movement, it is often enhanced on the other (Fig. 6) so that a response can be detected on one channel or another down to near threshold levels despite constant mobility (Fig. 7).

*The equipment*

The equipment used is summarized as a block diagram in Figure 8. It can also be used for electrocochleography and cortical evoked responses.

The stimulus is provided by a click generator which can produce positive, negative, or alternate phase 0·1 m.sec. rectangular pulses. These



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can then be filtered at 500, 1000, 2000, 4000 and 8000 Hz. so as to give a good indication of the hearing for various frequencies. The pulse generator produces stimuli suitable for cortical evoked responses.

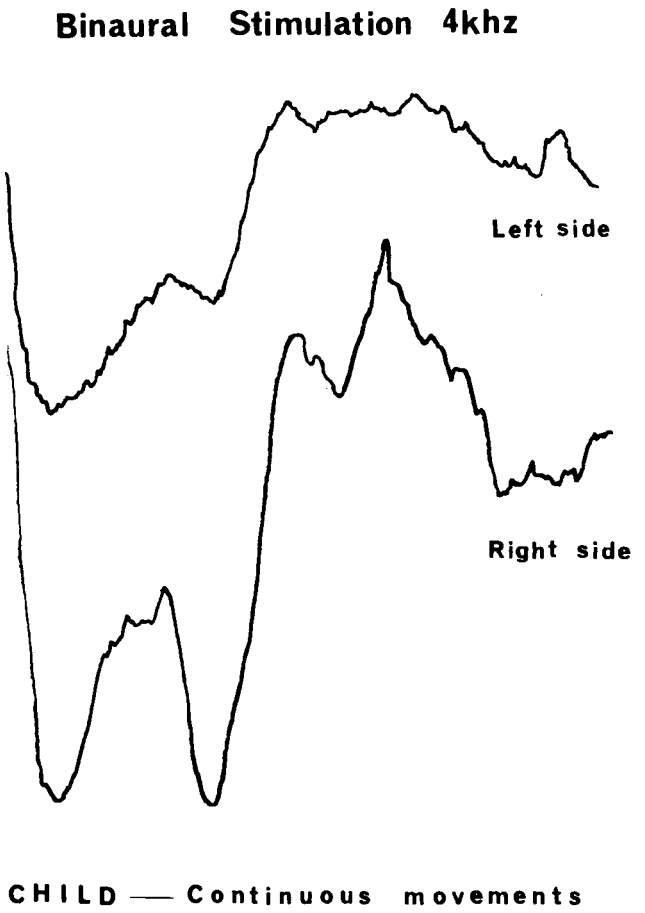



FIG. 6.

In order to use surface electrodes on the mastoid and therefore to avoid the necessity of reducing skin/surface electrode resistance and preparation of the skin we use a pre-amplifier with high input impedance and high common mode rejection.

After an extensive investigation of the possible electrode sites for recording this response we have discovered a site which not only seems to give reliable results but does not involve placing electrodes above the hairline or on the earlobe. Children do not like electrodes being glued into position and these sites allow us merely to press adhesive electrodes onto the skin surface.



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*The technique*

This is employed routinely for all children attending the language and hearing clinics at Guy's hospital.

Each child after being seen and tested subjectively in the clinic is sent to the objective audiometry section of the department. The child is not prepared in any way and often not in the best temper following his subjective testing. The child sits on his mother's lap and the electrodes, having been prepared prior to the child's arrival, are gently pressed into position. Figure 9 illustrates a child being tested. So far only one child has failed

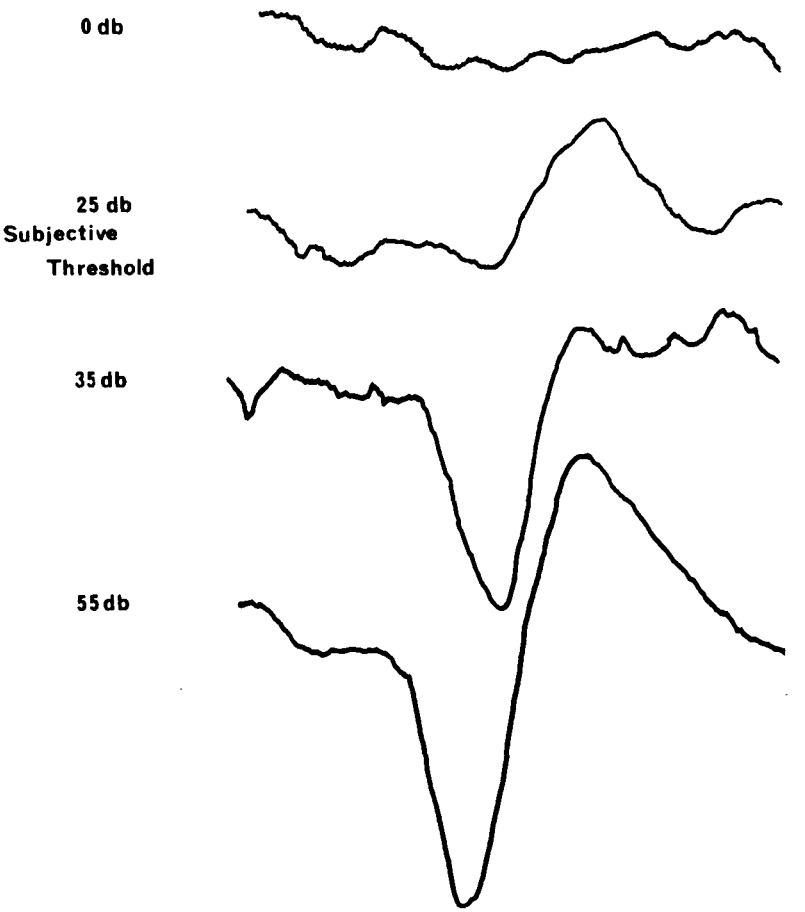



FIG. 7.

Responses can often be detected down to the level of the subjective threshold.



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to co-operate for long enough to test his hearing, but he had been sent to us after repeated attempts at venepuncture had been made.

The earth electrode is placed on the wrist. The active electrodes are placed one on the mastoid process immediately behind the meatus and the other on the neck immediately below the earlobe (Fig. 8). Electrodes

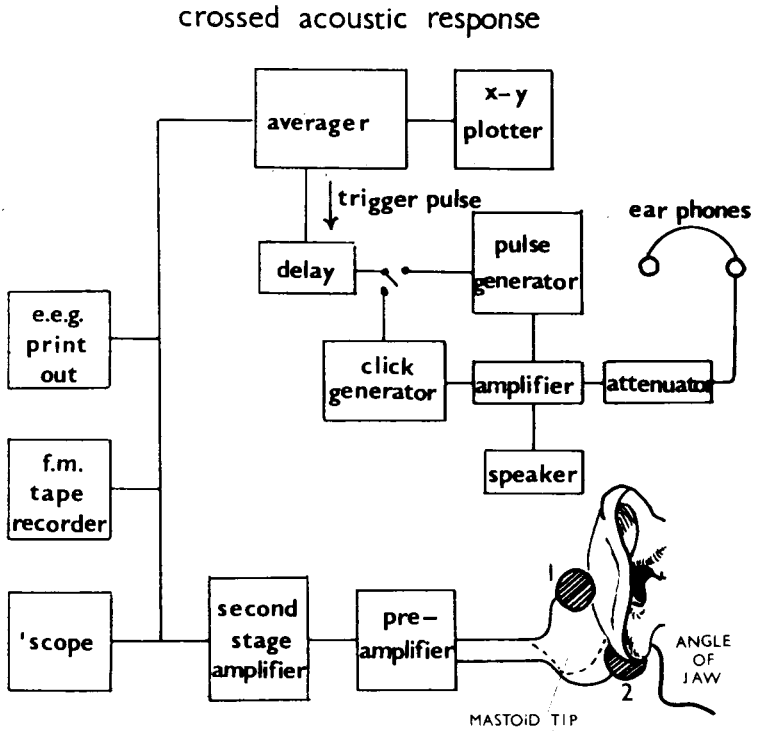



FIG. 8.
Block diagram of the equipment and electrode placing.

are placed around both ears and the responses recorded on two channels so that the better responses can be selected. So far we have not encountered any child who relaxes sufficiently in our company to to make the responses difficult to obtain. Fortunately the short latency responses are clear enough and the latency remains relatively constant so that, despite most children moving during the test session, the results are still identifiable.

A wideband click or various filtered clicks of frequencies varying from 500 c.p.s. to 8000 c.p.s. may be presented either binaurally through a loudspeaker or monaurally through a pair of headphones. If the child is sufficiently co-operative, we try to record one or two cortical responses, usually at levels above threshold, so demonstrating that hearing is occurring at this higher level.



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*The results*

Fifty-two children have been tested. Their ages ranged from 5 months to 11 years. The majority of the children have been between 2 and 5 years old.

Twenty-eight children, some normal and others with varying mental and physical disabilities, have been found to possess normal or near normal hearing since the responses obtained demonstrated that the hearing



FIG. 9.
Child in process of testing.

threshold was at various frequencies under 40 db. Attempts to get responses below this level rarely succeeded because the ambient background noise of the room was high, particularly during crying. Several of these children had been impossible to test subjectively and two had defied earlier attempts at evoked response audiometry.

Seventeen children showed varying levels of hearing impairment. Often the threshold was easily seen and the rapid rise in amplitude of the response suggested recruitment. Children with known conductive pathology, in general, proved more difficult to judge.

Five children only gave limited information since they produced intermittent electrical interference due to gross muscle movement. This activity suddenly obscures the averaged response and makes interpreta-



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ion difficult, though nevertheless possible. There are several known nethods of overcoming this difficulty and we are presently investigating ı method which should remove such interference automatically during the esting.

One child with Hurler's syndrome showed no recognizable responses ınd it was thought later that the latency of the response may have been ıltered.

One child refused to allow the application of the electrodes. He has ılready been mentioned in this article.

*Discussion*

The Crossed Acoustic Response is a new objective test of hearing. Its ıdvantages over the other available tests such as Cortical Evoked Responses and Electrocochleography are important if it is used in the ıroper context. It is a reliable and easily interpreted test of hearing which an be applied quickly and painlessly to patients of all ages in the context ıf a routine clinic and taking little longer than an audiogram. As a creening test, therefore, it has particular use in busy children's clinics, ınd it may find a place in adult compensation cases if they become more ıumerous with changing industrial legislation.

The C.A.R. does not, of course, give us direct information on the ochlea itself but it covers our needs in the vast majority of cases and only he remaining few need be subjected to the trans-tympanic procedure of he electrocochleogram.

## A general conclusion

We have studied the clinical uses and limitations of the Crossed ıcoustic Response in the two discussions.

The need for a general conclusion results from the fact that this reflex .as given rise to two widely different uses and that it may initiate a new pproach to the science of evoked audiometry. Our work in understanding his response and introducing it to clinical practice has suggested some ıoints of a general nature and it is with them that we conclude these ıapers.

Evoked audiometry, and by that we mean cortical evoked as well as he C.A.R. and the many other responses noted but not yet explored, ıill find its true value once the question of objective thresholds loses its ınportance. We feel that the most important use of responses evoked by coustic stimuli will be as an indication of the integrity of the auditory ıathways. These pathways cross the brain in such a manner that a better nowledge of their course, together with monitoring of the impulses which ıass along them, may allow us better and better to localize lesions within he brain.



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Regarding the investigation of hearing acuity, we do not think that mere ascertaining of the threshold of hearing is now a problem but as a corollary that threshold is not now answer enough. Our aim should not simply be to state that a patient, particularly a child, is deaf, but to say if he is deaf at cochlear level, at brain-stem level or at cortical level. Only when we become familiar with this new approach can we again face the real problem of management and treatment.

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REFERENCES

BICKFORD, R. G., GALBRAITH, R. F., and JACOBSON, J. L. (1963) *Electroencephalography and Clinical Neurophysiology*, **15**, 720P.

——, JACOBSON, J. L., and CODY, D. T. R. (1964) *Annals of the New York Academy of Sciences*, **112**, 204.

——, ——, and GALBRAITH, R. F. (1963) *Electroencephalography and Clinical Neurophysiology*, **15**, 922P.

GEISLER, C. D. (1960) *Technical Report*, Research Laboratory of Electronics, Massachusetts Institute of Technology, number 380.

——, FRISHKOPF, L. S., and ROSENBLITH, W. A. (1958) *Science*, **128**, 1210.

KIANG, N. Y-S., CRIST, A. H., FRENCH, M. A., and EDWARDS, A. G. (1963) *Quarterly Progress Report. Laboratory of Electronics*, Massachusetts Institute of Technology, **68**, 218.

LOWELL, E. (1965) *Acta oto-laryngologica*, Supplement 206, 127.

MILNER, BERYL A. (1970) *The physical study of bio-electric potentials generated in response to acoustic stimuli*, p. 268, Ph.D. Thesis, University of London.

PORTMANN, M., and ARAN, J. M. (1971) *Laryngoscope*, **81**, 899.

PREYER, W. (1881) In *Die Seele des Kindes*, Leipzig, T. Grieber. English translation 1888, New York. D. Appleton & Co.

RUHM, H. B., WALKER, E., and FLANIGIN, H. (1967) *Laryngoscope*, **77**, 806.

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