CLINICAL APPLICATION OF EVOKED-RESPONSE AUDIOMETRY*

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During my recent visit to the USA, I was invited by Dr Geary MacCandless, Head of Audiology and Speech Pathology, Division of Otolaryngology, of the University of Colorado, Denver, to participate in a project they were conducting on a series of 128 clinical patients, recording the summed evoked cortical responses to auditory stimuli.

For many years otolaryngologists, audiologists, paediatricians and others who work with acoustically handicapped individuals have expressed a need for an objective method of evaluating auditory acuity. In order to initiate educative and medical rehabilitation, it is essential that auditory dysfunction be carefully described as soon as possible. With children it is important to determine whether a hearing loss contributes to the child's failure to communicate. Careful measures of auditory acuity are also important at the earliest age possible to help define the site of an auditory lesion.

In the past many objective tests have been used to assess the hearing of children who were too young to respond to conventional tests and of other individuals who were unable or unwilling to respond, e.g. the mentally retarded (dyslogic), emotionally disturbed and those with non-organic hearing involvement.

Over 25 years ago the findings by Davis[1] that the electroencephalographic pattern was modified when a sound was heard, led researchers to investigate its possible use as an objective method to test hearing. These attempts have generally proved non-rewarding, because the electrical response in the cortex evoked by auditory stimuli is very small and is obscured in the background activity of the normal on-going brain potentials. These evoked responses are particularly difficult to visualize when an auditory stimulus is presented at low intensity levels. Recently, a variety of special-purpose computers have been constructed which, through a process of summation, extract the small potential from the background of electrical brain activity. Evoked responses which are related in time to the onset of a stimulus are averaged and stored, while the concomitant random activity of the brain is averaged out. This process greatly enhances the signal-to-noise ratio and allows small cortical potentials to be seen against the background of considerably greater amounts of biological noise. This technique, when used to assess auditory acuity, is referred to here as evoked-response audiometry (ERA).

Most research using summing devices has been aimed towards defining those factors which modify the evoked response, e.g. changes in stimulus parameters, stimulus repetition rate, number of observations, and placement of electrodes, etc. Of all the factors which seem to influence the evoked response, stimulus intensity and subject state have the greatest effect, although few reports have described the intensity function as reflected in the evoked response at sensation levels of less than 20 db. sound level.[2-4]

Since the effect of stimulus parameters and other variables on normally-hearing subjects has been rather carefully defined and the test techniques and instrumentation have been developed, the application of evoked-response measures to a clinical population is the next logical step. The present study was designed to assess the clinical usefulness of the evoked-response audiometric techniques on a variety of clinical subjects who were unable or unwilling to give appropriate responses to conventional clinic tests.

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MATERIAL AND METHODS

Subjects

One hundred and twenty-eight patients were seen at this centre for ERA testing, referred by audiologists, otologists and paediatricians. Table I lists the ages of the subjects and the referring diagnosis based on the history and medical evaluation. Ninety-one of the subjects were aged 6 years or younger. These children were referred for testing because they did not respond normally to environmental sounds and to speech. Of interest is the fact that of the 56 children with suspected hearing loss of undetermined aetiology, 26 showed evidence of physical involvement in addition to the suspected auditory deficit, such as brain damage, mental retardation, congenital heart defects, renal disease, congenital facial deformities, blindness, convulsive disorders and prematurity with precarious delivery. Of the 28 patients with suspected non-organic involvement, 24 were adults and 4 were children under 11 years.

TABLE I. AGE-GROUP OF SUBJECTS AND PRELIMINARY DIAGNOSIS FROM REFERRING PHYSICIANS

	Age-group						
Referring diagnosis	*8 days–1 yr*	*1–2 yrs*	*3–4 yrs*	*5–6 yrs*	*7–8 yrs*	*9–10 yrs*	*Adults*
Rubella	3	7	1	1			
Middle ear pathology			1	1			
Meningitis	1	2	1	1	1		
Hereditary-familial	2	2	2				
Foetal anoxia			1				
Ototoxic drugs			1				
Mumps encephalitis		1					
Hyperbilirubinaemia	4		2	1			
Non-organic					2	2	24
Noise-exposure							2
Unknown	18	16	14	8	6		
Totals	28	28	23	12	9	2	26

Procedure

Where possible, formal pure tone and speech audiometric information was obtained before the evoked-response recordings. For all infants, and in other cases where audiometric tests could not be done, the overt responses to speech, pure tones and calibrated noisemakers were carefully recorded, using the techniques usually employed in audiological clinics.

Infants were tested while being held in their mothers' arms or while lying in a crib, while other children and adults were seated on a chair. Most subjects were awake, but the younger children were allowed to doze or fall asleep naturally during the procedure. Testing was done in a sound-proof test suite having an ambient noise level of approximately 35 db. SPL recording electrodes were attached with electrode paste to the vertex on an interaural plane and were clipped to the left ear-lobe. A ground electrode was clipped to the right ear-lobe. The auditory stimuli available were 250, 500, 1,000, 2,000 and 4,000 Hz with a rise and decay time of 20 msec. The tone bursts were 700 msec. in duration, presented every 4 seconds. The stimulus programmer triggered the Enhancatron B-800 summing computer for a total scanning time of one second. The tones were presented via earphones, speakers or a bone-conduction oscillator, as appropriate. The total testing time rarely exceeded one hour. Wherever possible, the ears were tested individually. However, when time was a critical factor, binaural stimuli were presented through a calibrated free-field system. In a few cases retests had to be scheduled because of test artefacts produced by excessively myogenic response due to movement or because of highly variable evoked-response patterns.

A total of 50 stimuli were given for each evoked response and the stored responses were read out on a Houston model HR-98 X-Y plotter. The concomitant EEG activity was monitored, as well as the response being summed on a Tektronic model 502A oscilloscope. In this investigation it was decided to define the evoked-response thresholds as the stimulus intensity which produced a visually detectable response when one with an intensity 10 db. lower did not produce a wave-form which was similar. If the response pattern was not clear, a second measure was made for confirmation of response. An initial test was made at 80 db. hearing level at 500 Hz to serve as a reference pattern for subsequent runs. If no response was seen, the intensity was raised to 100 db. If a response was seen, the stimulus was lowered in 20 db. steps until no definable pattern was observed. The intensity was then increased by 10 db. until the evoked-response pattern was again discernible.

In order to obtain what was considered the most important audiometric information in the least amount of time, thresholds for 2,000 and 500 Hz were measured first (Table II). Other frequencies (250, 1,000 and 4,000 Hz) were then tested where time and behaviour of the subject permitted.

TABLE II. COMPARISON BETWEEN VOLUNTARY AND ERA THRESHOLDS IN 12 SUBJECTS AT 500 AND 2,000 HZ

Subject	Age	Threshold	Right ear		Left ear	
			500 Hz	*2,000 Hz*	*500 Hz*	*2,000 Hz*
G.K.	7	Vol.	5	0	5	5
		ERA	10	10	15	10
M.S.	6	Vol.	15	55	25	55
		ERA	20	NR	40	NR
M.G.	6	Vol.	80	90	75	85
		ERA	80	95	80	NR
R.A.	5	Vol.	85	NR	NR	NR
		ERA	90	NR	NR	NR
L.A.	4	Vol.	70	90	60	80
		ERA	70	80	70	80
S.G.	4	Vol.	65	70	45	NR
		ERA	50	70	45	70
S.C.	4	Vol.	25	50	20	30
		ERA	10	50	20	10
C.B.	3	Vol.	70	60	70	60
		ERA	70	60	70	70
S.B.	5	Vol.	30	50	60	NR
		ERA	50	60	60	NR
J.B.	3	Vol.	60	70	60	70
		ERA	60	60	60	70
M.F.	3	Vol.	100	NR	100	NR
		ERA	100	NR	NR	NR
R.P.	3	Vol.	40	65	40	65
		ERA	30	50	50	60

RESULTS

The typical wave-form has been described in considerable detail.[5,6] Although some investigators feel that the early components of this response might be related to myogenic artefacts produced by muscles of the neck, recent research has demonstrated the cortical origin of the slower vertex potential.[7,8] In normally-hearing adults the evoked response has excellent consistency of amplitude and wave-form and exhibits a similar pattern from subject to subject.

Earlier studies have indicated that ERA thresholds approximate voluntary audiometric thresholds within 0 - 15 db.[2,4,9,10] ERA and voluntary thresholds are not equivalent, since the evoked potential is an electrophysiological measure, and conventional audiometric threshold responses are psychophysical measures. The 2 measures may be compared, but an inherent relationship need not necessarily exist. In practice, however, there does appear to be an approximation of the voluntary to the evoked-response thresholds. Twelve children in the present study were sufficiently mature to respond to play audiometry, thus a comparison could be made between ERA measures and voluntary thresholds at 500 and 2,000 Hz. The voluntary thresholds were usually 5 - 10 db. more sensitive than ERA; however, in patients whose voluntary responses were felt to be unreliable, evoked-response thresholds tended to be lower.

Of the 102 children seen in this study, definable responses at some stimulus level were obtained in 90. Two children on whom no evoked response was elicited gave evidence of profound deafness. The absence of response may have been because no sound was heard. Table III lists the number of cases in those age categories which yielded technically unsatisfactory or unreadable responses; it can be seen that 10 of those 12 with poor recordings were in the 3-day to 2-year group. The most frequent cause of unsatisfactory results was myogenic artefacts, or intermittent electrode contacts resulting from movement.

TABLE III. NUMBER AND % OF TECHNICALLY UNSATISFACTORY RESPONSES FOR EACH AGE CATEGORY

Age-group	*No. in category*	*No. unsatisfactory*	*% unsatisfactory*
8 days - 1 year	28	6	21
1 - 2 yrs	28	4	14
2 - 4 yrs	23	1	4
5 - 6 yrs	12	1	8
7 - 8 yrs	9	0	0
9 - 10 yrs	2	0	0
Adults	26	0	0
Total	128	12	9

Rapid changes in subject state also alter the evoked-response wave-form. A characteristic evoked-response pattern was often absent or modified as a child began to drowse or fall asleep, making interpretation of presence or absence of response difficult or impossible, especially in children below 2 years of age.

Fig. 1 shows the changes in the evoked-response pattern of a normal child, 8 weeks of age, while it was normally asleep, drowsy and wide awake. Fifty presentations of a 2,000-Hz tone at 60 db. hearing level were used as stimuli for each evoked-response measure. All tests were made at 10-minute intervals over a 1-hour period. Specific alteration in wave-form can be seen resulting from changes in the alerting state. These natural changes must be considered in interpreting the presence or absence of the response in tests for auditory acuity.

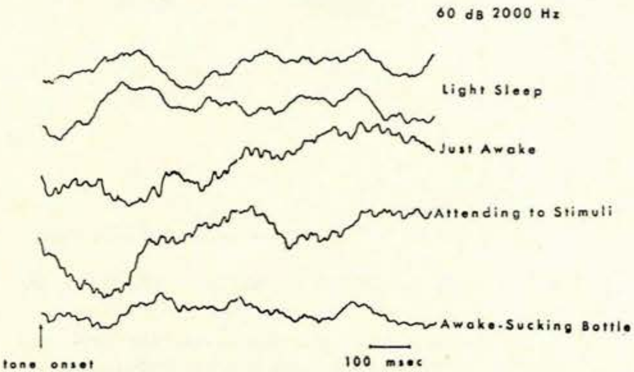

Fig. 1. Differences in the evoked-response pattern as a result of normal changes in the psychophysiological state of an 8-week-old child.

In the present study, 7 of the subjects were tested on more than one occasion and the results on retesting give some indication of the reliability of the method. In children who were cooperative and when the test was technically good, there was agreement to within 10 db. between test 1 and test 2. With children aged 2 years however, no such reliability was found, the retest thresholds often varying by as much as 30 db.

DISCUSSION

At first glance, the evoked-response technique, requiring little cooperation from the subject, appears to be easily adapted to clinical use. While it is true that the procedure requires no active participation, the best results are obtained when the patient is sitting quietly, is awake and is listening. Unfortunately, those for whom the technique is most needed are the poorest subjects, except perhaps older children and adults with non-organic hearing loss. Also, the procedure is time-consuming, requiring 3 - 5 minutes for each evoked-response measure.

Of major concern in the clinical use of ERA are the evaluation and meaningful interpretation of the evoked-response data. It is safe to assume that appearance of an evoked potential indicates that a sound has alerted the patient's cortex, but in no way does it imply that the patient can use auditory information meaningfully. The absence of a response, on the other hand, may not mean the child cannot hear, since some children with brain damage respond overtly to sound, but give inconsistent and sometimes absent evoked responses. The interpretation of evoked-response audiometry, therefore, must be undertaken with extreme caution. The fact that stimuli can be introduced via air conduction and bone conduction permits its use in obtaining conventional audiologic information. In addition, aberrant responses, measures of ER refractory function, may be important as tests for the site of the lesion.

The fact that, in a large majority of children, the tests yielded readable responses is encouraging. If approached with caution, and with the use of selected subjects, the test gives important audiologic information which could not otherwise have been obtained.

SUMMARY

Pure tone stimuli were presented monaurally and binaurally to 128 subjects who were seen at the University of Colorado Medical Centre, of whom 91 were children aged 3 days to 6 years. In general, these were subjects who were unwilling or unable to respond to conventional audiometric tests, but were suspected of having auditory dysfunction. There were 28 with non-organic hearing losses, and 53 had unknown aetiology. Discernible evoked responses were obtained in 90 of the 102 patients who comprised the organic group. In addition, 28 other patients were seen with functional hearing loss or autism. In 12 patients, on whom conventional audiometric tests could be performed, there was fair agreement between evoked-response measures and the subjective tests. In general, the evoked-response thresholds were 5 - 20 db. poorer than voluntary thresholds. In most regular clinical patients, clear tric tests could not be done. These tests agreed well with general estimates of the patient's functions, as determined by overt response to speech and pure tone stimuli.

The clinician considering the undertaking of an ERA testing programme should be cautioned that it is often difficult to detect responses near threshold because of movement artefacts, and that changes in subject state make identification of the response difficult in many cases. Therefore, interpretation of the data should be made only by extremely experienced personnel. Given experienced personnel, evoked-response audiometry can assume a place in the clinic as part of the audiometric armamentarium of the audiologist.

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