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The assessment of vision and hearing by means of evoked potentials

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OPSOMMING

Die rol van die Breinstam Ouditiewe Ontlokte Potensiaal in die beoordeling van gehoorverlies sowel as die Patroon-omgekeerde Visuele Ontlokte Potensiaal in die beoordeling van visuele akuiteit is bespreek. Pasient-en-stimulusfaktore wat potensiale beinvloed word beskryf. Sewe-en-negentig pasiente wat na die Afdeling Neuropsigologie vir beoordeling van gehoor verwys is is ontleed en vergelyk ten opsigte van: ouderdom, verwysingsbron, rede vir verwysing, sedasie wat benodig is vir toetsing en resultate. Nege gevalle wat verwys is vir die bepaling van visuele akuiteit is ontleed op dieselfde manier. Moontlike redes vir verwysings patrone en die relatiewe sukses van albei prosedures is bespreek. Sekere gevalle illustreer die nuttigheid van hierdie prosedure by kinders wat moeilik is om te toets.

SUMMARY

The role of the Brainstem Auditory Evoked Potential (BAEP) in the assessment of hearing loss and the Pattern-reversal Visual Evoked Potential in the assessment of visual acuity is discussed. Patient and stimulus factors influencing potentials are described. Ninety seven cases referred to the Division of Neuropsychology for hearing assessment were analysed in terms of age, source of referral, reason for referral, sedation required for testing and results. Nine cases referred for visual acuity assessment were simmilarly described. Possible reasons for referral patterns and the relative success of each procedure are discussed. Cases illustrating the usefulness of these procedures in difficult-to-test children are presented.

THE ASSESSMENT OF VISION AND HEARING BY MEANS OF EVOKED POTENTIALS

INTRODUCTION

Traditionally, visual and auditory acuity have been assessed using behavioural or psychophysical techniques. These methods requiring the cooperation of the patient and his subjective report on the sharpness of the image or the audibility of the stimulus have obvious limitations in certain cases. For example, very young or retarded children, or claimants in medico-legal cases who stand to benefit materially from malingering, are not amenable to testing by these methods. An objective approach to the assessment of visual and auditory acuity, where the patient's cooperation is minimal, would have many applications. Recent developments in the field of evoked potentials (EPs) provide the basis for such an approach.

An EP is a sequence of electrical events elicited by and "time locked" to a stimulus applied to a sense organ and is usually recorded from the scalp. The electrical events are initiated by the receptor organ and transmitted via the sensory pathways to the cortex.

Technological strides have provided the basis for the current emphasis on EPs, however, cortical EPs were described as early as 1875. Richard Caton's original publication, preceding that describing the recording of spontaneous activity from the brains of animals, mentioned what would now be called "slow potentials" (Halliday, 1980).

The K-complex is another form of EP described in an early publication. This is a transient appearing over the vertex in response to peripheral stimulation during sleep. It was first described in 1938 by Loomis, Harvey and Hobart (Halliday, 1980).

Sensory EPs recorded from scalp electrodes are of very low amplitude. They vary from a fraction of a microvolt, in the case of brain stem EPs, to about 30 microvolts in that of visual EPs. A variety of other potentials may also impinge upon scalp electrodes. These include background cortical activity (EEG), electrical activity from the pulsating blood vessels (ECG), the eyes (EOG) and the scalp muscles (EMG). These potentials may be hundreds of times larger than EPs and serve to obscure the latter. It is therefore necessary for the EP to be extracted from the other extraneous electrical activity.

This is achieved by means of the process of signal averaging. The EP waveform is time-locked to the stimulus while background activity fluctuates randomly. Thus EPs will be enhanced and the random backgroung activity cancelled out if a number of stimulus-evoked potentials are summated and averaged (Figures 1a and 1b).

An "averaging" technique using photographic superimposition of oscilloscope images was demonstrated by Dawson in 1947. This procedure allowed detection of the visual EP and of small somatosensory potentials over the Rolandic cortex. Dawson exhibited the first electronic averager four years later in 1951. It was not however until 1967 that the first short latency EPs were described by Sohmer and Feinmesser (Halliday, 1980). The finding that these brain potentials could be elicited in response to click stimulation revitalised the field of objective audiometry.

In the late 1960's it was shown that a reversing pattern of bars or checks with each reversal triggering the averager, yielded a stable potential. Harter and White (1970) used this form of stimulation and established that the ability to perceive the sharp margin between the light and dark areas was essential for evoking the potential. They also found that the amplitude of the pattern-reversal evoked potential (PRVEP), as it became known,

FIGURE 1(a)

VISUAL EVOKED POTENTIALS SHOWING TIME-LOCKED ACTIVITY REVEALED BY SUPERIMPOSITION OR AVERAGING.

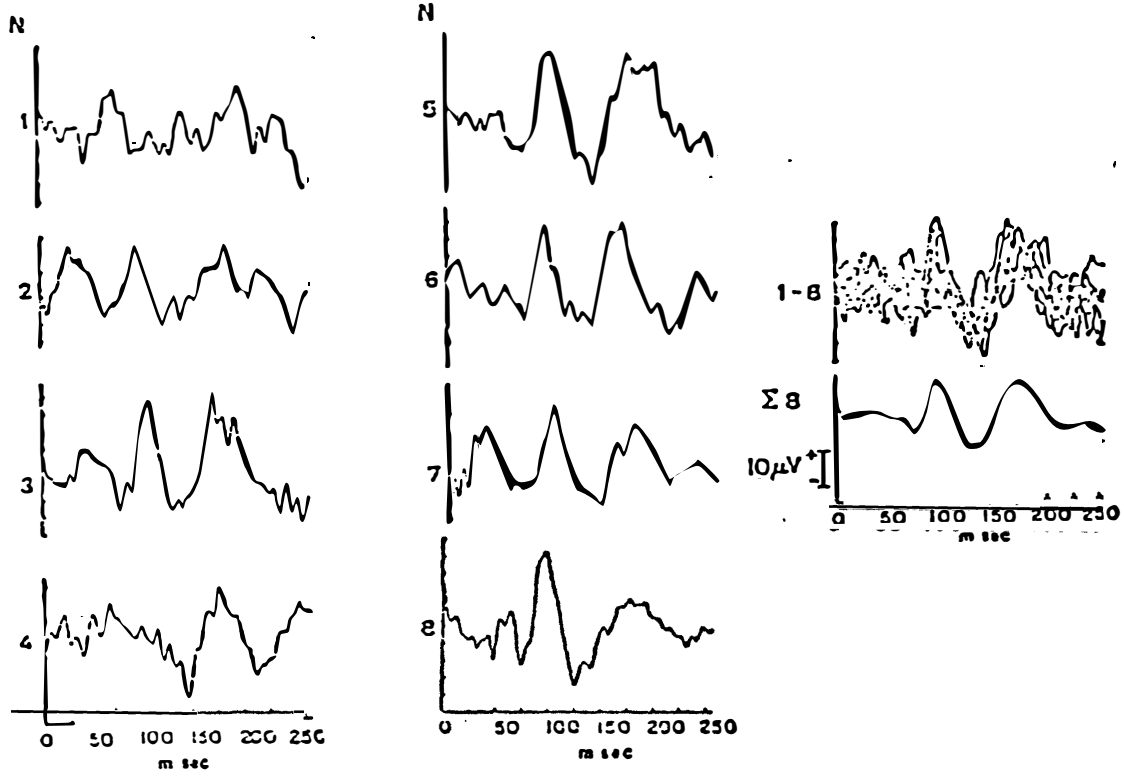
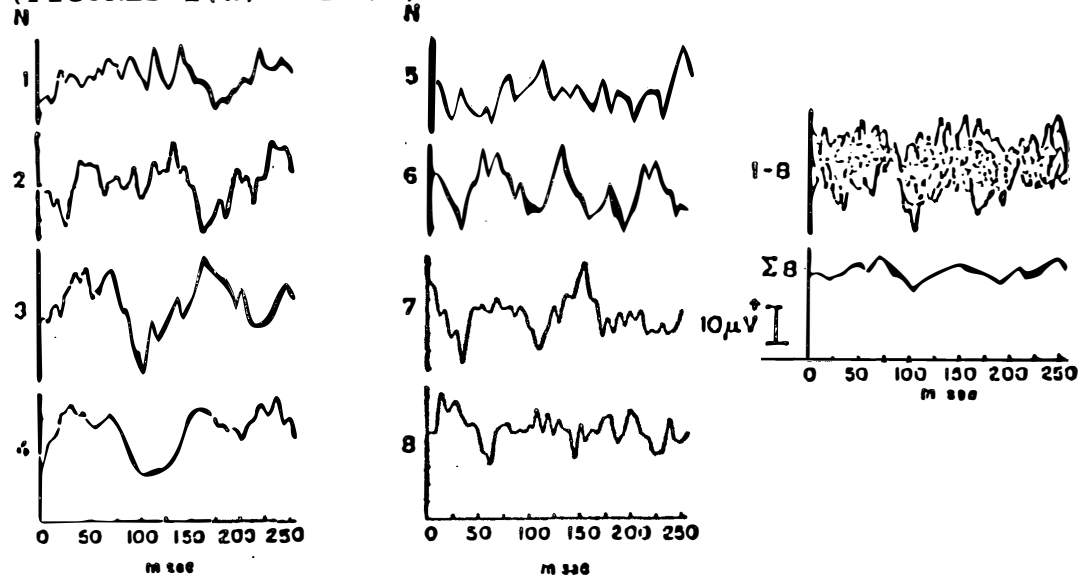


FIGURE 1-b
RANDOM EEG ACTIVITY (NO STIMULUS).
(FIGURES 1(a) AND (b) FROM PATHFINDER II MANUAL)



was a function of visual acuity.

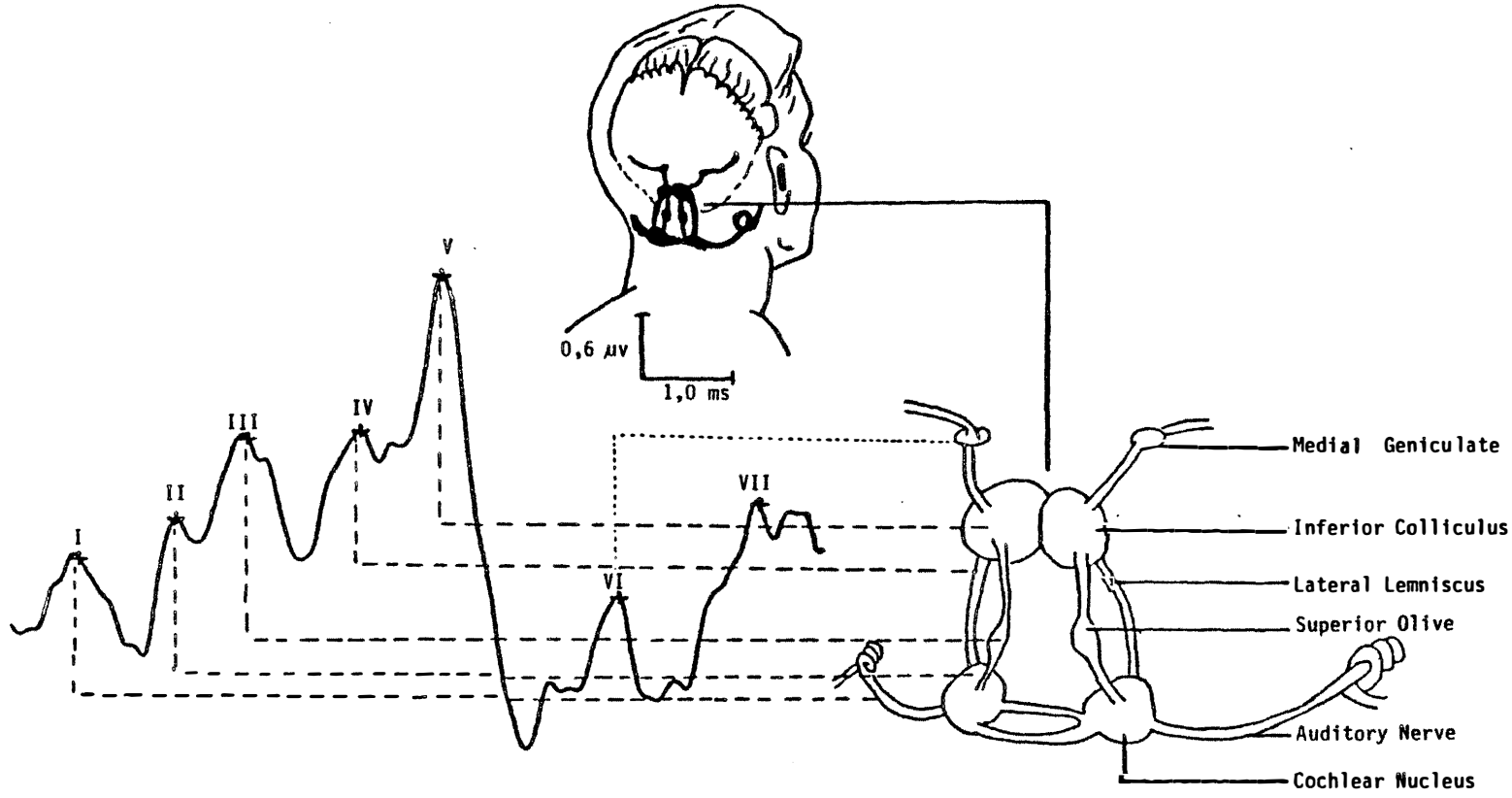
This report discusses the procedures and some of the difficulties encountered in the use of EPs for assessing visual and auditory acuity in children.

2. THE BRAINSTEM AUDITORY EVOKED POTENTIAL (BAEP) IN AUDITORY TESTING.

The responses of the auditory nerve and brainstem to sound can be extracted from the cortex's background electrical activity using the averaging procedure previously mentioned. The BAEP is recorded from scalp electrodes usually placed on the vertex (active electrode) and on the medial surface of the earlobes or mastoids (reference electrode), in response to brief repetitive click stimuli. It is seen in the 10 to 15 millisecond period following stimulation.

The BAEP comprises seven vertex-positive waves (Figure 2). These are thought to reflect the progressive activation of the auditory nerve and brainstem tracts and nuclei (Hecox and Galambos, 1974; Weber, 1979; Rowe, 1981) and are volume conducted throughout the head. For the purpose of auditory assessment waves one (I) and five (V) are the most important. Wave I reflects auditory nerve activity close to the cochlea, while wave V probably originates in the region of the inferior colliculus at the top of the brainstem (Picton et al., 1977; Rowe, 1981).

FIGURE 2
SCHEMATIC REPRESENTATION OF BAEP SHOWING ORIGIN OF PEAKS



2.1. FACTORS INFLUENCING BAEP PEAK LATENCY AND AMPLITUDE

2.1.1. Patient Factors

2.1.1.1. Core Temperature

Peak V latency increases linearly with decreasing body temperature. Picton et al. (1982)(in Chiappa, 1983) noted a 0.17ms increase in wave V latency for every degree Centigrade decrease in body temperature. The upper limit of normal for the wave I to V inter-peak latency (IPL) is exceeded at about 32 degrees Centigrade (Stockard et al., 1978). These authors conclude that body temperature should be taken into account when interpreting BAEP's in patients likely to develope hypothermia, as in coma cases.

2.1.1.2. Drug Effects

Most authors report no CNS depressant drug effect on the BAEP, for example, Chiappa (1983). Stockard et al. (1978) however report a delay in interpeak latencies after certain anaesthetics. Many patients require sedating to permit BAEP recording but, at the normal doses of the drugs used for sedation during BAEP recording, no drug effect has been reported.

2.1.1.3. Age

In the first 18 months of life, age is an important determinant of peak V latency, particularly in the case of premature infants. Despland (1982) used the BAEP to study the maturation of the peripheral and central auditory pathways in newborns and young children. He found that the BAEP appeared at about 26 weeks gestational age (g.a.) and that there was a systematic decrease in the latency of the peaks with increasing age. By studying the relative latency changes of peaks I and V he

concluded that most of the decrease of wave V latency prior to 34 weeks g.a. was due to maturation of the cochlea and thereafter the decrease was due to maturation of the brainstem pathways. Mochizuki et al. (1983) claim that the peak V latency changes up to three years of age and that wave I latency is only at mature levels at about two months of age.

Figure 3 shows a series of BAEPs recorded at 60 dB(nHL) in our laboratory from children of different ages. Peak I shows a small decrease in latency between one and two months but between two and twelve months it appears stable. The decrease in the peak I to V IPL is readily seen.

The interval between wave I and wave V is referred to as brainstem conduction time (BSCT). This is the time required for the nerve impulse to travel from the auditory nerve to the top of the brainstem. Salamy (1982) reports that BSCT decreases from about 5.09 ms at birth to 4.03 ms by three years of age and is then at about the adult value. Galambos (1978) however claims that BSCT reaches adult levels as early as 18 months of age. This agrees with Picton et al. (1977).

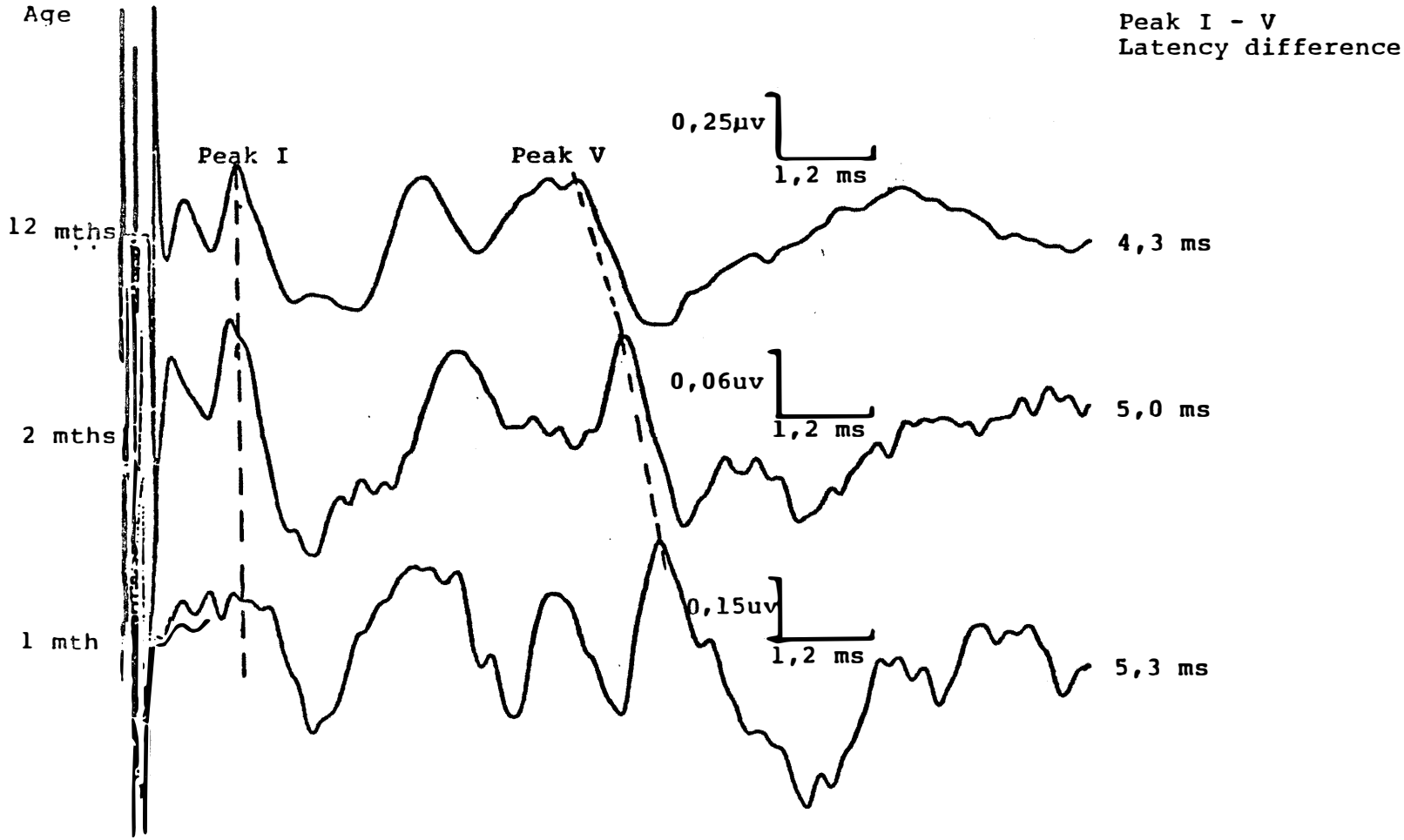
The BSCT shortens at about 0.2 to 0.5 ms per week in the weeks following birth and then more slowly up to 18 months, when it is close to the adult value (Galambos, 1978; Weber, 1979). The reduction of BSCT in the first few months of life is thought to reflect the maturation of the neural pathways due to myelination and more efficient synaptic transfer (Galambos, 1978).

The age of infant patients therefore needs to be considered in the analysis of BAEPs, whether for auditory or neurological assessment.

2.1.1.4. Sex

Most authors agree that females have shorter IPLs and absolute

FIGURE 3
EFFECT OF AGE ON THE PEAK I TO V LATENCY DIFFERENCE



peak latencies and greater peak amplitudes than males (Chiappa, 1983; Stockard et al., 1978. Chiappa (1983) claims this difference is evident in subjects above 8 years of age. Mochizuki (1983) however cites evidence of sex differences in peak V latency from about three months of age. Sex differences are probably due to differences in the length of the auditory neural pathways, although Stockard et al. (1978) found no significant difference in head circumference between males and females. They conclude that a simple relationship between head size and length of pathway is unlikely.

It is, therefore, important to take sex into account when analyzing the BAEPs of older children and, if Mochizuki (1983) is correct, even of infants.

2.1.2. Stimulus Factors

2.1.2.1. Intensity

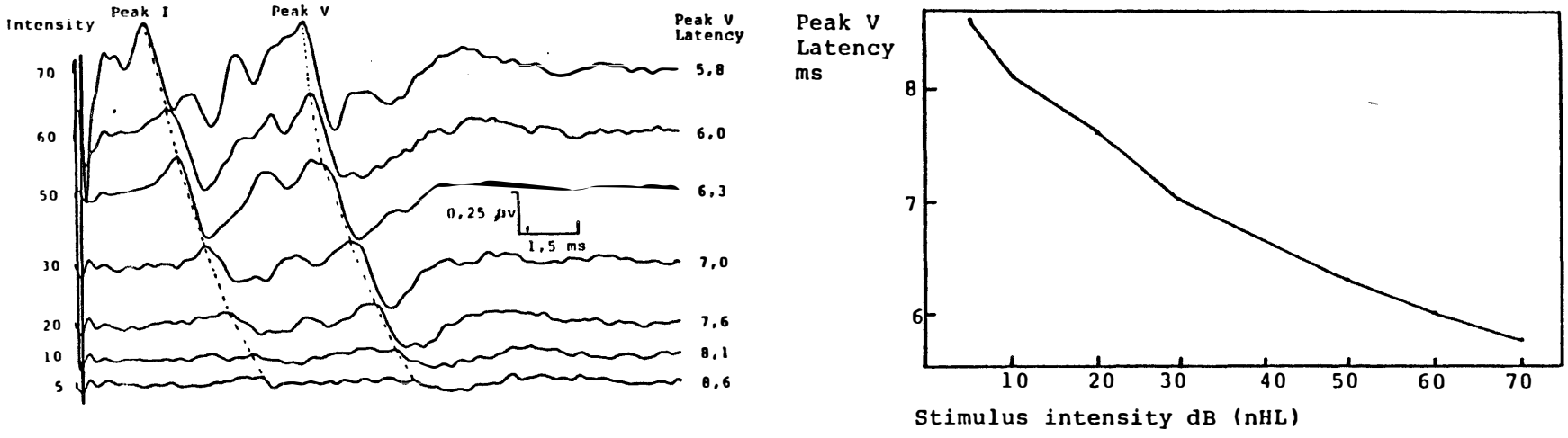
The latencies of all BAEP peaks change with changing stimulus intensity (Chiappa, 1983). The effect of intensity on peak I and V latencies as recorded in our laboratory, is shown in Figure 4.

As stimulus intensity decreases the latencies of both peaks I and V increase and their amplitudes decrease in near linear fashion. The peak I to V latency difference does not therefore change with intensity and peak V thus accurately reflects the latency of peak I plus BSCT at any intensity. However, at intensities below 60 dB, peak V amplitudes are consistently greater than those of peak I and this peak is still present near auditory threshold when the others are not visible.

2.1.2.2. Stimulus Rate

The effect of increasing the rate of stimulation has been

FIGURE 4
EFFECT OF STIMULUS INTENSITY ON LATENCY OF PEAKS I AND V OF THE BAEP



investigated by several authors. Stockard et al. (1978) report that peak V latency increases only slightly with increased rate. They found a 0.1 ms delay in latency for each 20/sec increase in rate. Hecox (1983) uses a correction factor of 0.006 ms/click when recording at increased click rates, which is equivalent to 0.12 ms for every 20/sec increase in click rate.

As the click rate increases the amplitude of the early BAEP peaks reduces, making peak identification more difficult. (Stockard et al., 1978; Chiappa, 1983; Lasky, 1984; Sand and Sulg, 1984).

Figure 5 shows a series of BAEPs recorded in our laboratory, from a 15 month old normal female at different click rates. Peak V latency increases by 0.1ms for each 20 per second increase in click rate. The decrease in amplitude of peak I relative to peak V can also be seen.

Testing time can be reduced by increasing the click rate but the increase in peak V latency must then be taken into account. Correction factors should be established for each age group as Lasky (1984) has shown that increasing click rate has more of an effect on the peak V latency of infants than adults.

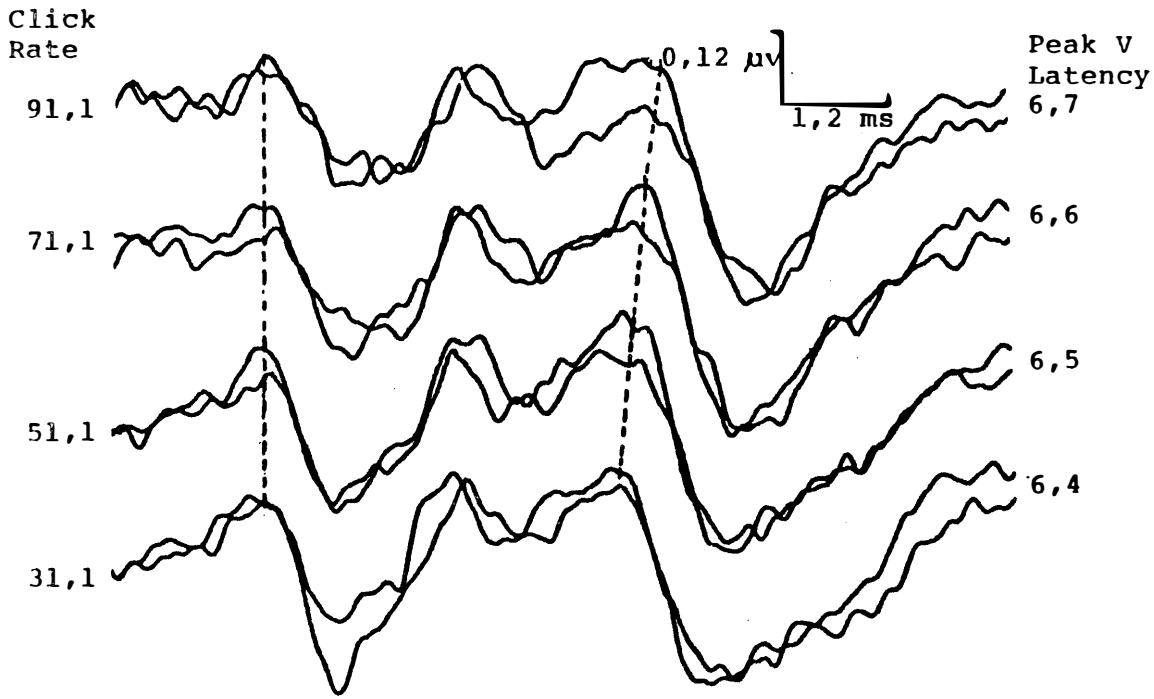
When using fast click rates peak I identification may be difficult. Most clinical assessments require the measurement of the peak I to V IPL and therefore it is necessary to include at least one recording at a lower click rate to ensure peak I identification.

2.1.2.3. Click Polarity

Most authors report little or no peak V latency change with different click polarities (Stockard et al., 1978; Chiappa, 1983; Sand and Sulg, 1984). The latencies of peaks I to IV however appear to be shorter with rarefaction clicks than with

FIGURE 5

EFFECT OF CLICK RATE ON PEAK V LATENCY



condensation clicks. This results in slightly longer peak I to V IPLs with rarefaction clicks but easier peak identification, as peaks IV and V separate from each other with the latter. Stockard et al. (1978) however report considerable inter-subject variability as a function of click polarity.

Disagreement exists as to whether condensation or rarefaction clicks should be favoured. Stockard et al. (1978) and Chiappa (1983) prefer rarefaction, Sand and Sulg (1984) condensation clicks. All agree that if possible both click polarities should be used in clinical testing. Alternating rarefaction and condensation clicks can be used when attempting to establish the presence of wave I or V near auditory threshold in a patient with a hearing loss requiring high stimulus intensities. The routine use of alternating clicks however is not recommended because the small changes seen with the different polarities may sum to produce peaks of longer duration than those generated by a single polarity (Chiappa, 1983).

2.1.2.4. Stimulus Mode

Binaural stimulation produces higher amplitude responses from the central auditory pathways (peaks III to V) than does monaural stimulation (Stockard et al., 1978). The use of binaural stimulation in either auditory or neurological applications however is not recommended as responses from a normal ear may mask those from an abnormal ear. Futhermore, lateralization of a dysfunction is not possible. As a means of reducing the contribution from the unstimulated ear with monaural stimulation, especially at high intensities, it is necessary to mask the contralateral ear using white noise, usually at an intensity 30 to 40 dB lower than the stimulus.

2.2 STIMULUS INTENSITY MEASURES

An understanding of intensity measures is necessary to appreciate the use of the BAEP in hearing assessment.

2.2.1. Sound Pressure Level (SPL)

SPL is the absolute standard in the field. It is measured by a sound-level meter and is expressed in decibels (SPL)[dB (SPL)].

2.2.2. Sensation Level (SL)

Intensity can also be expresed in dB sensation level (SL). This is the difference between the patient's threshold and the level of stimulation selected. If the patient's threshold is 20 dB and the stimulus intensity is set at 80 dB, this measure would be expressed as 60 dB(SL). This is the most most commonly used measure of intensity when recording BAEPs for neurological assessment as it makes allowance for the effect of any hearing loss the patient may have. Different patients with different degrees of hearing impairment may thus be exposed to the same absolute stimulus intensity.

2.2.3. Normal Hearing Level (nHL)

When recording BAEPs for hearing assessment the most commonly used intensity measure is normal hearing level or dB(nHL). Here intensity is relative to the normal hearing level for that particular stimulus. Normal hearing level is established by measuring the threshold of a stimulus for a normal hearing group and then calculating the mean. This is then regarded as 0 dB and patients are stimulated at a set level above this base line. For example, if the mean threshold for a number of normals is dicovered to be 5 dB for a particular stimulus and the stimulator is set to 65 dB, stimulus intensity would be expressed as 60 dB(nHL).

2.3. THE USE OF BAEPs IN HEARING ASSESSMENT

There are various ways in which the information obtained from BAEP testing can be used in assessing a patient's hearing.

2.3.1. Estimating Auditory Threshold

The lowest intensity to evoke peak V will approximate the sensation threshold. If this intensity is elevated a hearing loss equal to the difference between this value and the lowest intensity evoking a peak V in normal subjects may be indicated. At threshold, peak V may be difficult to identify. This is particularly true if there are technical difficulties in recording, such as the presence of EMG artefact or artefact due to high electrode impedances. In such cases the lowest intensity evoking peak V may be well above threshold. Using the peak V estimate of hearing threshold as the only means of assessing hearing is therefore not acceptable.

2.3.2. The Peak V Latency/intensity Curve

Hearing can also be assessed by plotting peak V latency as a function of intensity and comparing this to a similar curve plotted for normal subjects. As stated above, peak V latency varies with intensity. If the patient has a hearing loss the curve will be displaced to the right of the normal curve reflecting the extended peak V latency due to the loss at any stimulus intensity. The degree of displacement, expressed in dB, will be equivalent to the hearing loss in that patient.

When using the latency/intensity curve to estimate hearing loss, technical and patient factors effecting peak V latency must be taken into account. For example, if the patient has a delayed peak I to V IPL the latency/intensity curve will also be displaced to the right. Before estimating hearing loss in this case, peak V latency should be reduced by the amount the IPL

exceeds normal.

2.3.3. Extrapolating The Latency/intensity Curve

Hecox (1983) estimates threshold by recording BAEPs at suprathreshold intensities, over at least a 25 dB intensity range or a 1 millisecond latency range and then extrapolates the latency/intensity curve to 8.5 ms. He states that in his experience the intensity value corresponding to this latency correlates well with the behaviourally determined threshold. This method has the advantage of using high intensities producing easily identified peak Vs. The hazards associated with the use of alatency/intensity curve still apply however.

2.3.4. Shape Of The Latency/intensity Curve

Picton et al. (1977) report that the shape of the latency/intensity curve can be used to determine the type of hearing loss. With a conductive loss the sound energy reaching the cochlea is reduced resulting in the displacement of the curve to the right by an amount equal to the loss which is reasonably consistent over the intensity series (Figure 6a).

In a sensory neural impairment the latency/intensity curve is much steeper than the normal curve and takes on a characteristic "L" shape, with the bottom limb of the "L" located in the area of normal values. These normal values at the higher stimulus intensities are due to the recruitment seen in this kind of hearing loss (Figure 6b).

FIGURE 6a

LATENCY/INTENSITY CURVE IN CONDUCTIVE HEARING LOSS

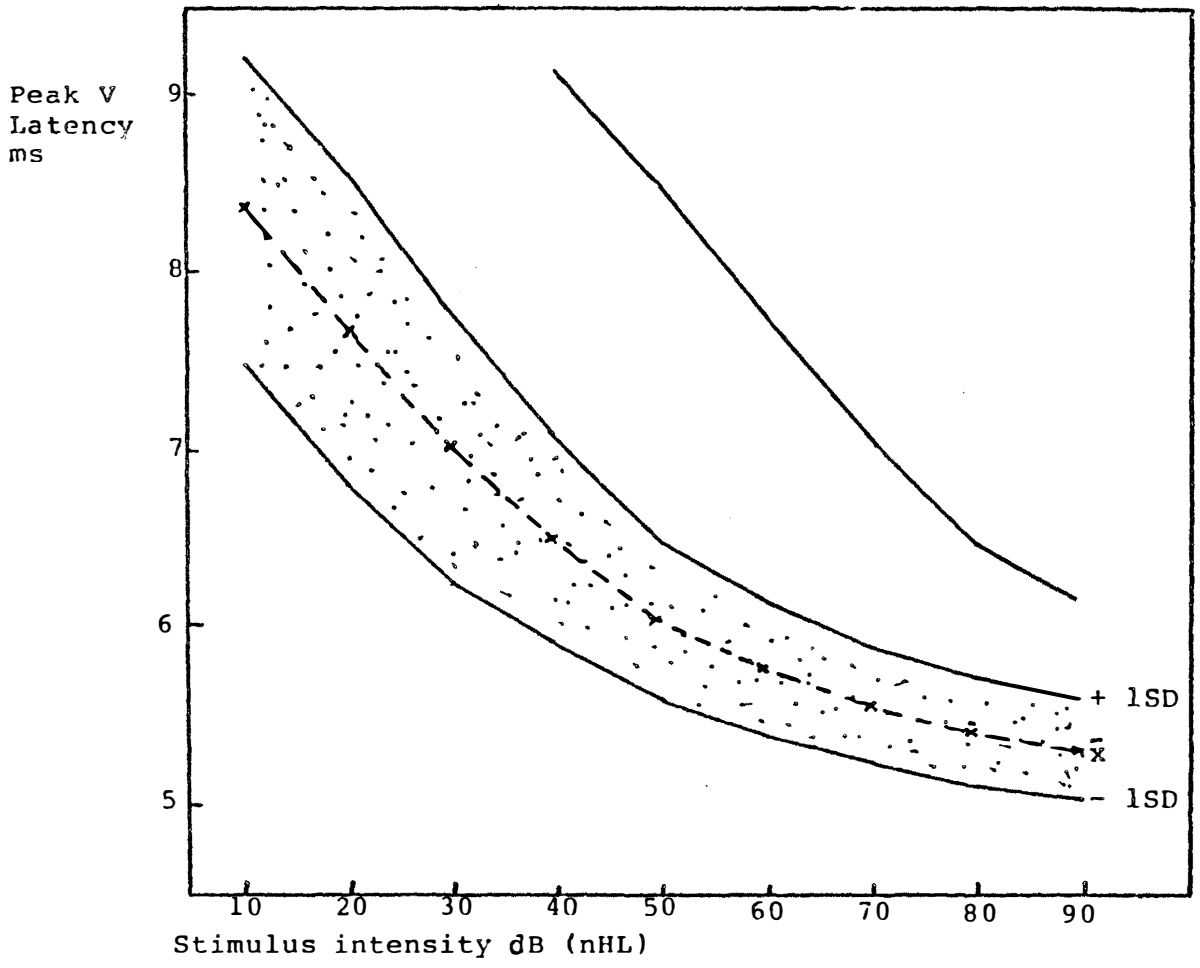
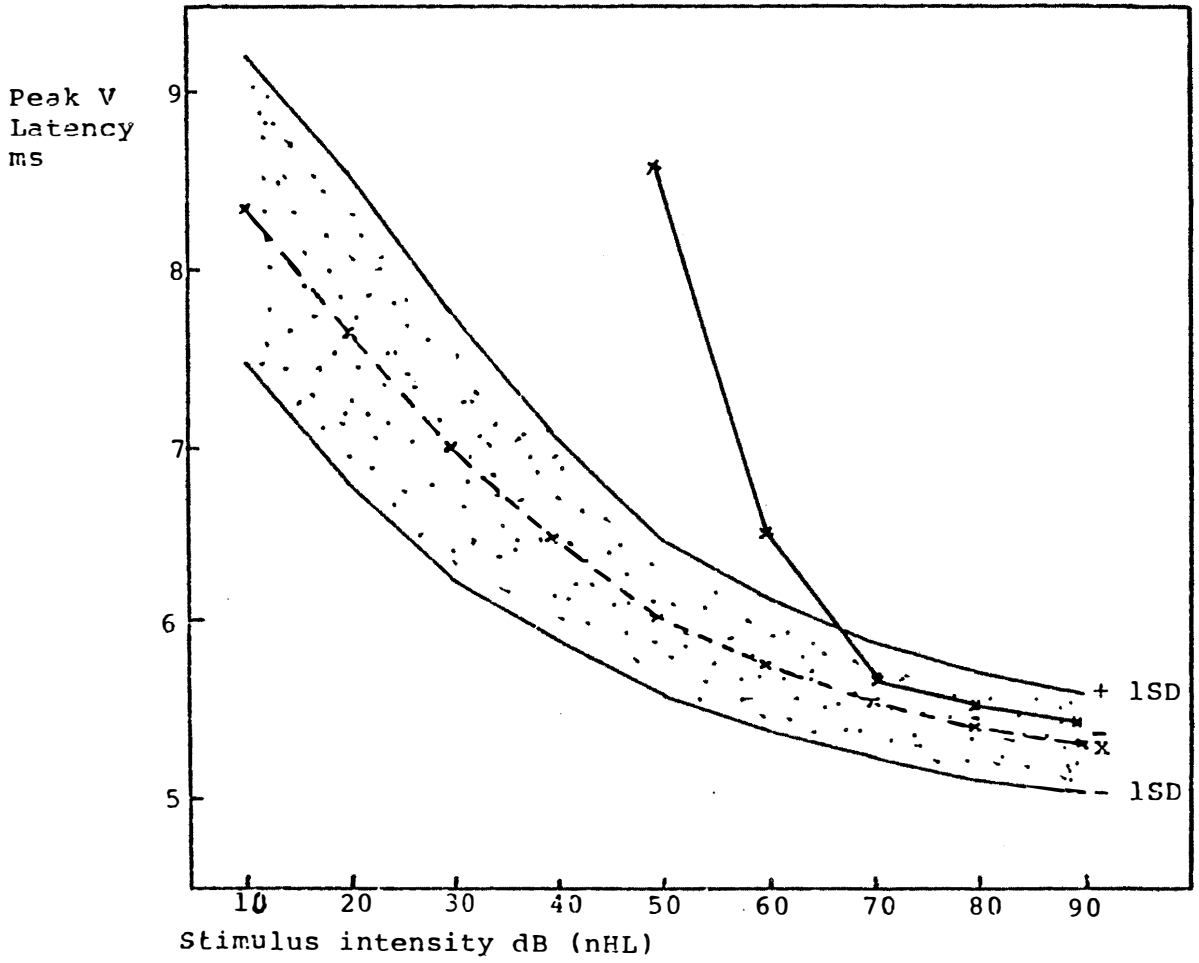


FIGURE 6b

LATENCY/INTENSITY CURVE IN SENSORY-NEURAL LOSS



2.4. BAEP ASSESSMENT OF HEARING LOSS IN RELATION TO OTHER METHODS

Hearing loss assessed using the BAEP correlates well with results obtained using conventional behavioural audiometry. Jerger et al. (1980) report that in children with no neurological impairment and with normal-to-mild loss, BAEP results accorded with behavioural and/or impedance test results in 60 out of 63 cases. The agreement was 100% in profoundly deaf children and, in those with moderate to severe loss, 19 of 21 results were consistent. The correlation between the types of assessment in children with neurological impairment was not as good as in those without. Four of 24 results showed no agreement, with all 4 in the normal to mildly hearing impaired group.

Cornacchia et al. (1982) found agreement between BAEP and behavioural audiometry in 77 % (n = 157) of their cases where a reliable audiogram was obtained. Serious disagreement occurred in only 5 % of cases. In the group where reliable audiograms were not obtained the methods corresponded in 34% (n = 113) and there were serious discrepancies in 20 %. They consider their results to indicate that behavioural audiometry yields generally inconsistent results in hyperactive, brain-damaged and psychiatrically disturbed children, and that in these cases objective techniques are mandatory. Generally in most cases where there were serious discrepancies subsequent audiometric tests confirmed the BAEP results. In only four cases did BAEP results suggest a severe or profound loss with subsequent behavioural testing revealing reponses to everyday sounds. In two of these cases high frequency losses were shown.

At the N I P R we have used the BAEP for assessing hearing in difficult-to-test children since March 1982. Our procedure, results and illustrative case histories are described below.

2.5 METHOD

2.5.1. Subjects

Subjects were 97 children (47 males and 50 females) aged seven weeks to 12 years referred to our laboratory, from March 1982 to August 1984, for BAEP assessment. In these children behavioural audiometry had either been attempted without success or behavioural audiometry, in the opinion of the referring source, would not have been possible. Most children (61 %) therefore required sedation for testing.

Table 1 shows the sources of referral and the age distribution of subjects. Paediatricians were responsible for most of the referrals (25,8 %). A large proportion (80 %) of these were younger than 3 years of age. ENT specialists referred 8,2 % and speech therapists (from a speech and hearing clinic as well as in private practice) 12,4 %. Most of the older children were referred by special schools (for the deaf, 11.3 %; cerebral palsied, 13,4 % and autistic, 14,4 %).

The most significant reason for referral in each age group is summarised in Table 2. In cases where there were more than one reason for referral, all were included. The most frequent reason for referral in the older children was failure to develope speech. In the younger children referral factors were those that may have predisposed to hearing difficulties (eg. meningitis, rubella in pregnancy).

2.5.2. Procedure

Electrodes were silver discs, the active electrode at the vertex referred to electrodes on the medial surfaces of the earlobes. The ground electrode was placed on the forehead. Electrode sites were cleaned with alcohol and the electrodes were held in place with Beckman adhesive paste and surgical tape. Most children

TABLE 1
SOURCE OF REFERRAL AND AGE DISTRIBUTION OF SUBJECTS

Source of Referral	Age							Total	%
	0-3m	4m-6m	7m-12m	13m-18m	19m-3y	4y-6y	+6y		
Neurologist	-	-	-	-	1	5	2	8	8
Paediatrician	1	3	4	3	9	2	3	25	26
ENT Specialist	1	-	1	1	2	1	2	8	8
Speech Therapists	2	-	3	1	3	1	2	12	12
C P School	-	-	1	-	2	7	3	13	14
Deaf School	-	-	-	-	3	6	2	11	11
Autistic School	-	-	-	-	-	9	5	14	15
General Practitioner	-	1	-	-	1	1	1	4	4
Community Nurse	-	-	2	-	-	-	-	2	2
Total (%)	4 (4)	4 (4)	11 (11)	5 (5)	21 (22)	32 (33)	20 (21)	97	100

TABLE 2
REASON FOR REFERRAL ACCORDING TO AGE GROUP.

Reason for Referral	Age							Total	%
	0-3m	4m-6m	7m-12m	13m-18m	19m-3y	4y-6y	+6y		
Poor Speech	-	-	2	1	12	14	8	**37**	**26**
Meningitis/ Rubella/ Measles	1	1	3	1	-	1	3	**10**	**7**
Otitis Media Grommets	1	-	2	1	1	4	1	**10**	**7**
MBD	-	-	-	-	-	3	1	**4**	**3**
Congenital Disorder	2	-	1	-	4	1	-	**8**	**6**
Brain Damage	-	3	5	3	6	7	5	**29**	**21**
Retarded	-	-	-	-	2	6	11	**19**	**14**
Birth Difficulties	1	1	2	-	2	-	1	**7**	**5**
Nil History	-	1	1	2	4	6	2	**16**	**11**

(The total is greater than the total number of patients as more than one reason for referral may apply in indivusual cases)

were sedated (Table 3) during testing. Ten children required more than one kind of medication, usually a combination of Vesparaxette and either Tricloryl or Vallergan.

Click stimuli were generated by a Pathfinder SM400 Auditory Stimulator and were presented monaurally at intensities ranging from 10 to 90 dB (nHL). The earphones were either individually held lightly over the ear by the mother in the case of very young infants or they were kept in position by a head band. If the latter, white noise at 30 dB below the level of the stimulus was presented simultaneously to the contralateral ear.

At least two averages, each of 1000 sweeps, were collected for all intensities employed for each ear. At 60 dB (nHL) contralateral and ipsilateral recordings were made using rarefaction and condensation clicks. At all other intensities only contralateral recordings with rarefaction stimulation were made. The potentials were digitised, averaged and stored on a Pathfinder II Evoked Potential System, retrieved later for inspection and plotted by means of an X-Y plotter. Peak V was identified for each BAEP and the latency/intensity curves were plotted. The lowest intensity evoking a peak V for each ear was also noted. The latencies and amplitudes of peaks I and V were measured and the IPL and V/I amplitude ratios calculated for the potentials evoked by 60 dB for left and right ears.

2.6. RESULTS

Results were obtained in 87 (89,7 %) cases. In most cases where results were not obtained the child had not been sedated (Table 4). In some instances results were obtained only after a second administration of sedation. Vesparaxette was by far the most successful sedative and testing was possible for all the children for whom it was prescribed. A number of the older and the very young patients were successfully recorded without sedation (Tables 3 and 4).

TABLE 3
SEDATION USED DURING RECORDING

Medication	Age							Total	%
	0-3m	4m-6m	7m-12m	13m-18m	19m-3y	4y-6y	+6y		
Vesparax(ette)	-	1	9	4	11	19	5	49	46
Tricloryl/ Vallergan	2	2	5	3	4	-	-	16	15
Valium	-	-	-	-	-	-	1	1	1
Phenobarb	-	-	-	-	1	1	-	2	2
Ativan	-	-	-	-	-	-	1	1	1
Nil	3	2	2	2	3	11	15	38	35
Total	**5(5%)**	**5(5%)**	**16(14%)**	**9(8%)**	**19(18%)**	**31(29%)**	**22(21%)**	**107**	

(The total is greater than the total number of patients as 10 patients received more than 1 kind of medication).

TABLE 4
NUMBER OF CHILDREN ON WHOM RECORDINGS COULD NOT BE PERFORMED ACCORDING TO MEDICATION USED

Medication	Age						Total
	0-3m	4m-6m	7m-12m	13m-18m	19m-3y	+6y	
Vesparax(ette)	-	-	-	-	-	-	-
Tricloryl/ Vallergan	-	-	2	-	-	-	2
Valium	-	-	-	-	-	-	-
Phenobarb	-	-	-	-	-	-	-
Ativan	-	-	-	-	-	1	1
Nil	-	1	-	1	3	2	7
Total not Tested	-	1	2	1	3	3	10

A summary of results appears in Tables 5 and 6. These show the result of the better ear for each child. For example, if one ear was found to show a profound loss and the other a severe loss, the child was included in the severe group. Hearing loss was categorised as follows. A threshold of 40 dB or less was considered as normal or mildly impaired. A threshold greater than 40 dB but less than 90 dB was considered moderately to severely impaired, while a threshold greater than 90 dB was considered profoundly impaired. Sixty-four percent of the children tested were normal or mildly impaired, and the next largest group was that with a profound loss (21 %). Fifteen percent showed moderate or severe losses. The groups with mild and moderate losses were subdivided into sensory-neural (12,6 %) and conductive types (5,8 %). The children with severe or profound loss could not be categorised in this way as their latency/intensity curves were inadequate to permit this.

Table 6 shows the frequency of hearing loss according to source. Eighty two percent of the chidren referred from the school for the deaf showed a moderate to profound loss. None of the children referred by neurologists and community nurses fell into this category. Speech therapists and ENT specialists had the next highest number of those with moderate to profound losses (58 % and 38 %) The school for cerebral palsied children had 23 % in this group and the school for autistic children had 14 %. This table should however be interpreted with care as the number of cases referred by some groups was small (neurologists, six; nurses, three) and the population in each case is by no means homogenous.

2.7. DISCUSSION

Behavioural audiometry was difficult or impossible to perform on all the patients referred, yet BAEP results could be obtained in 89 %. Jerger et al. (1980) successfully tested 94 % of the cases referred to them in a year. Eighty two percent of their cases

TABLE 5

RESULTS ACCORDING TO AGE GROUPS

Result	Age 0-3m	4m-6m	7m-12m	13m-18y	19m-3y	4y-6	+6y	Total	%
Normal to mild loss	4	3	5	4	11	18	11	56	64
Moderate to severe loss	-	-	2	-	5	2	4	13	15
Profound loss	-	-	2	1	4	9	2	18	21
TOTAL TESTED	4	3	9	5	20	29	17	87	

TABLE 6

HEARING LOSS ACCORDING TO SOURCE OF REFERRAL

Source of Referral	No Test		Possible		Normal to mild loss		Moderate to profound loss	
	N		%		N	%	N	%
Neurologists	1		13		7	87	-	-
Paediatrician	3		12		16	64	6	24
ENT Specialist	1		12		4	50	3	38
Speech Therapist	1		9		4	33	7	58
C P School	2		15		8	62	3	23
Deaf School	-		-		2	18	9	82
Autistic School	2		14		10	72	2	14
General Practioner	-		-		3	75	1	25
Community Nurse	-		-		2	100	-	-
Total	10				56		31	

required sedation while in our study 64,5 % were sedated. Six percent of Jerger et al.'s referrals could not be tested whereas we could not test 10,3 %. These statistics however are not directly comparable for the following reason. The Jerger group attempted to record without sedation and, if unsuccessful administered medication. In our laboratory, it was decided whether medication would be necessary when the appointment was made, after discussion with whomever referred the child. If testing could not be accomplished in those without medication, the child was placed in the "no test possible group" for purposes of this study, and was subsequently tested with medication.

Tables 3 and 4 summarise our experience in testing sedated and unsedated children. In the very young patient (under one year) sedation is often not necessary or if needed may be very mild. Children older than six years may also often be coaxed into sitting still for long enough for the test to be completed. Jerger et al. (1980) found a similar bi-modal age distribution of cases not requiring sedation. However they conclude that most children will require sedation for BAEP testing and attribute their successful application of this technique in a clinical setting to "this vigorous commitment to medication" (Jerger et al., 1980).

Table 3 and 4 show that Vesparaxette was the drug most often used and by far the most successful. Tricloryl or Vallergan were also used and were most successful on the younger children. Drugs such as Phenobarbitone, Valium and Ativan were so seldom used in our sample that it is not possible to comment on their effectivenes for BAEP recording.

In our sample 25,8 % were referred by paediatricians (Table 1). Jerger et al. (1980) report only 13 % of their cases from the same source. Most of their cases were referred by ENT specialists (45 %) or audiologists (28 %) compared with

corresponding figures in our sample of only 8,2 % and 12,2 %. This may be because the use of the BAEP for hearing assessment is relatively recent in South Africa but has been used in this context for some years in the USA. A limited number of sources who use our laboratory for other purposes, such as electroencephalographic examinations, may be aware that this procedure is available. Further, different diagnostic and treatment conventions in the USA and South Africa may be reflected in these statistics.

The reason for differences in abnormality rates (Table 6) among the samples referred by different professions probably reflects different motivations referral and the specificity of the population involved. For example 82 % of the cases referred from the school for deaf children were abnormal. These children were considered by the school to be deaf but the extent of their disability was not known and BAEPs were therefore requested. Referrals from ENT specialists and speech therapists were for the same reason. Paediatricians, neurologists and schools for brain damaged children however, often referred children who had failed to develope speech, in order to exclude the possibility of deafness. The paediatricians together with the community nurses also referred babies, whose mothers were concerned about their hearing, for screening. Fourteen of 18 (78 %) children referred for this purpose were normal and these cases helped to increase the number of normal children from these sources.

In our sample, BAEPs could be predicted to be most valuable in young children (below two years). Thus, had the test been available when the majority of our sample was younger, a diagnosis of hearing loss might have been made earlier and the correct intervention or educational placement made.

Some of the children were misplaced educationally. Four of the nine referrals from a school for brain damaged children had hearing losses (BAEPs indicated no neurological abnormality) and

two from the school for autistic children had hearing losses (no neurological abnormality). All of these however had language difficulties or were aphasic. Previous audiometry had not revealed the hearing loss.

It is clear that the BAEP is a useful procedure for assessing hearing in children. It does not however replace conventional behavioural audiometry.

The advantages of BAEP assessment compared with behavioural audiometry are as follows (Weber, 1979). Firstly, the hearing threshold can be assessed accurately using the BAEP. With behavioural audiometry, reponses are often only obtained, especially in difficult to test children, at levels well above threshold. This often results in hearing losses being over-estimated.

Secondly, the BAEP is not sensitive to level of arousal and does not habituate over time. This means that sedation can be used to facilitate electrode placement and testing, and results can be checked while the child sleeps. Sedation cannot be used with behavioural audiometry, resulting in sparse information obtained during brief periods of cooperation. An adequate assessment may therefore require many sessions.

Finally, the BAEP technique can be applied to very young children, even a hospital nursery population. For example, Galambos (1978) used BAEPs in a new-born nursery as a screening technique. He concludes that the BAEP can readily identify a baby with a significant hearing loss at an early age and that it is a reliable and precise method.

Weber (1979) also mentions some limitations of the BAEP technique. The most important of these is that it does not provide frequency specific imformation concerning the hearing loss when a click stimulus is used. More specifically it is not

sensitive to frequencies below 1500 Hz. A child with a low frequency loss may therefore be classified as normal and conversely a child with a high frequency loss may have his disability over-estimated. This limitation may be surmounted by recording the slow brainstem response using pure tones (Sanders, 1983) or mid-latency responses giving frequency specific information (Galambos et al., 1981).

Another limitation is that the procedure is time-consuming especially if an attempt is made to obtain frequency specific data. However, most children can be tested in one session, as opposed to the several sessions often required when using behavioural techniques.

The BAEP can also only indicate the functioning of the peripheral auditory apparatus and the neural pathways up to the level of the inferior colliculus. No information regarding the status of the neural substrate above the top of the brainstem is provided. High level auditory disorders such as receptive aphasia or auditory agnosia cannot be identified using this technique. In cases of severe or profound hearing loss it is also not possible to identify a neurological brainstem dysfunction unless the stimulus generator is set at supra-threshold levels.

A futher advantage of the BAEP is that it can be used to assess the effectiveness of a hearing aid. This is often difficult in young or uncooperative children and is most often achieved by adjusting the gain of the aid and watching for a reponse from the child. If the child shows discomfort the gain may be decreased. The BAEP offers an objective method of achieving the same aim. Hecox (1983) states that not only can the BAEP give an indication of the amplification required but can also indicate whether an aid with a high compression ratio is necessary. The latter is most often required in patients who have a sensory-neural loss. If an aid with a linear

amplification system is used in these patients to normalise hearing threshold, the maximum power output is often increased to such an extent that the aid cannot be tolerated. With compression amplification the maximum power output is reduced without sacrificing power at the lower intensities.

2.8. CONCLUSIONS

Although behavioural assessment should be the initial method of choice, the BAEP can be a useful procedure in assessing children who are not amenable to this kind of testing or where the accuracy of behavioural testing is in doubt. Such children include the very young or those who are unable to cooperate in the behavioural setting because of severe retardation, hyperactivity or poor concentration. The anxious child may also be included in this group. The BAEP cannot give frequency specific information but provides thrshold information and in most cases can allow the type of hearing loss (conductive / sensory-neural) to be determined. Infants at risk for hearing difficulties can be assessed very early in life and intervention stratergies planned. The BAEP can also provide useful information in the fitting of hearing aids. Referring sources should note that most children will require sedation for the procedure to be completed.

3. THE VISUAL EVOKED POTENTIAL IN VISUAL ACUITY TESTING

A reversing pattern of black and white checks when presented to the the visual system at a rate of four or less per second evokes a potential lasting about 250 ms. This occurs each time the pattern reverses, the cortex returning to the resting state before the next stimulus. This is termed the transient pattern reversal visual evoked potential (PRVEP) (Figure 7a). The major positive peak of the PRVEP occurs at about 100 ms and it is the amplitude of this peak that can be used to estimate visual acuity.

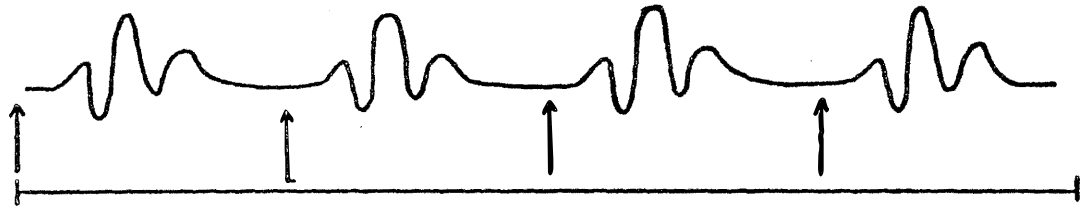
If the stimulus reversal rate is increased, successive reversals occur before the response to the preceding stimulus is terminated. This produces a sinusoidal response in the cortex, at the same frequency as the reversing stimulus and is known as the steady state visual evoked potential (SSVEP) (Figure 7b).

Because the amplitude of the visual EP is used in estimating visual acuity, the SSVEP has some advantages over the transient PRVEP. Firstly, the stimulus reversal rate for the SSVEPis much faster than that of the PRVEP and the procedure is therefore shorter. At least 100 reversals of the pattern at a rate of approximately 1/sec are needed to produce a reliable PRVEP. Using the SSVEP the 100 reversals can be presented at rates of 7.5 or 15 per second. When testing children who are awake this is an important consideration.

Secondly, the P100 amplitude of the transient PRVEP may be influenced by level of attention (Mallinson and Murdoch, 1982). The amplitude of the SSVEP is more resistant than the transient PRVEP to short term fluctuations in attention and it shows little intra-individual variability.

Thirdly, SSVEP amplitude is usually a more reliable measure than that of the PRVEP. SSVEP amplitude is the mean peak to trough

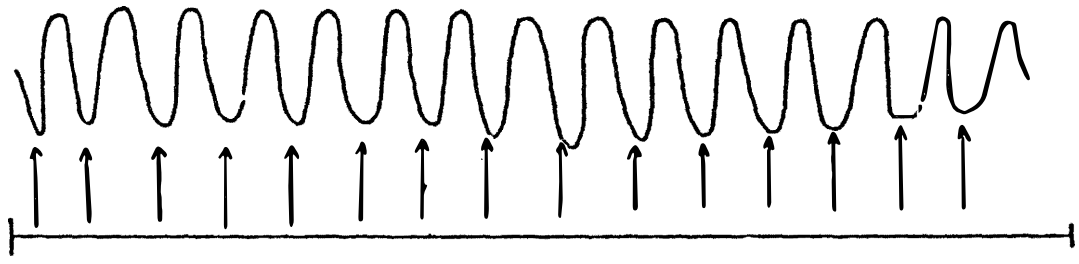
FIGURE 7 a
SCHEMATIC REPRESENTATION OF A TRANSIENT VEP



AN ARROW INDICATES PRESENTATION OF A STIMULUS

FIGURE 7 b

SCHEMATIC REPRESENTATION OF A STEADY-STATE VEP



AN ARROW INDICATES PRESENTATION OF A STIMULUS

measure of each sinusoid, whereas PRVEP amplitude is only measured from one peak. Small artefactual variations will therefore cancel with the SSVEP. This greater intra-individual reliability of the amplitude measure makes the SSVEP more suited to visual acuity assessment than the PRVEP.

3.1. FACTORS INFLUENCING SSVEP AMPLITUDE

Most studies reporting the effect of patient and stimulus factors on visual EPs have used the PRVEP and tend to focus on P100 latency. It is therefore not clear whether these factors affect amplitude or whether they have just not been studied. Their specific effects on the amplitude of the SSVEP have also not been reported in the liturature. Reported amplitude effects are listed below.

3.1.1. Patient Factors

3.1.1.1. Drugs

There has been no systematic study as to the effect of central acting drugs on the PRVEP (Erwin, 1980). Sedatives have however been shown to reduce the amplitude of flash EPs (Erwin, 1980) Rhodes et al. (1975), also using flash EPs, have shown that alcohol can have a profound attenuating effect. Woodson et al. (1982) have shown an increase in the amplitude of the flash EP during cigarette smoking. Chiappa (1983) however says there have been no reports of the effects of common therapeutic medications on the PRVEP.

When using the SSVEP for assessing visual acuity, patients must fixate the stimulus screen and therefore cannot be sedated. Any medication the patient has taken and the consumption of alcohol

or cigarette smoking immediately prior to testing should however be noted, and conservatism should be exercised in the interpretation of SSVEP data obtained from these patients.

3.1.1.2. Age

The amplitude of the PRVEP decreases significantly from childhood to adolescence (Snyder et al., 1981). The reason for this change is not clear but may be due to physical changes, for example, head circumference or brain mass (Buchsbaum et al., 1974) or may be chemically mediated (Snyder et al., 1981).

These changes take place over a long period and will not affect the SSVEP during the course of a visual assessment.

3.1.1.3. Sex

In the adult population there ere no sex mediated amplitude differences. Snyder et al. (1981) however report that females had significantly larger visual EPs than males during childhood and adolescence. These differences were thought to be caused by sex-related chemical differences.

3.1.1.4. Eye Dominance

Seyal et al. (1981) report that the PRVEP P100 amplitude for the dominant eye was significantly higher than for the non-dominant eye in both left and right dominant subjects although less so in left dominant subjects. Dominance was established on the basis of sighting dominance and two check sizes were used as stimulus. P100 amplitude did not relate to handedness.

When using SSVEPs for visual assessment most authors use binocular input. This is probably because it is difficult to

occlude an infant's eye without producing muscle activity. The effect of eye dominance is therefore not a problem.

3.1.1.5. Eye Movement

There has been no systematic investigation of the effect of eye movement on the PRVEP. Chiappa (1983) however reports no effect on P100 amplitude in one subject who attempted to synchronise eye movement with the reversing pattern. If this same subject however produced a voluntary nystagmus throughout the recording P100 amplitude was greatly reduced.

3.1.2. Stimulus Factors

3.1.2.1. Check Size

Harter and White (1970) showed that the amplitude of the visual EP varies systematically with check size. As check size is increased up to approximately 20 minutes of arc (20'), amplitude increases. Any further increase then results in a decrease in amplitude. Erwin (1981) also found that the highest amplitude was obtained at check sizes of between 15 and 30' with an amplitude attenuation for larger or smaller checks. If this is represented graphically (Figure 8) an inverted v-shaped function is seen.

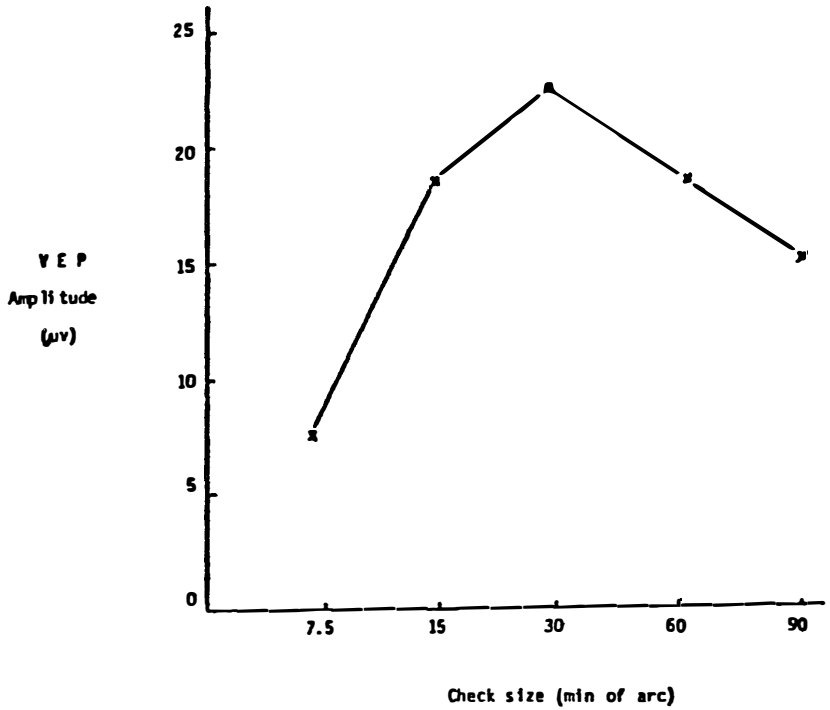
3.1.2.2. Luminance

No investigation into the effect of luminance on P100 amplitude could be found. Murdoch (1981) however shows small differences in P100 amplitude, in a single subject, with a dull and bright screen.

3.1.2.3. Screen Size

No report on the effect of screen size on amplitude could be

FIGURE 8
VEP AMPLITUDE/CHECK SIZE FUNCTION FOR A 4-MONTH-OLD INFANT
(FROM SOKOL 1978)



found. Many authors have however investigated the effect of retinal eccentricity on EP amplitude. Chiappa (1983) cites evidence that small checks produce a higher amplitude response when presented to the foveal retina but that when presented to the peripheral retina larger check sizes produce higher amplitudes. As screen size is increased so more of the peripheral retina is stimulated. The amplitude of the pattern visual EP depends on the response of both the foveal and peripheral retina and increasing screen size might therefore change the amplitude of the response.

3.1.2.4. Room Illumination

Erwin (1980) reports no effect of room illumination on PREVP amplitude.

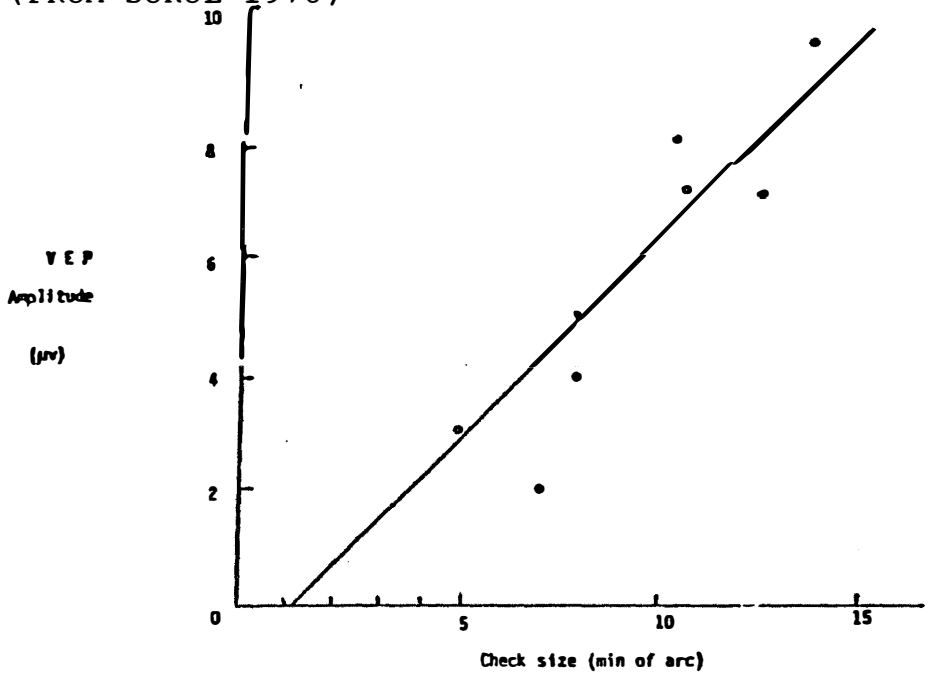
3.2. THE USE OF SSVEPs IN ASSESSING VISUAL ACUITY

Visual acuity can be estimated by examining the amplitude response of the SSVEP to different check sizes. The check yielding maximal amplitude however does not correspond to the acuity threshold. For example, an adult with normal vision is likely to have the largest SSVEP amplitude at a check size subtending a visual angle of 10′. This would correspond to a Snellen acuity of 20/200. The psychophysical measurement would be 20/20. Acuity threshold (the smallest check that can be seen before the screen appears uniformly grey) would correspond to the smallest amplitude measured as check size is decreased. Threshold is however difficult to measure in this way because artefact may obscure the SSVEP at these very low amplitudes.

It has been shown (Regan and Richards, 1971; Sokol 1978) that acuity threshold can be estimated. This is done by plotting check size against SSVEP amplitude and extrapolating the graph through the zero point on the amplitude axis (Figure 9). The check size corresponding to zero amplitude can then be converted

FIGURE 9

AMPLITUDE OF THE VEP AS A FUNCTION OF CHECK SIZE (FROM SOKOL 1978)



to a Snellen equivalent and this has been found to agree with the psychophysically obtained measure.

3.3. SSVEP ASSESSMENT OF VISUAL ACUITY IN RELATION TO OTHER METHODS

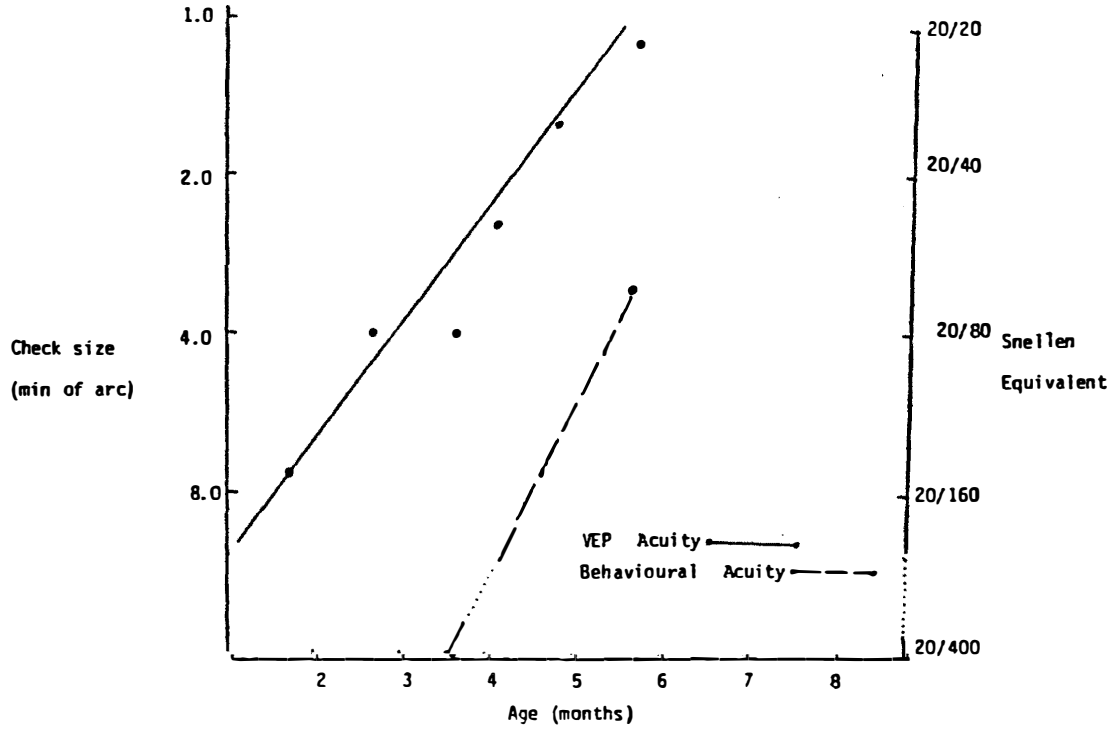
Using SSVEPs Sokol (1978) tested 12 normal infants at monthly intervals from two until six months of age. He estimated the development of binocular visual acuity in these infants (Figure 10). Acuity improved from 20/150 at two months to 20/20 at six months. This improvement probably reflects the maturation of the optic apparatus and myelination of the optic neural pathways..

These results however do not entirely agree with those obtained by behavioural methods. For example, using the preferential looking method with a reponse criterion of 70 %, Teller et al. (1974) estimated infant acuity to be 20/400 at 2 months, improving to 20/70 by 5,5 months (Figure 10). However, using a 50 % response criterion, Teller's results overlap quite closely with SSVEP measures (Sokol, 1978).

Sokol et al. (1983) compared the Forced-choice Preferential Looking (FPL) method of estimating visual acuity and VEP methods in paediatric patients. He states that in a clinical setting, the VEP procedure was more often completed in children under two years of age, than was the FPL method. Further, VEP results more often agreed with clinically determined acuities than the FPL results.

The differences between VEP and behavioural estimates of visual acuity could result from the differences in the stimuli. Modulated or static patterns, differences in luminance levels and total field size, and many others, may be relevant. Unless a study employing simultaneous behavioural and VEP assessment is done, using identical stimuli, a valid comparison of the accuracy of each is not possible. In the absence of such a

FIGURE 10
VEP AND BEHAVIOURAL ACUITY FOR INFANTS (2 - 7 MONTHS)
(FROM SOKOL 1978)



study, VEP assessment of acuity in infants would appear at least to have the advantages of objectivity and replicability.

At the N I P R we have attempted to assess visual acuity in difficult-to-test infants. Our procedure and results are described below.

3.4. METHOD

3.4.1. Subjects

Three male and six female infants, between the ages of two and 16 months, referred for visual testing, were tested. Six of the infants were referred by paediatricians and one each by a neurologist, neurosurgeon and opthalmologist. The reason for referral in all cases was that the infants responded poorly to visual stimulation. In some cases the visual following response was poor. There was a history of neurological dysfunction in seven of the nine subjects. In the remaining two there was no significant history but they were slow to repond to visual stimuli. Subjects' age, sex, source of referral and reason for referral are summarised in Table 7.

3.4.2. Procedure

3.4.2.1. Recording

SSVEPs were recorded from a silver disc electrode placed at OZ and referred to an electrode at FZ. An electrode placed at FpZ served as ground (Jasper, 1958). Electrode sites were cleaned with alcohol and the electrodes were held in place with Beckman adhesive paste.

The child was not sedated but was seated on it's mother's lap one metre from the television monitor in a semi-darkened room.

TABLE 7
AGE, SEX, SOURCE OF REFERRAL AND REASON FOR REFERRAL

CASE NUMBER	AGE (m)	SEX	REFERRAL SOURCE	REASON FOR REFERRAL
1	7	F	Neurosurgeon	Does not follow visual stimuli
2	4	F	Paediatrician	City health worker found poor response to visual testing
3	11	F	Paediatrician	Does not follow visual stimuli
4	12	F	Paediatrician	Appears blind
5	10	M	Opthalmic surgeon	Squint. Does not follow visual stimuli
6	16	F	Paediatrician	Motor vehicle accident. Poor visual alertness
7	6	F	Neurologist	Difficult birth. Brain damaged. No response to visual stimuli
8	2	M	Paediatrician	Occipital haematoma. Fixates but does not follow visual stimuli
9	6	M	Paediatrician	Suspected brainstem dysfunction. No response to visual stimuli

Visual stimuli were generated by a Nic 1005 stimulus generator. Checks varied in size from those subtending seven to 110′ of visual angle. The reversal rate was 7,5 per second.

Potentials were amplified and stored in a Pathfinder II Evoked Potential System with the preamplifier band-pass filters set to pass one to 35 Hz. One hundred sweeps were averaged for each checksize using an analysis time of 500 ms. The child′s attention was maintained by an observer, using small noise producing toys, positioned behind the TV monitor. The observer also monitored the child′s fixation and averaging only took place during fixation. Sweeps containing eye movement or EMG artefact were rejected by the averagers artefact rejection mode.

3.4.2.2. Analysis

The amplitude above baseline for each positive peak of the SSVEP was measured and the mean calculated for each checksize used. The checksize giving the largest amplitude was noted and binocular acuity was estimated by extrapolating the regression line (fitted to the amplitude/checksize function for the checks smaller than the peak value) to zero amplitude.

The Nic 1005 can only generate four checksizes smaller than those subtending 55′ of arc. In order to produce sufficient checks smaller than the check yielding the maximum amplitude, to permit an accurate plot, it was often necessary to move the TV monitor away from the subject to obtain suitably smaller check sizes. Only if amplitude measures for at least four check sizes less than that producing the maximum amplitude were obtained, was the regression procedure used to estimate acuity.

3.5. RESULTS

In one of the nine subjects no measurable response could be recorded. This patient was 16 months old and would not tolerate

prolonged electrode application. The electrode impedance could not satisfactorily be reduced and poor recordings resulted. This child was also very restless and EMG artefact dominated the recordings.

Responses from three subjects were obtained only to very large checks. All showed nystagmus and were not able to fixate the stimulus screen. Their results were excluded from the study.

Of the remaining five subjects it was necessary to move the TV monitor to 1,5m and 2m for four of the subjects. The check sizes yielding peak SSVEP amplitude, the subject's age and rating of abnormality for age, is given in Table 8. Data quoted by Sokol (1978) as well as the clinical signs were used as criteria of abnormality.

Sokol's regression procedure proved unsatisfactory in four of the five subjects. They obtained negative visual angles at the intercept with the amplitude axis. Only one subject obtained a positive result. Visual acuity for this subject was 20/100 which is normal for four months of age (Sokol 1978). This is the only subject where the distance from the TV monitor was held constant.

3.6. DISCUSSION

In our sample reliable results were obtained in only 55,5 % of cases. We were able to estimate only the degree of maturation of the visual system in four cases and acuity in one case. Sokol et al. (1983) used a transient VEP procedure and successfully tested approximately 76 %(no N given) of his subjects under one year old. Our relatively poor success rate can be attributed to several factors. Firstly, except for a few normal trial cases (mostly adults), the cases in this study represent our initial experience with this test. As our experience expands we expect to achieve a higher success rate.

TABLE 8
CHECKSIZE YIELDING MAXIMUM SSVEP AMPLITUDE AND NORMALITY RATING

CASE NUMBER	AGE (m)	CHECKSIZE IN MINUTES OF ARC	RATING
1	7	14	Normal
2	4	28	Normal
3	11	17	Normal
4	12	28	Abnormal
5	10	55	Abnormal
6	16	*	-
7	6	*	-
8	2	*	-
9	6	*	-

* No test possible

Secondly the sources of referral did not realise the procedural limitations of the test. Three cases were brain damaged children with severe visual problems. The degree of co-operation required in fixating the screen was beyond these children and flash-evoked potentials would have been a more appropriate test. Furthermore Sokol et al. (1983) reported difficulty in testing children with congenital nystagmus, using VEP methods. van Hof- van Dain (1983) also reported difficulty in recording VEPs from patients with spontaneous nystagmus, suggesting that the eye movement interfered with the visually evoked potential. Children with nystagmus are thus not suitable for testing using VEP methods. Sokol et al. (1983) reported greater accuracy in these cases using the FPL method.

Thirdly, Sokol (1978) used a narrow bandpass filter set to pass only a limited range close to stimulation frequency. Interfering harmonics and extraneous artefact were thus eliminated. The frequency components in an SSVEP are not necessarily related to the main frequency (Regan 1982) and may thus reduce the amplitude of the response. The effect of using a bandpass filter can be seen in Figures 11a and b. The wave forms were recorded simultaneously except that those in Figure 11b were passed through a narrow bandpass filter between the amplifier and the averager.

In none of our cases was a bandpass filter used. The recordings were therefore contaminated by artefact and other genuine but irrelevant frequencies. This probably accounted for the failures we experienced using Sokol's regression method.

The low success rate in estimating visual acuity may also have been related to the fact that in four cases SSVEPs were recorded with the screen at three distances from the subject. As explained, this was done to permit an adequate number of check sizes to be regressed against SSVEP amplitude. However this procedure had the effect of stimulating different sizes of

FIGURE 11 a
SSVEPs RECORDED WITHOUT A NARROW BAND-PASS FILTER

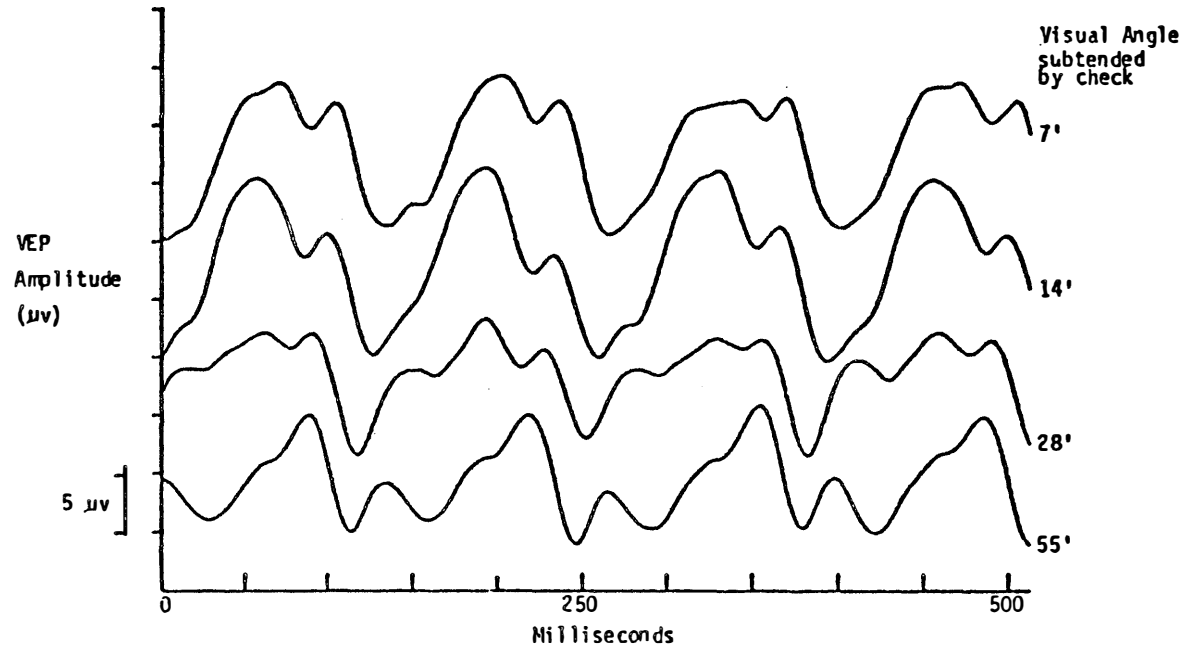
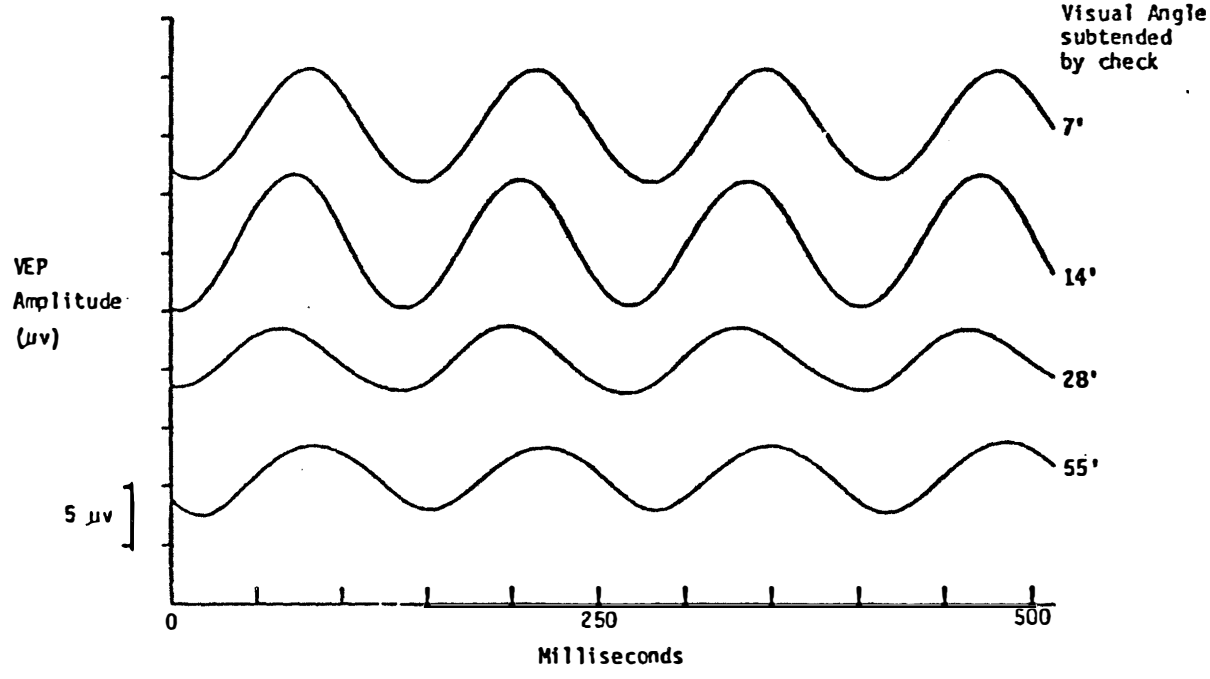


FIGURE 11 b
SSVEPs RECORDED WITH A NARROW BAND-PASS FILTER



visual fields. This may have had a confusing effect on the results.

To investigate this effect SSVEPs were recorded from a normal adult subject with the screen at 0,5, one and two metres from the subject, with the check size subtending the same visual angle for the three distances. Figure 12 shows that as the relative size of the stimulus screen decreases, so the amplitude of the response decreases, even though the visual angle subtended by the check remained constant. This effect can be controlled to a certain extent by masking the screen so that the visual field stimulated remains constant at various distances. Figure 13a shows SSVEPs recorded with the screen masked so as to keep field size constant but in Figure 13b both field and check size varied. The confusing effect of not keeping field size constant can easily be seen. The influence of this variable is therefore relevant in explaining our unsatisfactory results using the regression procedure.

In the only subject for whom an acuity estimate was possible, the screen was kept at a set distance from the eyes and check sizes alone varied.

Our experience in tracing and eliminating procedural shortcomings have resulted in refinement of the method. The SSVEP assessment of visual acuity can be offered as a clinical service. However not all prospective patients may be accommodated. Although the procedure is suitable for use in patients who are too young or cognitively impaired for psychophysical testing, a certain amount of cooperation is still required. The patient cannot be sedated, as is the case using the brainstem auditory evoked potential. He is required to sit reasonably still and to fixate the stimulus screen. (This makes the test unsuitable for children with nystagmus). Our experience is that succesful testing is more easily accomplished with children under one year of age than with older children.

FIGURE 12

SSVEPs RECORDED WITH SCREEN DISTANCES OF 0,5m, 1 m AND 2 m WITH CONSTANT CHECK SIZE

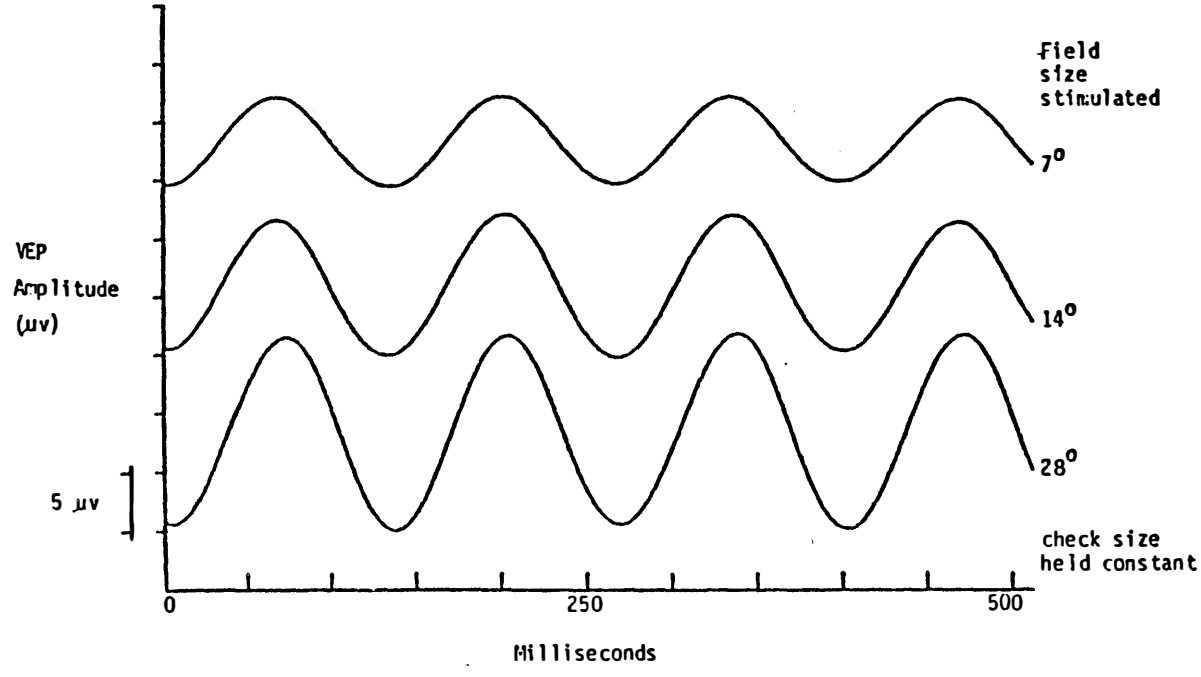


FIGURE 13 a

SSVEPs RECORDED WITH VARYING CHECKSIZES BUT CONSTANT FIELD SIZE

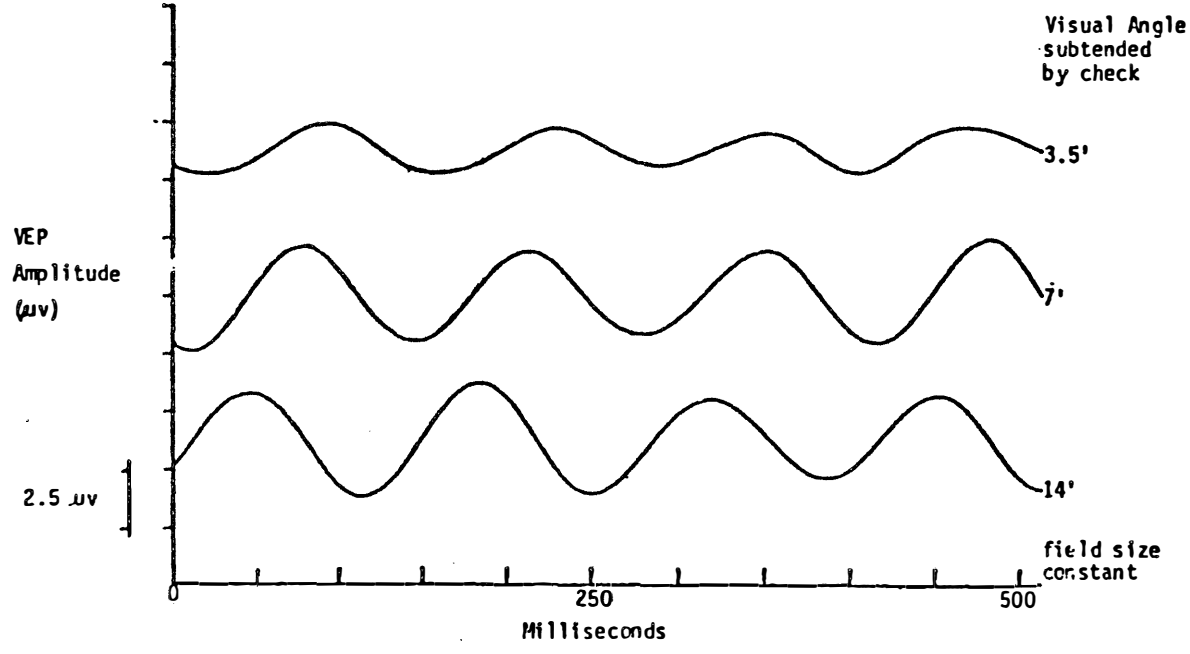
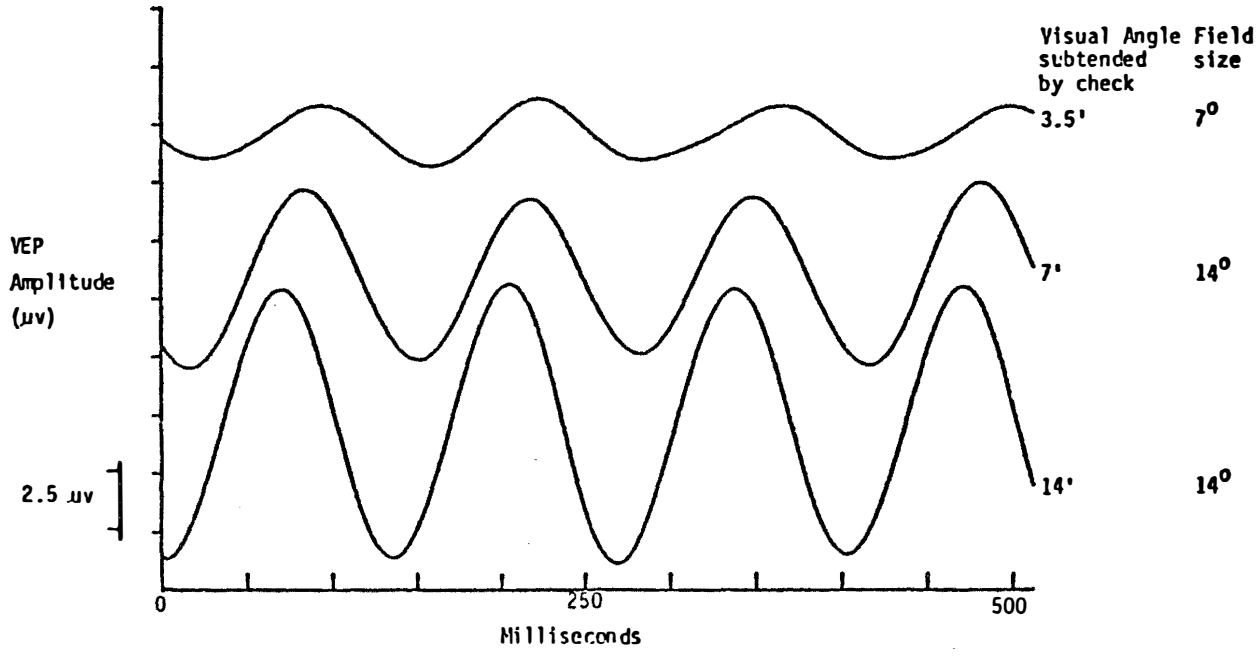


FIGURE 13 b
SSVEPs RECORDED WITH VARYING CHECKSIZES AND FIELD SIZES



Sokol (1983) reaches a similar conclusion

Regan (1977) provides an imaginative approach to dealing with the problems of acuity assessment using VEPs. He superimposes comic-strip videos onto the reversing checkerboard to augment fixation and uses Fourier Analysis of the potential rather than an averaging procedure. Only a few seconds of Fourier Analysis is necessary at each check size to produce a satisfactory checksize/amplitude function. As Fourier Analysis is frequency-specific the need for bandpass filtering is eliminated (Regan, 1982). It is possible that Regan´s approach could be adapted for use in our laboratory at some future date, and this is currently being explored.

4. APPENDIX A

4.1. REPRESENTATIVE CASE HISTORIES (BAEP ASSESSMENTS)

4.1.1. Case 1

This seven-week-old male was referred by a speech therapist for a hearing assessment. The child was being given up for adoption and because both biological parents were deaf it was considered necessary to check the child's hearing.

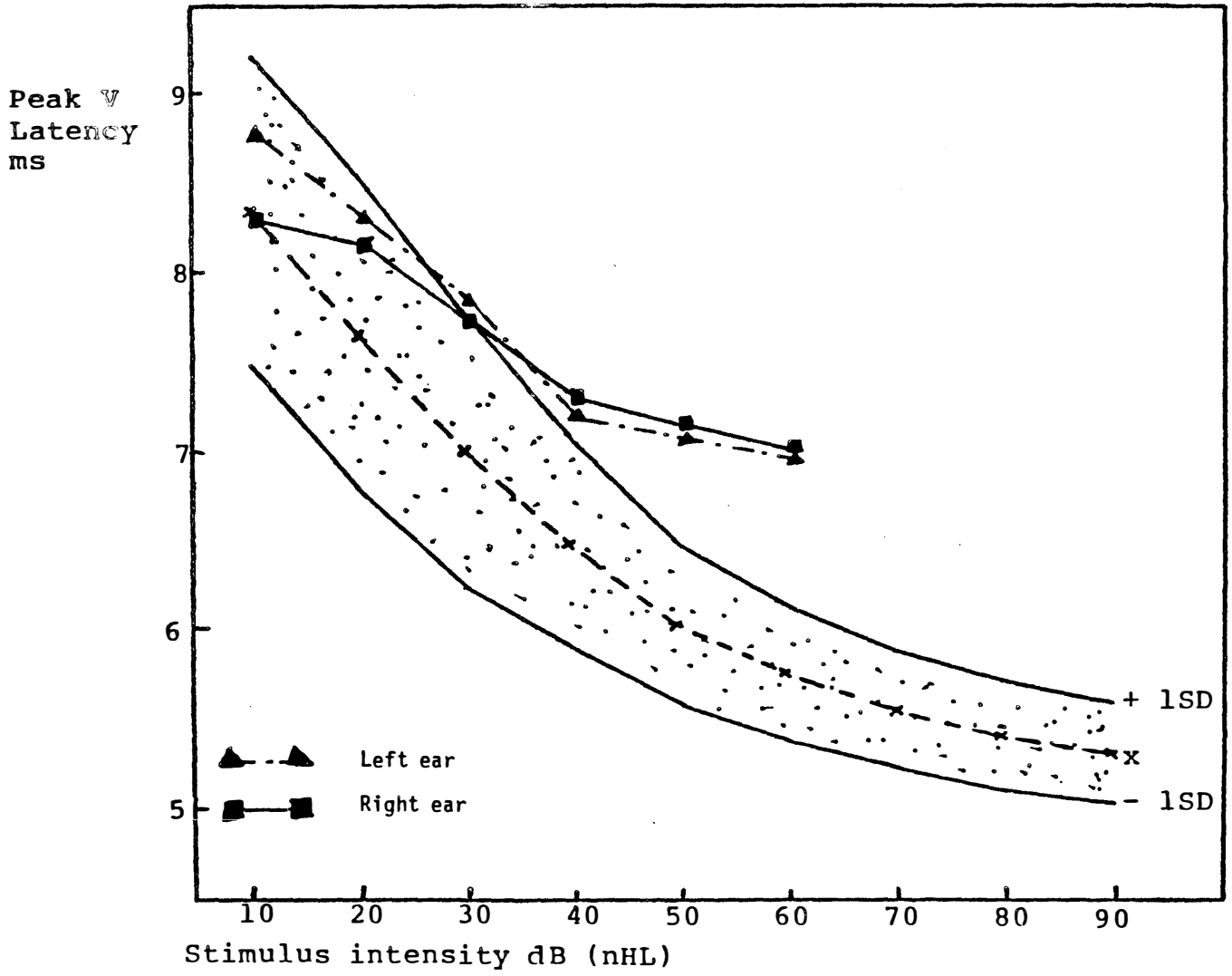
The child was sedated with Tricloryl (2.5 ml) and slept during recording. BAEPs were recorded using the procedure described in the body of the report.

Potentials with easily identifiable peak Vs were evoked at all intensities employed. The peak V latency/intensity curves followed the expected pattern with the latency increasing as intensity was decreased (Figure 14). At 60 dB (nHL) the peak V latencies for left and right ears respectively were: 6,94 and 6,97 ms. The peak I to V latency differences were 4,75 and 4,57 ms and the peak V/I amplitude ratios were 1,5 and 1,07 respectively.

Figure 14 shows the latency/intensity function for this child. This was shallower than the normal adult curve. We have noticed that this phenomenom has occurred in most of the very young children we have tested and we therefore feel it is a normal pattern. Hecox (1984) however claims that a shallow latency/intensity function is indicative of a high frequency hearing loss. Futher research into the maturational changes of the latency/intensity function should resolve this issue.

Threshold and inter-peak latency results appeared to be within normal age limits implying normal functioning of the peripheral auditory apparatus as well as of the auditory neural pathways up

FIGURE 14
PEAK V LATENCY/INTENSITY CURVES FOR CASE 1



to the level of the inferior colliculus. The speech therapist could reassure the adoptive parents that a congenital hearing loss was unlikely.

4.1.2. Case 2

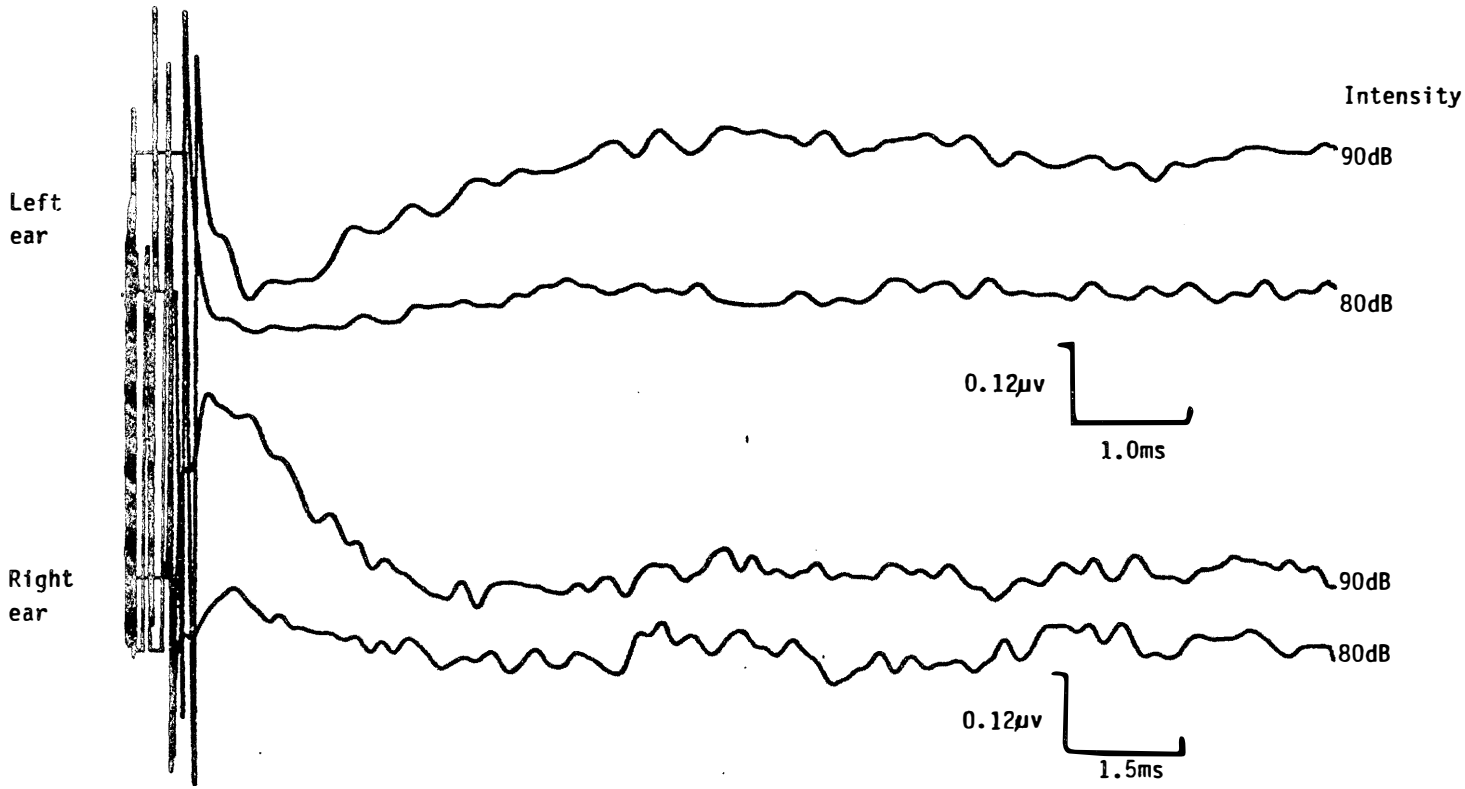
A four-year-old male attending a school for autistic children was referred by his principal for a hearing assessment because he was not yet speaking. The child displayed no typically autistic behaviour. He appeared to be very alert and he responded well to visual stimuli. Birth and medical history were normal except that he appeared hyperactive and was given medication to control this. His mother reported that at six months of age she felt he was not responding to sound. She discussed this with the city health sister who referred him to an ENT specialist. The mother was told his hearing was intact. When the child had not started speaking by two years of age the mother once again asked for his hearing to be assessed. She was told it appeared normal. Six months later she took the child to an audiologist who also assessed his hearing to be normal but the tests were not conclusive. In the light of this information the child was admitted to the school for autistic children.

BAEPs were recorded according to the usual procedure. The child was sedated (15ml Tricloryl and two Vesperaxette an hour later);his stimulant medication had been stopped two days before the test, and he slept during the recording.

No peak Vs could be identified in the potentials evoked for either ear at any of the intensities employed (Figure 15).

The results strongly suggested a severe to profound bilateral hearing loss. The child was referred to an ENT surgeon who examined him under anaesthesia and found him to have a very mild serous otitis with minimal fluid present in the middle ear. An

FIGURE 15
BAEPs RECORDED FROM CASE 2



acoustic impedence test done under anaesthetic showed a response only at 250 Hz and a complete absence of the stapedius reflex at all other frequencies.

It was recommended that the child be accustomed to the use of a hearing aid and that he be referred to a speech and hearing clinic for possible speech therapy.

This case illustrates how the BAEP can be used to check behavioural testing when inconsistent results are obtained. The successful use of the BAEP permitted this child to be transferred from an obvious misplacement in the autistic school.

4.1.3. Case 3

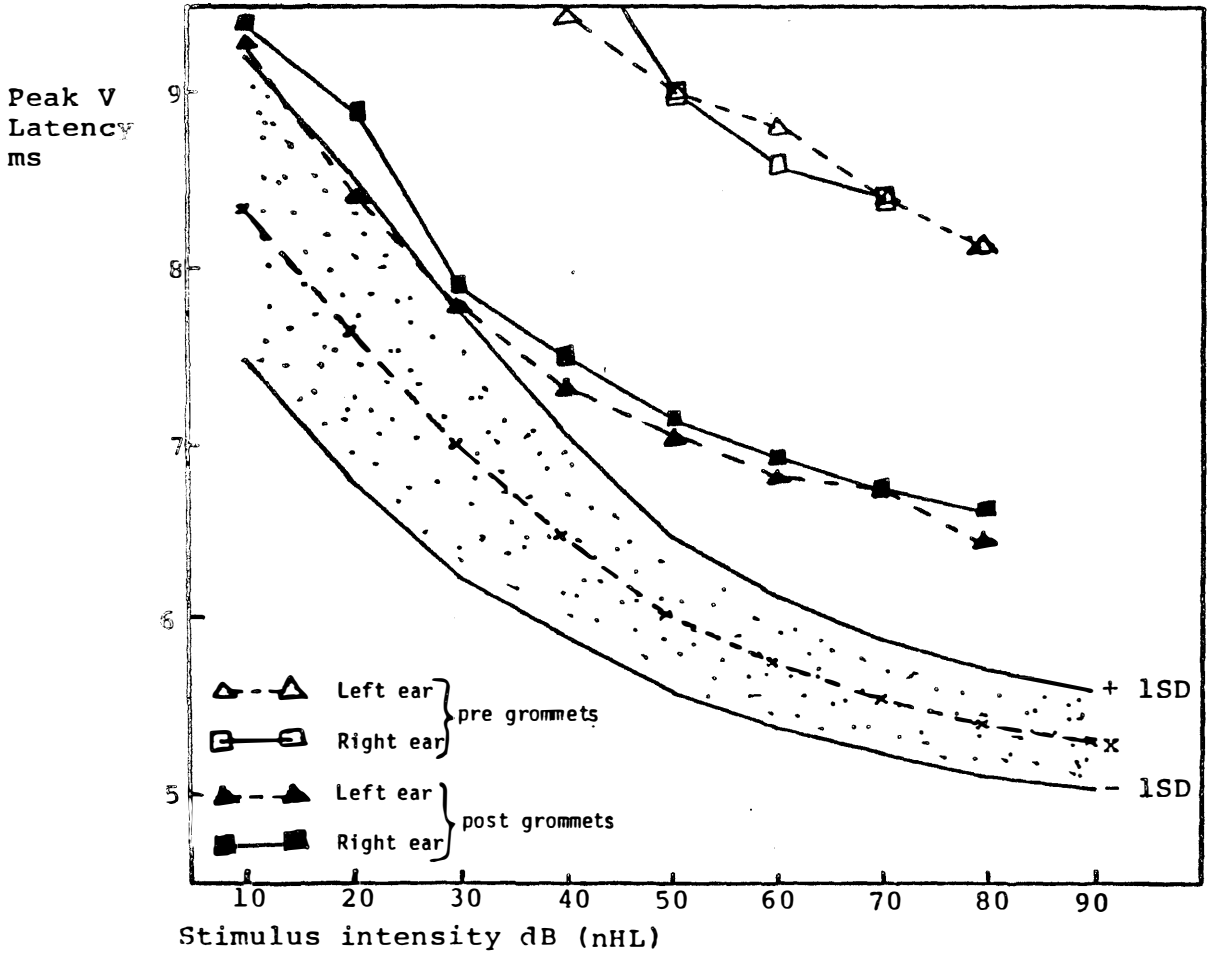
A four-and-a-half month old male was referred by a paediatrician for a hearing assessment. Birth and pregnancy were normal. The parents had however noticed that his head was very big and he had poor head control. He also pulled his head to one side. He vocalised at an early age. CT scan showed bilateral frontal hygromas.

BAEPs were recorded to rarefactory click stimulation presented monaurally at intensities ranging from 10 to 80 dB(nHL). Electrode CZ was referred to electrodes placed on the earlobes and ipsilateral recordings made. The child was not sedated but slept towards the end of the test.

The recordings were marred by muscle artifact and peak Vs could only be evoked at intensities above 40dB (nHL). The latency/intensity curves both followed the expected pattern but were displaced to the right of the normal adult curve by 50 to 60 dB (Figure 16). The peak I to V latency difference with right ear stimulation was 4,8ms. If a correction to allow for age is made results suggested a bilateral conductive loss of 30-40dB but a repeat recording, with sedation, was requested for

FIGURE 16

PEAK V LATENCY/INTENSITY CURVES FOR CASE 3 RECORDED BEFORE AND AFTER INSERTION OF GROMMETS



confirmation.

BAEPs were recorded six weeks later. Grommets had been inserted bilaterally four days before testing. On this occasion the threshold for the left ear was 20dB and for the right ear 30dB(nHL). The latency/intensity curve for the left ear was within normal age limits and for the right ear was displaced to the right by approximately 10dB. Results indicated normal hearing in the left ear and a mild conductive loss in the right ear, possibly due to post operative infection.

Four months later follow-up BAEPs were recorded at the request of the paediatrician. On this occasion peak V could be identified in both ears at an intensity of 10dB (nHL) and the latency/intensity curves were within normal limits (Figure 16). Insertion of grommets had resulted in normal hearing in this case.

4.1.4. Case 4

A 20 month old female was referred by a paediatrician because her mother felt the child was not responding to sound. The child had been diagnosed as having Pierre Robin syndrome and in addition to this had suffered several febrile convulsions since the age of six months. The child was microcephalic and probably retarded and there was therefore uncertainty as to whether the lack of response to sound was due to these factors. On the other hand there was evidence of a middle ear infection. It was hoped that the BAEP would indicate whether the child could hear.

BAEPs were recorded according to the procedure described above. The child was sedated (5 ml Tricloryl) and slept during recording. Results indicated a moderate bilateral conductive hearing loss with the left ear more severe than the right.

Seven months later the child was referred for a follow up

recording. Grommets had been inserted bilaterally and on this occasion left ear results were within normal limits but right ear results had deteriorated slightly. Figure 17 shows the potentials recorded post operatively and Figure 18 shows the changes in the latency/intensity functions for left and right ears before and after insertion of grommets. Unilateral improvement only was reported.

4.1.5. Case 5

A three and a half year old male who was attending a unit for hearing impaired children was referred for assessment because there was uncertainty regarding his hearing status. Behavioural audiometry yielded inconsistent results and the child imitated the speech therapist equally well with and without his aid.

The child was sedated (Vesparaxette) and BAEPs were recorded during sleep. Results strongly suggested a severe bilateral hearing loss. The latency/intensity curve appeared very steep suggesting a sensory neural loss. The peak V latencies at 90 dB(nHL) were within normal limits probably due to recruitment.

In an attempt to assess the effectiveness of the hearing aid binaural BAEPs were recorded with and without the hearing aid in place. The hearing aid improved the child's threshold by approximately 30dB. Further, it improved the level at which peak V was within normal limits by a similar amount.

Results indicate that the aid was of some use to the child but that the gain needed to be increased. The possibility of using an aid with a high compression ratio was suggested. Repeat BAEP recordings once the changes to the child's aid were made were recommended. Hecox (1984) suggested that a steep latency/intensity slope could be normalised by using a high compression aid, thus improving the child's effective dynamic range.

FIGURE 17
BAEPs RECORDED FROM CASE 4 AFTER INSERTION OF GROMMETS

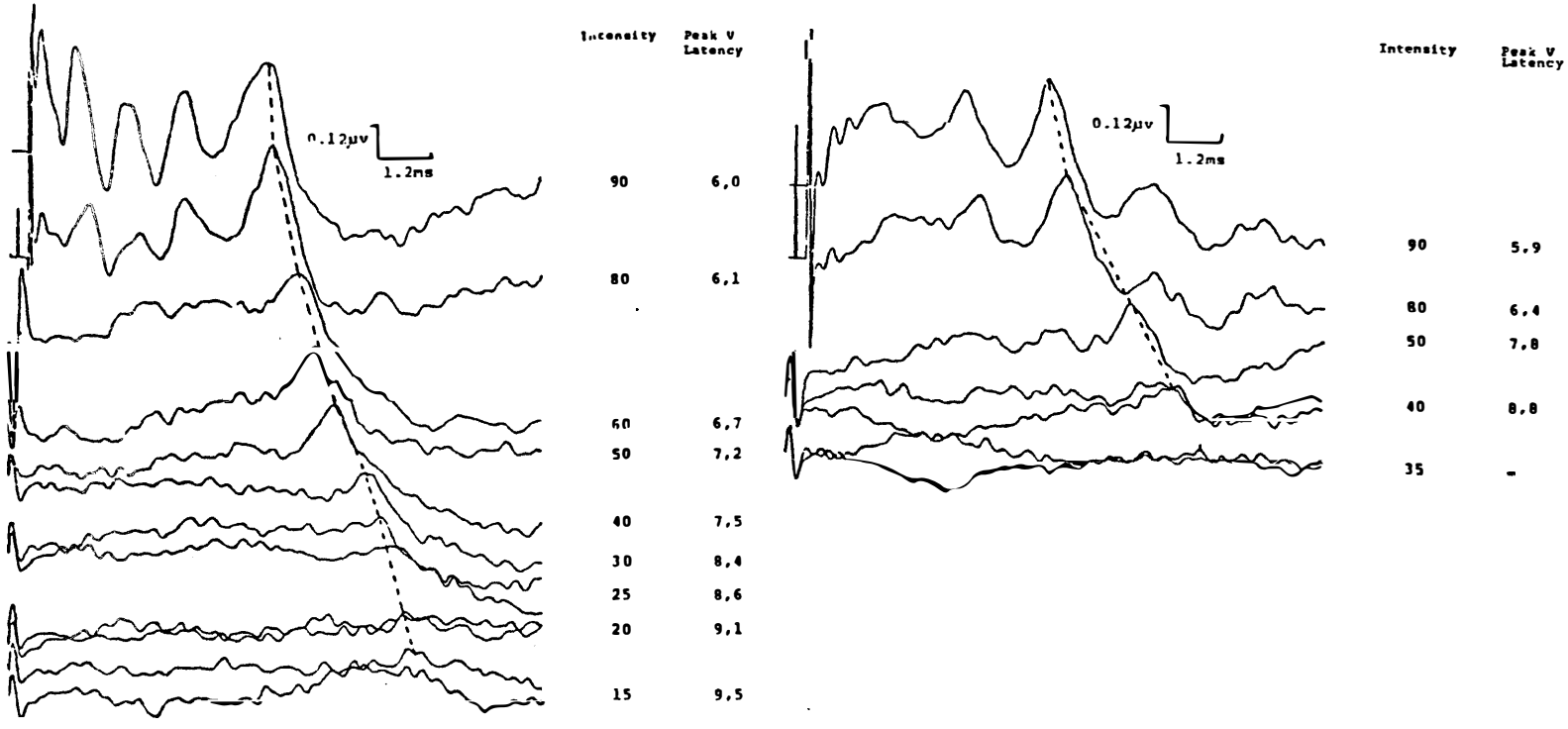


FIGURE 18
PEAK V LATENCY/INTENSITY CURVES FOR CASE 4 BEFORE AND AFTER INSERTION OF GROMMETS

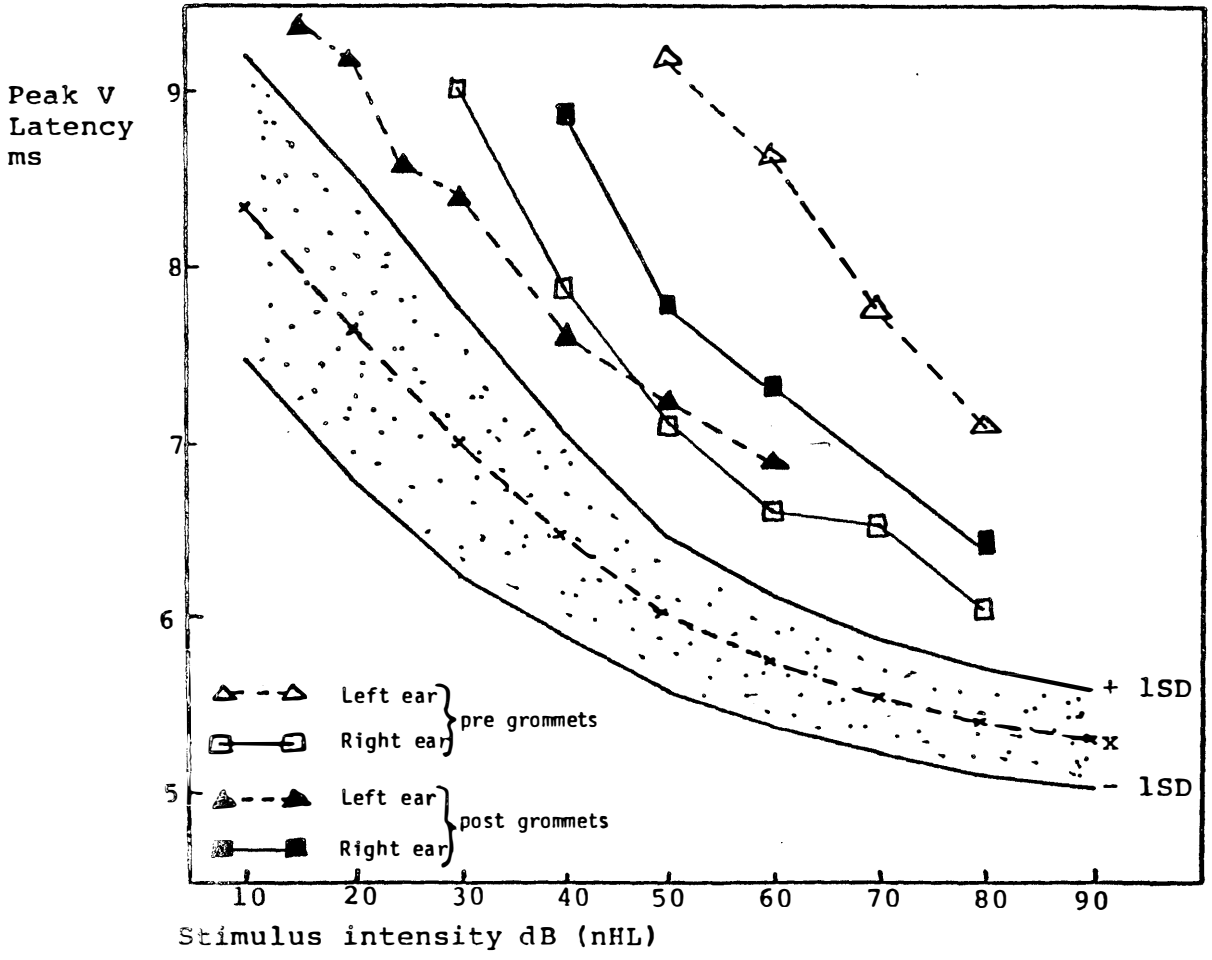
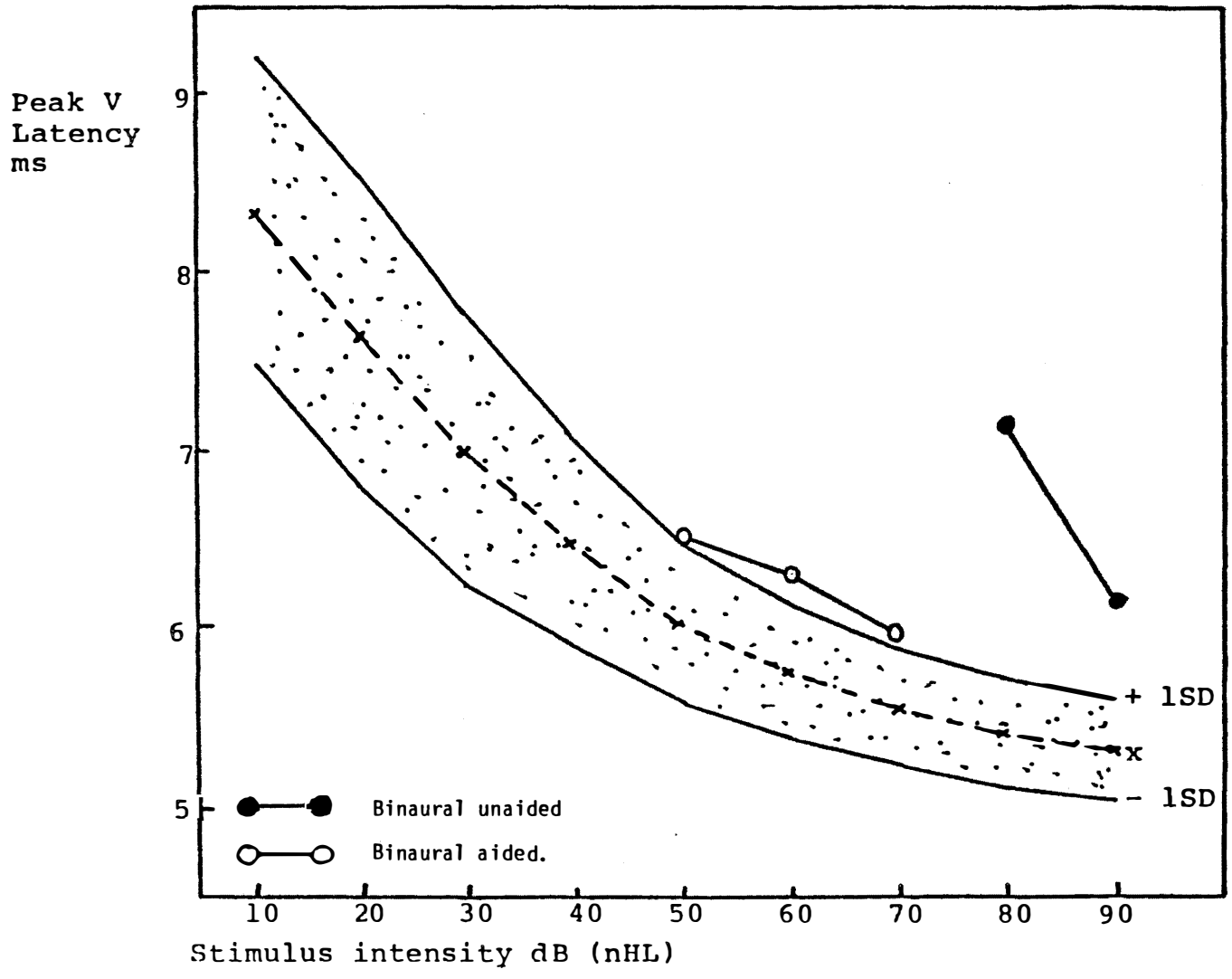


FIGURE 19
PEAK V LATENCY/INTENSITY CURVES FOR CASE 5 WITH AND WITHOUT HEARING AIDS



This case illustrates the role the BAEP can play in the prescription of the correct hearing aid. The information provided by the BAEP in this case could not have been obtained in any other way.

4.2 REPRESENTATIVE CASE HISTORIES (SSVEP ASSESSMENTS)

4.2.1 Case 1

A seven month old female was referred by a neurosurgeon for visual assessment. She had been born two weeks before term and immediately after birth had had a convulsion. She also had cardiac difficulties and pneumonia. When a few days old she had a cerebro-vascular accident. At the time of referral the child did not follow visual stimuli although she did appear to fixate.

SSVEPs were recorded according to the procedure described in the body of the report. Results were inconclusive although it appeared that some visual perception was taking place. A repeat recording was recommended.

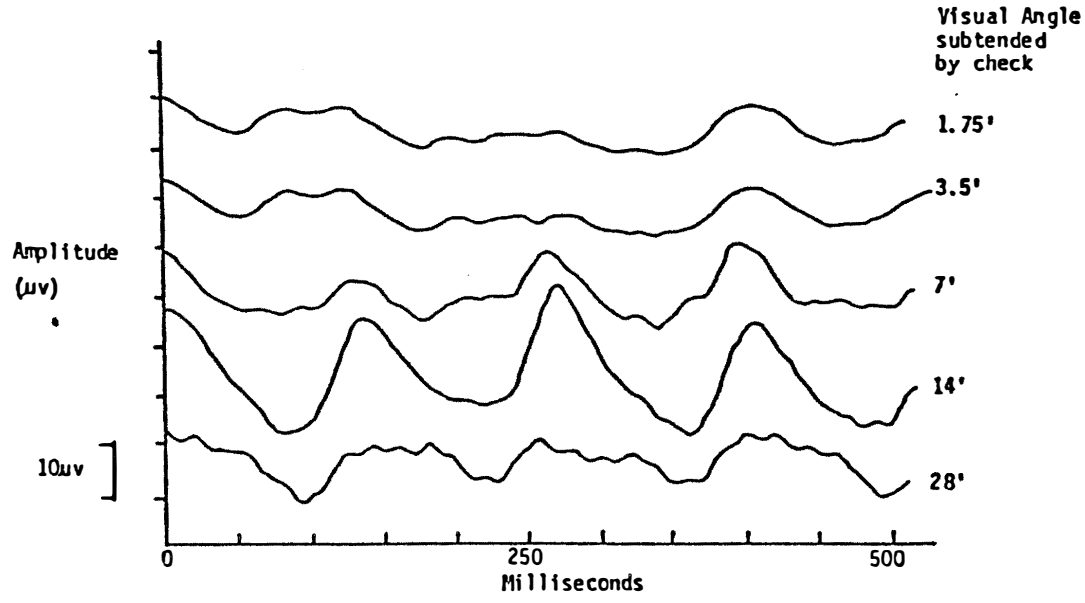
At 17 months of age the SSVEP was repeated. On this occasion clear SSVEPs at the same frequency as the stimulus were evoked. A checksize of 14′ of arc yielded maximum amplitude (Figures 20 and 22). This is within normal age limits.

Although Snellen acuity could not be estimated due to the technical difficulties described above the result did indicate that visual perception was present and that acuity was probably within normal limits.

4.2.2 Case 2

A four month old female with no significant history was referred to a paediatrician because a city health worker had found a poor response to visual stimulation. On examination the

FIGURE 20
SSVEPs FOR DIFFERENT CHECK SIZES RECORDED FROM CASE 1



paediatrician found no obvious defect but was still uncertain about the child's visual ability. The child was referred for SSVEP assessment.

SSVEPs were recorded to checksizes ranging from seven to 55' of arc and an amplitude/checksize function plotted (Figures 21 and 22).

A checksize of 28' yielded maximum SSVEP amplitude and the Snellen acuity, using Sokol's regression method, was estimated at 20/100. Sokol (1978) found the Snellen acuity for a four month old to be 20/80. This child was therefore close to normal limits and the parents could be reassured accordingly.

FIGURE 21
SSVEPs FOR DIFFERENT CHECK SIZES RECORDED FROM CASE 2

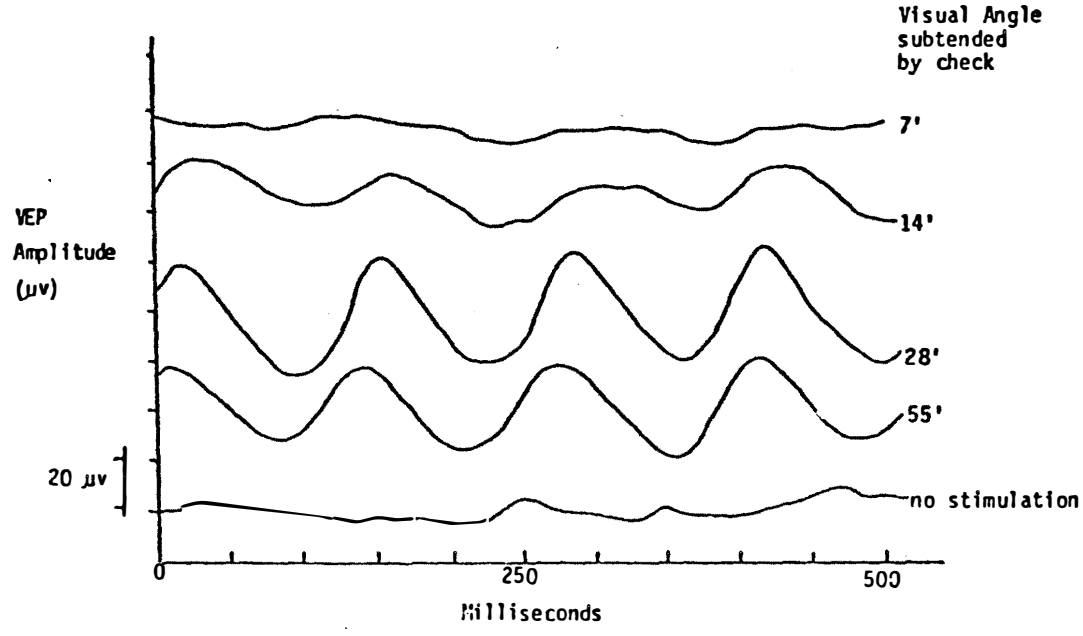
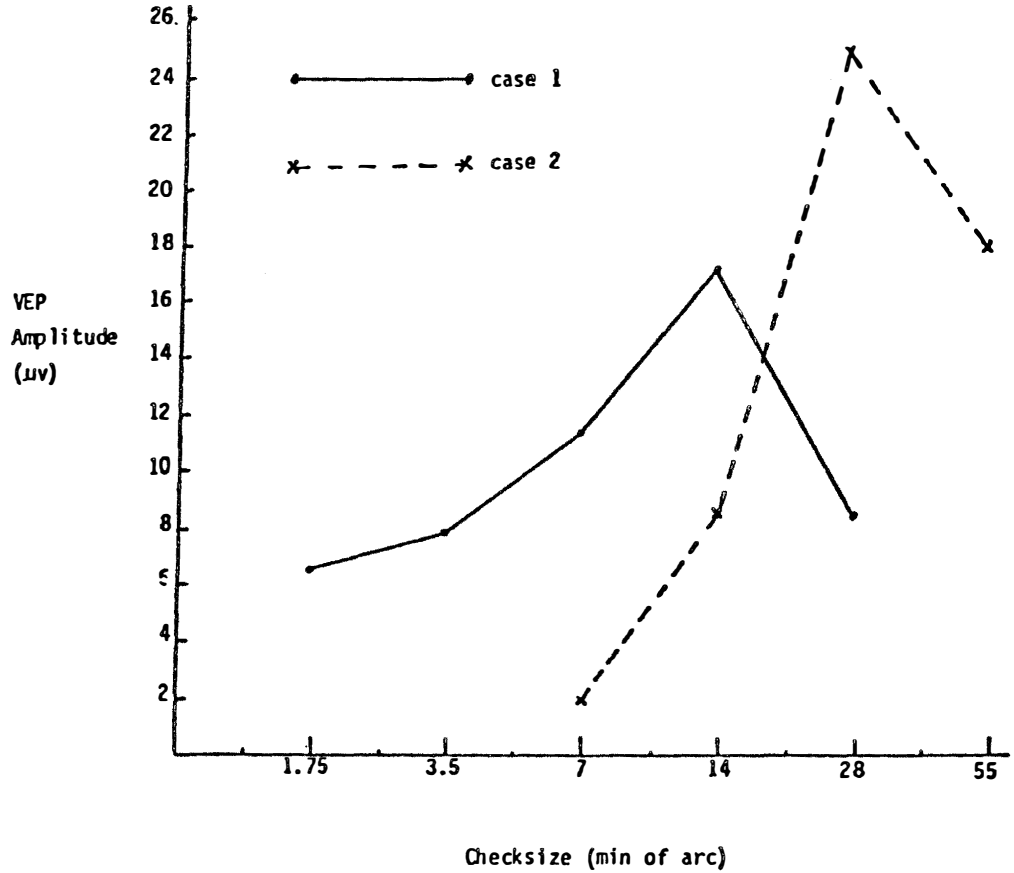


FIGURE 22
VEP AMPLITUDE PLOTTED AGAINST CHECKSIZE FOR CASES 1 AND 2



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