"THERE IS MORE TO THIS THAN MEETS

ANYBODIES EYE"

Dr Alison Blake - Visiting Research Fellow
(1983)

This thesis is dedicated to my

parents and to Kathy

AUTOMATED ASSESSMENT OF VISUAL FIELDS AND THEIR INTER-RELATION TO EVOKED POTENTIALS IN VISUAL DISORDERS

JOHN GERARD FLANAGAN BSc(Hons), M.B.C.O.

Thesis submitted for the Degree of

Doctor of Philosophy

The University of Aston in Birmingham

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THE UNIVERSITY OF ASTON IN BIRMINGHAM

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SUMMARY

The Octopus Automated Perimeter was validated in a comparative study and found to offer many advantages in the assessment of the visual field. The visual evoked potential was investigated in an extensive study using a variety of stimulus parameters to simulate hemianopia and central visual field defects. The scalp topography was recorded topographically and a technique to compute the source derivation of the scalp potential was developed. This enabled clarification of the expected scalp distribution to half field stimulation using different electrode montages. The visual evoked potential following full field stimulation was found to be asymmetrical around the midline with a bias over the left occiput particularly when the foveal polar projections of the occipital cortex were preferentially stimulated. The half field response reflected the distribution asymmetry. Masking of the central 3^{o} resulted in a response which was approximately symmetrical around the midline but there was no evidence of the PNP-complex.

A method for visual field quantification was developed based on the neural representation of visual space (Drasdo and Peaston 1982) in an attempt to relate visual field depravation with the resultant visual evoked potentials. There was no form of simple, diffuse summation between the scalp potential and the cortical generators. It was, however, possible to quantify the degree of scalp potential attenuation for M-scaled full field stimuli.

The results obtained from patients exhibiting pre-chiasmal lesions suggested that the PNP-complex is not scotomatous in nature but confirmed that it is most likely to be related to specific diseases (Harding and Crews 1982). There was a strong correlation between the percentage information loss of the visual field and the diagnostic value of the visual evoked potential in patients exhibiting chiasmal lesions.

Keywords: visual evoked potential - visual field - neural representation - source derivation - scotoma

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CONTENTS

FIGURES

TABLES - Page

INTRODUCTION

The development of new technology and its increasing application within medicine has left the clinician with a bewildering array of equipment and techniques designed to enhance the capability of assessing and diagnosing the problems presented by patients. It has also led to a more extensive understanding of the neurological and physiological processes and the way in which these are affected by disease. Examination of the visual system has certainly advanced in this way and has led inevitably to the re-examination of many basic principles regarding the visual process and its abnormalities.

This thesis was inspired by the growing contradictory evidence from two particular clinical techniques both of which have been designed to assist in the investigation of the visual system. The first and most problematic is that of the Visual Evoked Potential. This is a visually elicited, poly-phasic complex found within the electro-encephalogram over the occipital cortex. It was first described by Adrian and Matthews in 1934 but has only more recently established itself as a useful clinical technique.

The second is perimetry, the measurement of the limits of observed visual space to the stationary eye; otherwise known as the visual field. Assessment of the visual field and its abnormalities has been with us much longer than

evoked potentials. The first recorded reference to visual field loss is believed to be by Hippocrates in the 5th Century BC. It is beyond the scope of this thesis to discuss the full history of perimetry but essential to consider the recent developments due to new technology.

The two methods of investigation effectively measure the visual system at opposite ends. The visual field gives a measurement of the perceived sensory input and the VEP is a measure of the cortical activity generated as a result of this input. As such the two techniques have often been studied in conjunction with each other. The former provides an accurate mapping which can aid the localisation of lesions within the visual pathway. It depends on a purely subjective response and requires a high degree of patient co-operation. The latter requires far less co-operation and under certain circumstances can provide a useful clinical assessment even in the comatose patient (Bergstrom and Nystrom 1970).

That there is a relationship between the two would at first seem obvious. What may not be so apparent is the extent and usefulness of this relationship. There has been considerable controversy during the development of these techniques and even in the most simple of visual field defects like hemianopia, where half of the visual field is missing, there has been disagreement over the nature of the expected VEP result (Halliday, Harding and

Holder 1980). The effect of a central visual field loss has provided similarly diverse results (Blumhardt, Barrett, Halliday and Kriss 1978; Harding and Crews 1982).

The aim of this thesis is to isolate these areas of controversey; to establish a model of the inter-relationship between the visual field and the VEP; and to assess this model by the investigation of patients exhibiting classic visual field abnormalities. The literature reviewed will initially discuss the normal VEP and will then be followed by a review of the previously reported relationship between the VEP and the visual field. Perimetry will be discussed with regard to the new technology available and methods of relating the two techniques will be explored.

CHAPTER 1

THE VISUAL EVOKED POTENTIAL

1.1 Historical Background

Early studies of the electroencephalogram (EEG) indicated clear electrical responses of the human brain to visual stimuli. Berger (1928) demonstrated a 10cps alpha rhythm when a subject's eyes were closed which disappeared on eye opening. Adrian and Matthews (1934) used regularly repeated flashes of light to demonstrate an electrical "following" response recordable over the occipital cortex. It was only after the pioneering technical achievements of Dawson (1951) that these potential changes, recordable after visual stimulation, could be usefully investigated and became known as the Visual Evoked Potential (VEP). He developed the technique of averaging which was able to elicit the visually related "signals" from the background "noise" of the EEG. This was necessary as the EEG is relatively unrelated to incoming stimuli. It is important to stress that the "evoked responses must always be considered as a special part of electroencephalography rather than a separate entity in themselves" (Harding 1982).

The first systematic studies of the Visual Evoked Potential were published in the early 1960s. Cobb and Dawson (1960) studied the early components, less than 100 msec, employing low frequency diffuse flash stimulation. Vanzulli, Bogecz, Handler and Garcia-Austt (1960) went on further to investigate the flash VEP looking into the effects of stimulus intensity, arousal and eye closure, using longer

analysis times. They were undoubtedly among the first to point out the inter-individual variability within the normal population. They attributed this variability to the projection on the scalp from the folds within the visual projection in the medial surface of the cortex. They also suggested that the short latency components represented a primary response of the visual cortex and that afferent visual volleys reach the cortex not only along the specific pathway to area 17 but also through other poly-synaptic pathways.

Ciganek (1961) using bipolar midline occipital-parietal recordings gave the first important morphological description of the VEP. He identified a series of seven waves of alternate polarity with average latencies of approximately 40, 55, 75, 95, 115, 130 and 195 msec, which he labelled I-VII, wave I being surface negative at the occipital electrode. He suggested that the first three waves were a primary response with the secondary phase being due to a non-specific, more diffusely organised system.

Vaughan, Katzman and Taylor (1963) using an occipital vertex derivation and computer averaging, further investigated Ciganek's primary phase. They discovered a slight difference in latency which they attributed to stimulus intensity and electrode placement.

Kooi and Bagchi (1964) also found the VEP to be influenced by flash intensity and electrode placement. They further investigated the test-retest reliability of the VEP

finding a 0.87 - 0.97 correlation for unisessional recordings and a median value of 0.88 over longer periods of time. No correlation was found between individual variability and eye colour, colour blindness, refractive error type, pupil size, alpha frequency, alpha amplitude or an alpha persistence index.

Gastaut and Regis (1965) described a VEP which was essentially similar to that of Ciganek (1961). They went on to review results obtained by other workers and concluded that, in spite of a high variability, there was a consistent positive component at 100-150 msec. They described the VEP as being polyphasic (Figure 1.1) with an early phase of four waves (1-4) of alternating polarity with latencies of c.25, 40, 60 and 80 msec, wave I being surface positive at the occipital pole. The later phase had a single positive component (wave 5) with a latency of 130 $\pm$ 30 msec. They described wave 5 as being either monophasic or more commonly triphasic giving a positive (5a)-negative (5b)-positive (5c) appearance. They went on to experiment with light and dark adaptation and concluded that 5a was related to the photopic system and 5c the scotopic, ie. they disagreed with Ciganek's non-specific nature of the wave.

Rietveld, Tordoir and Duyff (1965) investigated the contribution of the fovea and parafovea concluding that not only the major positive component but also the preceding negative component was related to the fovea. Potts and Nagaya (1965) attempted to further evaluate foveal function

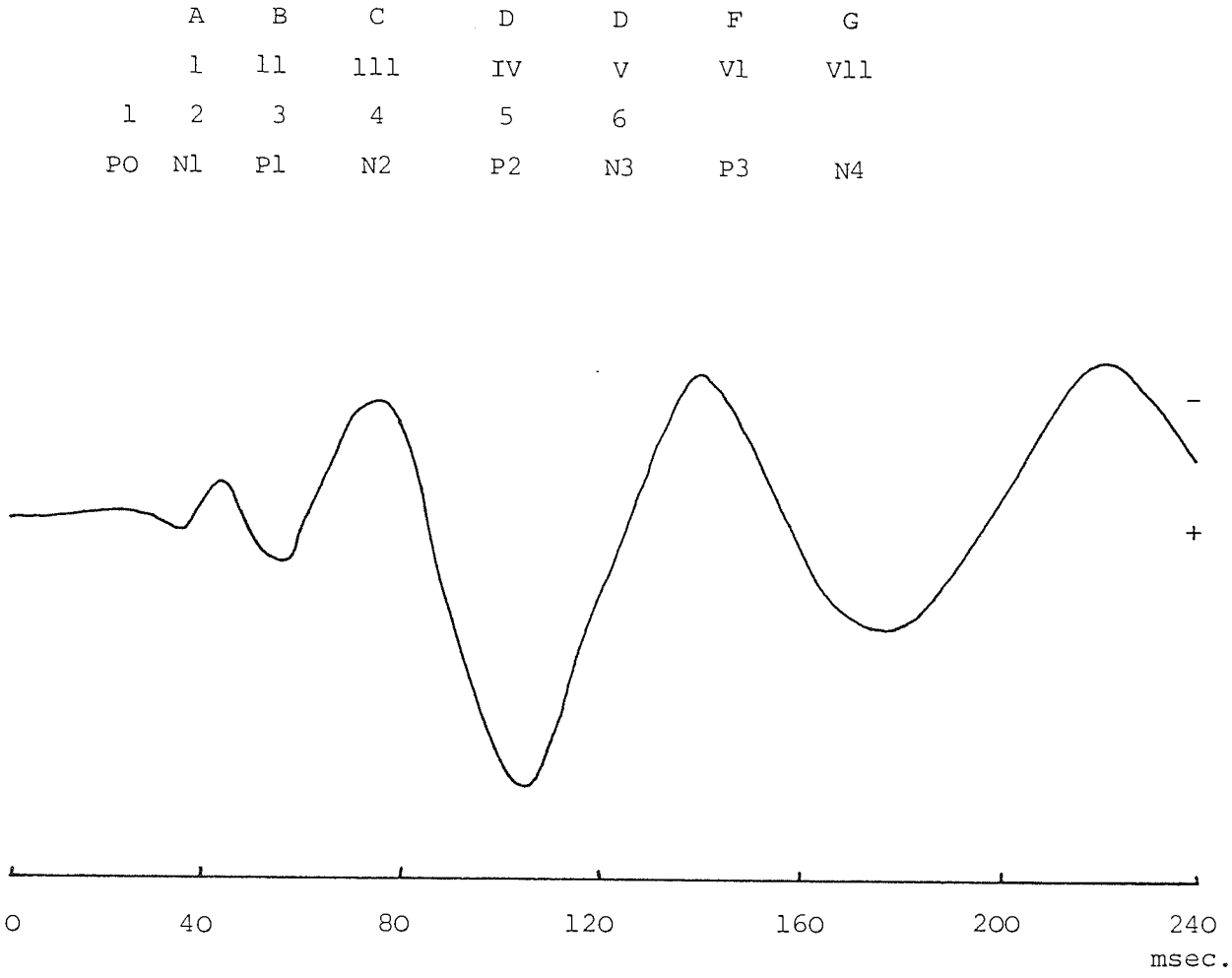


FIGURE 1.1 Schematic representation of the normal VEP to diffuse flash stimulation

A-G : Dustman and Beck (1969)

I-VII : Ciganek (1961)

1-6 : Gastaut and Regis (1965)

P_o-N_4 : Harding (1974)

(after Harding 1974)

using a 0.6^{o} red target. They found the major positive component to be preserved but all earlier components were extinct. Jonkman (1967) agreed that the major positivity should be considered a primary response.

For any diagnostic technique to establish itself as being clinically useful it is important to first evaluate the variability within a normal population. Vaughan et al. (1963) found little hemispherical difference for the three waves studied (N_1, P_1 and N_2) but did find a large intersubject variability in latency and amplitude. They pointed out the influence of technical factors, like stimulus intensity and electrode placement, affecting the VEP with relation to amplitude more than latency.

Kooi, Guvener and Bagchi (1965) examined the first five waves (N_1-N_3) in 80 normal adults and confirmed that there appeared to be little interhemispheric latency asymmetry but found that amplitude asymmetry was common, although this was never more than 50%, the figure adopted as the limit of normality. They did however find a much greater inter-subject latency and amplitude variability, particularly for the later components, the standard deviation for P_2 being c.11.00 msec (mean 118 msec). This was confirmed by Jonkman (1967).

Harmony, Ricardo, Otero, Fernandez, Llevente and Valders (1973) studied 139 normal subjects again confirming a high interhemispheric peak-latency symmetry with amplitude

differences generally under 40%. Dustman and Beck (1969) in their study on the maturation of the VEP found an interhemispheric correlation of 0.85-0.93 with no significant difference with increase of age.

Whilst this research was being conducted, Spehlmann (1965) became the first person to experiment with a patterned stimulus. By superimposing a grid over the flash stimulus the evoked potential elicited was found to be quite different in character (Spehlmann 1965; Rietveld, Tordoir, Hagenouw, Lubbers and Spoor (1967). Harter and White (1968, 1969) used this flashed pattern VEP to study the effect of refractive errors as there appeared to be a correlation between the response amplitude and visual acuity. Jeavons and Harding (1975) found this stimulus to be particularly useful in their studies of photosensitive epilepsy.

Towards the end of the 1960's Cobb (Cobb, Etlinger and Morton 1968; Cobb and Morton 1970) and Spekreijse (1966) started experimenting with a pattern-reversal, or counter-phase, stimulus. Brindley and Westheimer (1965) had shown how a flash stimulus confined to the "blind spot" could give rise to an electroretinogram due to the light scatter within the eye. It was considered that one of the advantages of a pattern-reversal stimulus was that there would be no overall luminance change therefore enabling the investigation of discrete areas of the visual field.

Halliday and Michael (1970) and Michael and Halliday (1971) demonstrated this quality by investigating the scalp distribution of the VEP to individual octant stimulation of the visual field.

Spekreijse (1966) also reported on a patterned stimulus in which the total luminous flux was maintained at a constant level whilst the pattern appeared and disappeared. This onset-offset response, or in-phase pattern modulation, was used by Jeffreys (1968) who attempted to separate the response to luminance onset and pattern. Duffy, Robb and Lombroso (1967) and Lombroso, Duffy and Robb (1969) used this type of stimulus to investigate patients with amblyopia.

The relative merits of pattern and flash stimulation have been argued extensively (eg. Harding 1982; Halliday 1983). There is little doubt that both methods have their advantages and disadvantages given a particular situation. The former is clearly a more sensitive technique in the localisation of pathology but is more severely affected by subject co-operation and extraneous factors such as "blur" (Halliday and Mushin 1980; Rover, Shaubele and Fuchs 1980; Harding 1982). The latter provides a more robust technique capable of giving a response in uncooperative or even comatose patients (Holder 1979; Harding 1982).

The aim of this study was to look carefully at the relationship between visual field abnormalities and the VEP. The following literature review will look closely

at the distribution over the scalp, or scalp topography, of the VEP to pattern stimulation in normal subjects. Particular attention will be placed on the stimulation of discrete areas of the visual field which is why, as explained earlier, the flash, or luminance, stimulus will not be considered in as much detail. If we are to consider the abnormal VEP it is essential to fully appreciate the nature and variability of the normal response. A later literature review will concentrate specifically on studies of patient groups which exhibit clinically measurable visual field abnormalities.

So far we have largely discussed the transient VEP. It is so called as the resultant, averaged, polyphasic waveform is produced by stimulus repetition which employs an inter-stimulus interval of a duration which enables the visual system to settle to its normal resting state between each stimulus presentation. There is an alternative method of evoking the VEP by using a rapidly repeated stimulus in which the individual components of the "transient" VEP merge to form a simple sinusoidal waveform which repeats at the same frequency as the stimulus. The response is assumed to reflect the dynamic steady-state of the visual system and is called the steady-state VEP. The techniques have both proved useful in investigating different aspects of the visual system but this study will concentrate on the transient response which has gained widespread acceptance in both normal and clinical studies.

1.2 The Normal VEP to Pattern-Reversal Stimulation

1.2.1 Full-Field Stimulation

The VEP to full-field pattern-reversal stimulation classically consists of a triphasic negative-positive-negative complex which is maximum on the midline and attenuates approximately symmetrically, as we progress away from the midline over each hemisphere. The major positive component, the P100, is both preceded and followed by a smaller, negative component called N75 and N145 respectively (Halliday and Michael 1970; Michael and Halliday 1971; Barrett, Blumhardt, Halliday, Halliday and Kriss 1976a,b; Blumhardt, and Halliday 1979; Harding, Smith and Smith 1980; Onofri, Bodis-Woollner and Mylin 1982; Kriss, Carroll, Blumhardt and Halliday 1982) (see Figure 1.2).

Spekreijse (1966), adapted a bar pattern-reversal stimulus which had been introduced by Riggs, Johnson and Schick (1964) to control the effect of stray light in the investigation of the electroretinogram. In an attempt to approximate more to the alleged circular shape of retinal receptive fields a checkerboard pattern was used instead of the bar pattern. The original hypothesis was that if the ganglion cell discharge was determined by algebraically summing the reaction to the light and dark patches of light falling within a receptive field then the response to a reversing checkerboard would not be larger than with a purely homogenous stimulus. It was quickly discovered

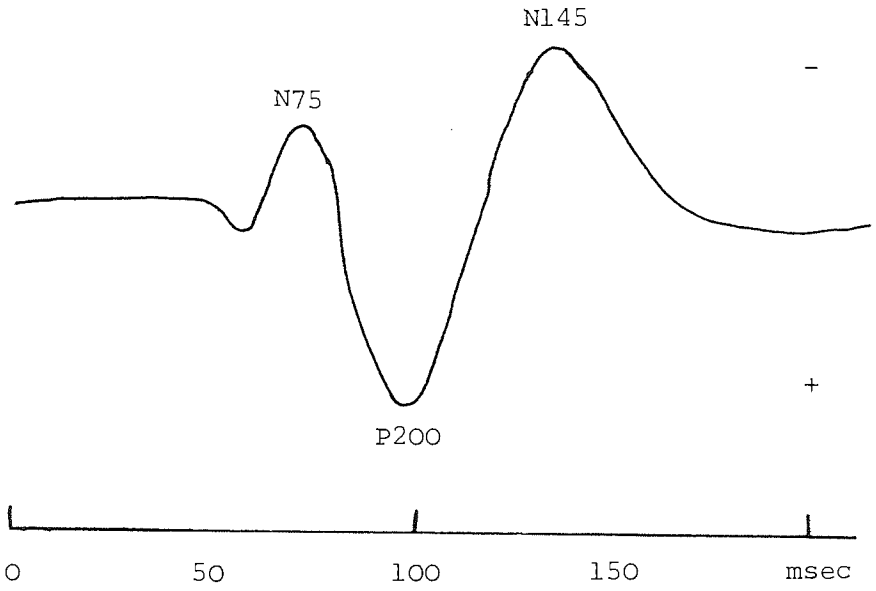


FIGURE 1.2 Schematic representation of the normal VEP to pattern reversal stimulation

however, that the response was larger and that it responded to changes in spatial contrast whether or not this was accompanied by an increase or decrease of mean luminance, whereas simultaneously recorded electroretinograms responded to such luminance changes (Spekreijse, Estevez and Van der Tweel 1973; Spekreijse, Estevez and Reits 1977; Reimslag, Spekreijse and Van Walbeck 1982). It was postulated that the pattern-reversal stimulus may contain a luminance contribution due to the luminance modulation of the separate spatial elements but it clearly behaved differently and provided more information about spatial contrast than those to unstructured stimuli. Spekreijse et al. (1973) indicated that motion was not necessary to evoke the response to spatial contrast in pattern reversal stimulation by using triangular waves which lacked the effect of motion.

Van der Tweel and Auerbach (1977) suggested that the pattern-reversal response was more reliable than that elicited by flash stimulation. Van der Tweel (1979) and Halliday and Mushin (1980) agreed that there was less inter-individual variation. Halliday (1980) in his review article of normative studies claimed that the major positive P100 component occurred between 90 and 120 msec in all of the 25 studies reviewed and between 90 and 110 msec in 20, in spite of a large range in the stimulus parameters and recording techniques used. Halliday (1982) advised caution when considering the large number of stimulus variables and proposed that each laboratory must determine its own control values using the

equipment which is to be employed in clinical testing.

Halliday, McDonald and Mushin (1973a) claimed that a decrease in average luminance of the stimulus leads to an increase in latency and a slight decrease in the amplitude of the P100 component. For a ten times reduction in luminance the latency increased by c.15-20 msec with a reduction in amplitude of c.15% (Halliday 1980). Unfortunately this study did not comment on the subject pupillary actions during the study. The overall trend is likely and has been corroborated by Behrman, Nissum and Arden (1972) and Spekreijse (1966) using steady-state pattern reversal stimulation but the degree of change could be severely affected by pupillary histereosis. Penne and Fonda (1981) demonstrated that a reduction in pupil size from 8mm to 2mm can cause a reduction in retinal illumination by a factor of 10. When the pupil diameter was pharmacologically reduced (Penne and Fonda 1981; Hawkes and Stow 1981) or reduced by artificial pupils (Penne and Fonda 1981; Sokol, Domar, Moskowitz and Schwartz 1981) there was an increase in the latency of the P100 component. Pharmacological dilation of the pupil, by each of the above research groups, showed an equivalent decrease in the latency of the P100 component. They all concluded that an 8mm change in pupil diameter can cause a change in the latency by c.20 msec and must therefore not be overlooked when judging the abnormality of a response due to age, drug therapy or pathology.

Allison, Goff and Wood (1979) demonstrated that there was little or no increase in latency of the P100 component until

the age of 50 which was in close agreement with Halliday et al. (1973a). Faust, Heintel and Hoek (1978) found the results to be similar between the ages of 15 and 65 and Stockard, Hughes and Sharborough (1979) claimed a similar lack of change between 20 and 55 years of age. All of these studies were using large fields and large check sizes. Asselman, Chadwick and Marsden (1975) and Halliday, Barrett, Carroll and Kriss (1982) showed that the increase in latency of the over 65s compared to the pre-20s was c.5-7 msec. Celesia and Daly (1977) and Sokol et al. (1981) found that the P100 component elicited by small checks gave a much greater increase in latency being between 10 and 15 msec between the ages of 20 and 70.

Shaw and Cant (1981) and Snyder, Dustman and Shearer (1981) both reported a rapid decrease in the amplitude of the P100 component between childhood and adolescence. The literature indicates a great diversity of opinion over the amplitude changes after the age of 20. Asselman et al. (1975) claim that the results are too variable to comment on any trends. Celesia and Daly (1977), Snyder et al. (1981) and Halliday et al. (1982) all report no significant change of amplitude with age but Shaw and Cant (1981) claim that there is a decrease in amplitude until the 30s with a gradual increase between 30 and 50 followed by another decrease after 50.

Wright, Williams, Drasdo and Harding (in press) investigated the influence of age on the VEP looking at 70 subjects

from the age of 10 to 70 years. They found the waveform of the pattern reversal VEP was constant over the entire range. The amplitude was initially very high in the teenage group but was constant from the early twenties onwards showing no further consistent age change. The latency increased with age but could be entirely accounted for by the decrease in pupil size with age causing a reduction in retinal illuminance.

Stockard et al. (1979) found a small but significant difference in the latency of the P100 component when performing normative, sex-difference studies. Halliday et al. (1982) confirmed this finding but also found a significant difference in amplitude as well, with women demonstrating an earlier and larger response. The mean latency change was between 3.5 and 4 msec with the amplitude being between 4 and 5uVs larger. These trends were found to be consistent over an age range from 20-50 years. Possible explanations include the greater head size and skull thickness in men (Parsons and Keen 1919; Johnston and Whillis 1938) and the higher deep-body temperature in women (Stockard et al. 1979; Christie and McCreatey 1977). The latency of the P100 component was also found to give a larger and earlier increase with age for women which may be related to metabolic or temperature changes associated with the menopause.

Celesia and Daly (1977) Blumhardt and Halliday (1979) and Kriss et al.(1982) reported that both the amplitude and latency

the P100 component tend to be similar whichever eye is stimulated. Kuroiwa and Celesia (1977); Blumhardt et al. (1977) and Streletz, Boe, Roeshman, Schatz and Savino (1981) claim that when hemispheric asymmetries and asynchronies are found they tend to be similar whichever eye is stimulated showing no preference for either hemisphere.

Halliday (1982) explored the range of normality by investigating 50 healthy subjects and comparing the individual variability across the group and the inter-ocular variability of each subject within the group. When looking at the latency of the P100 component he found only a small range of c. 20 msec over the entire group. The correlation coefficient for inter-ocular latency was high ($r = 0.83$) enabling him to state that an absolute difference of 8 msec in the latency of the P100 component on the midline electrode for each eye should be considered abnormal. In spite of the greater variability of the amplitude of the P100 (c.30uV), the inter-ocular difference had an even greater correlation coefficient (0.96). It was thus predicted that an absolute amplitude difference of 7uVs on the midline electrode for each eye should be considered abnormal. These observations were considered to be consistent between the ages of 15 and 50 years when large checks (30' - 70') and a large field size ($>10^{o}$) was used.

1.2.2 Right and Left Half-Field Stimulation

Cobb and Morton (1970) first looked at the lateralisation of the VEP to right and left half-field stimulation. Using an occipital, bipolar montage they found a gross asymmetry of the response over each hemisphere with the major positivity being lateralised over the hemisphere contralateral to the half-field stimulated. These results were confirmed by Shagass, Amadeo and Roemer (1976); Barrett et al. (1976) and Harding et al. (1980). When common reference recording was used the normal, triphasic negative-positive-negative (NPN) complex was found to lateralise over the hemisphere ipsilateral to the half-field stimulated (Barrett et al. 1976; Shagass et al. 1976). Blumhardt et al. (1978) found similar results and identified a positive-negative-positive complex over the hemisphere contralateral to the half-field stimulated. These results were confirmed by Van Lith, Henkes and VijFinkel-Bruinerga (1980); Harding et al. (1980); Crevits and Van Lith (1982) and Onofri et al. (1982).

This, so called, "paradoxical lateralisation" found when using reference recording appeared dependent upon the stimulus parameters and the electrode montage used. Barrett et al. (1976) found that small field sizes lateralised less well and may even show a predominance over the hemisphere contralateral to the half-field stimulated. This was confirmed by Harding et al. (1980) and Holder (1980) using small field sizes and reference

recording with widely spaced occipital electrodes. It was reported by Harding et al. (1980) that the lateralisation was dependent on field size rather than check size. A 0-16° radius field size produces the paradoxical lateralisation whereas small fields, 0-2° radius, produce a maximum on the midline or slightly contralateral to the half-field stimulated (Barrett et al. 1976; Shagass et al. 1976; Lehmann and Skandries 1979; Blumhardt and Halliday 1979; Harding et al. 1980). It was felt that bipolar recordings produced a maximum over the contralateral hemisphere, for large field sizes, because of the steep voltage gradient between the midline and the contralateral electrodes.

Barrett et al. (1976) explained the "paradoxical lateralisation" by the response generator being the transversely orientated neurones on the contralateral visual cortex situated on the posteriomedial surface consequently, it was argued, the ipsilateral electrodes are optimally placed to record the response.

The PNP complex reported over the hemisphere contralateral to the hemisphere stimulated is found to be somewhat variable particularly when compared to the NPN complex found over the opposite hemisphere (Barrett et al. 1976; Blumhardt et al. 1977). Blumhardt et al. (1978) felt that the contralateral N105 (the major negativity of the PNP complex) seemed to behave independently from the ipsilateral P100.

An alternative explanation for the distribution of the half-field response was put forward by Beauchamp, Matthews, Small and Stein (1976). They considered the importance of the transcallosal connections concerned with the representation of a vertical strip of the visual field up to 2^{o} out on either side of fixation (Myers 1962; Hubel and Wiesel 1967; Blakemore 1969; Mitchell and Blakemore 1970). They therefore suggested that at least part of the half-field response was derived from the ipsilateral occipital lobe. The main argument against this theory was the results obtained from people having undergone hemispherectomies. Blumhardt and Halliday (1979, 1981) and Blumhardt, Barrett, Kriss and Halliday (1982) found all elements of the normal VEP to half-field stimulation from the preserved hemisphere in such patients.

Blumhardt et al. (1977) found a much larger lateral NPN complex over the ipsilateral hemisphere for half-field stimulation than for full-field stimulation. He later discussed this along with the variability of the distribution and symmetry of the full-field response (Blumhardt 1982). He claimed that this was produced by the summation of the NPN complex at the lateral electrodes and the PNP complex produced by the opposite half-field causing a degree of cancellation of the most lateral NPN complexes.

Blumhardt and Halliday (1981) compared the mean hemispheric amplitude asymmetry of full-field stimulation with half-field stimulation using 50 normal subjects. The stimulus consisted of a large field size and check size and common

reference recording was used. By comparing the amplitude of the P100 component at electrodes placed 5cm either side of the midline they found an asymmetry of 1:1.6 with a standard deviation of 0.56. If an upper limit of 2.5 times the standard deviation above the mean is considered this would give an amplitude asymmetry of more than 1:3 before confidently predicting abnormality. When the mean asymmetry for the ipsilateral P100 component of the two half-fields was calculated, the ratio was less than 1:1.36 with a standard deviation of 0.331. Abnormality could thus be confidently predicted if an asymmetry of 1:2.2 was discovered. They went on to confirm their opinion clinically by investigating 26 patients with homonymous hemianopia and found an abnormal symmetry in only 62% of patients using full-field stimulation but in 81% of patients using half-field stimulation. Further discussion of the clinical evaluation of the half-field stimulus in patients with hemianopic visual field defects will be undertaken in Sections 1.5 and 1.6.

The interaction between the ipsilateral NPN complex and the contralateral PNP complex may also help clarify the reasons for a P100 containing abc components as reported by Picton (1979); Stockard et al. (1979); Shahrokhi, Chiappa and Young (1978) and Leudes, Lesser and Klen (1980). Blumhardt (1982) felt that this can be produced by unusually large P135 or P75 components on the midline or by slight differences in the peak latency of the P100 component from each hemisphere. He claimed that the

"true" P100 can usually be determined by half-field stimulation showing which peak is ipsilaterally lateralised.

Rowe (1981) introduced a technique for sequential half-field stimulation allowing both half-fields to be examined at the same time, each occupying half of a 500 msec time sweep. He considered this important in the reduction of examination time accompanied by a reduction in fatigue for patients which require half-field examination.

1.2.3 Upper and Lower Field Stimulation

Halliday and Michael (1970) and Michael and Halliday (1971) found that with lower field stimulation, using a large field and check size, they produced a P100 component with a maximum amplitude c.5cm above the inion using a medial chain of electrodes. When the upper field was stimulated the major component was found to be negative, peaking in amplitude more anteriorly, c.7.5cm above the inion. A positive component was found with a maximum amplitude below the inion. This posterior positive component was recorded with a mid-frontal reference but not with a linked ears reference and was found to be related to stimulation of the central 2^{o} of the visual field. The anterior negativity was considered to be related to stimulation of the more peripheral $4-8^{o}$ of the visual field. They concluded at the time that generator areas were unlikely to be striate in origin but were more likely extrastriate (area 18 and/or 19).

Halliday (1982) has capitulated a little since, stating

that the upper field response could be generated by the striate or from the parastriate areas, V2 and V3, but that whichever the case may be the response originates largely from the projection areas on or near the inferior surface of the occipital lobe. These are in general facing away from the surface electrodes. The lower field response, however, is claimed to be generated from areas much closer to the scalp electrodes.

Bartl, Benedikt, Hiti and Mendl (1978) reported that upper field stimulation by pattern-reversal using large checks (40' and 20') and large field sizes gave a smaller response than full-field stimulation.

Lesevre (1973) using multi-channel, average reference techniques, reported that stimulation of the upper hemiretina gave a maximal response more anteriorly than stimulation of the lower hemiretina. She also found that the maximal response of the P100 component was earlier for upper than lower hemiretinal stimulation. It was pointed out by Halliday et al. (1973) that such a difference in latency may have a great clinical importance when using the VEP diagnostically. Lehmann, Meles and Mir (1977) claimed that these latency differences may appear like waveform inversions in conventional recordings. He went on to exclude the possibility that this change was caused by "scalp field peak migration" towards the recording area and found that the median latency difference was significant being 12 msec (Lehmann and Skandries 1979).

They felt that the latency difference discovered was in accordance with both anatomical (Osterberg 1935 had discovered more human retinal cells) and behavioural observations with, Payne (1965, 1967 and Tartaglione, Favala and Benton 1979) reporting a delayed reaction time for lower hemiretinal stimulation. Millodot and Lamont (1974) had also recorded better visual acuity in humans in the upper hemiretina. They concluded that for clinical purposes the latency differences between the upper and lower hemiretinae should always be considered.

Lehmann, Darcey and Skandries (1982) constructed dipole models of the possible intracerebral and scalp field generators. They rejected the striate area as a generator of the pattern-reversal response, like Michael and Halliday (1971), because of the distribution of the response to upper and lower hemiretinal stimulation. It was felt that the extrastriate area would generate responses with the closest accordance to the recorded scalp distribution.

Adachi-Usami and Lehmann (1982) investigated the relationship between monocular and binocular VEPs to both upper and lower hemiretinal stimulation. They started with two opposite hypotheses both based on published single cell neurophysiology studies. The first hypothesis stated that, "monocular stimulation to the upper hemiretina would evoke responses which are more anterior (over area 18) than binocular responses (strongest over area 17), and vice-versa for the lower hemiretina". This was based

on the fact that for the upper hemiretina area 18 is more anterior and for the lower hemiretina area 18 is more posterior than area 17. Baker, Grigg and Van Norden (1974) had reported that many neurones in area 17 respond to one eye only. Zeki (1978) claimed that in area 18 or higher almost all units are excitable by both eyes, ie. binocular units driven by either eye.

The second hypothesis was that; "binocular stimulation to the upper hemiretina will evoke larger scalp field responses over more anterior (area 18) than posterior (area 17) locations, contrary to monocular stimuli (and vice-versa for lower hemiretina)". Bishop (1973) had suggested that area 17 consisted of principally binocular units which could be stimulated by either eye. Hubel and Wiesel (1970) had reported on a large number of units in area 18 which were exclusively binocular, ie. driven by simultaneous stimulation only with very few such cells in area 17.

The results obtained were in accordance with the second hypothesis. This would also seem to suggest that the monocular VEP to pattern reversal stimulation is more likely to be generated in area 17 which tends to disagree with the earlier suppositions of Michael and Halliday (1971) and Lehmann, Darcey and Skandries (1982). When comparing the monocular upper and lower field results, Adachi-Usami and Lehmann (1982) confirmed the difference in latency found by earlier researchers with a mean

difference of 16 msec. Kriss and Halliday (1980) also found a latency difference of 20 msec. Adachi-Usami and Lehmann (1982) concluded that this was understandable from a teleological view because "danger and prey for most mammals is below the horizon".

Wildberger (1984a) underlined the difficulties that this change in latency, accompanied by a difference in amplitude, can cause clinically in an investigation of patients with ischaemic optic neuropathy. He concluded that the VEP to full field stimulation is not greatly impaired by a visual field loss in the upper field whereas loss in the lower field will cause a reduction in amplitude. If the loss extends to the midline this will be accompanied by a delay in latency. He states that "the origin of this delay is different from a delay due to a disturbed condition in demyelinating diseases or due to more dominant paramacular VEP components".

Wildberger (1984b) found a normal, full field latency of 99.9 msec ($\pm$ 5.4) using 38 minute checks; a 94 msec ($\pm$ 6.2) latency when using a lower field stimulus; and a 113.5 msec ($\pm$ 4.9) latency when using an upper field stimulus. He concluded that an upper field loss may result in an earlier latency than the full field response, and that a simulated lower field scotoma can influence the VEP from $2\frac{1}{2}^{o}$ below fixation. He demonstrated examples of patients whose full field response was severely affected, when using large checks, by the lower hemiretina. This asynchrony between the upper and lower field

potentials could result in a relatively flat, abnormal looking full field response or give a twin peaked response which gives the appearance of a PNP-complex, with the earlier and later positive components corresponding independently to the upper and lower hemiretina. He found that this was not as great a problem when using small checks as these preferentially stimulate the central retina thus reducing the lower hemiretinal influence.

1.2.4 Central and Peripheral Field Stimulation

Blumhardt et al. (1978) and Halliday et al. (1979) showed that by progressively occluding the central portion of a $0\text{-}16^{\circ}$ half-field checkerboard stimulus, the ipsilateral NPN complex was increasingly attenuated in size and was accompanied by a progressive enhancement of the contralateral PNP complex. It was claimed that the attenuation of the ipsilateral P100 was approximately linear. The contralateral N105-component was less consistent but they felt it was simply "unmasked" by the occlusion of the stimulus from the macular field. They went on to stimulate the half-field of 5 subjects who had demonstrated a large contralateral PNP complex. They progressively reduced the field size in 3 stages ($0\text{-}16^{\circ}$, $0\text{-}10^{\circ}$, and $0\text{-}5^{\circ}$) and found the contralateral PNP progressively attenuated but the ipsilateral NPN complex remained unaffected. They believe that this phenomena explains the results obtained from patients with a central scotoma which often appear to give a central PNP-complex or a

"scotomatous negativity" (Halliday 1976; Halliday et al. 1979; Kriss et al. 1982). The existence of a true scotomatous negativity has been disputed and will be discussed at length in Section 1.3.

Asselman et al. (1975) progressively occluded the central field with black discs of increasing diameter and found a 50% reduction in the amplitude of the P100 component when the central 5-6^{o} were occluded. Yianikas and Walsh (1983) performed an interesting set of experiments using a 55' check size and progressively smaller full field presentations ranging from 32^{o} to 2^{o}. They also simulated central scotomata by progressively occluding the 2,4, 8 and 15^{o} of the visual field.

Their results confirmed previous reports that the fovea makes a major contribution to the amplitude of the P100 component, finding that the central 2^{o} contributed 25% of the maximal response. Stimulation of the central 4^{o} contributed 35%. They also found, however, that the peripheral 8-32^{o} of the retina also gave a significant contribution to the P100. On occlusion of the central 15^{o} of the visual field, 2 out of 5 subjects gave no clear P100 component and in the remaining 3 the amplitude was reduced to less than 50% of the full-field stimulation. Three subjects showed no evidence of an N105 component even with the occlusion of the central 15^{o}. This must cast serious doubt on the observations of Halliday et al. (1979) on the nature of this component. The latency of

the P100 component was found to be significantly increased when the central 2 or 4^{o} were stimulated compared to the 32^{o} full-field stimulation (2^{o} - 109.2 msec; 4^{o} - 102.1 msec; and 32^{o} - 96.2 msec). They identified possible explanations for this including the effect of check size on foveal stimulation, the reduction of mean luminance as the field size reduces and the problems caused by fixation at narrow visual angles. They warned of the problems associated with selective foveal stimulation as had been suggested as a useful clinical technique by Hennerici, Wenzel and Freund (1977) and Rossini, Pirchio, Sallazo and Caltagirone (1979). The large standard deviation of the P100 latency and the problems of fixation with field sizes subtending less than 4^{o}, even in normals, was felt to preclude the clinical usefulness of such a stimulus.

Two lateral electrodes placed approximately 15% above the inion and 20% out either side of the midline were also recorded and discussed. It was found that the difference in amplitude of the P100 component with the variation of field size was not as pronounced. When the central 4^{o} was stimulated they found the amplitude from the lateral electrodes was very similar to the midline as found by Michael and Halliday (1971). They concluded that this was consistent with the explanation of Blumhardt et al. (1979) that the full field response is a summation of the ipsilateral NPN-complex and contralateral PNP-complex from each half-field. Both half-fields generally give an NPN-

complex on the midline, therefore summating to give a larger midline P100 amplitude. In their own study, however, they could not produce a recognisable and reproducible PNP-complex in over half the subjects used, even with a central 15^{o} simulated scotoma. They concluded that a PNP-complex found on full-field stimulation requires the presence of a large, central scotoma along with an anatomical variation in the occipital lobes "such that the relative amplitude and latency of the components is altered".

The studies mentioned so far have all used relatively large check sizes (between 50-55'). If we consider the spatial summation of the retina and the invariance properties of the visual system to be discussed in Chapter 4, we may find alternative explanations for some of their results. Yianikis and Walsh (1983) did in fact point out that the check size they had used was not ideal for encouraging the foveal response. They also felt that the pattern reversal stimulus itself may favour a foveal response due to the higher concentration of cones which being more "sustained" in cellular response, are sensitive to pattern stimulation compared to the more "transient" movement detectors found in the peripheral retina (Ikeda and Wright 1972; Stone and Freeman 1973).

It is clear that the spatial characteristics of a checkboard stimulus affect the amplitude of the VEP. Harter

(1970) produced the largest amplitude for the P100 component for the central 3^{o} by stimulating with a check size of between 7.5 and 30' of arc. Much larger checks of 30-60' of arc produced the greatest amplitude for the peripheral retina between 4.5 and 7.5^{o}. He suggested that the peak of the check size relates to the size of the anatagonistic centre-surround receptive fields in the retina. The maximum response would correspond to the production of a maximum excitatory and minimum inhibitory response, thus larger or smaller checks would stimulate both of these areas resulting in a smaller response. Similar aspects of "spatial tuning" have been noticed by Eason, White and Bartlett (1970); Armington, Corwin and Marsetta (1971); Van der Tweel (1979); Ristnovic and Hajdukovic (1981) and Armington and Brignell (1981).

Spekreijse et al. (1977) discussed how additional factors in the relationship between check size and receptive field size may affect the strength of the signal transmitted along the optic nerve. A response could be generated by antagonistic cells with smaller receptive fields than those ideally suited to the check size used, which coincide with edges of the checks. Luminance detectors may also add to the response by stimulation provided by the white checks. These responses would all provide a cortical input which is a total response to the fundamental and harmonic frequencies of the stimulus. Regan and Richards (1973) found however, that the peak

of the amplitude-check size function was not affected by stimulus contrast between 4 and 100%.

Van Lith (1977) claimed that the peripheral retina beyond 7^{o} was not responsive to a patterned stimulus. This clearly contradicts the observations of Yiannikas and Walsh (1982). Harding et al. (1980) when investigating the lateralisation of the half-field response found that, by keeping the check size constant (27') but reducing the field size, the lateralisation of the P100 component could switch from ipsilateral to contralateral. If the field size remained constant however, and the check size was decreased, the lateralisation remained ipsilateral. If we consider that the check size of 27' is within the limits set by Harter (1970) for eliciting the maximum response centrally then there is clearly a very complicated relationship which must be considered if we are to ensure that the stimulus parameters used for any given experiment are capable of giving the desired degree of cortical stimulation. For all of the above reasons the normal values expected for a given stimulus can be very greatly affected. It is clear that a far greater understanding of the spatial characteristics of the visual system, both in terms of retina receptive fields, as also discussed in relation to upper and lower field stimulation in the previous section, and cortical magnification, as discussed in Chapter 3, is required. Only then can the stimulus parameters be utilised to their full advantage.

With this debate in mind, Todd Meredith and Celesia (1982) decided to investigate further the relationship between retinal eccentricity and the VEP to pattern reversal stimulation. They used three stimulation paradigms. The first involved a 2^{o} field containing 16 checks (34' 30") which was used centrally and then in 2^{o} steps to 18^{o} in each major meridian and the oblique meridians. The amplitude of the response was found to reduce rapidly when the stimulus was moved away from fixation with no response elicited outside of the 4^{o} isopter (see Figure 1.3). The amplitude was found to be similar at all locations within the 2^{o} isopter but was slightly larger in the lower and nasal field. Nasal and temporal field stimulation gave an ipsilateral response but there was no mention of a contralateral PNP-complex with any stimulus. There was no phase-reversal of the P100 component observed between upper and lower field stimulation but 6 out of 8 subjects who had an electrode over the inion showed a 70% reduction or absence of response at the electrode on lower field stimulation. They felt that these results correlated with the decline in cone density with eccentricity (Osterberg 1935), the human ganglion cell density along the horizontal (Van Buren 1963) and the relationship between visual acuity and eccentricity (Wertheim 1894; Weymouth, Hines, Acres, Raaf and Wheeler 1928). They felt that for a stimulus to be effective outside of the foveal region it needs to "reach the threshold of visual perception and needs to activate sufficient numbers of

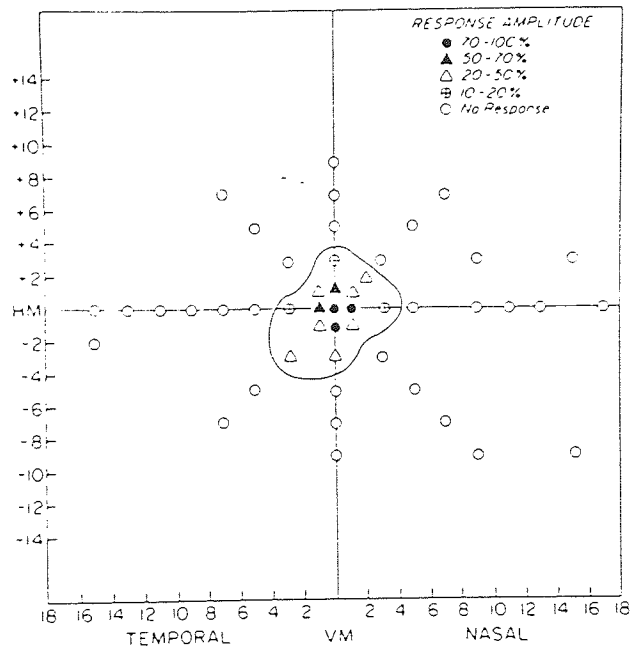


FIGURE 1.3 Mean response amplitude in relationship to retinal eccentricity. The mean amplitude of the P1 potential evoked with stimuli located at the fixation point was assigned the value of 100. The amplitude of the potentials evoked at other eccentricities was expressed in percent of the response at the fixation point. Pluses indicate upper field and minuses indicate lower field. HM = horizontal meridian; VM = vertical meridian. Open circles indicate the retinal position where the stimulus failed to elicit an evoked response.

(after Meredith and Celesia 1982)

receptor and ganglion cells".

The second stimulus paradigm consisted of a variable field and check size to discover the smallest area which could elicit a reproducible VEP at three different eccentricities: fixation; beyond 8^{o} nasally; and beyond 14^{o} nasally. The luminance was kept constant at all but the very smallest ($<1^{o}$) field sizes.

The smallest field size found to elicit a response at fixation had a range of 6'54" to 20'42" (mean: 13'17" $\pm$ 5'4") with a check size of between 3'27" to 10'21" (ie. 4 checks per stimulus). Beyond 8^{o} nasally the range for field size was 3^{o} to $3^{o}27'$ (mean: $3^{o}18' \pm 34'$) with check sizes between 34'30" and 51'45" (mean: 44'39" $\pm$ 10'). Beyond 14^{o} nasally the range for field size was $4^{o}36'$ to $6^{o}54'$ (mean: $5^{o}45' \pm 56'$) with check sizes between $1^{o}9'$ and $2^{o}7'$ (mean: $1^{o}43' \pm 14'$).

They found no relationship between the parameters capable of eliciting a response and visual acuity. Smaller checks could often be seen without generating a measurable response. They found that VEPs could be elicited in the more peripheral regions by using larger field and check sizes. From the results they estimated the amount of striate cortex activated by each stimulus mean using the M-factors of Rovamo and Virsu (1979) and Cowey and Rolls (1974). They found that all but the central value using the M-factor of Rovamo and Virsu, indicated c.7mm^{2} of striate cortex had been activated by

each stimulus. It was concluded that the VEP was not purely a central phenomena and that if stimuli were M-scaled with eccentricity a VEP of similar amplitude should be elicited. The results were felt to substantiate the "invariance principle" of Rovamo, Virsu and Nasanen (1978), but that the M-factor of Rovamo and Virsu (1979) for the fovea was too small.

The third stimulus paradigm involved the M-scaling of 3 different field sizes for the 3 different eccentricities used in paradigm 2. The M-factor of Cowey and Rolls (1974) was used to balance the more peripheral stimuli with a central field size of $2^{\circ}18'$, as used in paradigm 1. The stimulus at 8° nasally had a field size of $16^{\circ}32'$ with a check size of $2^{\circ}4'$ whereas the field size used at 14° nasally was 30° with a check size of $7^{\circ}30'$.

It was discovered that the amplitude at fixation was approximately twice that elicited by the two more peripheral stimuli. This was considered to be predictable as the central stimulus activated both occipital cortices. The largest response for the nasal stimuli were ipsi-lateral to the hemisphere stimulated. Some subjects showed no phase-reversed PNP-complex when the peripheral stimuli were used and it was generally found that the latency was more variable and morphology broader in nature. In spite of this the onset of the major component, whether positive or negative, was identical at each eccentricity even though the peak latency was delayed

for the more peripheral stimuli. They conclude that "the unfavourable remote location of the source generator for the peripheral retina will result in a partially distorted and smeared evoked potential at the scalp".

Although not part of the original stimulus paradigms, the authors went on to investigate the spatial tuning characteristics of the peripheral retina. Using a field size of $7^{o}41'$, at 8^{o} nasal eccentricity, they found an optimum response with a check size of $2^{o}33'$. At 14^{o} eccentricity they used a field size $13^{o}14'$ and found an optimum response with a check size of $3^{o}28'$.

Todd Meredith and Celesia (1982) conclude that their results confirm that visual resolution and receptive field size vary across the visual field and that "visual resolution and M-scaling are the two most important variables that influence the nature of the stimulus needed to elicit a pattern evoked potential".

This work was both timely and important as it went a long way towards answering many of the queries raised in the earlier literature. Like much good research, however, it raised as many questions as it answered. In their acceptance of the invariance principle they dismiss the foveal M-factor of Rovamo and Virsu (1979) as being too small and conclude that Cowey and Rolls' (1974) M-factor is nearer to the true value. If we examine the results carefully and accept the limitations of the VEP technique, it is quite possible to argue that

the results support the much lower M-factor. The VEP is a very distant recording of electrical activity in the visual cortex. When we consider the medial orientation of the majority of the cortex (as discussed in Section 1.4), then the bias towards foveally generated potentials will still probably influence the amplitude and morphology of the VEP even if the stimulus is sufficiently M-scaled. Once we are stimulating peripheral areas within the occipital fold the relationship will most likely be more predictable, as it appeared to be for the 8^{o} and 14^{o} nasal eccentricities considered. It is quite possible that the M-factor of Rovamo and Virsu (1979) is too low centrally (see Chapter 3) but it is not likely to be as high as the value proposed by Cowey and Rolls (1974).

Todd Meredith and Celesia (1982) identify the importance of spatial tuning and yet it was clear from their own results that the maximum response may not have been elicited for each stimuli presented. The relationship between M-scaling and optimum check size certainly deserves further investigation perhaps by M-scaling the field size and then comparing the maximum VEPs elicited by spatial tuning. This would be particularly interesting in different meridians of the visual field. There are equations available for M-scaling of each meridian of the visual field, as discussed in Chapter 3. It would also be interesting to consider the truly peripheral retina. The greatest eccentricity used was between 14 and 44^{o} nasally. Would it be possible perhaps by an

annular stimulus, to elicit a response with a similar onset of the major component, beyond this point, or would the deeper generator areas further distort the nature of an M-scaled response?

The principle of M-scaling, as used in this study and by the author, is that the pattern-reversal VEP is generated by the striate cortex. The bulk of evidence presently available would tend to suggest that this is probably the case, at least for the earlier components if not the entire response. Unfortunately, it is unlikely that the higher cortical areas have no influence on the response and as pointed out earlier, several authors have suggested the extrastriate as the most likely generator. If this is the case, the value of striate M-scaling, although still very important, would be further complicated.

Further insight on this discussion may be gained by an examination of work presented by Tyler and Apkarian (1982). Unfortunately, their results were stimulated by a rapid spatial frequency sweep at high temporal frequencies introduced by Regan (1975). We cannot, therefore, directly compare results but there may still be some value in discussing their findings. They attempted to identify the spatial tuning characteristics of approximately M-scaled field sizes at different eccentricities this time based on the data of Hitchcock and Hickey (1979). They found that with increased eccentricity the peak spatial period (bar width on the retina in degrees per

cycle) also increased which is again clearly supportive of the invariance principle. It was noted, however, that there were two clear groups of spatial frequency peaks within the scatter of results. This is likely to reflect origins from different cortical representation, the most likely candidates being visual areas V_1 and V_2, ie. the striate and extrastriate areas. Whether the types of potential evoked by this method of stimulation reflect a similar cortical response to the transient pattern-reversal evoked potentials is not clear. It is quite possible that it is reflecting the characteristics of both pattern onset and pattern reversal responses which, between them, clearly have generators in both of these cortical areas. Clearly, such discussion is at present speculative but is fundamental to the development of electrodiagnostic techniques.

1.3 Visual Evoked Potentials in Pre-Chiasmal Lesions (excluding demyelinating lesions)

A detailed account of the type and extent of visual field loss expected as a result of the conditions discussed in this section is beyond the scope of this thesis. They are summarised in Figures 1.4 and 1.5. For further information the reader should refer to Harrington (1976).

Vaughan and Katzman (1964) used diffuse flash stimulation to investigate patients with severe retinal or optic nerve disease. They demonstrated that the VEP showed a

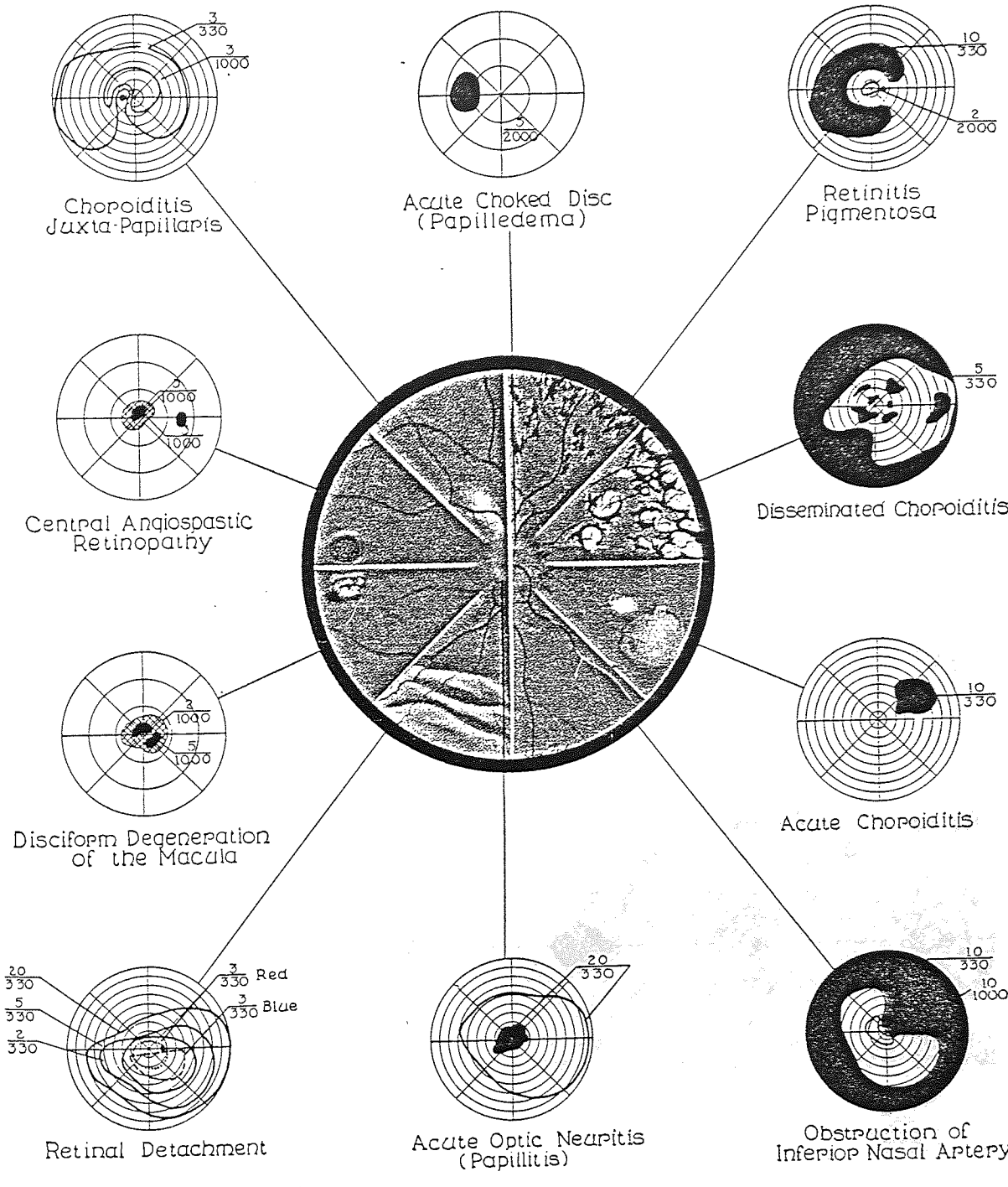


FIGURE 1.4. Summary of the visual field defects caused by retinal lesions.

(after Harrington 1976).

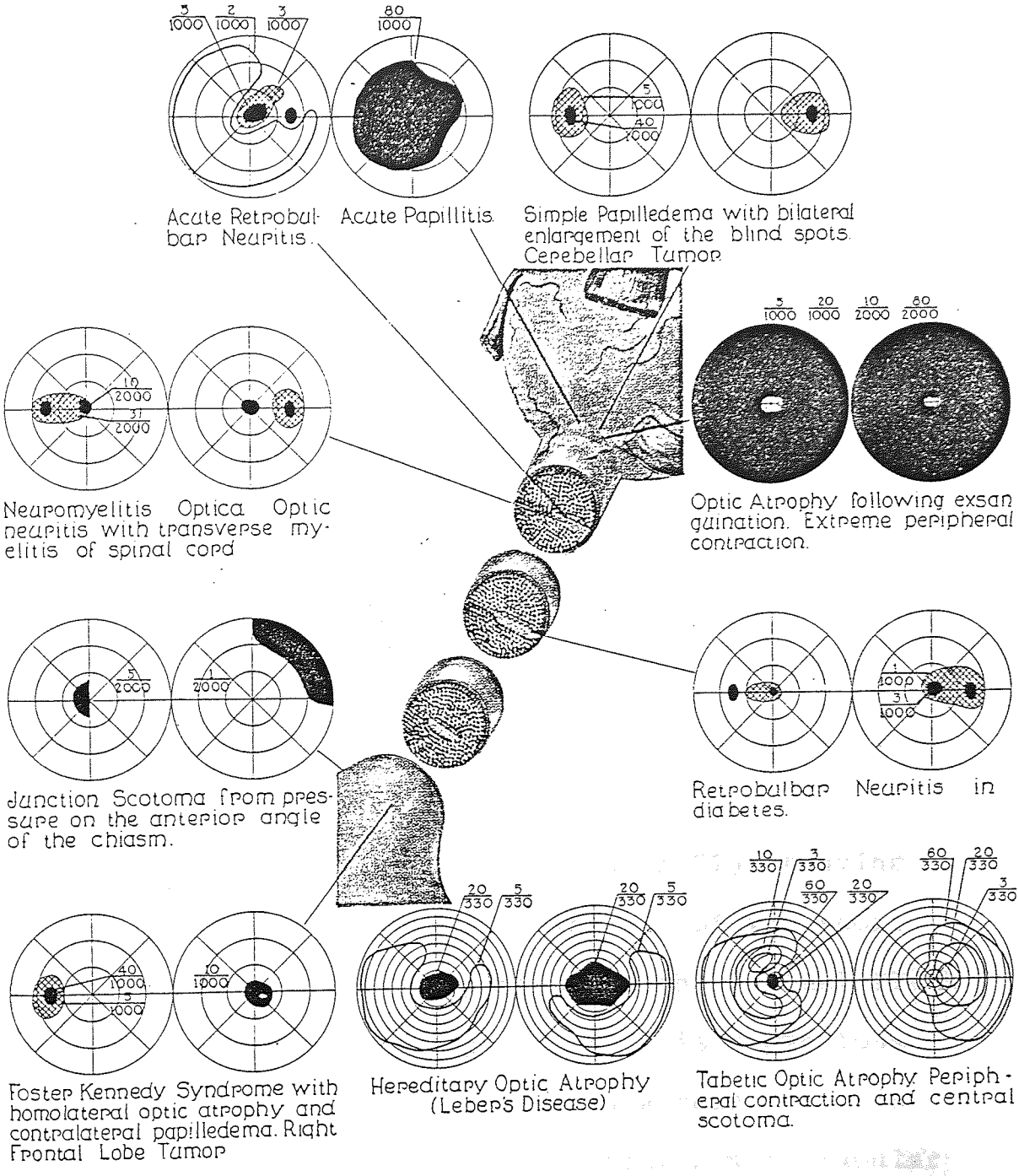


FIGURE 1.5. Summary of the visual field defects caused by optic nerve lesions.

(after Harrington 1976)

loss, suppression or alteration in the affected eye. Copenhaver and Perry (1964) showed VEP amplitude reduction >50% in 14 out of 18 patients who had macular scars, tumours, degenerations and optic neuritis, those patients with reduced visual acuity showing a greater loss. Jacobsen, Hirose and Suziki (1968) found a variable amplitude reduction in 8 patients with retinitis pigmentosa all of whom had unrecordable ERGs. They also investigated 13 patients with optic atrophy or neuritis and found a reduced amplitude with occasionally a latency delay in the affected eye.

Babel, Stangos, Karol and Spiritus (1977) studied 53 eyes with macular degeneration and found the flash VEP response was absent in 17%, reduced in amplitude in 66% and delayed in latency in 26%. Borda (1977) studying a similar patient group found an absence of the short latency FVEP components in patients with a normal flash ERG, ie. the opposite finding to retinitis pigmentosa. Harding (1977) using flash VEPs found a reduction in amplitude of the P2 component in patients with macular degeneration. It was also found that the phase reversal of the FVEP was abnormal in disciform degeneration.

Wildberger (1984b) evaluated the effect of maculopathies on the VEP and concluded that the amplitude decreased, with an increased destruction of the macular elements, in a similar way as visual acuity, with an increased rate of reduction for smaller check sizes. A delayed

latency was less common in maculopathies than for amblyopia probably due to the more stable central fixation found in maculopathies. In a case of Stargard's disease, with a severe destruction of the central retina it was felt that the delayed VEP may be due to the paramacular subcomponents as proposed by Carroll, Halliday and Kriss (1982). Similarly, the latency may be delayed in conditions resulting in a parafoveal lesion of the upper hemiretina but similar lesions in the lower hemiretina would have little influence on the VEP. Small foveal lesions, like those caused by lamellar micro-holes or central serous retinopathy in early stages, may severely reduce the visual acuity but have little or no effect on the VEP. He concluded that changes in latency provided the most important parameter for the evaluation of the VEP. Amplitude measurements were valuable if a comparison of the uniocular responses were made in a unilateral condition; if the amplitude relationship for different check sizes could be considered; and the presence or absence of a response for different check sizes.

Babel et al. (1977) investigated the VEP to flash stimulation in patients with ischaemic optic neuropathy (ION), which generally causes an altitudinal field loss, and found a large variety of abnormalities. They concluded that milder cases may be of normal latency but with a reduced amplitude and abnormal morphology. More severe cases may show a slight delay in latency but recovery of the VEP may parallel clinical improvement. Ellenberger

and Ziegler (1977), using flash stimulation, found a delayed latency in 8 out of 15 eyes with ION. Six out of 9 patients with unilateral ION showed a significant reduction in amplitude.

Wilson (1978), using both pattern reversal and flash stimulation, showed that 13 out of 15 patients with ION had significant amplitude reductions (<50% of normal mean amplitude). This was thought to be related to the extent of the visual field loss particularly the involvement of a central field defect. Both Asselman et al. (1975) and Hennerici et al. (1977) reported a delay in the latency of the VEP to pattern reversal stimulation in ION, but the number of patients used in both cases was very small. Ikeda (1978) described a delayed response, with a reduction in amplitude, to pattern reversal stimulation.

Harding et al. (1979) used both flash and pattern reversal stimulation and found a markedly reduced amplitude and occasionally reduced latency, the latter occurring most markedly in patients with temporal arteritis. Many of the patients discussed showed a triphasic PNP complex. Holder (1981) described the results of both flash and pattern-reversal stimulation on 9 patients with ION. All but one patient showed a reduction in amplitude but there was generally no significant delay in latency. He pointed out the vast difference between patients with ION and those with optic neuritis associated with

demyelinating disease, where an increase in latency is normally seen. The clinical significance of this was later supported by Cox, Thompson, Hayreh and Snyder (1982). Interestingly it was noted that the two patients with a measurable central scotoma did not exhibit the "scotomatous" negativity described by Halliday (1976).

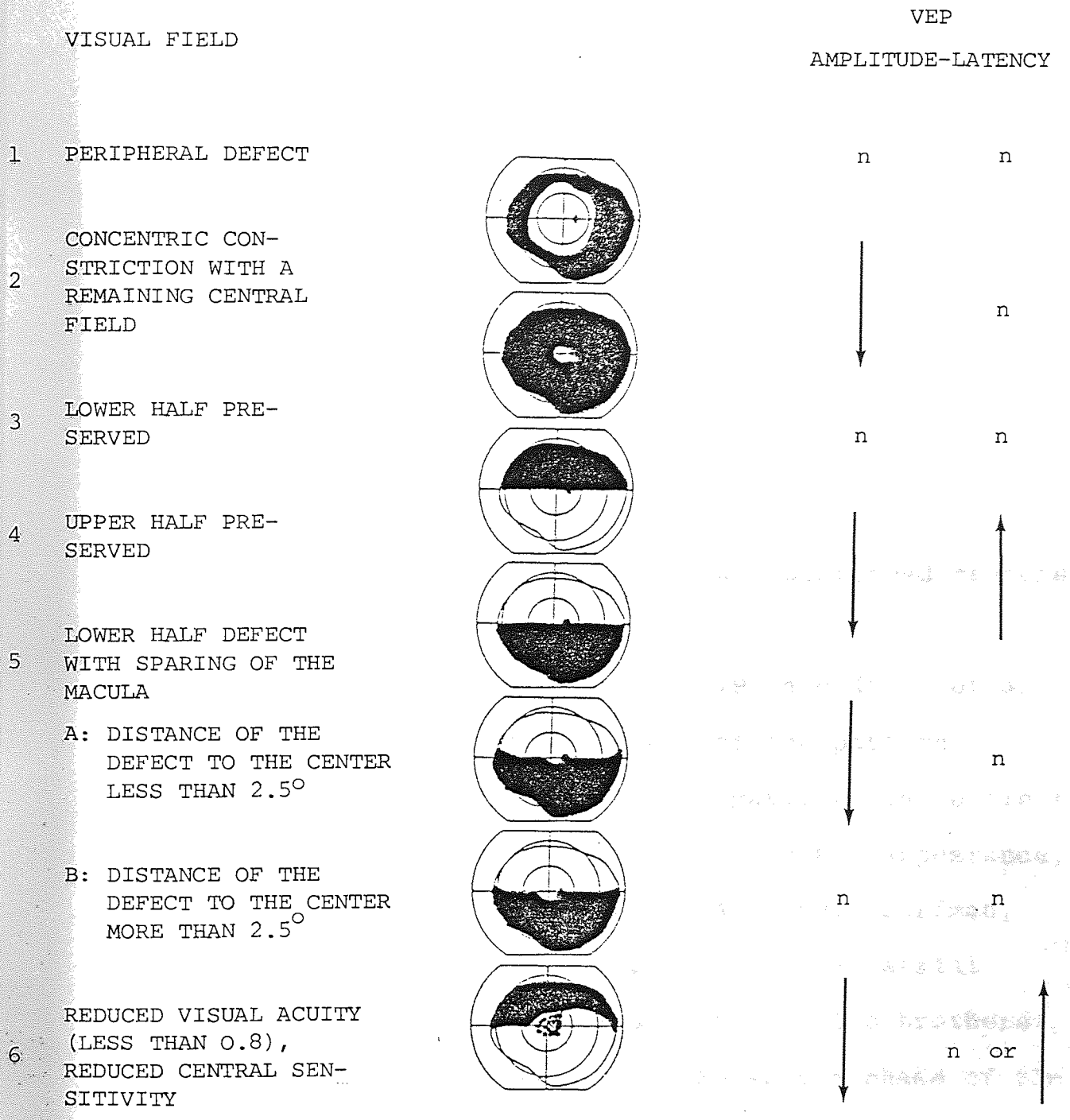
Wildberger (1984) further discussed the difference between patients with ION and those with optic neuritis. He pointed out that peripheral field defects in patients with ION did not severely effect the VEP even when accompanied by total disc oedema. Optic neuritis, however, with a peripheral field defect will usually give a delayed latency even if the central retina appears unaffected. Large paracentral scotomata in the lower field associated with some cases of ION must be very close to fixation to affect the VEP amplitude. Conditions causing an upper field scotomata can often result in an increase in amplitude and earlier peak latency. This observation also holds true for glaucoma and certain vascular retinal conditions. ION with an associated reduction of central sensitivity, combined with a reduction in visual acuity, reduced the amplitude of the VEP but not always the latency. Of those subjects which gave a delayed latency, there was no correlation with the level of visual acuity and no mention of a significant phase-reversal of the major component on the midline. These results are less surprising when considering the normal results discussed in Section 1.2.3 and are

summarised in Figure 1.6.

Ebe, Mikami and Ito (1964); Vaughan and Katzman (1964); Hillman, Myska and Nissim (1975); Crews, Hillman and Thompson (1975); Crews, Thompson and Harding (1978) and Harding et al. (1979) all reported on the usefulness of flash stimulation in the assessment of optic nerve damage following major trauma of the eye. They generally conclude that a reduction of 50% or more in the amplitude or a marked delay in latency compared to the good eye would mean that the eye is irrepairably damaged.

The VEP has also been used to investigate the effect of optic nerve compression. Feinsod and Auerbach (1971) used flash stimulation both pre- and post-operatively on two patients with tuberculum sellae meningiomata. The VEP was reduced or absent prior to decompression with an improvement mirroring the post-operative improvement in one patient. Halliday provided a more detailed analysis of optic nerve compression (Halliday 1976; Halliday et al. 1976). Delayed pattern-reversal VEPs were found with the maximum delay being less than the mean delay for optic nerve demyelination. It was suggested that reduction in amplitude and distortion of waveform were more characteristic but very sensitive even at an early stage when visual acuity appears unaffected and clinical signs are normal. Orbital lesions show less marked changes in the pattern reversal

FIGURE 1.6 Schematic representation of visual field defects in Ischaemic Optic Neuropathies and their influence on VEP amplitude and latency (after Wildberger 1984)



AD 3 and 4 : THE VEP - CURVES SHOW THE CHARACTERISTICS OF THE NORMAL REMAINING HEMIFIELD

VEP particularly in early stages (Halliday et al. 1976), although this is perhaps predictable considering the compressability of the orbital content. Intracranial tumours, particularly sphenoidal wing and suprasellar meningiomas produce early marked changes.

Babel et al. (1977) investigated 17 patients with compression due to tumour using flash stimulation. In 5 patients the response was absent, 10 had a reduced amplitude and 4 a delayed latency. Hume and Cant (1976) and Ikeda, Tremain and Sanders (1978) have described a similar phenomenon.

Van Lith et al. (1982) found similar results to Halliday (1976) and stated that it was direct pressure on the optic nerve which caused a delayed and disturbed response.

Halliday (1976); Halliday et al. (1979) and Kriss et al. (1982) all described a replacement of the pattern reversal VEP major positivity by a negativity in patients with central scotomata giving the classic PNP appearance, eg. in Leber's and Hereditary Optic Atrophy. Dorfman, Nikoskelainen, Rosenthal and Sogg (1977) used serial recordings of the pattern reversal VEP on two brothers with Leber's optic atrophy during the active phase of the disease. The VEPs had previously been recorded as being normal but with the onset of the disease a prolongation of latency and morphological distortion by a double positive peak was found, ie. PNP appearance. During the

subsequent reduction in visual acuity there was a further increase in latency with a less consistent reduction in amplitude. The VEP eventually became extinct. Asymptomatic relatives showed no abnormality of the VEP.

Carroll and Mastaglia (1978) undertook a massive clinical and electrophysiological study of 54 members of a family with Leber's optic atrophy. The results supported the findings of a delayed VEP using pattern reversal stimulation but disagreed with Dorfman et al. (1977) in that atypical VEP changes were recorded in asymptomatic family members some "at risk" and "some not at risk". These findings were thought to indicate demyelination with axonal degeneration.

Babel et al. (1977) investigated patients with dominant hereditary optic atrophy (HOA) using flash stimulation. They were only able to record a response in one out of 6 subjects, which showed a reduced amplitude but a normal latency. Halliday et al. (1977) claimed there to be a response of normal latency but reduced amplitude proportional to the level of visual performance. He goes on to describe how half-field stimulation showed a reduction in the ipsilateral NPN complex together with an increase in the contralateral PNP complex.

Harding and Crews (1982) using both flash and pattern reversal stimulation investigated 27 patients from 6 families with HOA. The flash VEP showed a PNP complex

in most of the affected eyes. The pattern reversal VEP also showed this but in fewer cases. There was however, a definite reduction in amplitude. Not all of the patients exhibiting these results had a central scotoma thus casting doubt on the previously mentioned link between the PNP complex and central visual field defects.

Cappin and Nissim (1975) used steady-state PVEPs to investigate glaucoma. They presented each quadrant within the visual field with the stimulus and found a delayed response in each of those quadrants affected by the condition, except those in which the response was absent. They concluded that the technique was not suitable for bilateral field defects, patients with lenticular or corneal opacities or those with a visual acuity less than 6/24. Halliday (1982) doubts whether the change in "relative latency" is due to the field loss as it could be due to the "changes in topography of the PVEP associated with changes in the cortical generator areas corresponding to the preserved field".

Huber and Wagner (1978) did, however, establish a delayed latency of the P100 component using pattern reversal stimulation. The longest delays occurred in the eyes with the worst visual field defects but there would appear to be no direct relationships between the two. They concluded that pattern reversal stimulation may be useful in monitoring optic nerve pathology in glaucoma.

Huber (1981) repeated tests on the above patient group along with the measurement of visual fields using a static automated perimeter. He found a significant relationship between central field loss and the delay in the VEP to pattern reversal stimulation, but that gross field loss at an eccentricity of 6^{o} or more would not necessarily affect the response. If, however, there was a generalised reduction in retinal sensitivity, the VEP could be delayed even with normal visual acuity.

Sokol, Domar, Moskowitz and Schwartz (1981) found delays in the P2 component in glaucoma but stressed the relevance of controlling variables like pupil diameter. Fox, Blake and Bourne (1973), Bartl et al. (1975) and Ulrich, Bohne, Reinmann and Wernecke (1980) all performed investigations using an artificially induced increase in intra-ocular pressure (IOP).

Motolko, Drance and Douglas (1982) found that 50% of subjects with early chronic open angle glaucoma had a normal VEP latency. Towle, Moskowitz, Sokol and Schwartz (1983) found 50% of glaucomatous subjects and 25% of the ocular hypertensives gave an abnormal delay in latency which could be correlated with both the severity and location of the visual field abnormality. Wildberger (1984b) found that when the visual acuity was normal the latency was usually normal. Almost normal amplitudes and normal latencies were found in patients with large arcuate scotomas in the upper visual field. A reduction in the

differential light threshold was found to parallel the reduction in VEP amplitude even when the visual acuity was unimpaired.

For additional reading on the effect of pre-chiasmal lesions on the VEP the author refers the interested reader to Holder (1979); Halliday (1982); Williams (1983) specifically for toxic amblyopias; and Wildberger (1984).

1.4 The Visual Evoked Potential in Chiasmal Lesions

Hemianopic field defects are commonly caused by compression on the optic chiasma by a suprasellar mass. This generally causes a bitemporal hemianopia by the resulting compression of the crossing nasal retinal fibres projecting to the contralateral hemisphere. Occasionally compression of posterior chiasmal fibres will give an homonymous defect and even more occasionally this compression will give rise to a binasal hemianopia. A space occupying lesion involving the chiasma, unlike those lesions anterior to the chiasma, will involve the visual fields of both eyes. The type and extent of visual loss is summarised in Figure 1.7. For further information please refer to Harrington (1976).

Muller (1962) used flash stimulation to investigate 10 patients with bitemporal hemianopia, 5 of which showed an increased latency. Vaughan and Katzman (1964) looked

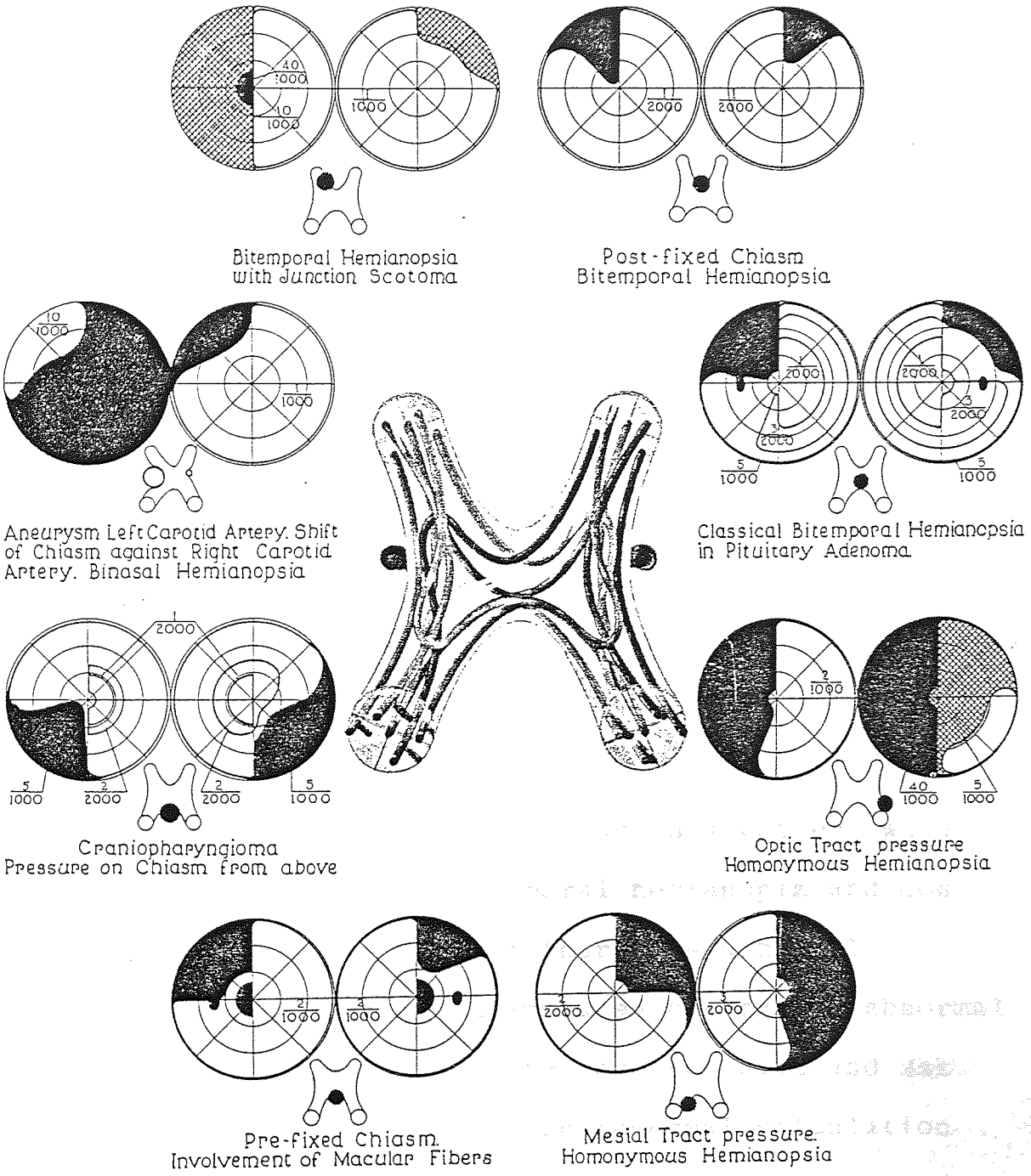


FIGURE 1.7. Summary of the visual field defects caused by chiasmal lesions.

(after Harrington 1976)

at a single asymmetrical bitemporal hemianopia and showed that flash stimulation of the left eye gave a reduced amplitude over the right hemisphere and stimulation of the right eye gave a bilaterally reduced response. Jacobson et al. (1968) found a small VEP to flash stimulation ipsilateral to the stimulated eye with a reduced or absent contralateral response in a single patient with bitemporal hemianopia. Fisher, Jampolsky, Scott, Morris, Lehmann and Alden (1968) described an interesting patient with a split optic chiasma. They found a normal ipsilateral response with an inverted contralateral response. Analysis of these results by Lehmann, Kavanagh and Fender (1969) suggested that potentials evoked could be explained by a single generator in the ipsilateral cortex.

Kooi, Yamada and Marshall (1973) studied a patient with craniopharyngioma causing bitemporal hemianopia and confirmed previous results in that there was a normal response ipsilateral to the stimulated eye but an abnormal response contralaterally. Wildberger, Van Lith and Mak (1976) used a steady-state pattern reversal stimulation to study six patients with bitemporal hemianopia caused by chiasmal compression. Stimulation of the right eye resulted in a reduced amplitude over the left hemisphere and stimulation of the left in a reduction over the right hemisphere, ie. an amplitude reduction contralateral to the stimulated eye.

Halliday et al. (1976) used pattern reversal stimulation to investigate 10 patients with chiasmal compression, 9 with pituitary tumours and one craniopharyngioma. The authors used a 32^{o} field with 50' checks and recorded the VEP from electrodes 5cm anterior and lateral to the inion referred to a mid-frontal reference. Amplitude reduction, latency delay and in some cases morphological distortion were seen in all patients but, contrary to most previous literature, the abnormalities were found ipsilaterally to the stimulated eye. One patient was found to exhibit an abnormal response to stimulation of a clinically normal eye. Such results were later confirmed by Blumhardt et al. (1977) and Halliday (1978), thus demonstrating that the VEP asymmetry may be clinically significant before other clinical abnormality.

Conversely, more recent work suggests that the VEP may recover very quickly following operative decompression. Gutin, Klemme, Logger, Mackay, Pitts and Horobuchi (1980) recorded the re-establishment of the VEP to flash stimulation three hours after the aspiration of a cystic craniopharyngioma. Wilson, Feinsod and Lehmann (1977) recorded a recovery after 2-3 minutes of chiasmal manipulation during parasellar surgery.

Hume and Cant (1976) describe, like Halliday (1976), an ipsilateral abnormality in a single patient with pituitary adenoma. They used a 40' reversing check over a 20^{o} field recorded at O_1 and O_2 referred to linked ears.

Holder (1978) investigated 10 patients with chiasmal compression using a pattern reversal stimulus. He agreed with Halliday et al. (1976) that there was a constant abnormality in the VEP. Holder, however, found without exception that the maximum abnormality was contralateral to the field defect. He goes on to argue that these results "correspond with the findings predictable from a neuroanatomical view" and that the "gross discrepancy" between the two studies is due to the differences in stimulus and recording parameters. In Holder's study, an 11^{o} field was used with 26' checks recorded at bipolar occipital-sylvian and occipital-parietal electrodes. A similar montage was used by Wildberger et al. (1976). In 7 patients the responses to a 13' check were also examined in which 6 showed the lateralisation to be contralateral to the remaining half field.

Aminoff, Maitland, Kennard and Hoyt (1984) (also Maitland and Aminoff, 1982) examined 8 patients with a variety of chiasmal lesions, using pattern reversal stimulation. In 4 of the 8 patients the results to full-field and half-field stimulation confirmed the results of Halliday et al. (1976) and Blumhardt et al. (1977). They used a very similar check size and electrode montage. The remaining 4 patients, all with total or partial bitemporal hemianopia, gave results which were not considered adequate to permit "reliable detection of the visual field defect". They concluded that the VEP is "not a reliable means of detecting subtle visual field defects, and that the VEP responses

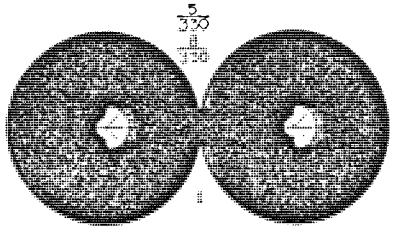
obtained from patients with similar field defects may differ considerably". They also felt that the level of patient co-operation required was often too difficult for patients with neurological lesions. It must be noted, however, that the field size used was only a 10^{o} square, with half-field stimulation, therefore only being $0\text{-}5^{o}$.

The author refers the interested reader to Section 1.2.2 for a discussion of the normal results expected from half-field stimulation. A discussion of the importance of recording parameters to half-field stimulation will take place in the Summary of the next Section.

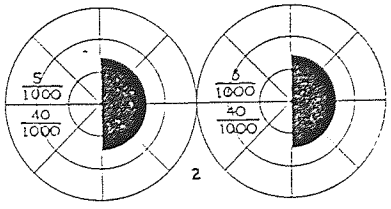
1.5 The Visual Evoked Potential in Post Chiasmal Lesions

A detailed account of the type and extent of visual field loss expected as a result of a post-chiasmal lesion is beyond the scope of this thesis. They are summarised in Figure 1.8. For further information please refer to Harrington (1976).

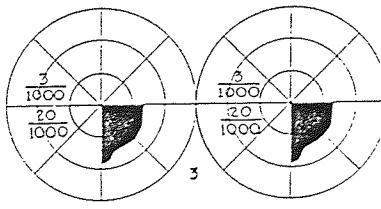
Cohn (1963) used flash stimulation of 3-10 per second to investigate patients with homonymous hemianopia and found an asymmetry in all subjects. He noted that the higher frequency flash stimulation gave more consistent responses than 1 per second flash. Vaughan et al. (1963) investigated 19 patients with unilateral cerebral lesions but no visual field defect and 30 patients with homonymous field defects using flash stimulation with closed eyes and 1.5 flashes



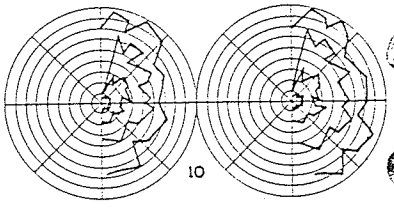
Bilateral Occipitol Lobe injury. Double Homonymous Hemianopsia. Destruction of both Occipital Lobes.



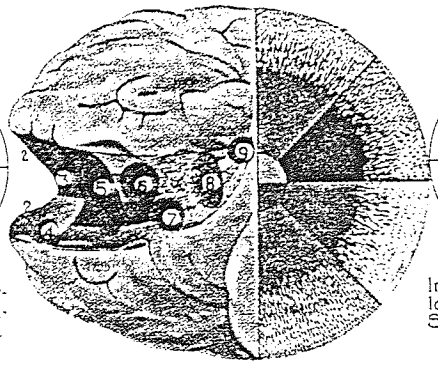
Lesion of the left Operculum or external surface of the Occipital Pole



Occipital Pole. Posterior tip of the Upper Lip of the left Calcarine Fissure.

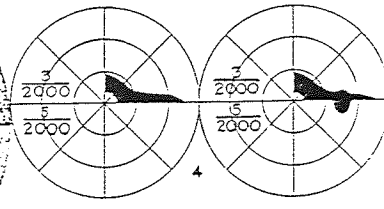


Successive phases in the Homonymous Scintillating Scotoma (Fortification Specter) of Migraine.

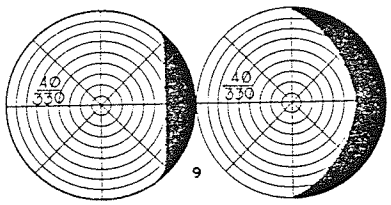


Mesial surface of the left occipital lobe showing the Area Striata (Brodmann's area 17) with the lips of the Calcarine Fissure held apart and the projection of the area on the visual field. The extension of area 17 onto the external surface of the hemisphere, (the Operculum) is not shown.

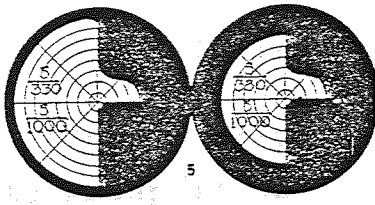
The visual defects are characterized by complete symmetry (congruity), sharp outline with steep edges and great density. The macula is usually spared.



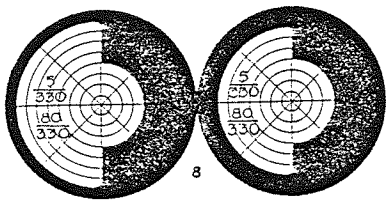
Inferior Anterior portion of the Macular Projection in the left Area Striata. Ice pick wound.



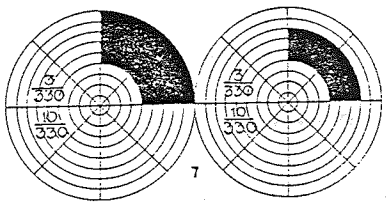
Anterior Tip of the Calcarine Fissure. The Temporal Crescent



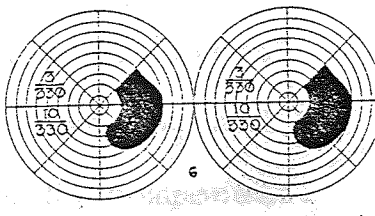
Inferior Quadrant Anopsia combined with partial Superior Quadrant defect.



Very large area of Macular sparing Anterior portion of both Lips of the Calcarine Fissure.



Anterior, Inferior Lip of the Calcarine Fissure.



Middle Superior portion of the Calcarine Fissure.

FIGURE 1.8. Summary of the visual field defects caused by lesions of the visual cortex.

(from Harrington 1976)

per second. The analysis was confined to the first three components (N_1, P_1 and N_2) and found significant inter-hemispheric asymmetries in both groups of subjects. This asymmetry was greatest in the hemianopic group, with the most significant delay in latency also being in this group. The authors found those subjects with macular sparing least likely to show an amplitude reduction thus, they concluded, showing the importance of the central visual field with regard to the VEP. Vaughan and Katzman (1964) went on to investigate 18 patients with homonymous hemianopias involving the central 10^{o} and found 15 displayed significant amplitude asymmetry ($<$50%) with the abnormality occurring contralaterall

Kooi, Guvener and Bagchi (1965) using flash stimulation examined 23 patients with homonymous visual field defects and 19 patients with unilateral hemisphere lesions but no visual involvement. All of the hemianopic group illustrated an asymmetrical response with macular involvement being of no significant. Two out of 6 patients with quadrantic field defects showed no asymmetry. The unilateral hemisphere lesion group as a whole showed delayed N_1 and P_1 components and an amplitude reduction of the N_3 component. Absence of component P_1, as found by Vaughan et al. (1963), was not found indicative of visual pathway involvement as unilateral absence was found in five normal subjects.

Crighel and Botez (1966) investigated patients with acquired occipital lobe lesions following surgical intervention for intracranial space-occupying lesions. They studied 9 patients using flash stimulation and

generally found the response to be absent or reduced. Two patients exhibited an increased amplitude from the parietal areas on the side of the lesion.

Jonkman (1967) investigated a large number of patients with varying neurological disease some involving the posterior visual pathway and some with space-occupying lesions not directly involving the pathways. Contrary to the findings of Kooi et al. (1965) some patients with homonymous hemianopia did not show a significant asymmetry. Some cerebral lesions, however, showed highly asymmetrical response in spite of there being no clinical signs of visual pathway involvement. Twenty-nine of the 39 patients showed an asymmetry that was greater than 50% in at least one component. Nineteen cases showed a delay in latency of more than 5 msec and 24 of the 39 patients showed marked asymmetry with respect to the morphology. In some cases the asymmetry was so gross as to preclude amplitude or latency evaluation. Some frontal or fronto-temporal tumours showed an increased amplitude on the side of the lesion, occasionally being of a shorter latency. Bergamini and Bergamasco (1967) investigated the VEP to flash stimulation in patients with intracranial space-occupying lesions and found that in all cases involving the visual pathway the ipsilateral VEP was altered.

Schneider (1968) confirmed the relevance of the lesion location as reported by the several previous authors.

He concluded that the more posteriorly situated tumours had a more marked effect on the VEP to flash stimulation. Unilateral reduction or abolition of the rhythmic after activity was also noted in some patients on the side of the lesion, thus agreeing with Jonkman (1967).

Crighel and Poilici (1968) found an inter-hemispheric VEP asymmetry, using flash stimulation, in patients with sub-thalamic lesions, but no visual field defect. Similar asymmetries were not found in medullary or midbrain lesions but late components appeared to be bilaterally increased.

Jacobson et al. (1968) examined 7 patients with homonymous hemianopia with macular sparing using flash stimulation. They reported that gross inter-hemispheric asymmetry was characteristic with the P_1 and N_2 components showing amplitude reductions or latency delays.

Oosterhuis, Ponsen, Jonkman and Magnus (1968) studied 30 patients with cerebrovascular disease, six of whom exhibited hemianopic visual field defects. Using flash stimulation they concluded that the absence of the N_1 and P_1 components was not pathological thus agreeing with Kooi et al. (1965) but disagreeing with Vaughan et al. (1963). They reported that an asymmetry of the secondary response only occurred in patients with visual field defects thus confirming the findings of Jonkman (1967), but their results included two patients with homonymous

hemianopia and a normal VEP. They suggest the possibility of loss or reduction of the rhythmic after activity on the side of the lesion but report on two patients with an ipsilateral increase in rhythmic after activity. They concluded that parieto-occipital VEPs provided a more consistent indicator of cerebral disturbances than the occipital to ear recordings.

Harding et al. (1969) made an important contribution to the recording of VEPs to flash stimulation in patients with homonymous hemianopic field defects by introducing the EEG technique of phase reversal in an attempt to localise the VEP. They found an absence of phase reversal at the occipital electrode contralateral to the visual field defect concluding that the technique eliminates some of the interpretative problems resulting from the large VEP variability in the normal population.

Bergstrom and Nystrom (1970) investigated 32 patients with cerebral pathology, half being conscious the other half comatose. Using flash stimulation they found no significant difference between the two groups. The most frequent findings were significant inter-hemispheric amplitude asymmetries or absence of response, the former indicating a predominantly unilateral lesion. The authors were left posing the question whether or not absence or severe distortion of the VEP represented the greater degree of abnormality.

Crighel and Sterman-Marinchescu (1971) investigated 19 patients between the 2nd and 5th day following a severe stroke. Seven patients gave a normal response, 3 gave no response and an asymmetry occurred in 6 patients, 5 with sylvian artery thrombosis and one with carotid thrombosis. They concluded that the VEP to flash stimulation was an indicator of the background cerebral function as a result of cerebral atherosclerosis.

Feinsod and Auerbach (1973) predicted a good prognosis for visual recovery in a patient with bilateral occipital lobe damage following a gunshot wound, in spite of clinically predicted cortical blindness. They could not, however, assess asymmetry as only midline recording electrodes were used. Duchowny, Weiss, Majlessi and Barnet (1974) investigated six cases of "cortical blindness" in children following trauma or bacterial meningitis. In one case of homonymous hemianopia they reported a reduction of the VEP to flash stimulation contralaterally to the visual field loss.

Abraham, Melamed and Levy (1975) found that in patients with occipital blindness from basilar artery occlusion responses of normal morphology and amplitude were followed by complete visual recovery. They reported that "unequal and subnormal VEPs obtained after monocular stimulation and even small responses reached after binocular stimulation accompanied permanent occipital lobe damage resulting in homonymous hemianopia" which is interesting as only

mid-line recordings were used. Jayle et al. (1971) had previously reported on a single subject giving similar results.

Feinsod and Auerbach (1973) concluded that lesions of the optic radiations gave a delay in the initial VEP component, to flash stimulation, striate cortical involvement obliterated both the early and late components, and that involvement of the supra-striate gave a selective loss of late components over the affected hemisphere. Kooi, Yamada and Marshall (1973) used flash stimulation to investigate post-traumatic changes suggesting that the VEP could distinguish between organic and non-organic post-traumatic visual impairment, a deduction later supported by Feinsod and Auerbach (1973). The authors most dramatic example being a patient who exhibited a virtual absence of the VEP over one hemisphere but with no recordable visual field loss.

Galkin, Grezditsku, Aleksondrava and Kazlava (1975) studied 28 patients with homonymous hemianopia, 21 of which were said to be "complete". All of the latter group gave a contralateral abnormality to flash stimulation exhibiting an absence, decreased amplitude or delayed latency. Half of those patients with lesions affecting the mediobasal areas of the temporal lobe and with hemianopic defects due to the optic radiation interestingly showed an increased amplitude on the affected side.

Regan and Heron (1969) were the first to report the effects of a patterned stimulus on patients with homonymous hemianopia and macula sparing. They found the response to pattern was normal although the sinewave modulated flash response was reduced over the affected field attributing the results to the dependence of the pattern response on central vision.

Wildberger et al. (1976) used steady-state VEP to pattern reversal stimulation, 30' checks at 8 cycles per second, to investigate patients with homonymous hemianopia. They found no difference between those patients with or without macular sparing with all cases exhibiting a reduced amplitude over the affected hemisphere.

Blumhardt et al. (1977) reported on a single patient with homonymous hemianopia following the removal of an arteriovenous malformation at the right occipital pole. They used a pattern reversal stimulus of 50' checks with a 32^{o} field and found an ipsilateral abnormality. Further recordings from patients with more severe occipital lobectomies showed this paradoxical lateralisation where the response was being recorded from the hemisphere clearly opposite the generating hemisphere.

The same authors had previously reported similar findings using half-field stimulation of normals (Barrett et al. 1976) and from full-field stimulation of patients with bitemporal hemianopia as discussed earlier (Halliday

et al. (1976), and have carried on defending their arguments (Halliday 1978; Blumhardt et al. 1982; Halliday 1982).

Holder (1980) investigated 19 patients with homonymous visual field defects using pattern reversal stimulation with bipolar occipital-sylvian and occipital-parietal recordings. He found that each patient exhibited abnormalities contralateral to the visual field defect, and in 3 patients with bilateral lesions the VEP "correctly" localised the more abnormal hemisphere. The type of abnormality seemed partially dependent on the pathological nature of the lesion. In three cases where infarction had caused the field defect the only abnormality was a significant amplitude reduction. In 7 cases of severely distorted morphology the lesions were space-occupying.

These results are in direct contradiction to the work carried out by Halliday and his colleagues. Holder (1980) went on to further investigate a sample of patients from his study using varying check and field sizes and found that the large stimulus parameters used by Halliday gave the paradoxical lateralisation which they have reported. He concluded that the field size appeared to be the predominant factor. He also demonstrated how electrodes used 2cm anterior and lateral to the inion (as used in his own study) are relatively unaffected by changes in the stimulus parameters whereas the electrodes used by

Halliday and colleagues, ie. 5cm anterior and lateral to the inion, are severely affected. This has also been found by Barrett et al. (1976) when they reported that the normally ipsilateral response could have a more contralateral predominance if stimulation was confined to the macular area.

Harding et al. (1980), as discussed in Section 1.2.2, had also investigated the effect of stimulus parameters on the lateralisation of the VEP. They concluded that normative half-field stimulation studies may not provide a good basis on which to judge clinical half-field results.

Blumhardt and Halliday (1981) investigated 26 patients with cortical abnormalities comparing the full-field VEP to pattern reversal stimulation with half-field stimulation. Two sub-groups were used, 16 of the 26 patients having "complete" homonymous hemianopia and the remaining 10 "incomplete" which consisted of 8 quadrantic defects and 2 with "subtle homonymous scotomata".

The overall results showed full-field abnormalities in 62% of the patients and abnormal half-field results in 84%. When this is broken down to relate to each sub-group we find 69% of the "complete" defects showing an abnormality to full-field stimulation and 100% to half-field stimulation, the former result disagreeing with Holder who found 100% success with full-field stimulation.

The "incomplete" group shows 50% abnormal responses to full-field stimulation and only a 10% increase for the half-field stimulation.

The authors criticise previous studies for their "over-simplified concept of the relationship between the anatomy of the visual pathways and the scalp distribution of the VEP". They claim that those researchers who expect a contralateral response ignore the importance of the "position and orientation of generator neurones in the visual cortex", asserting that "lateralisation of maximal amplitudes on the scalp have no constant relationship to the hemisphere of origin".

They propose that the usefulness of half-field stimulation "is limited by the increasing variance as the half-field is fractionated so that the detection rate for quadrantic defects falls off to about 50%", thus supporting the findings of Regan and Milner (1978).

They suggest that the VEP to pattern reversal stimulation will only detect an abnormality if there is a field defect the extent and type of which determines the "degree of response asymmetry". This disagrees with the majority of work discussed earlier in which the VEP to flash stimulation found abnormalities without a visual field defect. The authors question whether this implies a fundamental difference between the flash and pattern reversal VEP or whether the VEP to flash stimulation was correctly interpreted.

Kuroiura and Celesia (1981) investigated 16 patients with retro-chiasmatic lesions using pattern reversal stimulation to elicit both transient and steady-state VEPs. They found that full-field stimulation was not a reliable indicator of retro-chiasmal lesions with only 50% of the patients giving the expected asymmetrical response (Halliday et al. 1976). This was further complicated by such an asymmetry being present in 2 out of 23 normal subjects. Half-field stimulation was considered more rewarding, the results agreeing with those of Blumhardt et al. (1977). They proposed a set of criteria which were likely to identify lesions of this type.

1 An amplitude of less than luV or absent VEP after stimulation of the affected hemifield.

2 Reversal of the normal VEP distribution after stimulation of the affected hemifield.

3 An abnormal lateral occipital ratio, ie. the amplitude of the P100 component at the contralateral electrode divided by the amplitude at the ipsilateral electrode.

4 An abnormal mid-occipital ratio.

and 5 An amplitude of less than luV or an absent steady-state VEP after stimulation of the affected hemifield.

Three and 4 were considered to be the most sensitive indicators of a retro-chiasmal lesion. They also reported a delay in the latency of the P100 component in 25% of the patients examined following full-field or half-field stimulation. They consider that reliable results will only be obtained if multiple measurements, using different stimulus parameters, with large electrode montages are used.

Blumhardt et al. (1982) in a major presentation summarising and adding to all of their previous work on both normal half-field stimulation and patients with hemianopic defects, discussed the delay of the response mentioned by Kuroiura and Celesia (1981) and Streletz et al. (1981), who found a delay in 11% of patients. He felt that neither had accurately distinguished between the contralateral and ipsilateral half-field positivities. It was felt that the slight increase in the group average latency found in the hemianopic patient group may be due to the problems of identifying peak latencies with very small amplitudes. There appeared to be no correlation between the latency and the presence or laterality of the field defect, or the pathology. Blumhardt supports the use of multichannel recording but warns that the usefulness of the half-field stimulation is limited by the normal variability of the hemisphere response and the correct identification of the resultant waveforms.

Celesia, Todd Meredith and Pluff (1983) examined 50 consecutive patients with retro-chiasmal lesions to compare the relative merits of perimetry, confrontation, VEP and visual evoked spectral array testing. Interestingly only 60% of the patients were able to be tested with Goldmann perimetry but 77% could tolerate the VEP recordings. Of this 77% only 79% demonstrated abnormalities in the results (c.60% of the total). This is a very similar detection rate to many other authors (Blumhardt et al.(1982) 75%; Haimovic and Pedley (1982) 86%; Maitland, Aminoff, Kennard and Hoyt (1982) 83%) all using techniques employing both full field and half-field stimulation. It was considered that two factors play an important role in explaining the rate of failure:

1 The topographic variability of the visual cortex and
2 The large cortical representation of the macular region.

Anatomical studies of the human striate cortex had noted considerable hemispheric asymmetry. It was not always found to reach the occipital pole and that the amount of exposed striate if it did was often larger on the left occipital lobe (Stensaas, Eddington and Dobell 1974; Brodmann 1918; Smith 1907).

Cortical representation of the visual field is discussed

in Chapter 3. In vivo, confirmation of these concepts has been provided by Reivich, Cobb, Rosenquist, Stein, Schatz, Savino, Alavi and Greenberg (1981) using positron emission tomography and regional cerebral glucose utilization. They demonstrated the large macula representation in patients with homonymous hemianopia with macular sparing. Celesia et al. (1982) found similar results looking at patients both with and without macula sparing.

Celesia et al. (1983) suggest that only by preferentially stimulating the periphery will the detection rate of VEPs for retro-chiasmal lesions be improved.

Hoeppner, Bergen and Morrell (1984) examined three patients with unilateral occipital lobectomies. They hoped to investigate the discrepancies noted in the literature by using flash full-field stimulation, pattern reversal full-field and half-field stimulation. They used a full gamut of electrode montages and recording techniques investigating the differences between common reference recording,with both a mid-frontal and earlobe references, and bipolar recordings, with both closely spaced and widely spaced montages. They found the [illegible] lateralisation using both the Queens Square montage (ie. that of Halliday and co-workers) and the 10-20 system using common reference recording to be ipsilateral to the remaining half-field. Although an ipsilateral earlobe reference, particularly in junction with electrodes O_1 and O_2 which are 'relatively' close to the midline, gave

less consistent results. The authors suggest that electrodes O_1 and O_2, even when referred to F_z, are too close to the midline and show a considerable variability even in the normal population (Haimovic and Pedley 1982). Similar observations were made by Harding et al. (1980) when they suggested the use of the O_3 and O_4 electrodes. Lateralisation did not differ between flash and pattern reversal stimulation although the asymmetry was sometimes clearer using pattern. When a closely spaced bipolar recording montage was used, like that of Cobb and Morton (1970), the response lateralised contralaterally, ie. abnormal over the ablated hemisphere. Using a widely spaced bipolar montage, in this example O_1-A_i and O_2-A_2, the results gave an ipsilateral lateralisation in two patients and a contralateral lateralisation in the remaining patient thus indicating a less reliable result.

1.6 The Effect of the Reference Electrode on the VEP

There has been much work over the years to try and establish the best possible reference for common reference recording. Lehtonen and Koivikko (1971) suggested the use of a non-cephalic reference but that this can lead to distortion of the VEP due to extraneous artifacts. Michael and Halliday (1971) and Halliday et al. (1977 and 1980) have shown that certain cephalic sites commonly used as reference points were moderately active and that the morphology of the VEP may change with different common reference positions. They concluded

that the earlobe or mastoid was clearly active and that the vertex was active with respect to the middle and later components of the VEP. They therefore suggested the use of a mid-frontal reference electrode. This can at times also have a disadvantage as it may be affected by the ERG, although a forehead or frontal electrode is affected more severely (Nakamara 1978). Peters (1967) also found that a frontal electrode is prone to contamination by eye movement potentials. Tepas and Armington (1962) attempted to use the chin as a reference but found it was affected by myogenic potential artifact.

Lehmann and Brown (1980) suggested that any topographical assessment of the VEP should use a common reference site and that any quantification of waveforms should be relative to a pre-determined baseline level, considered to be of zero potential, and latency values should be measured from stimulus onset. It is clear that such a reference site should be, as far as possible, outside the field of activity being investigated and to avoid alteration in relative amplitude the inter-electrode distance should be approximately equal.

It would seem timely, following this discussion of the variability in results obtained by different electrode montages, to examine in part the discussion of Halliday, Harding and Holder (1980). The results obtained and the different techniques used, by each of these authors, have been outlined earlier in this review. The discussion

centered around the relative merits of using a single, largely inactive reference electrode at F_z with a lateral chain of electrodes as commonly used by Halliday, or using the rolandic C_3 and C_4 electrodes in a widely spaced bipolar montage with electrodes O_1 and O_2, known as the Modified Maudsley montage, as used by Harding and Holder. The results obtained using common reference recording (as previously outlined), gives a response ipsilateral to the stimulated hemisphere in both normal half-field stimulation and with full-field stimulation of patients with hemianopic field defects. We have also discussed the variability of these results, particularly if the electrodes are close to the midline, due to normal anatomical variability affecting approximately 20% of the population. Using the bipolar occipital-sylvian and occipital-parietal recordings the response is found to be contralateral to the remaining hemifield in patients with a hemianopic defect. Clinical experience using half-field stimulation of normal subjects, also tends to give a response contralateral to the hemifield stimulated although the lateralisation may not be as consistent (Jones and Furlong 1985).

The authors showed general agreement over the effect of different stimulus parameters and could replicate each others results. Probably the most telling comment came from Harding who stated that the:

"orientation of the derivation between active and reference electrode may be critical for different dipoles. It is probably not without significance that contrasting results can be obtained where the derivation used by Dr Halliday differs from our own by approximately 45°. If the vector of the major positive component of the evoked potential can also alter in a similar manner, according to various stimulus parameters, then totally contrasting results could be obtained".

Let us examine more closely this idea of orientation but this time with respect to the type of visual field defect which can give these results rather than the stimulus parameters. Let us also accept, as did Halliday, that the rolandic electrodes are relatively inactive. Taking an extreme example of an absolute right homonymous hemianopia without macula sparing in which the left hemisphere would arguably be completely inactive. Consider next the relative orientation of the common reference montage compared to the occipital-sylvian and occipital-parietal montage and a stimulus consisting of large checks (50-56') and a large field size (28-32°) the results of which are well documented for both montages (Figure 1.9). Electrodes O_2 - F_z have a largely medial orientation and give an ipsilateral result; electrodes O_z - O_2 and O_2 - O_4 like those of Cobb and Morton (1970) are largely transverse and measure the

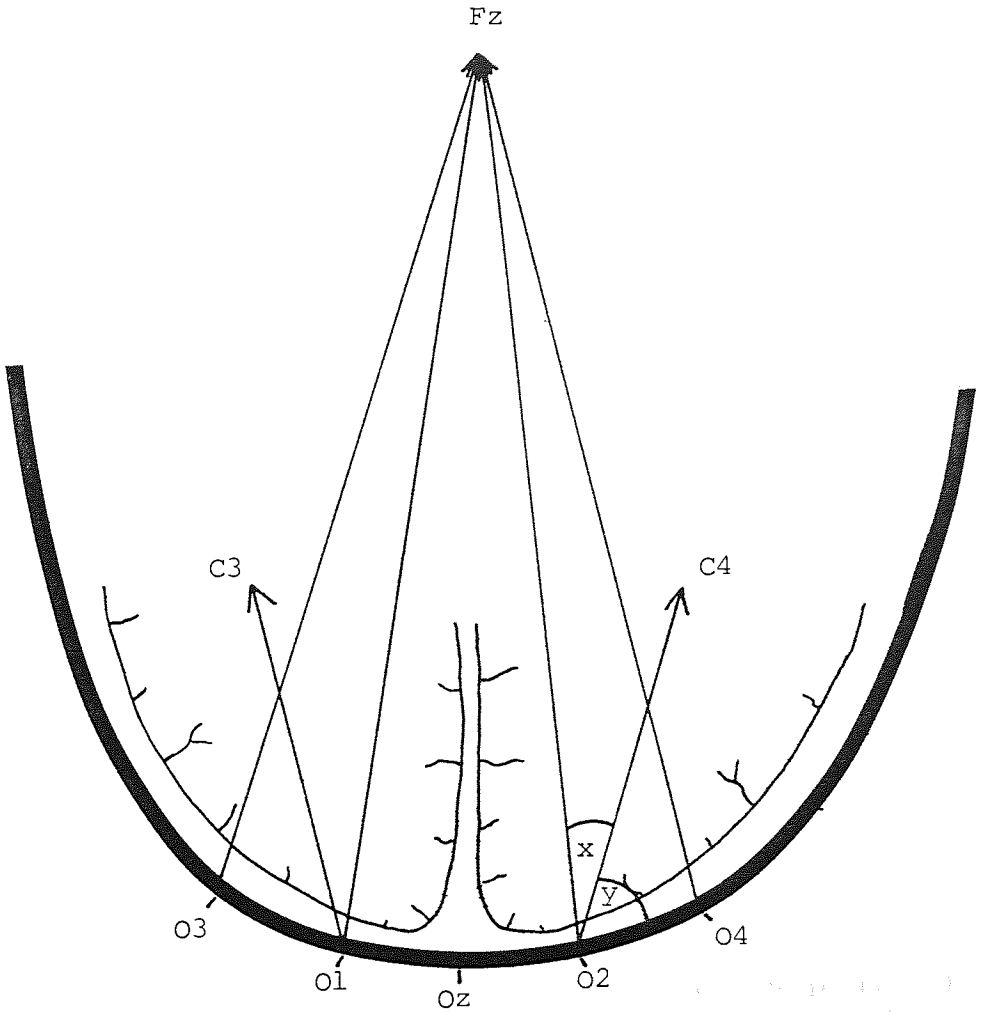
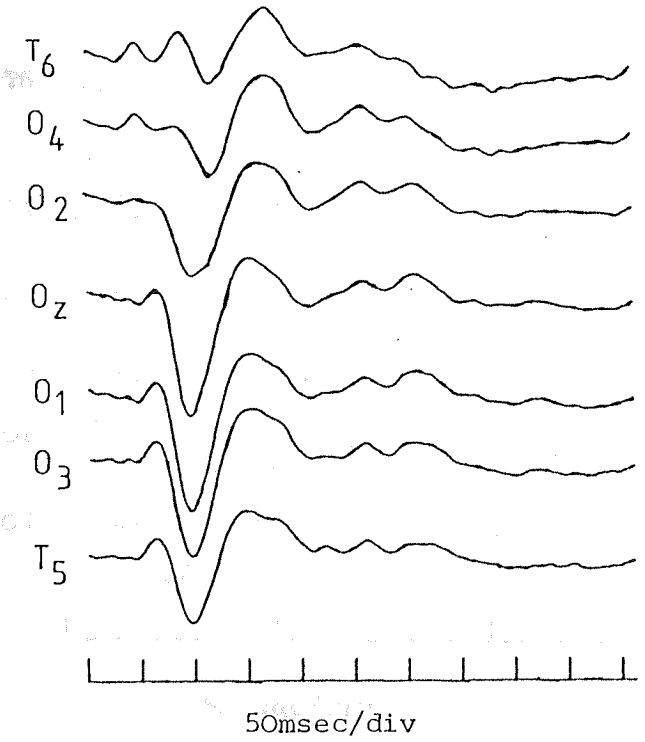


FIGURE 1.9. Showing the relative orientations of a common reference montage (O1-Fz and O2-Fz); a widely spaced bipolar montage (O1-C3 and O2-C4); and a closely spaced bipolar montage (O1-Oz and Oz-O2).

potential gradient of this orientation giving a contralateral result; electrodes O_2 - C_4 differs in orientation from the former by angle X and from the latter by angle Y and, being a bipolar montage, measures the potential gradient at this orientation.

Rather than considering the possible dipole generators and the way in which these may vary with both stimulus and pathology, let us consider the scalp potential field generated by the cortex. A potential field is a scalar field, see Chapter 4, and can be represented diagramatically as in Figure 1.10, where the size of the circle represents the magnitude of the P100 component at that position over the scalp. Consider first the results obtained using the F_Z reference. It can clearly be seen that the potential is greater at electrode O_1 than electrode O_2 therefore comparing them to the same baseline level at F_Z would give a bigger result over the ipsilateral left hemisphere on full-field presentation. It can also be seen that the more lateral electrodes at O_3 - O_4 and T_5 - T_6 show an even bigger difference in measured potential. There is however, a much steeper gradient of potential change over the right hemisphere consequently the transverse bipolar chain would record a contralateral result, being greatest over the right hemisphere, this is more clearly represented in Figure 1.11. If we now consider the difference between O_1 - C_3 and O_2 - C_4 it can again be seen that if these are a bipolar derivation there is a far steeper change in the potential gradient

1. COMMON REFERENCE (to Fz)



2. SCALP POTENTIAL FIELD

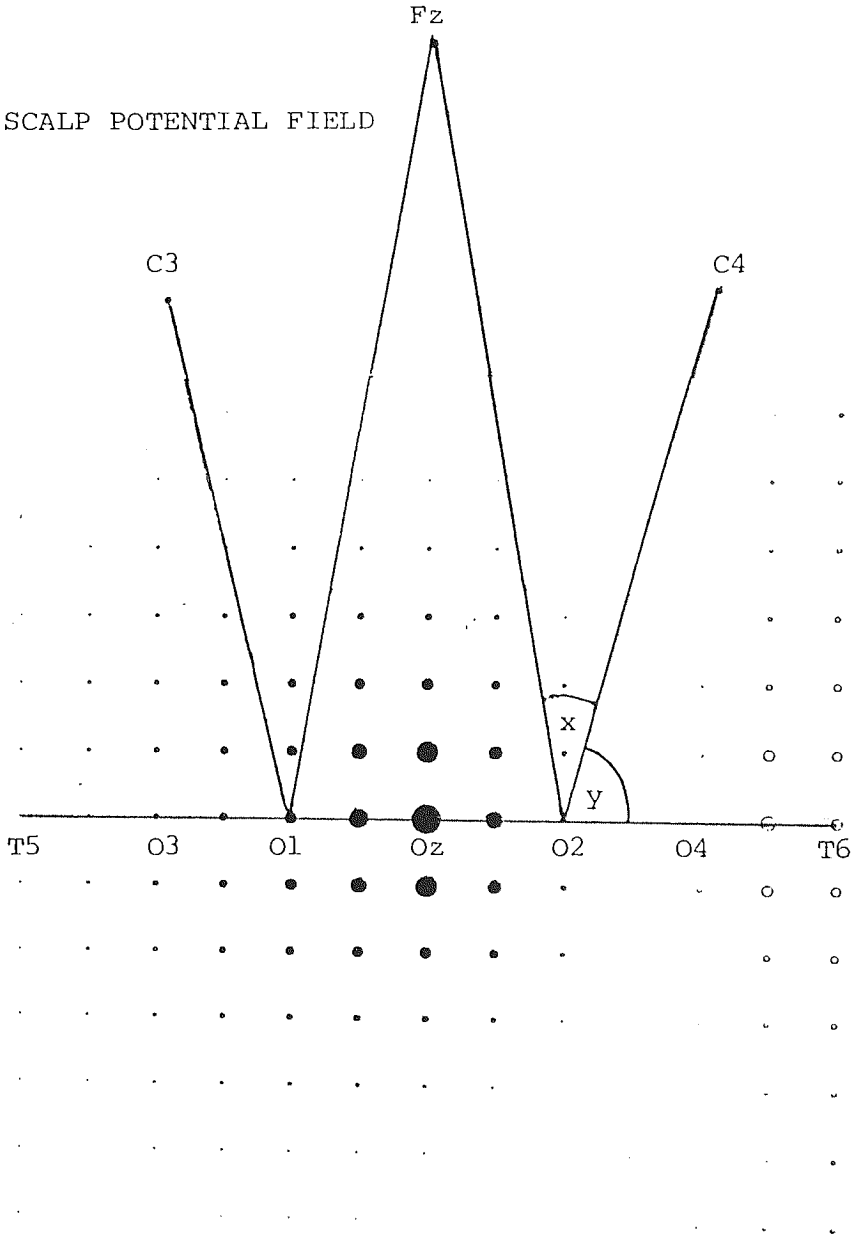


FIGURE 1.10 The visual evoked potential to left half field pattern reversal stimulation using a common reference montage (1) and the diagrammatic representation of the resultant scalp potential field (2).

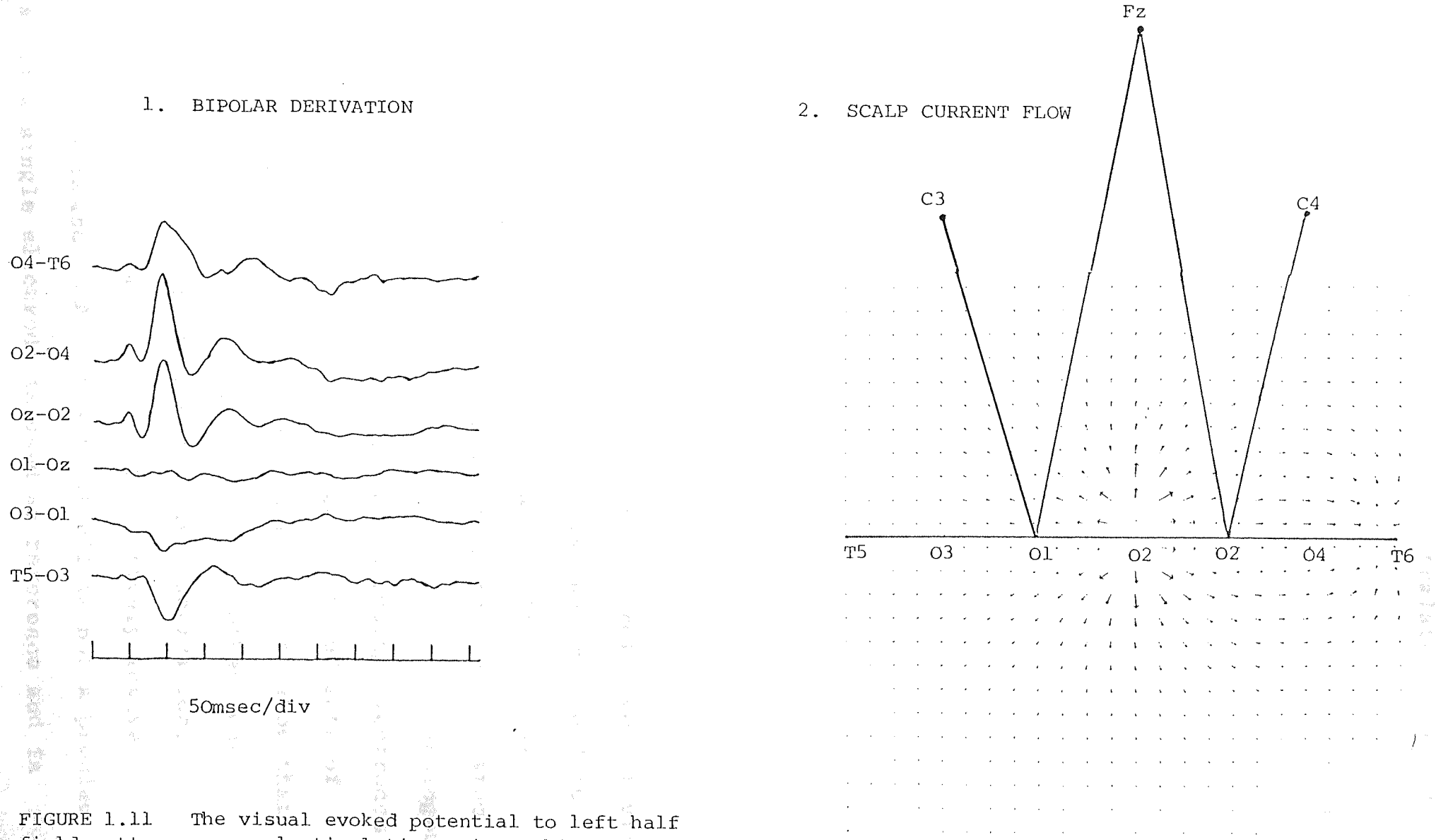


FIGURE 1.11 The visual evoked potential to left half field pattern reversal stimulation using a bipolar montage (1) and the diagrammatic representation of the resultant scalp current flow (2).

between O_2 and C_4 and therefore a contralateral result. It can also be understood why this montage, on normals, is more prone to anatomical asymmetries as the gradient difference is not as marked at this orientation as with either the transverse or medial orientation. These arguments also apply if we consider the O_1 - F_Z and O_2 - F_Z derivation to be a widely spaced bipolar montage. The potential gradient is steeper between O_1 and F_Z therefore records an ipsilateral result. There is a problem, however, if we consider C_3, C_4 and F_Z to all be distant and inactive, therefore giving a similar baseline measure. If this were the case then both sets of results should be ipsilateral with the absolute difference between the various electrodes always being greater for O_1 than for O_2.

It has become necessary to question the relative activity at electrodes C_3, C_4 and F_Z when only one hemifield is stimulated. Thickbloom, Mastaglia, Carroll and Davies (1984) investigated 30 electrodes from the 10-20 system to left half-field pattern reversal stimulation, analogous to the right homonymous hemianopia, including electrodes O_1, O_2, C_3, C_4 and F_Z and investigated the effects of different types of reference. Their results show that no matter what reference type is used, whether non-cephalic, average reference or source derivation, electrodes C_3, C_4 and F_Z are all relatively active (Figures 1.12 and 1.13). This in itself is not a problem as if a single electrode is used as reference and is

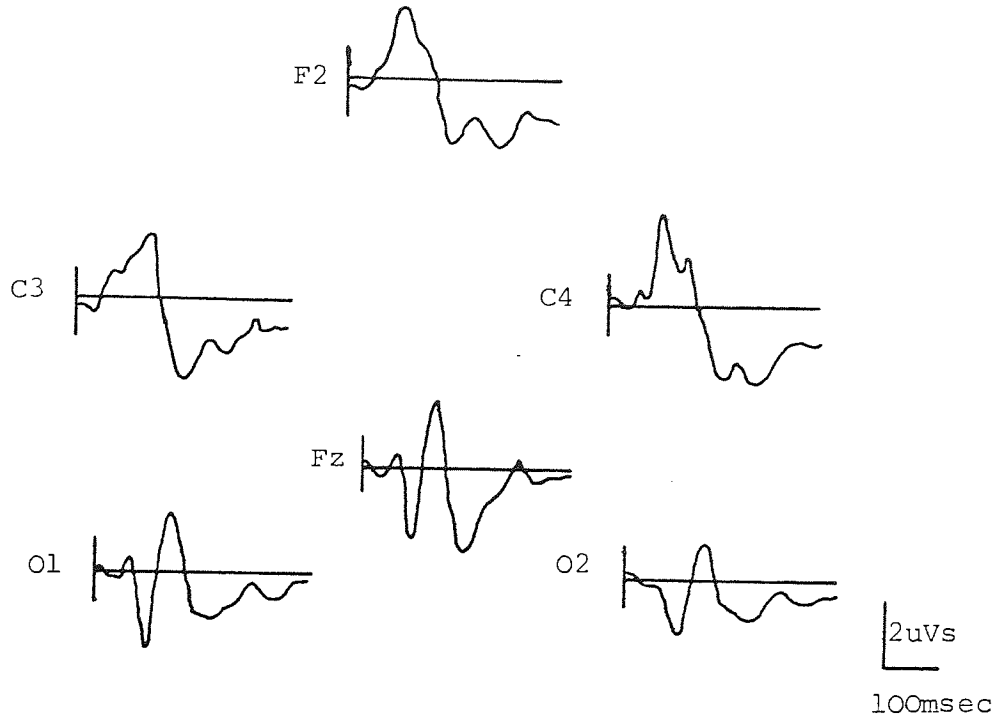
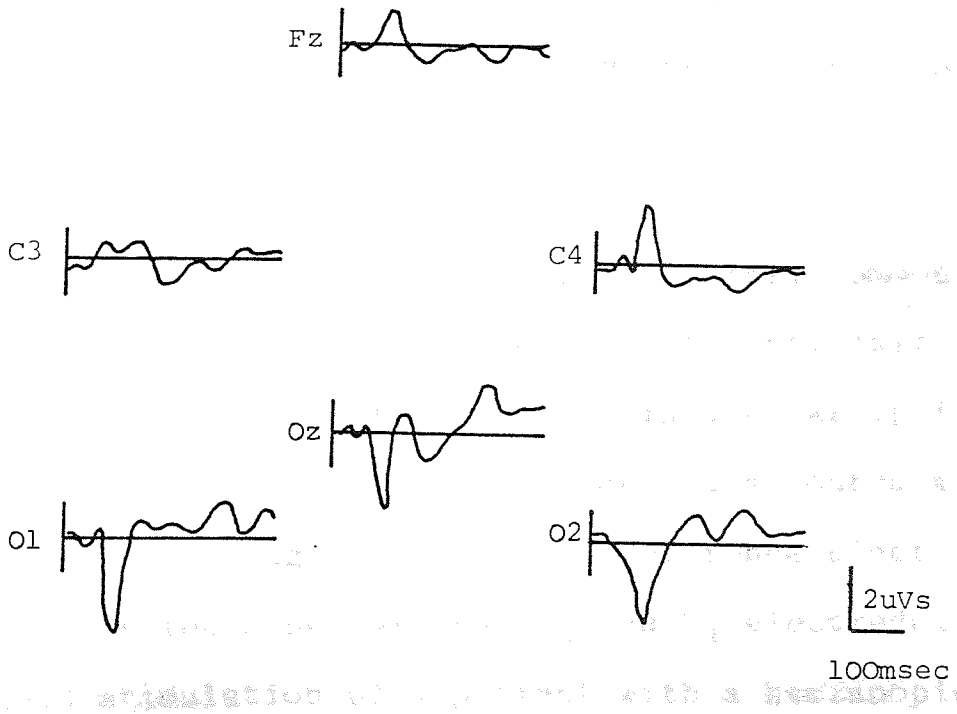


FIGURE 1.12 Left half field visual evoked potentials recorded with a sternoclavicular reference

(after Thickbloom et al. 1984)

FIGURE 1.13 Left half field visual evoked potentials recorded with a common average reference

(after Thickbloom et al. 1984)



relatively equidistant for the recording electrodes, it provides a baseline level for comparison. Unfortunately, the results indicate a clear asymmetry between the activity of C_3 and C_4. This results in an absolute potential difference which is always larger between O_2 - C_4 than O_1 - C_3, thus giving a contralateral response, but is always larger between O_1 - F_z than O_2 - F_z thus giving an ipsilateral response.

In conclusion, it is obviously important to understand all of the possible stimulus and recording parameters used within a particular laboratory and the way in which these will react with anatomical and pathological differences in the visual cortex. In principle, as long as this is done and the results are predictable, each technique will have its own merits and be of service. Unfortunately, such an approach negates the possibility of a standardised approach to VEP assessment, but in the long run this may be of benefit as it will have forced us to examine very carefully the reasons behind our observations.

Figure 1.14 compares simultaneously recorded common reference and rolandic reference sites to left half-field pattern reversal stimulation. There is a clear ipsilateral lateralisation using the F_z reference and a contralateral lateralisation using the C3 and C_4 reference electrodes. The asymmetry found between the C_3 and C_4 electrodes on half-field stimulation of a patient with a hemianopic

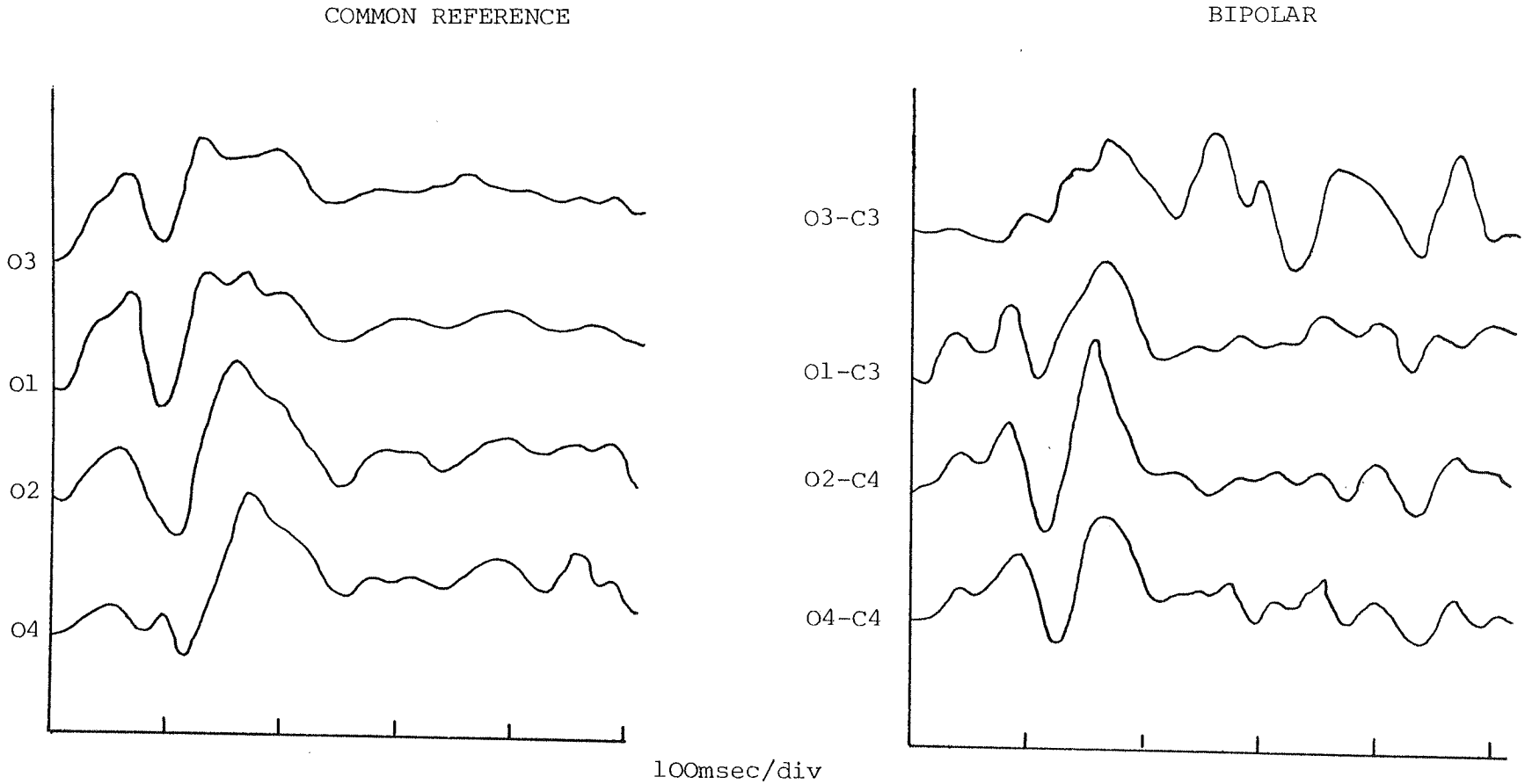


FIGURE 1.14 The VER following left half field stimulation of the right showing an ipsilateral response using reference recording and a contralateral response using a widely spaced bipolar montage

defect may result in a more exaggerated scalp potential asymmetry for the $O_1 - C_3$, $O_2 - C_4$ montage than for the common reference montage. Such a consideration would be less important to consider, however, if half-field stimulation is used as stimulation of the affected hemisphere would result in a relative flat response whichever montage is used.

CHAPTER 2

THE AUTOMATED ASSESSMENT OF THE VISUAL FIELD

2.1 Introduction

The Visual Field is that portion of space in which objects are simultaneously visible, no matter how indistinct, to the steadily fixating eye (Harrington 1976).

It is somewhat more than one half of a hollow sphere, situated before and around each eye of the observer within which objects are perceived while the eye is fixating on a stationary point on its inner surface. Objects that are visible on the inner surface of such a sphere act to stimulate the various portions of the retina through the conducting nerve fibre bundles of the visual pathway to the visual cortex in the calcarine area of the occipital lobes.

Within the visual field the sensitivity of the eye, defined as the inverse of the threshold, varies according to various stimulus parameters, eg. adaptation level, target size, target colour and target exposure time. The fovea is the most sensitive area in "normal" photopic levels of illumination but in the dark this is superceded by a region 10-30^{o} peripheral to the fovea (Greve 1973). Visual fields are normally examined in the lower photopic ranges.

The normal monocular visual field is a slightly irregular oval measuring from fixation approximately 60^{o} inwards, $70-75^{o}$ downwards, $100-110^{o}$ outwards and 65^{o} upwards (Harrington 1976). The extremes of the visual field are limited by the facial features, ie. the nose, brow, cheek bone and eyelid.

The measurement of the visual field is known as perimetry and is related to the limits of the visual sensitivity of the stationary eye. Kinetic perimetry involves the use of a moving stimulus of constant size and luminance to determine these limits. Static perimetry involves the measurement of stationary targets each with a variable luminance.

2.2 Reasons for Automation

The full history of the development of visual field instrumentation is beyond the scope of this thesis. The author refers those who are interested to Harrington (1976) and Henson (1983). There can be little doubt however, that until the mid-1970s the standard measurement of the visual field was by kinetic perimetry with the major "diagnostic" instrument being the Goldmann Bowl Perimeter. The Tubinger and Bjerrum Screen are two other examples. Over the years these instruments have been found to be reliable and to give repeatable results when operated by a skilled perimetrist. There are problems however, over the standardisation of operator technique

inherent within any form of manual, kinetic perimetry (Bedwell 1983). Greve (1973) established that the perimetrist can influence the results considerably.

There was a consequent trend, particularly for the investigation of the central 30^{o} of the visual field, towards static perimetry (see Bedwell 1983). Such measurements give an indication of the intensity of field loss as well as the extent and can give a differential threshold sensitivity curve for a given profile. The influence of the perimetrist is generally less when using a well designed static perimeter but is not completely controlled. A major criticism of the early, manual, static perimeters was that the test was usually very time consuming.

The obvious progression away from manual perimetry was to fully automate perimetric techniques. The most advanced of the automated perimeters are those controlled by computer. The advantages offered by such computer assistance are: (adapted from Henson 1983),

1 The perimetrist is relieved of the tedium of visual field measurement. A technical assistant may still be required to monitor and correct poor fixation and to ensure the instrument is performing normally, but all of the clinical decisions made throughout an examination are consistent.

2 The examination strategy is exactly defined and reproducible.

3 The computer allows flexibility of examination. If a more detailed analysis of a particular area of the visual field is required there is the potential to modify the programme accordingly.

4 Data storage, retrieval and analysis are possible given the correct soft-ware.

5 The excess computer capacity usually available can be used to give additional graphical information, thus aiding diagnosis, monitoring and analysis of variables such as reaction time of response.

6 A computerised perimeter will work without fatigue for an indefinite time and storage facilities are only limited with respect to time in accordance with the present level of technology employed.

The only major disadvantages of computerised automated perimeters are:

1 The cost both in terms of initial outlay and maintenance.

2 The risk of the instrument being rapidly out-dated and superceded.

These two considerations are becoming increasingly less of a problem as new technology becomes more widely applicable, thus reducing its cost and the manufacturers are becoming aware of the desire for soft-ware updating of their instruments.

2.3 Computer Assisted Perimetry (CAP)

At the outset of this research project there were relatively few commercially available computer assisted perimeters (Greve 1982). Of those that were available (Keltner and Johnson 1981a,b) there were even fewer which boasted a soft-ware capability enabling research studies as distinct from routine clinical testing. The Octopus Automated Perimeter was, and some would argue still is, the most advanced of the available CAPs. Since 1980 there has been a proliferation of commercially available CAPs, several of which rival the largest of the Octopus perimeters in terms of soft-ware capability (The Dicon 3000; The Humphrey Field Analyser; The Squid). It was, however, the Octopus Automated Perimeter that was available for this research and the following literature review will concern itself entirely with this instrument.

2.4 The Octopus Automated Perimeter

Fankhauser, Schmidt and their colleagues at the University of Bern started work in 1965 to design an automated perimeter based on extensive clinical and theoretical

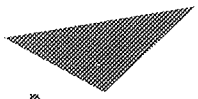
research. This resulted, in 1973; in a prototype model which was further developed, in conjunction with Interzeag, into a commercially available instrument which was launched at the International Perimetric Association meeting in Tubingen in 1976, and called the Octopus Automated Perimeter.

The currently available model consists of two main units, the perimetric unit consisting of perimetric cupola and patients seating; and the control unit consisting of a microprocessor, floppy disc drive and rotatable monitor for fixation control (Figure 2.1).

An Intel 808 microcomputer is used with a 32k bytes RAM, 2k PROM memory and a twin IBM dual floppy disc memory store of 256k bytes a discette. For printing the data a Qume Sprint 5 daisy-wheel printer is used with special characters for displaying the visual field data.

The perimetric cupola is a matt white surfaced bowl of 50cm radius thus enabling a larger projection of the visual field than the traditional 33cm cupola of the Goldmann Perimeter. The cupola is evenly illuminated by a light source at the top of the bowl which is screened from the patients. This background luminance is calibrated, monitored and automatically adjusted by the microprocessor.

A background adaptation level in the lower photopic range of 1.27 cdm^{-2} (4 asb) is chosen to give a greater dynamic



Aston University

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range compared to the higher photopic level of the Goldmann Perimeter of 10.3 cdm^{-2} (31.5 asb) (Fankhauser and Bebie 1979).

The stimulus is projected onto the cupola via a light beam and rotating mirror system placed above the patient's head. The maximum stimulus luminance is 318 cdm^{-2} (1000 asb), the stimulus intensity being varied by six sets of neutral density filters giving a range from 1-51dB. An electro-mechanical shutter controls the stimulus exposure of 100 msec with a rise and fall time of 10 msec.

The projected stimulus areas are based upon the Goldmann targets giving an angular subtense of 0.054^{o} (0), 0.108^{o} (I), 0.216^{o} (II), 0.431^{o} (III), 0.862^{o} (IV) and 1.724^{o} (V).

For a normal routine investigation a fixation light is positioned at the centre of the bowl. For subjects with central scotomata or further measurement of macular thresholds there is a ring projector giving four possible alternative fixation aids. There are three circular rings of 5^{o}, 10^{o} and 20^{o} and four points on a 3^{o} circle. Fixation is also monitored using an infra-red sensitive TV camera giving a 6 x magnification of the eye on a swivelling monitor on the control desk. It is also possible to automatically monitor eye closure on stimulus presentation.

The patient is alterted to the possibility of stimulus presentation by a "click". The attention is monitored by introducing 5% of false positive stimuli, providing no stimulus when one is expected, and 5% false negative stimuli.

The inter-stimulus interval is continually monitored and adjusted for each subject by measuring the preceding eight reaction times which is then doubled with the addition of random variable time.

In the final print-out an assessment of patient reliability is given by the number of false positive and false negative responses and threshold fluctuation from true threshold fluctuations.

2.4.1 Test Strategies

The Octopus attempts to find the minimum stimulus intensity required to produce a "seen" response from the subject, ie. the threshold intensity. This threshold response is described as the luminance at which the target is perceived with a 50% probability. In order to raise the probability of a seen response from 16% to 84% the stimulus luminance has to be raised by a factor of c.2 to 4 (Fankhauser and Bebie 1979) thus to give a reliable estimate of the 50% threshold level a large number of stimulus presentations would theoretically be required.

The frequency-of-seeing-curve for a subject, valid at a specific retinal point, as a function of the logarithm S of the stimulus luminance represents the probability p(S) of perception. All other parameters such as target size, duration of exposure and background illumination are constant. p(S) may be expressed as the cumulative normal distribution.

$$p(S) = \int_{\infty}^{S} dS' \frac{1}{R\sqrt{2\Pi}^{\epsilon}} \qquad -\frac{(S' - S_o)^2}{2R^2}$$

where S_o = threshold stimulus, ie. that stimulus which is perceived with the probability p=0.5(p(So)=$\frac{1}{2}$), and R = the increase of the stimulus above threshold that is required to make the probability of perception almost one (see Figure 2.2) (Bebie et al. 1976).

To arrive at a level of accuracy which is acceptable, (2dB within a reasonable time of observation according to Bebie, Fankhauser and Spahr (1976a,b)) and which is clinically acceptable, a number of measurements must be taken and interpreted. This may however, lead to an extensive examination time resulting in patient fatigue. Haider and Dixon (1961) stated that the visual differential threshold rises between the 2nd and 10th minute then steadily deteriorates. This was attributed to a fatigue decrement of a central state of alertness. On repeated examinations, however, experience tended to mask the

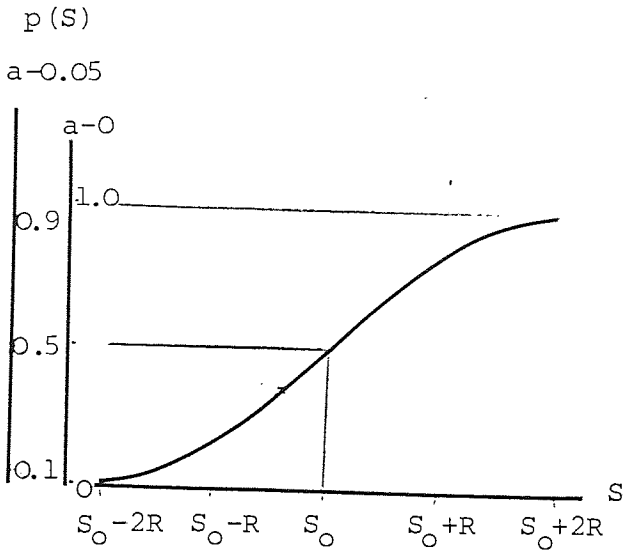


FIGURE 2.2 The psychometric function

S : the logarithm of stimulus luminance

S_o : threshold

p(S) : detection probability (after Fankhauser and Bebie 1976)

fatigue effect and led to a change in the criterion of judgement.

The optimal strategy will have a maximal information gain per target presented and a minimum standard deviation (SD) (Spahr 1975). To achieve a close approximation to this there must be:

1 previous knowledge of the luminance sensitivity distribution over the retina,

2 previous knowledge of the patient's reliability, ie. magnitude and frequency of fluctuations and mistakes

The reliability of the patient's response has a substantial influence on information gain and on the accuracy of the result, the presentation pattern being less critical (Spahr 1975).

The Octopus presents its targets at random so that the location and intensity are not predictable. Each test location is presented with a target between 4 and 7 times before the threshold is determined.

To achieve an adequate test logic the "staircase" method of presentation is employed. An initial stimulus value is presented and is reported as being "seen" or "not seen". When that point is then retested there is a choice:

1 If "not seen" the luminance will be increased by amount Δ until the stimulus is seen. The stimulus is then reduced by Δ until it is "not seen"

2 If "seen" the luminance will be decreased by amount Δ until the stimulus is "not seen". The stimulus is then increased by Δ until it is "seen".

If Δ was a very small value, eg. 1dB, a very accurate threshold may be expected, but unless the initial presentation was very close to the threshold it would take an undesirable length of time to assess the threshold. Heijl (1977) found that an increased examination time gave a decrease in contrast sensitivity. Over a half-hour period the mean threshold increment for a normal eye was found to be $<$ 1.5dB but may be 6-10dB in pathological cases.

Bebie et al. (1976) concluded that the "staircase" strategy gave a good "schematic approximation" of the optimal strategy described by Spahr (1975). They concluded that "the gain of information per response is percentually only slightly below that of the optimal strategy. The accuracy of single threshold determinations in both cases being almost identical".

In practical terms the Octopus has adopted a 4-2-1dB

step strategy resulting in a threshold measurement to a single dB step, thus shortening the examination time. The real measurement accuracy, or reproducibility, is between 1 and 3dB depending on the patient. The RMS Fluctuations (Global Fluctuations) value is printed with each examination and gives an estimate of the reproducibility.

2.4.2 Fluctuations

The variation in patient response may be divided into short term fluctuations, ie. variation in response during the examination, and long term fluctuations, affecting the results obtained when comparing subsequent examinations.

Bebie et al. (1976) calculated that the RMS value for short term fluctuations over a 15 minute period should account for ½-1dB for the Octopus perimeter. Long term fluctuations are composed of two parts; the first is independent of retinal location and affects the threshold of all points; the second is statistically independent for all points tested in the visual field. Their effect is variable depending on the length of time between each examination and the pathological change found if any. With both the short and long term fluctuations acting together in this way a change of up to 4dB may be considered acceptable and may be reversible on subsequent examinations.

Long term fluctuations are only important when monitoring the progress of any pathological or suspect pathological visual field changes. Short term fluctuations, however, can be used to assess the reliability of any examination. The Octopus calculates an RMS value for fluctuations by taking two separate threshold measurements at 10 points in the field.

This value was carefully calculated by Bebie et al. (1976) to achieve an accuracy of $\pm$ 25% which they consider reliable enough to allow a partition into three classes:

Fluctuation R.M.S. 1.5dB = small threshold fluctuation
1.5-3.0dB = average threshold fluctuation
3.0dB = large threshold fluctuation

The smaller the RMS fluctuation value the more consistent the patient response. This may consequently be used as the criterion by which to assess the reliability of results. If the value is low the reliability of the results should be good since the patient has successfully maintained concentration. It is important to remember that no matter how accomplished the strategy an accurate result still demands full patient concentration.

2.4.3 Background Luminance and Target Size

i) Historical Background

The background luminance must fulfil certain requirements

regarding level, uniformity, constancy and measurability. The level of background luminance determines the adaptation level of the eye. Blair (1940) was the first to realise the importance of this during the examination of the visual field. He recommended a value of 0.01 mL for topographic investigation as at this mesopic level rods and cones are stimulated approximately equally. He argued that (after Greve 1973):

1 The "reduced illumination" applied to both the background luminance and the luminance of the stimulus. The ratio $L/\Delta L$ is larger at the mesopic level than the photopic level therefore the object luminance will be nearer to the threshold at the mesopic level.

2 At this adaptation level the sensitivity curve is relatively flat, ie. the central area is relatively isoliminal. For the methods of examination in use at that time this was extremely advantageous as it meant that any given eccentricity the visual field could be examined by a single kinetic stimulus.

3 At this adaptation level the effect of ametropia on the light difference sensitivity is less marked than at higher adaptation levels.

4 In a comparative study of photopic and mesopic campimetry, Bair (1940) considered that he had shown the latter to be more sensitive.

Work by various researchers has shown that the determination of threshold levels depends upon several variables, eg. retinal adaptation, determined by background luminance, and stimulus size. To relate background luminance directly to retinal adaptation, however, the patient must be fully adapted before the examination begins. Greve (1973) suggests an adaptation time of 5-10 minutes for photopic levels and at least 30 minutes for scotopic levels.

Sloan (1950) demonstrated the variation in the threshold gradient for a stimulus seen in different areas of the visual field in the dark adapted and partially light adapted eye. Harms (1952) demonstrated an increase in the general sensitivity when background luminance was reduced from 10 to 1mL.

Bedwell and Obstfeld (1972) found that when using different target sizes the spacing between successive isopters tended to decrease with increasing background luminance. On examining these sensitivity gradients it was found that for a linear increase in stimulus eccentricity there was a linear relationship for neutral density filter units required to obtain threshold, thus indicating a logarithmic relationship between eccentricity and stimulus luminance.

This relationship tends to be more stable along the horizontal nasal meridian. Bedwell (1972) used this meridian to investigate the effects of retinal adaptation on stimulus luminance and eccentricity for stimuli subtending 12' and 24' of arc at the eye using background luminance levels of 1.0mL, 0.5mL and 0.1mL. He found the 0.1mL level gave a flatter sensitivity gradient. Fankhauser (1979) stated that low adaptation levels increased the dynamic range of stimuli luminance over which threshold sensitivity could be determined. Rose (1977) took this a step further by using an adaptation level well into the mesopic range and found an increased dynamic range but only at the expense of increased photon noise giving a poorer signal to noise ratio and making threshold determinations more difficult.

Background luminance also affects pupil size. Fankhauser (1979) and Bedwell and Davies (1976) investigated the effect of pupil size on the Octopus Perimeter and Friedmann Visual Field Analyser respectively. Using drug induced miosis and mydriasis Fankhauser found differences of 0.5 to 1dB while Bedwell and Davies found a maximal difference of 1.4dB. Both concluded that this is negligible as background illumination changes will produce only a fraction of this maximal effect.

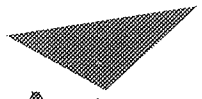
Fankhauser and Bebie (1979) investigated the influence of target size and intensity. It is often found that perimetrists will investigate the visual field with the

smallest target possible thus, in a changing field, plotting several different isopters. One would expect that the smaller the target the smaller the resolution therefore the smaller the scotomata that may be investigated. The authors found that the detectability of absolute defects in static perimetry with a target subtending 0.2^{o} at the eye is very poor and still worse or hopeless for relative defects. They concluded that a target subtending 0.2^{o} served no purpose.

Due to spatial summation occurring in the ganglion cell layer of the retina a small stimulus of a given threshold luminance has less stimulating power than a larger stimulus of the same luminance (Sloan 1962). It is well established that spatial summation is greater in the peripheral retina (Sloan 1960; Fankhauser 1979).

If the stimulus size is increased from Goldmann I (0.11^{o}) to Goldmann III (0.43^{o}) the threshold value is decreased and the dynamic range is increased. Fankhauser and Bebie (1979) calculated that for a background luminance of 1.27 cdm^{-2} at an eccentricity of 50^{o} the dynamic range is increased by 12dB, whereas at fixation the gain is about 3-4dB as spatial summation is less.

The larger target size also has the ability to minimise the effect of blur. Sloan (1960) demonstrated that a target subtending 0.43^{o} or greater is virtually unaffected up to three dioptres of blur even in the central visual



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field where the effects are generally more pronounced. Fankhauser (1979) does however suggest the use of a relevant working distance related correction for the central 30^{o} when using the Octopus although little work has yet been carried out to validify this strategy.

In conclusion the combination of a relatively low background illumination of 1.27 cdm^{-2} and a "standard" target size of 0.431^{o} subtended at the eye results in a greatly increased dynamic range.

ii) The Octopus Automated Perimeter

The Octopus Automated Perimeter employs a standard background luminance of 1.27 cdm^{-2} (4asb) which is supplied by a 20 watt halogen bulb. The supply is automatically monitored and corrected for luminous intensity by the micro-processor via a power driven iris diaphragm both before and during each examination. Uniform illumination is easily achieved in accordance with the principle of Ulbricht's Sphere.

The target sizes used by the perimeter are identical to the full range of Goldmann targets. The stimulus light source is a 50 watt halogen incandescent lamp with a maximum intensity of 1000 asb. The intensity is monitored and adjusted automatically to a reproducibility of $\pm$10% ($\pm$0.5dB). The light intensity is selected using a series of six neutral density filters which are positioned

in the light beam by an electromagnetic system. The transmission factors are

Filter 1	79.4% ± 1%	(1dB)
Filter 2	63.1% ± 1%	(1dB)
Filter 3	39.8% ± 0.5%	(4dB)
Filter 4	15.8% ± 0.5%	(8dB)
Filter 5	2.5% ± 0.1%	(16dB)
Filter 6	1.0% ± 0.1%	(20dB)

In combination this allows for a range of 52 1dB steps from OdB to 51dB.

2.4.4 The Effects of Stray Light

When a target is presented by projection onto the inside of a cupola, there is a tendency for the "target light" to spread, ie. there is not a vertical " cut-off". This is known as Stray Light and may effectively change the angular subtense of the target at the eye. Fankhauser and Haeberlin (1980) used a Spectra Pritchard Photometer to examine light diffusion beyond the boundaries of the test targets on the Octopus Perimeter.

They found that all the Goldmann O-5 targets gave similar stray light characteristics. This effect is mainly due to the optical imaging system employed with only a small part due to diffusion from the surface of the cupola. The effect is enhanced, however, by the

stray light generating properties of the dioptric media.

The authors used the "blind spot" of two subjects to represent a model scotoma and were able to conclude that:

1 The dynamic range is limited by the falsifying effect of stray light. When the target intensity is high the resolution will be reduced. Efforts to increase maximum target luminance are therefore wasted unless applied to more extensive areas of heavy visual field loss as they will otherwise lead to falsification of results.

2 The disturbing effect of stray light, providing the same dynamic range is maintained, is independent of the background luminance and depends only upon the stray light generating properties of the illuminated area.

The stray light problem only really exists in areas of reduced sensitivity where high target intensities are required. Its effect is to produce false negative results, ie. scotomata may be missed.

2.4.5 Presentation Time

The Octopus Automated Perimeter uses an electro-magnetic shutter which is controlled by the microprocessor to present each target for 100 msec. The rise and fall time

of each presentation is less than 10 msec with the total exposure time being reproducible to ±5%.

The short presentation time has a number of advantages (after Fankhauser 1979).

1 It is not possible for the patients to direct their gaze to the place where the stimulus appears. The latent period for eye movements is c.150 msec.

2 To maintain a stable retinal image the eye is constantly "tremoring" at c.50Hz when fixating. Greve (1973) stated that as long as the movement is smaller than the area in which total spatial summation takes place the movement will not influence the threshold recorded. With larger presentation times, however, the image will pass over a relatively large area of retina giving a result which would be lower than the true threshold.

3 The total examination time will be reduced for a short presentation time.

The Octopus employs a suitably short presentation time to take advantage of the above points. There is no advantage in extending the presentation time.

2.4.6 Signal Rate

Jenkins (1958) performed a number of experiments in order to assess patient performance levels. He concluded that:

1 Low presentation rates were accompanied by a higher percentage of false positive answers.

2 The latency of the response increased with the time of the examination.

3 The introduction of frequenct brief interr-uptions improved the patient's performance and reduced the latency of response.

In accordance with these observations the Octopus perimeter has a flexible signal rate. The interstimulus period is continually adjusted by summating the previous eight reaction times, doubling them and adding a random time to each. The range possible is between 1 and 3 seconds with the starting period being 2 seconds. It is also possible, with particularly difficult patients to interrupt the programme and select a fixed signal rate between 1 and 3 seconds (with a choice in 0.5 second steps), or a random signal rate not deduced from the previous patient responses.

To maintain patient concentration over longer periods of time than the optimum generally considered feasible (Haidler and Dixon 1961) the Octopus cues the patient before a stimulus is presented.

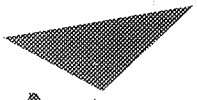
A mechanical "scraping" noise begins 0.5 seconds before the stimulus, ending with the "click" of the shutter. It is important, however, to inform the patient that a target will not always be seen. The mechanism is also used to assess the number of false negative and false positive results.

In accordance with Jenkins's(1958) observations with regard to frequent brief interruptions it is possible for the patient to rest at any time during the examination by depressing the response button.

2.4.7 Range of Programmes

It is not intended to detail the exact specification of all available programmes. The reader is referred to the Interzeag Operator Manual (1980) for further detail.

The standard Octo discette provided with the perimeter gives an extensive range of prepared visual field investigation programmes. The 19 available programmes (see Figure 2.5) range from full-field investigation to specialised neurological or blind-spot programmes. The investigation time varies between 5 and 20 minutes per



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eye. Some of the programmes offer a two stage analysis of a particular area of the visual field with the normal, high accuracy mean threshold determinations and a fast version reducing examination time by c50%. The computer analyses the normal local threshold values for the age-group of the particular patient and accepts them as being normal, only undertaking the "staircase" threshold strategy on points lying outside this limit.

New soft-ware is being developed continually but only two packages are presently available at the Birmingham and Midland Eye Hospital and therefore relevant to this report.

I Sargon

The Sargon programme allows the operator to specify test locations at will within a 60^{o} field. Up to 66 test locations may be specified in each user defined programme, with a maximum resolution of 0.2^{o}. Eighty user-defined self created programmes may be stored on the Sargon diskette at any one time. Strategies are "normal" or "fast" as with Octo. There are a limited number of printouts available compared to the Octo programmes (see Appendix).

II Delta

The Delta programme does not execute an examination but

statistically analyses the results of other progammes. It collects the results of an examination to create a Database which is analysed to decide whether or not the assumption can be made that:

(a) there is a deviation of an individual master field from the normal or

(b) there is a trend in a series of examinations performed on different occasions. (After Bebie and Fankhauser 1981).

The programme also tests changes in the visual field as a function of time for their statistical significance. Delta will characterise between one and six fields as to:

1 The size of the disturbed area in %

2 The total loss in dB for the field as a whole, and

3 The total loss in dB per examination per mean number of disturbed points (after Gloor et al. 1980).

2.5 The Validation of the Octopus Automated Perimeter

2.5.1 Introduction

In recent years there has been a proliferation of Computer Assisted Perimeters (CAPs) and Semi-Automated Perimeters (SP). This has resulted in the availability of a much wider range of test logics for the assessment of the visual field. The importance of assessing the performance of such instrumentation and the test logics they now provide, has been stressed by many authors (comprehensive references are given by Greve 1982).

The Octopus Automated Perimeter, as used in this study, has been compared to other CAPs such as the Fieldmaster (Dannheim 1979; Neuhann and Greite 1980); the Competer and the Perimetron (Heijl and Drance 1980); and the Peristat (Dannheim 1979). Comparisons have also been made with manual instruments such as the Goldmann and/or Tubinger perimeters (Li, Spaeth, Scimeca, Shatz and Savino 1979; Kampik, Lund and Greit 1979; McCrory and Faignon 1979; Schmied 1980; Krieglstein, Schrems, Gramer and Leydhecker 1981; Heijl and Drance 1981). In general, these studies have evaluated the performance of a specific Octopus programme on a particular diagnostic group such as glaucoma or neurological disorders. It was felt that our own evaluation of the Octopus was necessary for three reasons:

I The stimulus parameters to be used to elicit the Visual Evoked Potential employ a maximum field presentation extending to an eccentricity of 15^{o}. There are several instruments available to the author which can be adapted to give differential threshold measurements over this area. It was therefore considered necessary to investigate any advantages which may be gained by using the Octopus in preference to these instruments, particularly the Friedmann Visual Field Analyser Mark II. No clinical evaluation of the Octopus have been discovered which compare it to instruments of this type.

II The Octopus has two standard programmes available which cover the central 30^{o} of the visual field but with differing spatial target resolutions. It was considered necessary to evaluate whether or not there would be any advantage in using either one of these programmes compared to the other.

III The aim of this thesis was to investigate various different types of visual field abnormality. It was therefore considered important to evaluate the Octopus over a large range of abnormalities.

Consequently, it was decided to use the Goldmann Bowl Perimeter, the Bjerrum Screen, the Friedmann VFAs Mark I and II, and the Octopus Automated Perimeter programme 31 and 21, on a patient sample incorporating as many different abnormalities as possible.

2.5.2 Method

The sample consisted of 75 patients (75 eyes) from the Retina Department of the Birmingham and Midland Eye Hospital. The patients were all volunteers and participated in the study following a request contained in a formal letter. The desired number of abnormal subjects was achieved by approaching 250 (approximately) patients all of whom were known to exhibit varying levels of field loss. The sample contained 10 subjects with no known history or symptoms of either visual or neurological disorders. Individuals younger than 5 or older than 80 years of age, those with a poor record of attendance, those likely to require transportation by ambulance and those residing more than 25 miles from the hospital were excluded from the study. The appropriate administrative procedures were undertaken by a single clinician. Confirmation of diagnosis and the eye designated for visual field investigation was determined by a second clinician. The resultant sample comprised 35 males and 40 females with a mean age of 39.5 years (range 10.0 - 69.5 years). The diagnostic categories are given in Table 1.1.

Each of the five instruments was operated by a single experienced clinician and a double blind protocol was followed throughout the study. The full field (Programme 21) Octopus and the Goldmann perimeter were performed at the Birmingham and Midland Eye Hospital on a single occasion. The Bjerrum and VFA Mk 1 and Mk II examinations

TABLE 2.1

THE DIAGNOSTIC CATEGORIES OF THE 75 PATIENTS IN THE SAMPLE

Retinitis Pigmentosa	8
Hereditary Optic Atrophy	5
Optic Atrophy (with various related conditions)	4
Ischaemic Optic Neuropathy	3
Papilloedema	2
Papillitis	2
Intracranial Hypertension	1
Angioma of Optic Nerve	1
Optic Nerve Lesion	1
Periorbital Abscess	1
Orbital Pseudo Tumour	1
Retro-bulbar Neuritis	1
Demyelination	2
Vascular Insufficiency	1
Glaucoma	9
West Indian Amblyopia	1
Anisometropic Amblyopia	1
Macular Degeneration	3
Stargardt's Macular Dystrophy	1
Vitelliform Macular Dystrophy	1
Ethambutol Toxicity	1
Homonymous Hemianopia	1
Homonymous Quadranatanopia	1
Pituitary Tumour (including erosion of pituitary and Acromegaly)	9
Posterior Vitreous Detachment	1
Trauma	2
Unknown Aetiology	1
Normal	10

were undertaken on a second occasion at the University of Aston. The detailed Octopus investigation (Programme 31) was performed on a third occasion. The sequence of the two initial sessions and the order of examination within each session were both randomized. All patients were refracted prior to the initial examination and wore the appropriate near vision correction for each instrument. The examination of each individual patient was completed within a maximum period of three weeks.

The Octopus programmes were used with target size 3 (0.431^{o}). The bowl luminance was 3.15 asb.

The Goldmann investigation comprised kinetic isopters III4, I4 and I2 plotted consecutively in a clockwise manner every 15^{o} up to fixation. The examiner had free range to investigate the blind spot and any field loss encountered. In cases where the III4 target could not be detected the IV5 isopter was plotted. The bowl luminance was 31.5 asb.

The Bjerrum screen examination employed a similar routine to that of the Goldmann investigation. The 3/1000 white isopter was plotted initially followed by that for the 1/1000w. The 5/1000w and 10/1000w isopters were plotted in cases where the 3mm target could not be seen. The screen illuminance was standardised at the recommended level of 75 lux.

The Friedmann VFA Mk.I and Mk.II were used according to the normative age setting. The screen illuminance was 11 and 14 lux respectively. A sample of 16 patients, the majority of whom exhibited either a normal field or minimal levels of field loss, were subsequently re-examined on a further occasion using the threshold technique of Greve (1971) in which two out of three correctly identified presentation were designated as 'seen'.

The Octopus results were considered abnormal if two or more adjacent points were greater than 2.5x, or any single point 10x, the R.M.S. fluctuation below the normative values. The test location closest to the blind spot nasally and on line with fixation was ignored for the purposes of analysis as this point was frequently found to be within the normal blind spot.

The Goldmann results were considered abnormal if there was a contraction or depression of the peripheral isopter of $\geqslant 10^{o}$, a central scotoma of $\geqslant 5^{o}$ or a mapped scotoma.

The Bjerrum screen results were considered abnormal if there was a contraction or constriction of $\geqslant 5^{o}$ or a mapped scotoma.

The Friedmann VFA results were considered abnormal if a point was 0.4 log units below the specified manufacturers' normative age values (Friedmann 1966). The test location M for the VFA Mk. II, immediately inferior to the blind spot of the right eye, was ignored for the

purposes of analysis as this point was frequently found to be within the normal blind spot.

The field plots for each instrument were designated as either abnormal or normal by the appropriate clinician in isolation.

The visual field loss is considered in terms of type, shape, area, depth and location. The analysis is undertaken at four separate levels. The first two levels evaluate the diagnostic potential of each instrument in isolation whilst the third and fourth levels compare the results of each instrument relative to the others in the study. Following tabulation of the data, this system enables a between-instrument evaluation across any of the four levels of analysis and a within-instrument evaluation at any single level. Thus, any given instrument can be evaluated in isolation or in comparison with any number of instruments in the group.

The first level determines whether the visual field is considered abnormal for each instrument according to the established criterion of abnormality for that instrument. The second level considers whether the visual field result obtained for each instrument is consistent with the diagnosis of a patient's condition (Figure 2.6).

The third level considers whether the visual fields for each individual patient are compatible with one another.

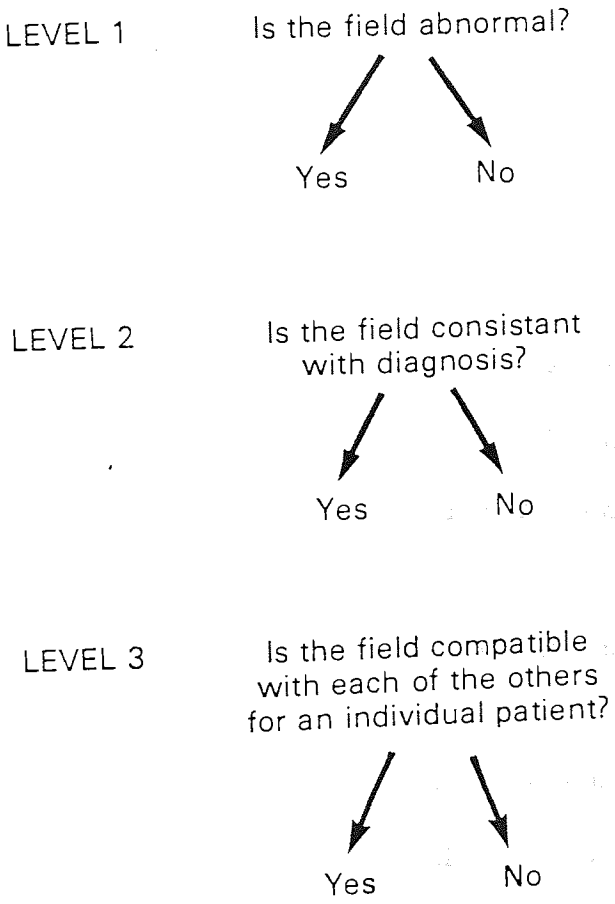


FIGURE 2.6 The first three levels of the scoring system

This is important as it is possible to have a series of results which are all abnormal, all consistent with the diagnosis and yet display loss in different areas of the visual field.

The fourth level of analysis is considerably more complex. The results are compared to one instrument, acting as the reference. Each visual field result is judged to be either compatible or incompatible when compared to the reference field. This process is then repeated with each instrument, in turn, providing the reference field. If the reference and comparison fields are considered compatible then the comparison field is scored as to whether it possesses:

(i) more visual field loss (Score I+)

(ii) a similar degree of field loss (Score I)

or (iii) less visual field loss (Score I-)

relative to the reference field (Figure 2.7).

If, however, the two fields are considered to be incompatible and the reference field is abnormal, then the comparison field is scored as to whether it is:

(i) abnormal but exhibits a different field loss (Score II)

or (ii) normal (Score III)

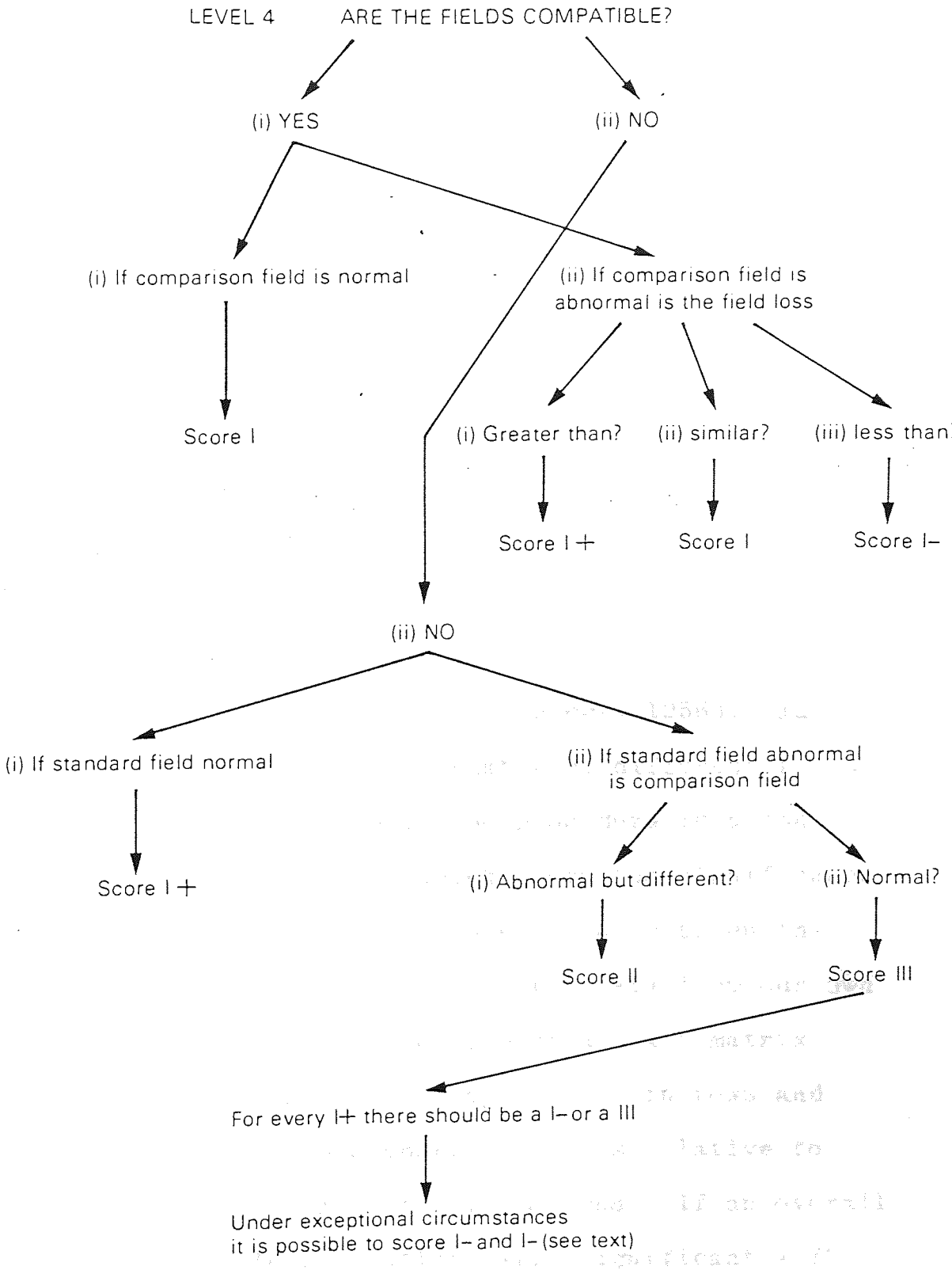


FIGURE 2.7 Level 4 of the scoring system

If the reference field is normal then the comparison field is either abnormal scoring a I+ or normal scoring a I.

Finally, a combination may occur where both the reference and comparison fields are considered compatible yet have areas exhibiting different visual field loss, eg. instrument one records a paracentral scotoma with a contraction in the superior nasal quadrant whilst instrument two records the same paracentral scotoma with a contraction in the superior temporal quadrant. Given such unusual circumstances, the two visual fields score I- when either is designated as the reference field. An example of the Level 4 scoring is given in Figure 2.8.

The results are appropriate for analysis by a Chi-square (X^2) test for K independent samples (Siegel 1956). In this instance, K represents the number of different field plots or instruments employed. The procedure is a non-parametric statistical method which tests the significance of differences in visual field scores found between instruments. For example, at level 4, the data from our own study would be tabulated in the form of a 5 x 5 matrix with the individual instruments represented in rows and the scoring levels of the comparison fields relative to the reference field, represented in columns. If an overall difference is found to be statistically significant a X^2 test for two independent samples, using a 2 x 5 matrix, can be applied to test for significant differences between any two of the 5 samples relative to the chosen reference field.

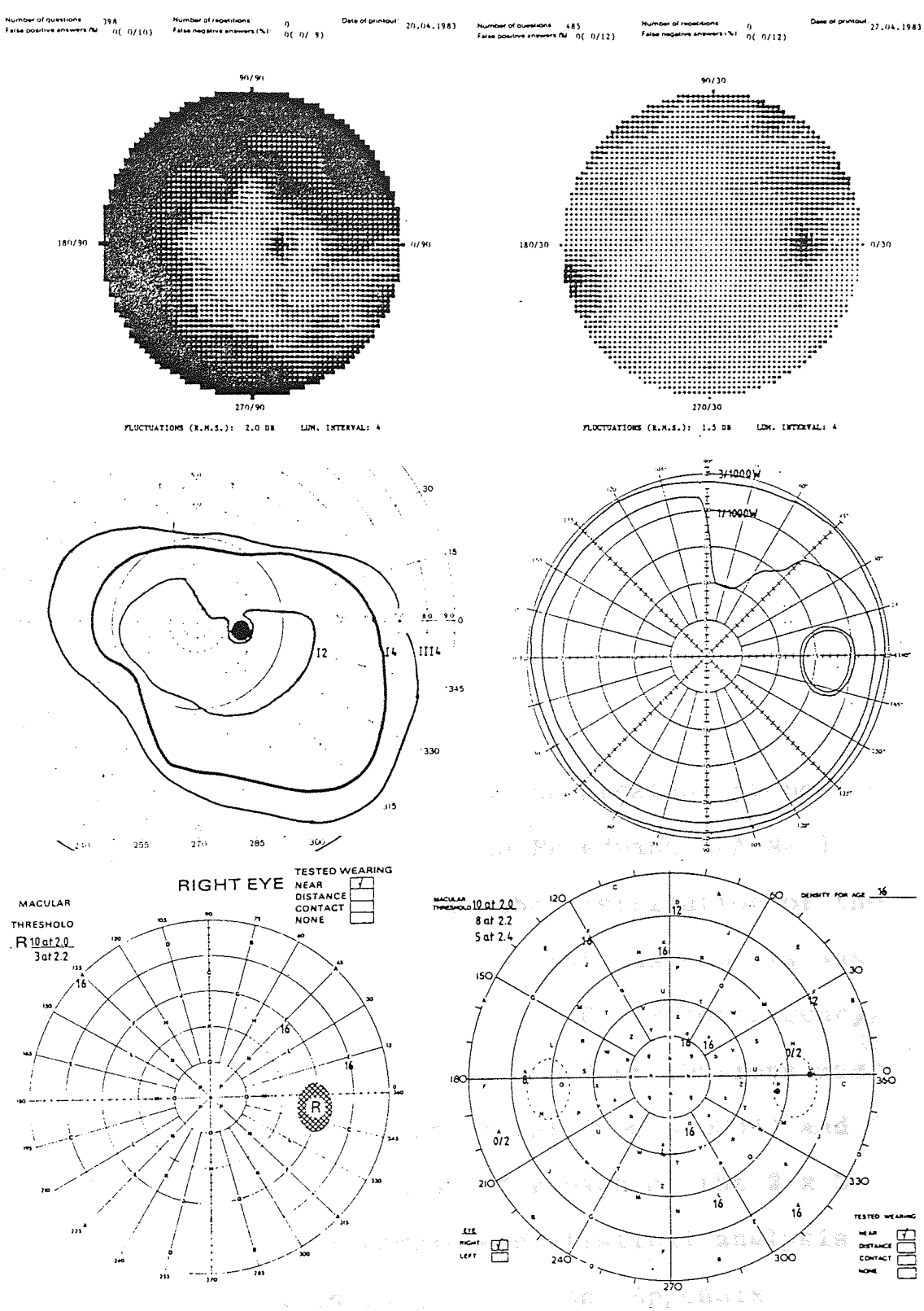


FIGURE 2.8 Example of level 4 scoring for a patient with suspected chiasmal lesion, Programme 21 as reference (top left). Programme 31 (top right) scored as category I; Goldmann (middle left) as I; Bjerrum (middle right) as I-; VFA Mk I (bottom left) as III; VFA Mk II (bottom right) as II

2.5.3 Results

Five patients failed to complete all of the six investigations. The results for the remaining 70 patients were considered in terms of the four level analysis.

Level 1

The results of the first level are given in Table 2.2. This illustrates the incidence of abnormal and normal fields detected by each of the six investigations and is based upon the criteria for abnormality detailed previously. The results represent the incidence of abnormal and normal field plots and are not considered in relation to the clinical diagnosis.

The Octopus Programme 21 detected the greatest proportion of abnormal fields (67) whilst the Friedmann VFA Mk 1 recorded the least number (52). The distribution of the visual field status between each of the instruments was analysed using a X^2 test based upon a 6 x 2 contingency table. The overall difference in the distributions was found to be statistically significant ($p < 0.0034$) and further analysis was carried out for each of the 2 x 2 contingency tables. The complete statistical analysis for each of the 4 levels is given in the Appendix.

It was recognized that the 2 x 2 samples were not independent of the overall 6 x 2 sample. Indication of the relative differences between the various distributions

TABLE 2.2

The frequency of abnormal and normal fields detected by the six test strategies (Level 1 analyis)

TEST REGIME	CATEGORY OF FIELD AND NUMBER OF PATIENTS	
	Abnormal	Normal
Programme 21	67	3
Programme 31	61	9
Goldmann	58	12
Bjerrum	64	6
Friedmann VFA Mk. 1	52	18
Friedmann VFA Mk.11	55	15

$X^2 = 17.64$; degrees of freedom = 5; two tailed probability $p < 0.0034$

is therefore provided by the ranked order of the significance levels rather than by the actual values themselves. This form of analysis and interpretation of the associated significance levels was adopted for all the subsequent scoring levels.

Statistically significant differences were found between the results for Programme 21 and those for both the VFA Mk I, VFA Mk II and the Goldmann ($p < 0.004$, $p < 0.0024$ and $p < 0.014$ respectively). Further inspection of the data, however, revealed that Programme 21 recorded 7 of the 9 normal subjects to be abnormal (Table 2.3). The results closest to the expected distribution were those obtained from the Goldmann (58 from a possible total of 61 abnormal fields and 9 out of 9 normal fields) and the detailed Octopus programme (58 and 6 respectively).

In 3 of the 9 subjects with an expected normal field, the results from the majority of the instruments clearly showed an abnormality which was not detected by the Goldmann. When these findings are taken into account, the Goldmann would appear to have performed less well than Programme 31.

Level 2

The results for the second level of analysis are given in Table 2.4. This illustrates the number of field plots for each instrument considered to be consistent with diagnosis. The score closest to the ideal distribution of 70 is

TABLE 2.3

The frequency of abnormal and normal fields detected by the six test strategies considered in relation to the category of patient.
(Level 1 analysis)

TEST REGIME	Visual field designated as abnormal		Visual field designated as normal	
	Abnormal Patients	Normal Patients	Abnormal Patients	Normal Patients
Programme 21	60	7	1	2
Programme 31	58	3	3	6
Goldmann	58	0	3	9
Bjerrum	58	6	3	3
Friedmann VFA Mk I	50	2	11	7
Friedmann VFA Mk II	51	4	10	5

TEST REGIME	Visual field designated as abnormal		Visual field designated as normal	
	Abnormal Patients	Normal Patients	Abnormal Patients	Normal Patients
Programme 21	60	7	1	2
Programme 31	58	3	3	6
Goldmann	58	0	3	9
Bjerrum	58	6	3	3
Friedmann VFA Mk I	50	2	11	7
Friedmann VFA Mk II	51	4	10	5

TABLE 2.4

The frequency of field plots from the six test strategies scored in terms of consistency with diagnosis and considered in relation to the category of patient. (Level 2 analysis)

TEST REGIME	Visual field designated as consistent with diagnosis			Visual field designated as inconsistent with diagnosis		
	Abnormal Patients	Normal Patients	Total	Abnormal Patients	Normal Patients	Total
Programme 21	55	2	57	6	7	13
Programme 31	56	6	62	5	3	8
Goldmann	56	9	65	5	0	5
Bjerrum	54	3	57	7	6	13
Friedmann VFA Mk I	44	7	51	17	2	19
Friedmann VFA Mk II	48	5	53	13	4	17

$X^2 = 13.59$; (based upon 6 x 2 contingency table of total scores)

Degrees of freedom = 5; two tailed probability $p < 0.018$

demonstrated by the Goldmann whilst the poorest is given by the Friedmann VFA Mk I. The scores for the Goldmann are significantly better than those for Programme 21, the Bjerrum and both VFAs ($p<0.021$, $p<0.021$, $p<0.0008$, and $p<0.0026$ respectively).

Programme 31 also performs better than the two VFAs ($p<0.009$ and $p<0.016$). Further analysis reveals that both the Octopus strategies, the Goldmann and the Bjerrum yield almost identical scores for the abnormal plots consistent with diagnosis. Programme 21 and the Bjerrum, however, would seem to incorrectly classify a greater proportion of normal patients than either the Goldmann or the detailed programme. When the three anomalous normal cases, discussed earlier, are removed from the analysis the Goldmann and Programme 31 yield identical scores. Interestingly, of the 5 abnormal fields designated as inconsistent with diagnosis only 2 were common to both instruments.

Level 3

The results for the third level of analysis are given in Table 2.5. This illustrates the number of field plots for each instrument considered to be compatible with those derived from the other instruments, for a given patient. The closest to the ideal score of 70 is exhibited by Programme 31 whilst the poorest scores are shown by both VFAs. The appropriate X^2 analysis reveals that the score

TABLE 2.5

The frequency of field plots from each of the six test strategies scored in terms of compatability with the remaining plots derived from any given patient. (Level 3 analysis)

TEST REGIME	Number of fields considered to be consistent/inconsistent with the majority of the fields from any given patient	
	Consistent	Inconsistent
Programme 21	62	8
Programme 31	67	3
Goldmann	63	7
Bjerrum	57	13
Friedmann VFA Mk I	53	17
Friedmann VFA Mk II	53	17

$X^2 = 18.00$; degrees of freedom = 5;

two tailed probability $p<0.0029$

for Programme 31 is significantly better than the scores from the VFA Mk I ($p < 0.00035$), Mk II ($p < 0.00035$) and Bjerrum ($p < 0.004$). The Goldmann and Programme 21 also exhibit significantly better scores than the two VFAs but the magnitude of the significance level is considerably less than that for Programme 31. Neither the Goldmann nor Programme 21 show a significant difference when compared with the Bjerrum.

In 33 of the 70 patients, the fields from each of the six techniques were considered to be in complete agreement and 17 patients exhibited only one discordant result.

In one case no concordance was found among any of the six fields and was undoubtedly due to the poor responses from this particular patient.

Level 4

The fourth level describes the compatibility of each individual visual field from the various instruments, to that derived by the reference field.

Programme 21 as reference

The results for the five techniques, when compared to Programme 21 are given in Table 2.6. The major differences relative to Programme 21 are found between Programme 31 and the two VFAs (Table 2.6 rows 1 and 4 and rows 1 and 5). In particular, column 2 shows that in 42 cases

TABLE 2.6

The frequency of field plots from the 5 comparison strategies in each of the 5 scoring levels relative to the reference strategies.
(Octopus Programme 21)

TEST REGIME	Number of patients and scoring level for comparison field relative to reference field (Programme 21)				
	Compatible Information			Incompatible Information	
	1+	1	1-	II	III
	More	Similar	Less	Different Field Loss	Normal
Programme 31	9	42	10	3	6
Goldmann	8	31	16	4	11
Bjerrum	6	27	22	9	6
Friedmann VFA Mk I	4	17	20	14	15
Friedmann VFA Mk II	4	18	20	15	13

$X^2 = 44.27$; degrees of freedom = 16;

two tailed probability $p < 0.0002$

Programme 31 gave a highly compatible field to that of Programme 21 whilst a similar agreement was only found in 17 and 18 cases respectively with the VFA Mk I and Mk II.

The differences in compatibility between Programme 31 and each of the two VFAs, when compared to Programme 21, are highly significant ($p<0.00002$ and $p<0.00004$ respectively).

Programme 31 as reference

When compared to Programme 31 as reference (Table 2.7), the results for Programme 21 are very much better than either of the two VFAs and the differences between the distributions are highly significant ($p<0.000005$ and $p<0.00003$ respectively). The Goldmann also provides a closer agreement to Programme 31 than the VFA scores, although the differences between the distributions are much less significant than those corresponding to Programme 21 ($p<0.015$ and $p<0.04$ respectively).

Only the results concerning the two Octopus programmes are relevant to this thesis. A more detailed analysis is discussed by Flanagan, Wild, Barnes, Gilmartin, Goode and Crews (1984) and Wild, Flanagan, Barnes, Gilmartin, Goode and Crews (1984) (see Appendices). I am grateful to Dr J Wild, Mr D Barnes, Dr B Gilmartin and Mr P Goode for their assistance in performing the other visual field examinations and the analysis of the results. Thanks are also extended to Mr S J Crews for allowing us to

TABLE 2.7

The frequency of field plots from the 5 comparison strategies in each of the 5 scoring levels relative to the reference strategy.
(Octopus Programme 31).

Number of patients and scoring level for comparison field relative to reference field (Programme 31)

TEST REGIME	Compatible Information			Incompatible Information	
	1+	1	1-	II	III
	more	similar	less	Different field loss	Normal field
Programme 21	15	42	10	3	0
Goldmann	9	39	12	4	6
Bjerrum	9	35	13	10	3
Friedmann VFA Mk I	5	23	19	12	11
Friedmann VFA Mk II	6	24	19	11	10

$X^2 = 43.97$; degree of freedom = 16; two tailed probability $p < 0.0002$

approach his patients and for providing the patient diagnoses.

2.5.4 Discussion

Inspection of the first three levels of analysis reveals that the detailed Octopus programme was superior to all test logics at Levels 1 and 3 and identical to that of the Goldmann at Level 2. The validity of the Goldmann fields to the diagnosis may, however, break down as in some instances the prior diagnosis would undoubtedly have been made in conjunction with previous Goldmann plots. The Goldmann proved to be slightly superior to Programme 21 at Level 2 and similar at Level 3. A difference in the scores occurred at the first level due to the false classifications of the normal patients by Programme 21, and the abnormal patients by the Goldmann. The false classification of the patient by Programme 21 was also the explanation for the difference in the scores at Level 2.

A similar trend can be seen in the Level 4 analysis. Compared to Programme 21, Programme 31 ranks slightly better than the Goldmann which, in turn, is better than the Bjerrum which is better than either of the two VFAs. It might be argued, however, that evaluations of the scores from the Goldmann would be biased towards those from the full field Programme 21. When comparing

the central field plots with those of the peripheral field, however, great care was taken to ensure that only the central information was utilized. The superiority of Programme 31 arose because a surprisingly high proportion of the plots contained more peripheral loss than was evident in either the Bjerrum or the two VFA plots.

When compared to Programme 31, a similar trend is present in that the full field Octopus programme and the Goldmann are comparable but the former produced more information (1+ scores) than the latter. The Bjerrum again proved superior to either of the VFAs. It is interesting to note the similarity of the results from the two VFAs when compared to either Programme 21 or to Programme 31; the greater number of stimuli on the Mk II would appear to provide no further advantage here.

When compared to the Goldmann, Programme 31 is superior to Programme 21 in that it provides fewer 1+ scores and more I scores. It would appear, therefore, that Programme 21 gives a greater field loss when compared to either Programme 31 or to the Goldmann.

This observation could be explained by differences in the depth and/or area of field loss recorded by Programmes 21 and 31 was therefore undertaken by evaluating the difference between the points on the 4 cardinal meridians at 30^{o} eccentricity which were common to both programmes and which exhibited field loss. In the majority of cases,

there was no difference in the depth of the field loss between the two programmes indicating that the extra information recorded by Programme 21 resulted from a difference in area.

Both programmes exhibit a high proportion of 1+ scores when the Goldmann acts as reference but Programme 21 yields a greater score than Programme 31 in this respect. The extra information recorded by the two programmes is attributable to both a greater depth and area of field loss. These findings are in accord with the work of Korner, Fankhauser, Bebie and Spahr (1976) who reported a steeper sensitivity gradient and a more severe visual loss with Programme 21 when compared to the Goldmann and Tubinger. This conclusion can now be extended to Programme 31.

Further comparison of the Octopus data also reveals that the extrapolated central value for Programme 21 was repeatedly lower (less sensitive) than that for the measured central target of Programme 31 and also lower than the corresponding expected value from the normative data.

The VFAs were assessed at threshold for 16 patients exhibiting superficial field loss ($\leqslant$ 0.4 log units below the normative age value). It appeared that approximately half of these cases gave an improved result but any advantage gained was devalued by the excessive examination

time required. It was the observations related to examination time which provided the most surprising results of the study. Automated perimetry is frequently criticised on account of the time but in the majority of cases Programme 31 was quicker than all of the other techniques apart from the VFAs used with normative age settings.

A more detailed discussion of these results is available in Wild et al. (1984) (see Appendices).

2.5.5 Conclusions

Programme 21 exhibits a slightly greater loss than Programme 31. Both exhibit a deeper and greater area of loss when compared to the Goldmann. The peripheral information derived from Programme 21 and the Goldmann is more consistent with Programme 31 than with the VFAs. This would support the observation that the Octopus results produce a deeper field loss.

When considering a heterogenous patient sample, therefore, the Octopus Programme 31 would appear to give the most consistent and exacting assessment of the visual field. The VFA Mk II does not appear to justify further consideration and Programme 21 of the Octopus gives too high a level of false positive results.

2.6 Clinical Analysis

2.6.1 Introduction

The previous section discussed a hetereogenous sample of 75 patients. It was considered necessary to extend this analysis to investigate the possible variations which may arise in specific conditions or types of field loss. Programme 31 appeared superior in all aspects when the overall sample was considered. If, however, it performed particularly unsatisfactorily for a particular sub-group it is important, in terms of the thesis, that this is identified and compensated for.

2.6.2 Method

A detailed description of the sample and method used is given in the preceding section. The results, thus obtained, were then classified in terms of location of field loss using a system modified from that of Greve (1982). This classification is given in Table 2.8. The essential difference between Greve's classification and the one adopted in this study is that, due to the limited number of glaucomatous, central and hemianopic patient groups, the sub-classifications defining depth of loss have been omitted. In some cases, more than one area of field loss was present and therefore, the number of defects used in the analysis exceeds the number of patients in the study.

TABLE 2.8

Classification and number of field defects

for the 70 patients

Classification of Visual Field Defects	Number of Patients
Normal	9
General reduction of sensitivity (GRS)	16
Local reduction of sensitivity (LRS)	12
Glaucomatous visual field defects	8
Central island	4
Central defects	9
Miscellaneous paracentral defects inside 25^{o} eccentricity	4
Peripheral defects outside 25^{o} eccentricity	3
Blind spot defects	26
Hemianopic defects	9

Difficulty sometimes arose in the differentiation between general and local reduction in sensitivity. If the loss constituted the majority of the peripheral part of the field, it was designated as a general reduction. If an over-riding, deep, local reduction in sensitivity was present in conjunction with a general reduction in sensitivity, the field was designated as being a local reduction. In addition, some fields contained more than one area with a local reduction in sensitivity.

2.6.3 Results and Discussion

The results are illustrated in Figure 2.9 and are presented in terms of location and scoring for each instrument against the reference instrument.

1. Local Reduction in Sensitivity

When Programme 31 was used as the reference field, Programme 21 scored the greatest proportion in Category 1 (ie. 9 out of 12). No instrument scored highly in the 1+ category, but the Goldmann and VFAs all scored 4 out of 12 in the 1^- category. Both the VFA Mk I and Mk II gave 3 out of 12 normal results when compared to the abnormal Programme 31.

When Programme 21 was used as the reference, Programme 31 scored highly in the I category (9 and 8 out of 12

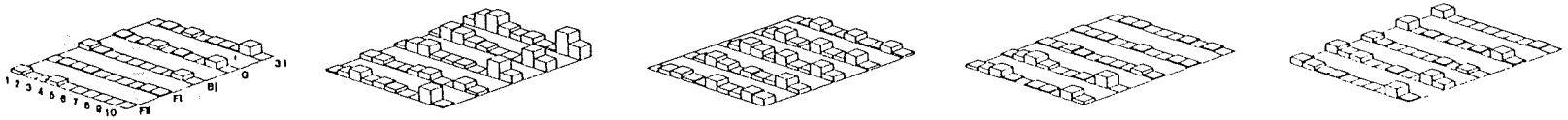
FIGURE 2.9

Category of field loss, test logic and frequency of level 4 score relative to the reference instrument (top Programme 21 as reference; middle Programme 31 as reference, bottom Goldmann as reference).

1 = normal, 2 = local reduction of sensitivity, 3 = general reduction of sensitivity, 4 = glaucomatous visual field defects, 5 = central island, 6 = central defects, 7 = miscellaneous paracentral defects inside 25^{o} eccentricity, 8 = peripheral defects outside 25^{o} eccentricity, 9 = blind spot defects, 10 = hemianopic defects

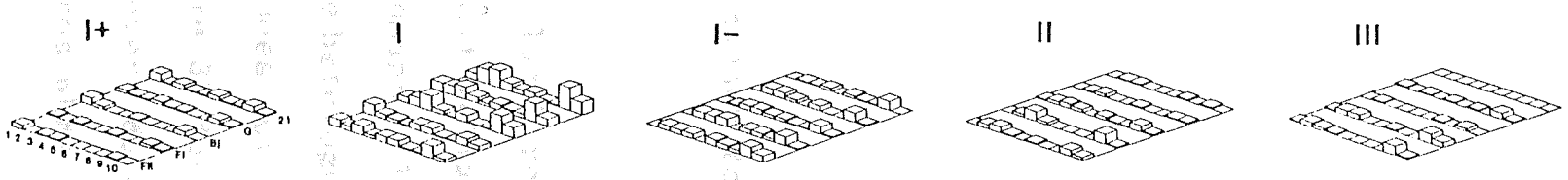
PROGRAMME 21

I+ I I− II III



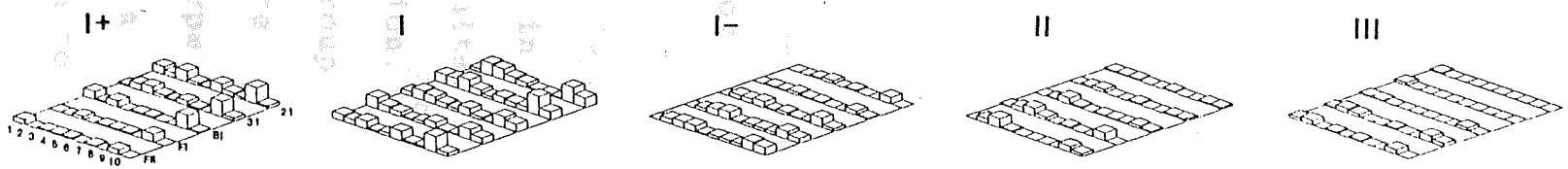
PROGRAMME 31

I+ I I− II III



GOLDMANN

I+ I I− II III



respectively). The VFAs both scored poorly (3 out of 12). All instruments scored in the 1^- category, particularly the VFA II (3 out of 12). Both VFAs scored 3 out of 12 in the II and III categories. These results indicate that for the limited number of subjects Programme 31 showed a high consistency with Programme 21 for local reduction in sensitivity, whereas the VFAs provided a relatively poor prediction of the Octopus results with only half of the fields giving any form of compatibility.

When the Goldmann was used as a reference, Programme 21 scored the highest proportion in the I category (8 out of 12). Programme 31 gave the highest score in the 1+ category but both Octopus programmes showed a relatively high proportion of results which exhibited more information. The VFAs scored in a similar manner to that for Programme 21 as reference.

It would appear, therefore, that for local reduction in sensitivity Programme 31 gives the most reliable results, followed by Programme 21 and the Goldmann. In addition, contrary to the results found for the heterogenous group by Wild et al. (1984), Programme 21 does not give more information when compared to Programme 31 for this type of field loss. Both programmes, however, do exhibit a relatively high proportion of 1+ scores when compared to the Goldmann.

2 General Reduction in Sensitivity

When Programme 31 was used as the reference, Programme 21 gave the highest score in the I category (11 and 10 out of 16 respectively). Programme 21 scored 3 out of 16 in the 1+ category; the remaining instruments exhibited similar scores in the 1^- category.

Programme 31 demonstrated a greater field loss than all the strategies with the exception of Programme 21 which indicated an even greater loss thus confirming, for the general reduction group, the observations for the heterogenous sample (Wild et al. 1984).

When Programme 21 was used as the reference, Programme 31 gave the highest score in the I category (11 out of 16). A high score was recorded for all instruments in the 1^- category, again giving support to the hypothesis that Programme 21 shows a greater degree of field loss.

When the Goldmann was used as the reference, the two Octopus programmes gave the highest scores in the I category, with VFA II scoring significantly less. Programme 21 exhibited the highest score in the 1+ category, followed by Programme 31 thus giving a deeper or greater field loss than any other instrument.

3 Glaucomatous Visual Field Defects

Although the glaucoma group only constitutes eight

patients, agreement is found between the Octopus programmes. The VFAs, however, both show a low score in the 1 category when compared to these instruments and the results for the VFA Mk II record that 2 out of 8 patients showed no level of compatibility.

4 Central Island

There were too few subjects in this group to observe any obvious trends. It must be noted, however, that the VFAs were the only instruments to score 4 out of 4 in the 1 category when compared to the Octopus 31 programme.

This result would appear to support empirical clinical observations, which have not yet been substantiated experimentally, that retinitis pigmentosa patients find difficulty observing target size 3, but not target size 5 on the Octopus 21 programme. It is generally accepted that a static test logic is more reliable than a kinetic test logic and certainly subjectively easier for these patients. Although it must be stressed that such opinion has not been substantiated experimentally, compared to a threshold static regime, a suprathreshold static regime may possibly be more reproducible and certainly of equal benefit to the clinician.

5 Central defects

When Programme 31 was used as the reference, no particular

trend was evident in the results. Programme 21, however, gave the highest score in the 1+ category (3 out of 9).

When Programme 21 was used as the reference, it is interesting to note that the VFA I gave an identical score to Programme 31. The most significant finding, however, is that every instrument gave the highest score in the 1^- category with the VFAs scoring similarly to any other instrument. These results again indicate that Programme 21 exhibits a greater degree of field loss.

6 Miscellaneous Paracentral Defects $< 25^o$

Peripheral Defects $< 25^o$

There are insufficient subjects in these two groups to observe any trends.

7 Blind Spot

Although this group constituted the largest sample, no trend is evident. Programme 21, in this case, does not give the greatest score in the 1+ category, but both the Octopus programmes do score highly in this category when compared to the Goldmann (11 and 10 out of 26 respectively). The two VFAs, however, scored a high proportion of normal fields when compared to the remaining instruments with the Mk I scoring slightly worse than the Mk II throughout. This finding is compatible with the differences in the distribution of the targets around the blind spot for

these two instruments.

8 Hemianopia

When compared to Programme 31 as reference, Programme 21 gave the highest proportion in the I category (8 and 7 out of 9). The VFAs again scored badly with little difference between the two instruments.

When Programme 21 was used as reference, Programme 31 gave the highest proportion in the I category and the VFAs gave the poorest results.

The two Octopus programmes both scored 2 out of 9 in the 1+ category when compared to the Goldmann, but there is no suggestion that in hemianopic patients Programme 21 gives a greater field loss than Programme 31.

9 Normals

When Programme 31 was used as the reference, Programme 21 scored 5 out of 9 for the 1+ category indicating a greater degree of field loss. This is further supported when Programme 21 is used as the reference as each instrument manifests its highest score in the III category.

When the Goldmann was used as reference, the results were very similar to those obtained when the Octopus 31 acted as reference.

It is apparent that Programme 31 previous the most consistent and most desirable results for each condition when compared to the other instruments and techniques used throughout the study. It is interesting to note, however, that certain of the trends discussed in the previous section seem limited to specific sub-groups only. Programme 21, for example, only exhibits the greater degree of field loss mentioned for general reductions, central defects and normals. It is useful to know, for the subsequent experiments within the thesis, that the results from a hemianope, for example, would be comparable to that found using Programme 31 although the difference found in the normal group would cause some concern. The VFA Mk II could still not be considered as an option for the assessment of the visual field for the purposes of this thesis. It is interesting, however, that it seems to perform remarkably well, compared to Programme 31, for conditions resulting in a central island or a central field defect. A more detailed analysis of these results and a discussion of the wider implications is given by Flanagan et al. (1984) (see Appendices).

It has become evident from the studies undertaken that there is a great advantage in assessing the differential threshold of the visual field by the Octopus Automated Perimeter. All subjects to be used in subsequent investigations of the visual field within the scope and aims of this thesis will be examined using the Octopus Programme 31.

Both Huber (1981) and Wildberger (Wildberger and Urner 1982; Wildberger 1984a,b) have found the assessment of the differential light threshold as recorded by the Octopus Automated Perimeter to be useful when considering the affect of various lesions of the visual pathway and comparing them to the results obtained from visual evoked potentials (see Chapter 6).

CHAPTER 3

THE NEURAL REPRESENTATION OF THE VISUAL FIELD

3.1 Introduction

It is clear from the literature reviewed so far that the relationship between the visual field and the visual evoked potential is far from simple. Equally clear is the potential advantage in clarifying the inter-dependence of the VEP on the visual sensory input. If it were possible to quantify the visual field in such a way as to provide an estimate of the amount of cortical activity expected we may then be able to relate the effect of a damaged sensory input, in this case visual field loss, with the VEP, a recording of the cortical activity generated.

The concept that there is a non-linear relationship between the projection of visual space and the corresponding area of stimulated visual cortex in man has been accepted on clinical neurological evidence for some time (Holmes 1945; Spalding 1952; Taeber, Battersby and Bender 1960). More recently quantitative estimates of cortical magnification (M), the amount of striate cortex in millimetres corresponding to one degree of arc in visual space (first defined by Daniel and Whitteridge 1961), have been attempted.

Richards (1971) investigated migraine scotoma dimensions in man to calculate an M-factor of 12mm per degree at the

fovea. Cowey and Rolls (1974) used the cortical phosphene studies of Brindley and Lewin (1968) and related these to the visual acuity studies of Wertheim (1895), as they had calculated that M was directly proportional to visual acuity. They postulated a foveal M-factor of 15.6mm per degree.

Several studies on the neuroanatomy of the monkey (Talbot and Marshall 1943; Daniel and Whitteridge 1961; Rolls and Cowey 1970) had supported the possibility that M could be estimated from the density of retinal ganglion cells. It was therefore generally accepted that M was proportional to $\sqrt{Dc}$ (where Dc is the projected ganglion cell density in cells per solid degree of visual space) for peripheral angles greater than 10^{o}, the relationship breaking down centrally due to cell displacement. Drasdo (1977) suggested that the same relationship should be true for ganglion cell receptive field density (Dr) down to the fovea, such that M is proportional to $\sqrt{Dr}$. He also predicted that the errors in estimates of ganglion cell density (Dc) by some earlier researchers, could easily approach 100% because they did not allow sufficient correction for the progressive peripheral compression of the projection of the visual field even at a retinal level. He used a specially designed schematic eye developed in previous research (Drasdo and Fowler 1974) to correct the earlier data of human ganglion cell density in an attempt to avoid such errors. He also examined estimates of foveal cone density. From this data he was able to obtain

a relationship between $\frac{1}{\sqrt{Dr}}$ and eccentricity extending to the fovea and calculated a foveal M-factor of 11.5mm per degree.

This work is best summarised in three basic equations each having slightly different applications. The first describes the variation of $\frac{1}{\sqrt{Dr}}$ with θ, where θ is the peripheral angle.

Equation 1: $V = k\left[1+S\theta\,(1+3\,\theta^{2}\times10^{-5}+8(S\,\theta)^{5.5}\times10^{-10})\right]$

V provides an estimate for $\frac{1}{\sqrt{Dr}}$ and S determines the initial slope of the regression curve. The last two terms determine the peripheral slope and limit of the visual field.

$V = k\,(1+0.59\theta)$ is a useful approximation if θ is less than 30^{o}. Different values for k can give different correlates, eg. ganglion cell separation, cortical magnification and visual acuity. If k is the foveal threshold of resolution, in minutes of arc, then V provides that value at θ, thus its reciprocal $(\frac{1}{V})$ provides the Snellen decimal acuity.

Equation 1 can be extended specifically to the temporal, nasal, superior and inferior areas of the visual field, as the ganglion cell density and therefore Dr vary with each meridian, by substituting different values for S.

The second equation gives a cumulative estimate if θ is

less than 10^{o}.

Equation 2: $$C = \frac{2\Pi\,\theta\,\delta\theta}{k(1+S\theta)^2}$$

If θ is greater than 10^{o} it overestimates, eg. by 5% at 45^{o}.

When receptive field counts and solid angle were examined the cumulative count is given by the third equation.

Equation 3: $$Q = 100\,(1 - \exp(-0.0574\theta)$$

where Q approximates the "percentage of total receptive fields, striate area or information capacity for a concentric solid angle of visual space with angular semi-diameter of θ^{o}".

Rovamo and Virsu (1979) agreed with Drasdo (1977) that M is proportional to $\sqrt{}$ Dr and used a very similar mathematical approach for calculating the M-factor. They disagreed, however, with Drasdo's figures for central cone density and the total number of ganglion cells in the retina, calculating a foveal M-factor of 7.99mm per degree. One year earlier, Rovamo, Virsu and Nasanen (1978) had stated a foveal M-factor of 7.75mm per degree.

3.2 Drasdo's Graticule

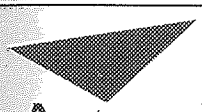
Drasdo went on to give a practical basis to the above

study (Drasdo and Peaston 1980) in an attempt to give a "speedy and convenient method of field quantification". The problems of analysing the results of any visual field investigation are all too familiar to those involved in clinical studies. The need to give different areas of the visual field a specific weighting and therefore allow a quantitative analysis has often been suggested (Spaeth, Fralick and Hughes 1955; Esterman 1968; Drewniak, Chmiekwski, Imielinski and Kopcynski 1970; Collenbrander 1975) but have all so far been based on clinical judgement. Drasdo considered the need to base such a quantification on the "functional properties and dimensions of the visual system".

Doeschatte (1947) had first proposed the idea of a chart based on integrated visual acuity and Crick (1957) commented on a projection based on cortical area. Drasdo and Peaston (1980) based their chart on information channel capacity (Jacobson 1951) calculated from the equations mentioned earlier (Drasdo 1977).

The resulting chart (see Figure 3.1) in which each cell is proportional to its maximal information intake and the neural representation of the corresponding visual field, needed further adaptation to be used on standard perimetric charts.

The final chart divided the visual field into areas of equal weighting superimposed on a conventional perimetric



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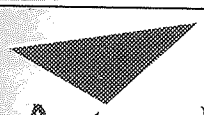
projection (see Figure 3.1). A further extension in this work resulted in a graticule giving dots representing 1% units, whilst taking into account various anatomical and diagnostic factors (see Figure 3.2). The graticule chart has been used by Harding et al. (1979) to assess field defects in patients with hereditary optic atrophy.

The original work of Drasdo and Peaston (1980) also describes two other graticules relating solid angle criterion and retinal image projection but it was felt that the neural representation criterion was most relevant to this study. I am grateful to Mr N Drasdo for his help and encouragement in further developing his graticule for the assessment of the visual field.

3.3 The Adaptation of Drasdo's Graticule for the Assessment of the Visual Field

3.3.1 Reasons for using Neural Representation

It has been previously outlined that two independent studies (Drasdo 1977; Rovamo and Virsu 1979) have established that the best estimates of information density at any point in the visual field are highly correlated with those of its neural representation. A series of well established equations can now determine the number of bits per solid degree at any point in the visual field and by integrating these values provide a system of quantification relating to the channel capacity or loss



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of channel capacity with neural damage in the visual pathways.

It was felt necessary to investigate the visual field in this way for:

1 The quantitative assessment of visual fields relating to the function of the visual system without relying on clinical judgement

and 2 The need to relate more fully the visual field with the visual evoked potential. Drasdo's graticule relates to the neural representation of the visual field and the VEP is a measurement of the electrical activity generated by these neurones, although somewhat complicated by the largely medial orientation of the striate cortex

3.3.2 The Advantages of using the Octopus Automated Perimeter

The Octopus Automated Perimeter records a differential threshold measurement for a number of given points in the visual field. If these points coincide with those given by Drasdo's graticule, originally designed for use with the Goldmann Bowl Perimeter, it would allow for the possibility of an extra dimension (ie. the Z-axis, giving

an assessment of depth) in the analysis of the visual fields. This could be related to the relative nature of the scotomata to be investigated. In the previous Chapter it has been established that the Octopus Automated Perimeter gives an accurate and reliable measurement of the visual field, particularly over the central 30°, for a wide variety of abnormal conditions.

3.3.3 The Sargon Programme

A series of programmes have been written for the Octopus Automated Perimeter using the Sargon Programme (see previous Chapter). The programmes were written to include only the central 30° as this covers the same area of visual field as programme 31. The points to be examined were based on the graticule of Drasdo and Peaston (1980), consequently the number of test locations within the central 30° was 84. In order to use a Sargon programme each subject is required to have an established patient file and was therefore initially assessed using Programme 31.

The Sargon programme has a limitation of 66 test locations so the test had to be divided into two separate programmes. To obtain clinically useful RMS fluctuation values for each programme it was necessary to repeat eight test locations for each programme. To monitor the consistency between the two programmes two test locations were repeated twice in each programme, one peripheral and one at fixation. The final number of test locations required

OCTOPU

Form M

Surname, given names:
Date of birth: 24.04.1915
Patient number/eye:
Examination number, date, time: 4 29.07.1983 3.31
Correction, (sph., cyl., + axis): + 4.00 + 0.00 + 0
Diameter of pupil, headposition: 5.90 69
Size of stimulus: 3
Fixationring:
Program number: A1

Number of questions: 290
False positive answers (%): 0(0/ 7)
Number of repetitions: 0
False negative answers (%): 0(0/ 7)
Date of printout: 29.07.19

USER-DEFINED PROGRAM. LABEL : NR1 (DATE OF PROGRAM:01/04/1983)

	X / Y	V	NORM	MEAN +- S.D
0	- 8.0/- 5.2	26 28	27	27.0 +- 1.4
1	17.6/-11.6	25 26	24	25.5 +- 0.7
2	- 4.6/- 4.4	30 30	27	30.0 +- 0.0
3	- 9.6/- 9.4	28 28	25	28.0 +- 0.0
4	- 3.2/- 0.6	30 31	29	30.5 +- 0.7
5	-15.0/ 10.0	26 16	23	21.0 +- 7.1
6	0.8/ 4.2	28	27	
7	-11.6/- 2.0	0	26	
8	- 5.4/ 0.0	30	27	
9	- 9.2/ 0.0	27	26	
10	- 4.2/ 4.4	30	27	
11	22.6/-22.6	12	20	
12	0.8/- 4.2	27	28	
13	12.0/-17.6	28	23	
14	0.0/- 1.6	26	30	
15	-15.4/-10.0	28	25	
16	- 3.0/ 1.8	31	28	
17	10.4/-10.2	28	25	
18	4.6/- 4.4	29	28	
19	- 3.2/ 16.2	26	23	
20	1.6/ 8.4	33	26	
21	27.6/- 5.2	23	22	
22	- 6.6/- 1.0	30	27	
23	-24.2/ 15.8	21	22	
24	- 0.8/ 4.2	30	27	
25	-18.8/-18.4	3	24	
26	- 1.8/- 2.8	32	29	
27	12.0/ 17.8	27	22	
28	5.4/ 8.2	29	26	
29	1.8/ 3.2	31	28	
30	10.4/ 10.2	30	25	
31	- 2.2/-12.6	29	26	
32	-17.0/ 4.6	21	24	
33	- 3.0/- 1.8	29	28	
34	- 0.8/- 4.2	29	28	
35	- 1.8/ 2.8	33	28	
36	8.0/ 5.0	33	26	
37	-16.0/ 24.2	12	21	
38	11.0/ 0.0	26	27	
39	- 1.0/ 1.0	28 27	29	27.5 +- 0.7
40	- 0.4/- 0.4	26	31	
41	1.0/ 0.8	28	29	
42	- 1.4/ 0.0	29	30	
43	- 0.4/ 0.4	28	31	
44	0.0/ 0.0	26 29	31	27.5 +- 2.1

RMS FLUCTUATION : 2.7
STRATEGY : UP-DOWN (NORMAL)

FIGURE 3.3 Numerical printout following examination with Octopus Sargon programme

therefore was 86 with a total of 102 presentations.

3.4 The Spirally Scanned Visual Field Depression Profile

When using the Sargon programme there is a limitation to the type of printouts available. Unfortunately, there is no way of summating the data recorded from the two programmes required to assess the neural representation. Consequently, even if the ideal print-out was available, it would be of limited value in this instance. Fortunately one of the print-outs is purely numerical and compares the measured differential threshold to the extrapolated Octopus normative value. It also provides all the raw data used to assess the short term fluctuations (see Figure 3.3). Having measured the points in visual space which correspond to Drasdo's Graticule it therefore became necessary to develop an external method of display to enable a clear assessment and analysis of the results.

Clearly the overall quantification could be performed directly from the numerical data. The reduction in channel capacity being the cumulative total of the negative differences between the expected normative value and the measured differential threshold. This would present a rather arduous tabulation of results allowing little freedom to manipulate the data or qualify it in terms of type and location of visual field loss.

The most sensible approach to the graphical presentation of the data seemed to be to plot the differences in terms of eccentricity. By rectangular plotting of the points selected in a spiral sequence from fixation outwards in terms of eccentricity and then superimposing the normative age values given by the Octopus, as shown in Figure 3.4, it would be possible to assess the depression profile for a given subject.

There are three primary advantages of such an approach:

1 The Shape Factor

If we take the example of a classical hemianopic subject with macula sparing, Figure 3.4, we could get an oscillation in the profile outside of the macula region. The two affected quadrants would show a depression from the expected normative values but the two nasal quadrants would appear normal. Similarly a quadrantic defect would give an oscillation involving one quadrant only. A central scotoma, however, would appear as a notch at the beginning of the profile whereas a contraction would show a general depression below the normative line with a notch at the extreme of the x-ordinate.

This may at first appear to miss the point as the learning factor involved in interpreting such a visual display would be both impractical and arguably no better than the traditional forms of visual field assessment, particularly

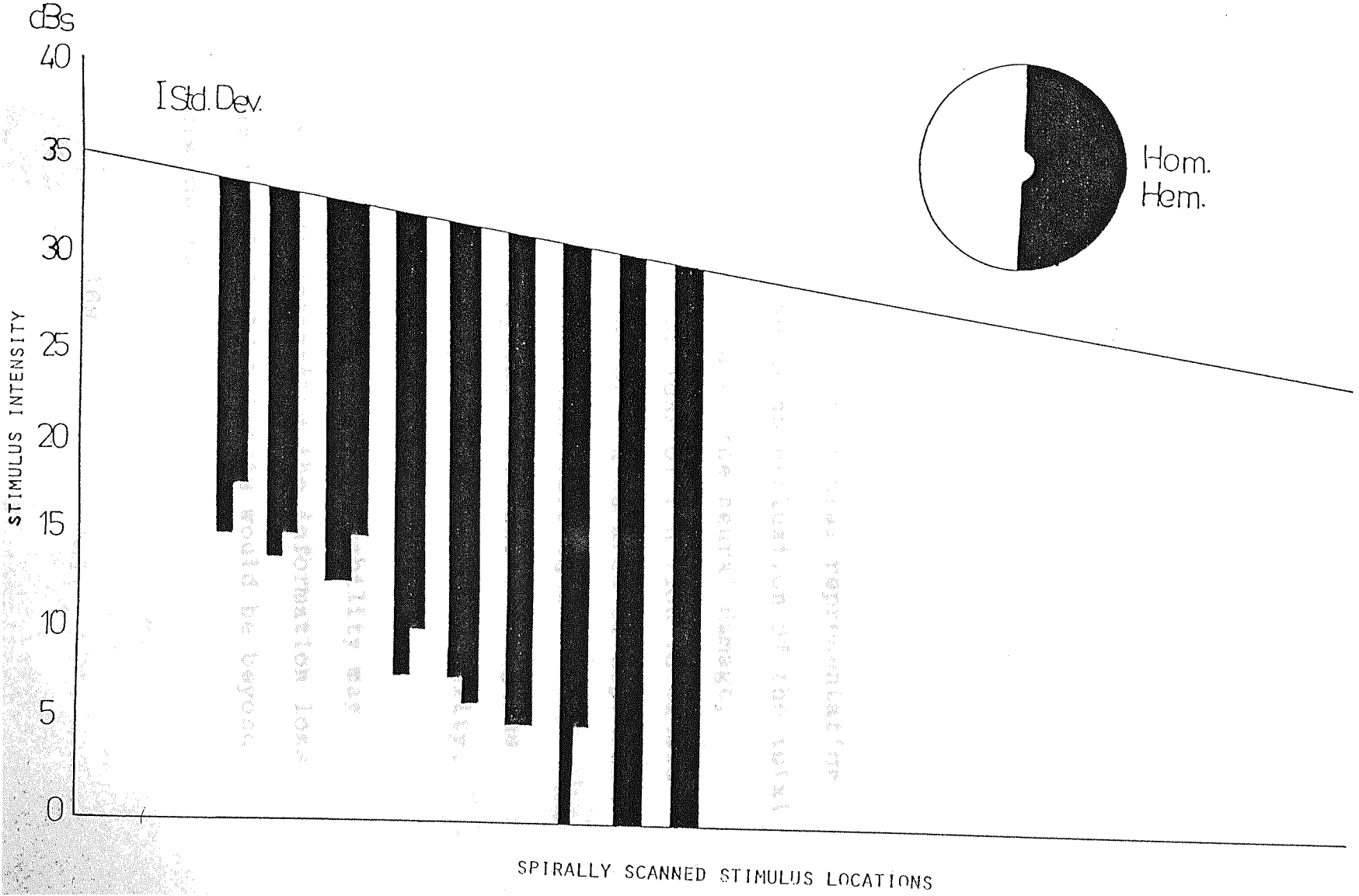


FIGURE 3.4

Illustration of the characteristic oscillatio of the depression profile for a hemianopia with macula sparing

when considering the grey scale approach of the new generation of automated perimeters outlined in the previous Chapter.

It may, however, increase the opportunity of automated visual field assessment progressing closer towards it ultimate goal of the automation of obvious diagnosis or rather, in this case, profile recognition. Computers are relatively well equipped for the function of profile recognition and if careful consideration is given to levels of significance certain classic visual field defects may be automatically recognised.

2 The Quantification of Visual Field

The results obtained relate to the neural representation of the visual field and give us an evaluation of the total visual information loss caused by the neural damage, whether or not such damage or loss of function is caused directly or indirectly. The integrated area of depression or the area under the curve is therefore equal to the information loss suffered by that individual and gives us a quantification of one aspect of visual disability.

A more realistic evaluation of visual disability may be gained by further investigating the information loss of the binocular visual field but this would be beyond the scope of this thesis.

3 The Assessment of Visual Field Survival

One of the most important and difficult aspects of visual field investigation is the monitoring and assessment of the progress of a visual field defect or the visual field survival. Traditional visual field displays, including the print-outs from the new automated perimeters, present great difficulty in recognising small changes in the visual field from one examination to the other. By superimposing the depression profiles (Figure 3.5) we have an extremely sensitive way of monitoring small changes in the depth and distribution of a known scotoma. This could again be easily automated with the change in the visual field being expressed as a percentage of the original loss.

Figures 3.6 and 3.7 show a range of spirally scanned visual field depression profiles with accompanying percentage information loss and compare the results to traditional perimetric mapping.

3.5 Neural Representation of the Visual Field and the Visually Evoked Potential

Since undertaking this project two recent research papers have attempted to relate the neural representation of the visual field and the visual evoked potential, and are discussed in greater detail in Chapter 1.

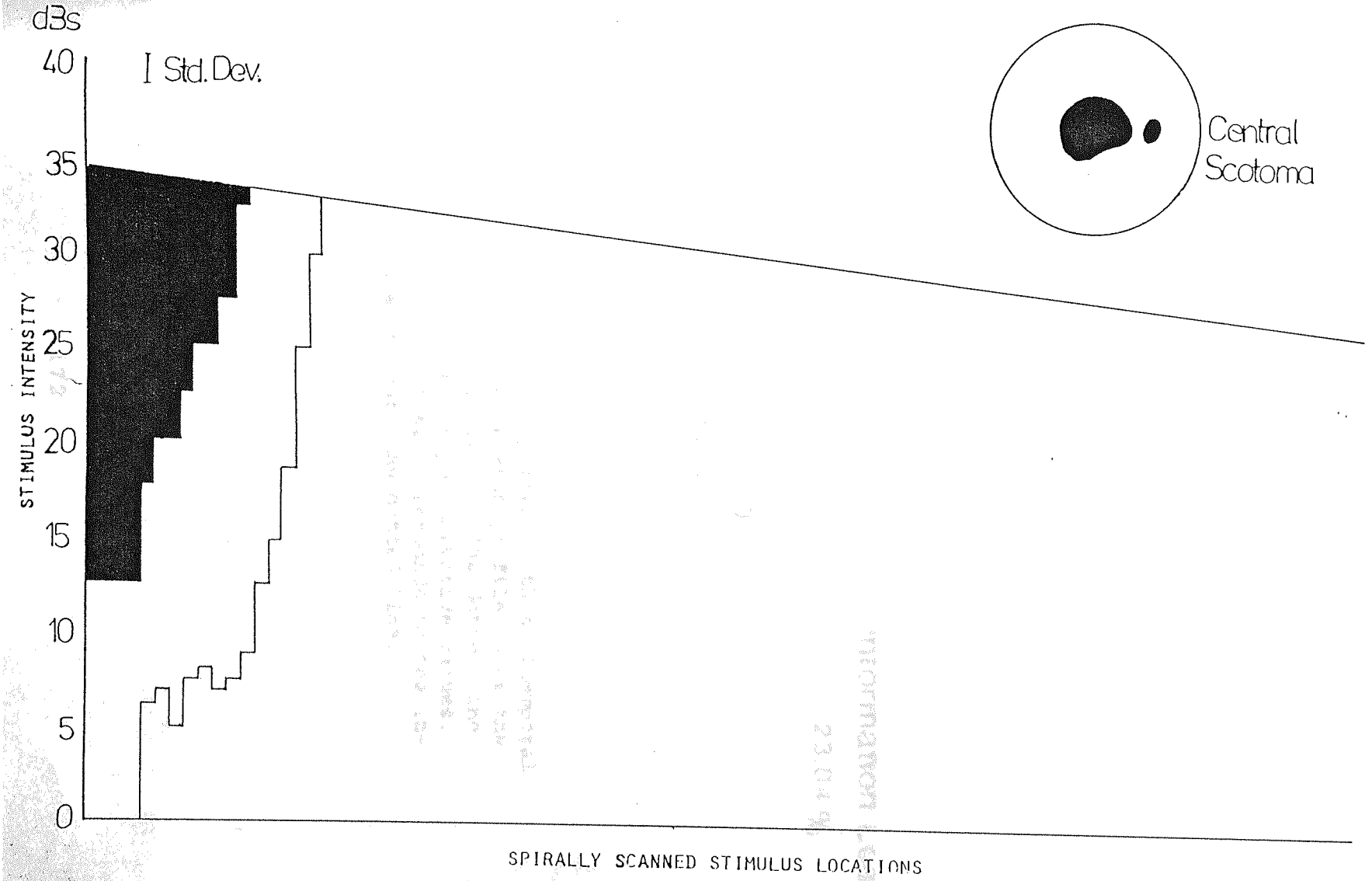
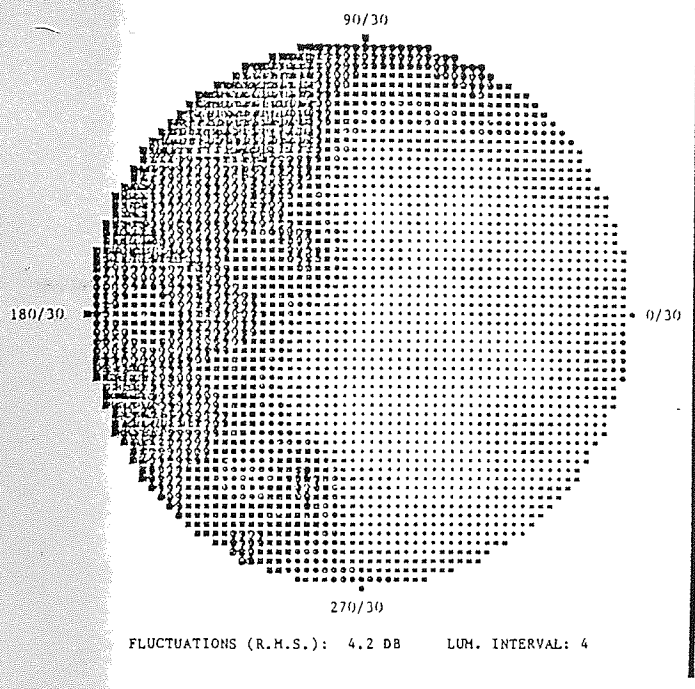
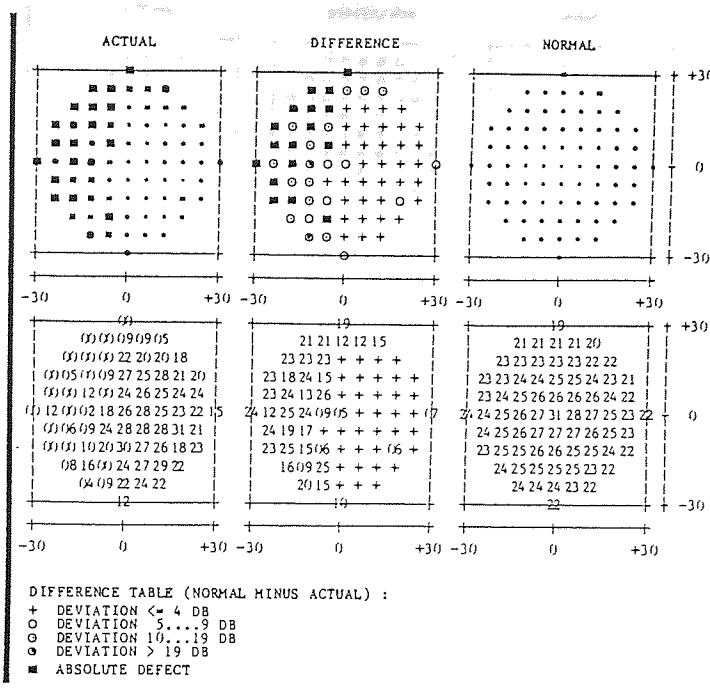


FIGURE 3.5

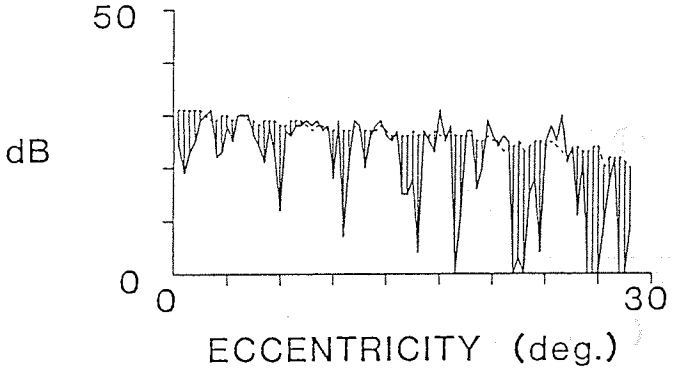
Illustration of the superimposed depression profiles sequentially recorded on an imaginar subject with a progress ing central scotoma

VISUAL FIELD





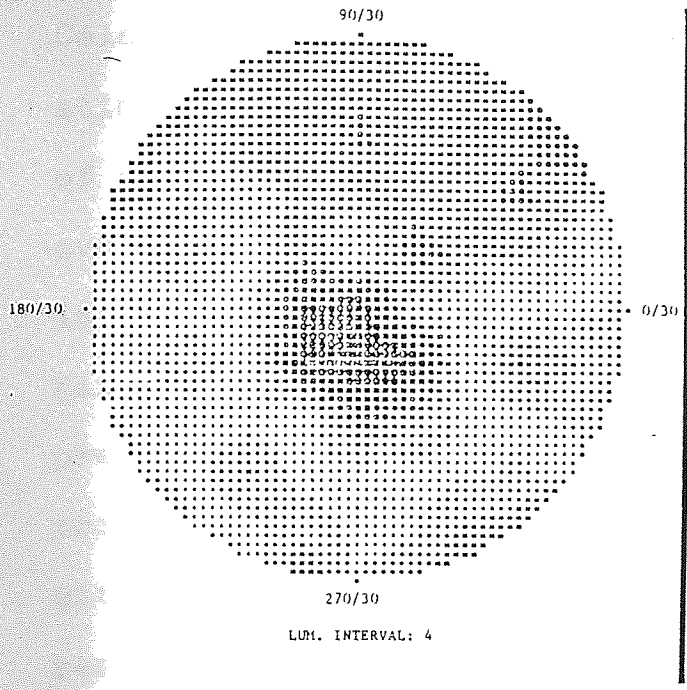
DEPRESSION PROFILE

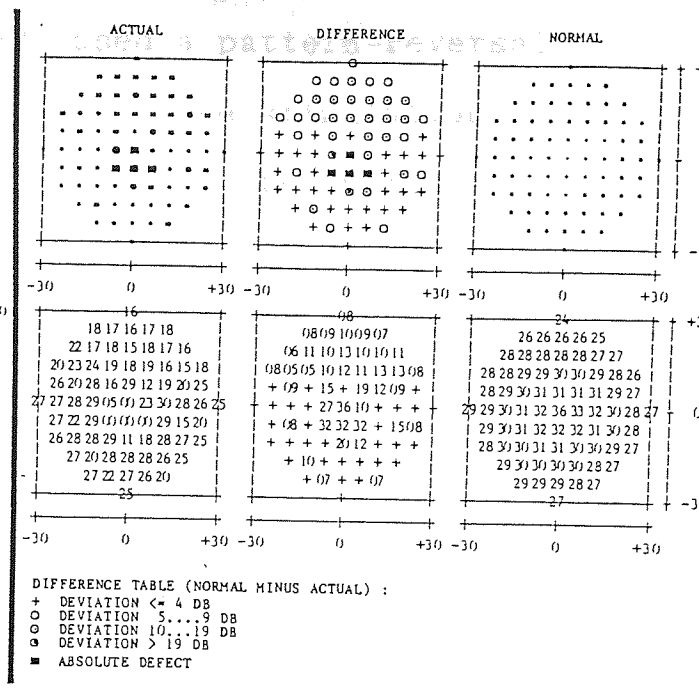


Information Loss
23.04 %

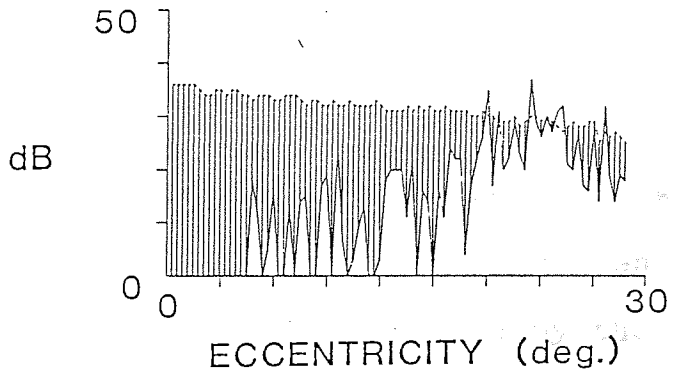
FIGURE 3.6. The visual field of a patient with a bitemporal hemianopia. The depression profile shows the characteristic oscillation. The dotted line corresponds to the Octopus normative values. The % information loss corresponds to the integrated area beneath the dotted line.

VISUAL FIELD





DEPRESSION PROFILE



Information Loss

58.52 %

FIGURE 3.7. The visual field of a patient with a central scotoma. The depression profile showed the characteristic notch at the left of the X-ordinate. The dotted line corresponds to the Octopus normative values. The % information loss corresponds to the integrated area beneath the dotted line

Celesia and Todd Meredith (1982) used a pattern-reversal stimulus to investigate the effect of the stimulation of discrete areas of the visual field on the visual evoked potential of 16 normal subjects. They used a 2^{o} 18' square-field with 16 checks subtending 34'30' each. Fixation was carefully controlled and the stimulus was presented along the four major meridians at varying eccentricities. The results showed a rapid amplitude reduction with the increase in eccentricity. There was no detectable response outside the 4^{o} isopter.

They further investigated four subjects finding the smallest field size which would elicit an evoked potential at fixation and at 8^{o} and 14^{o} eccentricity along the horizontal meridian. They found that increasingly larger field and check sizes were required with the increased eccentricity. The results were then related to the theoretical cortical area stimulated by the pattern reversal stimuli at each retinal eccentricity, based on the magnification factor (M) of both Cowey and Rolls (1974) and Virsu and Rovamo (1979). The resulting correlation was closer to the Cowey and Rolls calculations. The calculations based on Virsu and Rovamo's work disagreed for the central area only.

The authors concluded that the results are "further supportive of the invariance principle of Rovamo et al. (1978) stating that photopic stimuli presented anywhere in the visual field are equally effective if the stimuli are

equivalent in terms of calculated cortical projection images and number of cortical neurones activated".

Tyler and Apkarian (1982) studied the effect of retinal eccentricity on the VEP taking "radial mapping into account". They estimated the stimulus field size required to give an equal VEP by pattern stimulation for various eccentricities, based on the schematic representation of the visual field on the striate cortex by Hitchcock and Hickey (1979). They found roughly equivalent amplitudes for each area stimulated up to an eccentricity of 32^{o}. They conclude that "this suggests that equivalent evoked potentials can be recorded from regions of cortex subserving any part of the retina, rather than being specialised for macular regions".

These observations are interesting as they cast doubt on the earlier literature which states that the VEP is a purely central phenomeon (see 1.2.4). It also provides at least an initial basis for the supposition that the assessment of visual fields in terms of neural representation may provide a closer correlation with the VEP than traditional perimetric techniques. We would expect that equivalent M-scaling of the stimuli used to elicit the VEP would evoke cortically generated potentials of equal power. How the potentials from these equivalent sources will be attenuated by the depth and orientation of the generators remains to be seen. The work of Todd Meredith and Celesia (1982) would suggest they are very little affected.

CHAPTER 4

THE SOURCE DERIVATION OF THE VISUAL EVOKED POTENTIAL

4.1 Introduction

The literature review in Chapter 1 has isolated many of the complex problems which presently inhibit a full appreciation of the VEP and highlight our fundamental lack of understanding about the origin and nature of this potential. We can no longer doubt the clinical usefulness of these techniques but the frustration at our basic lack of knowledge has been well documented even by the earliest pioneers of the electroencephalogram. Brazier (1949) stated that "most of our work in human electroencephalography is a study of the voltage distribution on the surface of a volume conductor - the brain. We would like to know what kind of generators inside this volume conductor would give us the voltage distribution which we find experimentally". It is not surprising, therefore, that there has been a pre-occupation from the earliest days of VEP recording, to try and ascertain the areas of the cortex which generate the resultant scalp potentials (eg. Halliday and Michael 1970).

This problem of source localisation is by no means trivial. First we must assume that the recorded scalp potentials reflect electrophysiological activity in the brain. Cruetzfeldt and Kuhnt (1967); Babel et al. (1977) and Goff, Allison and Vaughan (1978) all proposed, in slightly different ways, that the electrical activity consists of

post-synaptic excitatory and inhibitory potentials produced largely by pyramidal cells (Vaughan 1982), in the fifth and sixth cortical layers (Babel et al. 1977), whose axons are largely oriented perpendicular to the cortical surface. The next objective, according to Darcey (1979), "is to use electric field theory to trace the internal neuroelectric sources which give rise to scalp potentials". Such an approach has become known as the Inverse Problem. Helmholtz, as far back as 1853, pointed out that there is an infinite number of possible source locations which could give rise to the same surface potential in the inverse source problem, but only in the absence of knowledge about the generating sources. Plonsey (1966) investigated this further, with respect to the ECG, discussing the problem of infinite theoretical sources and the further complication of signal to noise ratios inherent within potential recordings. It was concluded, however, that if reasonable assumptions can be made to restrict the number of possible sources it could be possible to define an equivalent model source from surface potential measurements.

If we accept the ideas of synchronous depolarisation and hyperpolarisation, as mentioned above (Vaughan 1982), activated areas of cortex will have opposite electrical charges on its inner and outer surfaces, and will act as a dipole generator varying in strength over time. Thus, by studying the distribution of the VEP over the scalp the approximate position and orientation of the equivalent

dipole generators can be calculated or estimated.

An alternative approach is that of the direct source problem in which the theoretical scalp potentials are calculated from a designated source. In this way various likely models can be investigated and compared to actual results and conclusions may be made as to the most likely source configuration.

The problems and approximations inherent within these methods are many. They include assumptions of cellular symmetry, the orientation of cellular layers, far-field theory, equivalent dipole theory, head media properties, head geometry and source properties. A full discussion of these problems and the mathematics employed in dipole modelling is beyond the scope of this thesis. Interested readers are referred to Goff et al. (1978); Kavanagh, Darcey, Lehmann and Fender (1978); Henderson, Butler and Glass (1978); Darcey (1979) and Wood (1982).

The desire to use these modelling techniques in the hunt for the generating sources, rather like the quest for the holy grail, is both honourable and yet at times rather reckless. The model proposed, whether extrapolated from recorded data or a best fit of the data subsequently recorded, is still a reflection of the scalp potential field. As such it is prone to the inherent problems of stimulus parameters, recording techniques and anatomy outlined earlier. The literature therefore discusses as

many dipole models as it does potential distribution. These observations are perhaps best summarised by Lesevre (1982).

> "Even in the case of the most complete topographical analysis possible, the problems of the interpretation of scalp components in terms of underlying generators would still remain unsolved, since no scalp component, even when isolated by a proper spatiotemporal analysis, is ever a "unitary phenomenon" comparable to a single action potential".

She goes on to describe the existence of a single dipole generator as an "over simplification" but that;

> "despite the fact that evoked potentials can be fruitfully utilized without our knowing their sources, we still are persuaded that the understanding of these sources is the most fascinating problem to tackle".

Lesevre (1982) also discusses the ideas of Donchin (1978) and Goff et al. (1978) that the spatial distributions of evoked potentials should be used as variables dependent on temporal sensory, motor or cognitive processes rather than independent variables for anatomical source localisation. She concludes that such an approach is probably;

"wiser and more immediately profitable than its use for determining where the generators are".

It was felt that somewhere between scalp potential distribution and dipole modelling there was somewhat of a missing link. Perhaps it would be more beneficial to explore in detail the information which we can record on the scalp before supposing too much about the cortical generators? Katznelson (1981) discussed the need "to develop a method that records sources and sinks of current, an approach which seems to be more relevant to the question of generator locations, intensity or relative phase".

It was felt that such a method of mapping the scalp current sources and sinks would be beneficial. The development of the necessary mathematics and computing were all performed by Mr R Clement, a neurobiological mathematician, to whom I am most grateful.

To do this, we must first accept that the scalp potential field (Φ) is a scalar field, one that has magnitude only, and that it is related to the charge field ($\vec{E}$), which specifies the force on a unit charge at every position in three dimensional space, by the relationship:

$$\vec{E} = -\vec{\nabla}\,\Phi$$

Where ∇ = the specific direction, for a given point, along which the rate of change of potential is greatest.

Secondly, we must accept that the current flow density ($\vec{J}$) for a potential field is specified by:

$$\vec{J} = -\sigma \vec{\nabla} \vec{E}$$

Where σ = a constant specifying the conductivity of a Linear Volume Conductor. Consequently a current source (an area of current exit) for a given potential field corresponds to the point where $\left[-\sigma \vec{\nabla}^2 \Phi \right]$ is maximal or the Laplacian of the potential (Clements 1983). The equations of Laplace and Poisson which are relevant to this discussion, have been established for over 150 years and their application is discussed in detail by Freeman (1975) and Darcey (1979).

To make use of these concepts the head has to be considered in three layers comprising of the brain, skull and scalp, all of which are considered to be linear volume conductors. The brain and scalp have a relatively high conductivity and the skull a relatively low conductivity. The relationship $\vec{J} = -\sigma \vec{\nabla}^2 \Phi$ does not relate to the absolute size of the potentials recorded by scalp electrodes but to the rate of change or the current flow across the cortex. This is an important consideration as we must remain aware, as discussed earlier in dipole modelling, that the scalp potential field "will be an attenuated and weighted average of the potentials on a finite region of the cortical surface below, with the weighting dependent on the smearing effects of the tissues between the cortex and scalp" (Darcey 1979). The principles

used do assume a degree of homogeneity and isotropy of the medium although Plonsey and Heppner (1967) did suggest they could be applied to an inhomogenous medium if it consists of a finite number of homogenous sub-regions. Such considerations can be devastating when attempting dipole modelling but we are attempting a more qualitative approach to help visualise the current flow over the scalp therefore reducing the quantitative effect of these errors and assumptions.

A technique for the source derivation of the EEG was first introduced by Hjorth (1975) in which the second spatial or laplacian derivation was used to localise foci in the scalp field. He very eloquently described the principles of source derivation diagramatically (Figure 4.1) in which he used the analogy of an elastic membrane subjected to lifting forces (Hjorth 1976). This clearly demonstrated the difference between common reference, common-average reference and bipolar recordings and the way in which these relate to source derivation. He predicted that the method would not only be useful in the localisation of focal abnormalities but also give an improved signal to noise ratio. Wallin and Stalberg (1980) used these techniques clinically and found them useful in the interpretation of the EEG.

Katznelson (1981) had first suggested the application of source derivation techniques to evoked potentials but no attempts had been reported in the literature. It was our

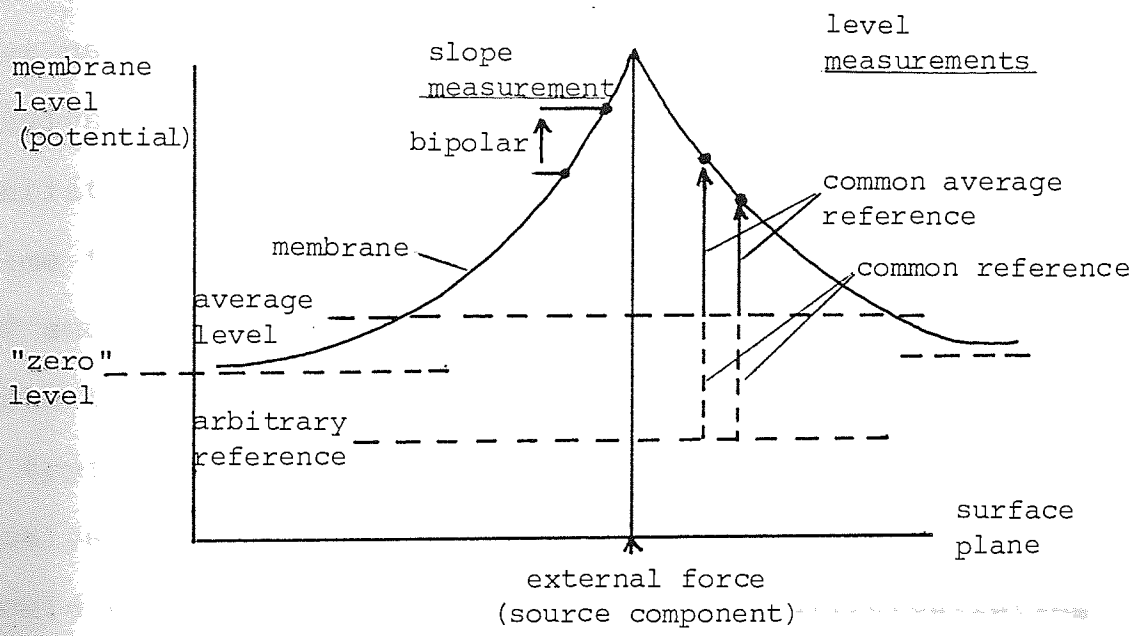


FIGURE 4.1 Illustration of relationship between common-reference, common-average and bipolar derivations using the analogy of an elastic membrane subjected to lifting forces

aim to establish whether the application of a source derivation technique would be useful in the analysis of topographically recorded visual evoked potentials.

4.2 The Computation of the Source Derivation and the Modelling of the Scalp Potential Field

Let us consider the way in which two variables can be analysed using the concept of Rate of Change or Differentiation. This is usually performed with respect to time thus, as in classical mechanics, if we take a graph of successive positions of an object we can differentiate once to obtain velocity and twice to obtain acceleration. A typical clinical application of this would be the analysis of saccadic eye movements. Differentiating once would give the velocity of the eye and differentiating twice would give the eye's acceleration.

Differentiation can also be performed with respect to spatial position. One of the theoretical approaches to artificial intelligence in edge detection by computer involves differentiating the luminance profile twice. The computer could then locate the zero-crossing, the precise location of the switch from a positive peak to a negative peak, in the twice differentiated waveform.

When considering the scalp distribution of the VEP we can apply the above concepts to aid the analysis. Using common reference recording the distribution can be

differentiated once to give the bipolar distribution and differentiated twice to effectively give the bipolar of the bipolar distribution which we refer to as the Source Derivation. In practical terms these can be recorded directly and Figure 4.2 illustrates the relationship between the three.

When considering the VEP the distribution of changes in the head sets up a Scalar Potential Field across the scalp, ie. it has magnitude only (Figure 4.3). Positive charges move from regions of lower potential and vice-versa for negative charges. This transfer of charges is called the Scalp Current Flow. When we differentiate we are actually differentiating a field. The first spatial derivative of the field is known as the Grad operator (Schey and Norton 1973). When this is applied to a point in the Scalar Field it produces a Vector in the direction in which that point undergoes the greatest rate of increase and whose magnitude is equal to the rate of increase in that direction, thus producing the vector Current Flow Field (Figure 4.4.).

The second spatial derivative requires the Div operator to be applied to the vector field (Schey and Norton 1973). When the Div operator is applied to a point in a Vector field it produces a scalar value which reflects the net direction of the vectors near the point. If they are toward the point then that point constitutes a Sink whilst if they are away from the point it constitutes a Source. Thus, the application of the Div operator to the current

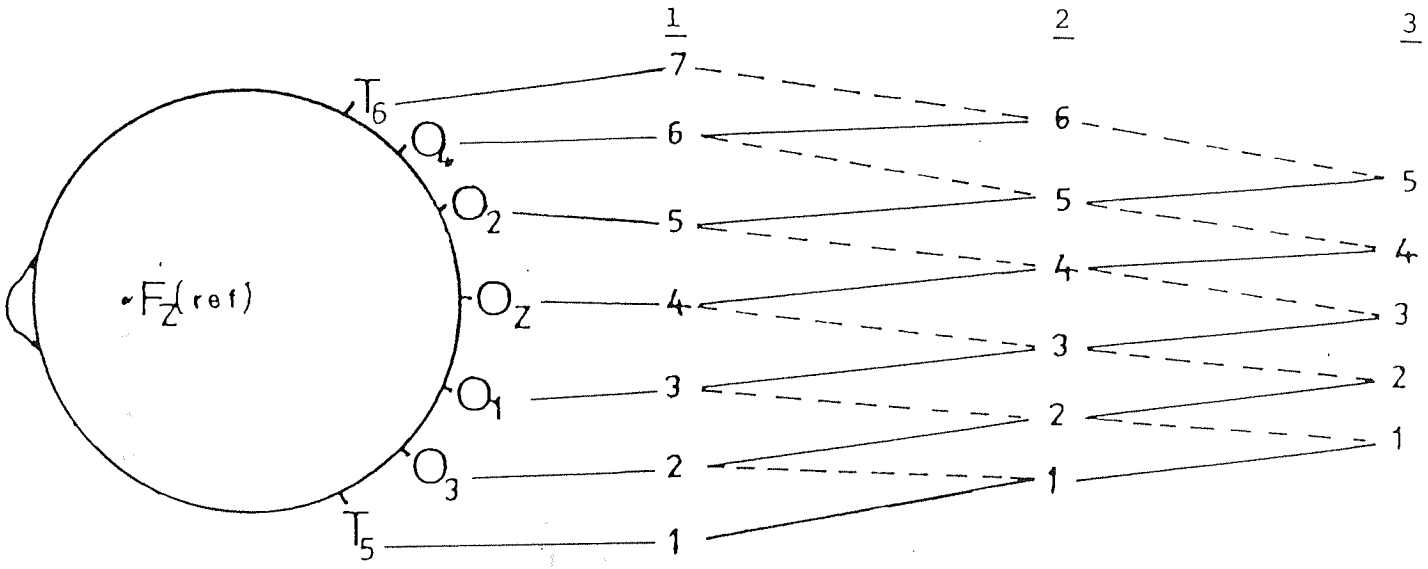
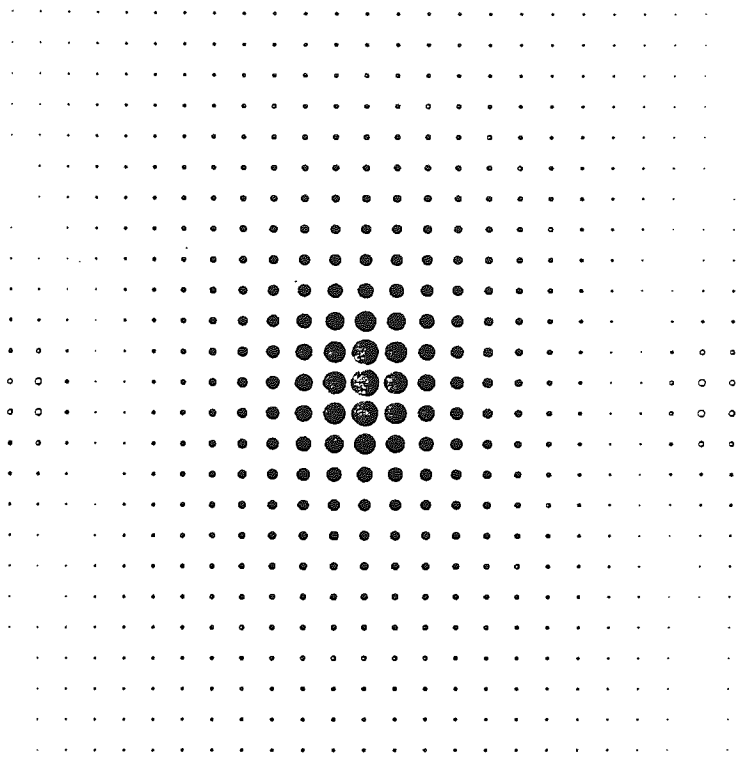
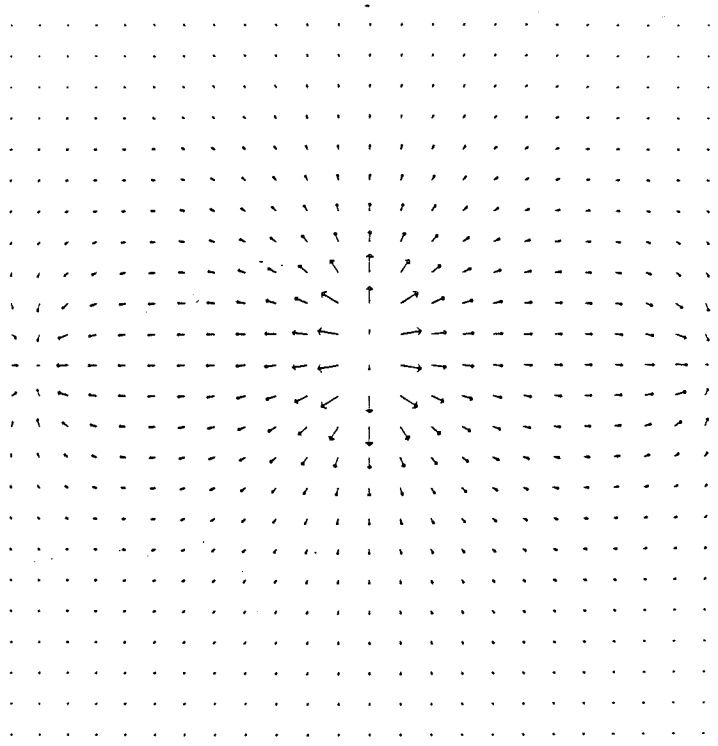


FIGURE 4.2 Montage for 1/ Common Reference
2/ Bipolar
3/ Source Derivation



● SIZE OF CIRCLE PROPORTIONAL TO SIZE OF POSITIVE POTENTIAL

FIGURE 4.3 The Scalp Potential Field



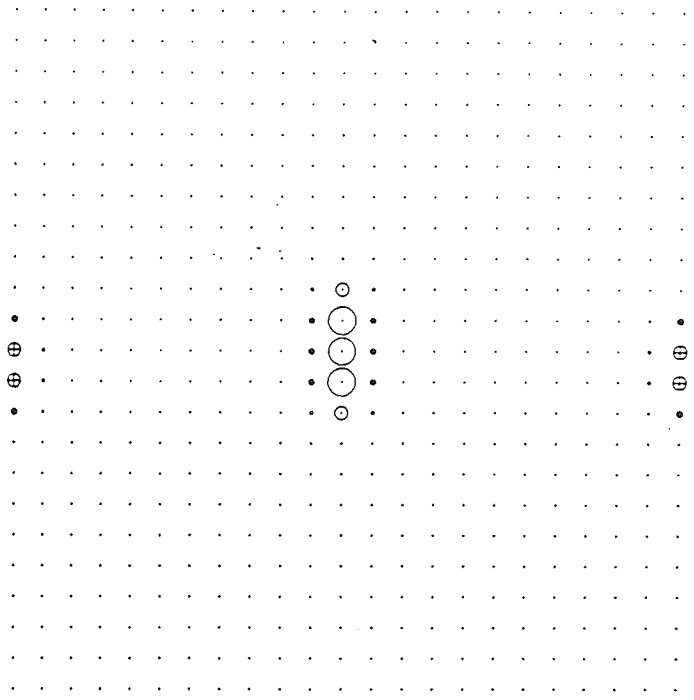
↑ LENGTH OF ARROW PROPORTIONAL TO POTENTIAL DIFFERENCE BETWEEN TO POINTS

FIGURE 4.4 The Scalp Current Flow

flow field reveals the Current Sources and Sinks in the scalp, the Source Derivation (Figure 4.5). A scalp current source would reflect flow out of the cortex into the scalp whilst a scalp current sink reflects flow into the cortex from the scalp.

This provides the basis of a model of the way in which the Scalp Potential Field, clinically recorded as the VEP, behaves (Figure 4.6). By identifying the sources and sinks present in the scalp current flow it was hoped that this would provide a helpful alternative to the analysis of the VEP.

It can be seen that by application of the Grad and Div operators the first and second spatial derivatives can be computed rather than directly recorded. This is an important consideration as it is hoped that the source derivation technique will add to standard, topographic recordings rather than replace them. To record directly, as suggested by Figure 4.2, would destroy vital information or, if all three distributions were recorded simultaneously, render the technique impractical. Bipolar recordings have been utilised by many authors and have frequently been compared to common reference distributions (Barrett et al. 1976; Harding et al. 1980). Theoretically, however, the results from recording directly and computing should be identical. When calculating the bipolar, the gradient between two electrodes, the effect of the reference electrode F_Z, which is by no means distant and inactive,



⊙ SOURCE

⊕ SINK

FIGURE 4.5. The Source Derivation

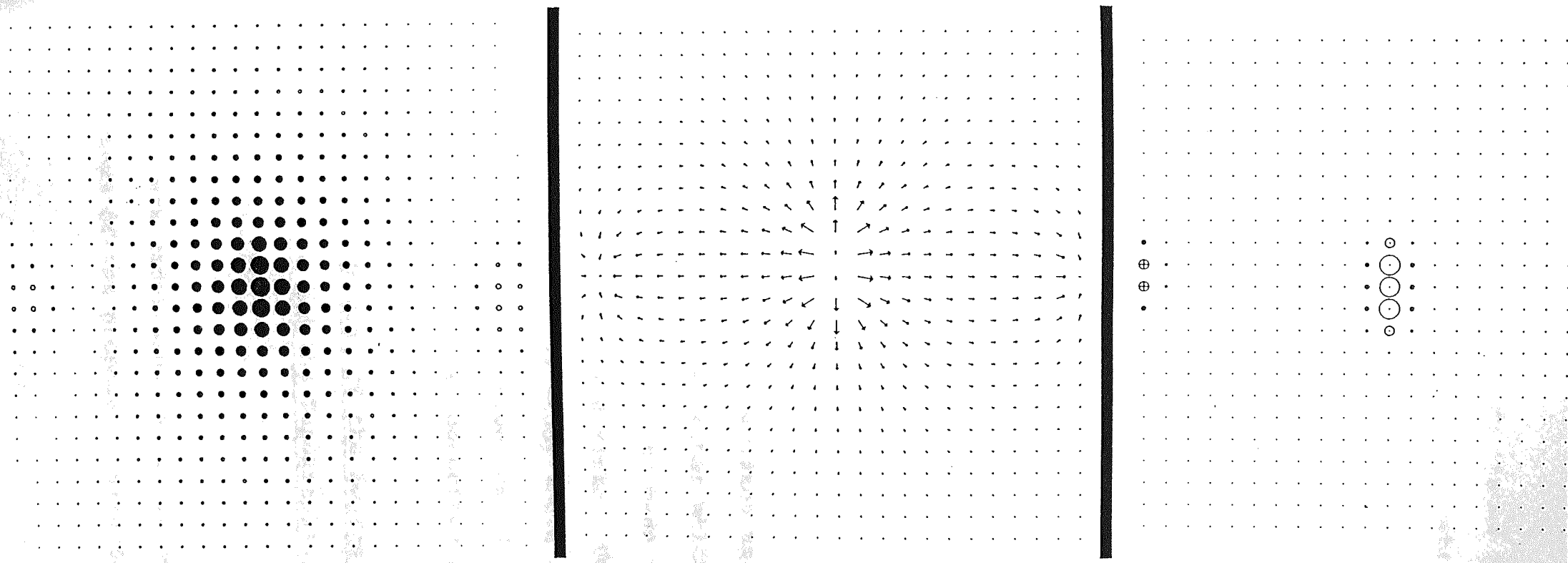


FIGURE 4.6 Computer generated model representing full field pattern reversal stimulation. (1) The VEP can be described as a scalar potential field across the scalp. (2) Differentiating any point in the scalar potential field produces a vector in the direction in which that point undergoes the greatest rate of increase and thus produces the vector current flow field which we can relate to the bipolar distribution. (3) Applying the second spatial derivative to a point in the vector field produces a scalar value which reflects the net direction of the vectors nearest to that point. This can be related to our source derivation.

is cancelled out. It could be argued in terms of vectors that the effect of F_z is not equal over all electrodes. In reality, F_z gives the best available "equality" in distribution and pilot studies to compare the directly recorded bipolar distribution with the computed distribution showed no significant difference.

The source derivation has previously been recorded using montages in a rectangular or triangular grid (Hjorth 1975; Wallin and Stalberg 1980) in an attempt to have equidistant electrodes surrounding the recorded electrode. In attempting to collate useful clinical information as an adjunct to the standard common reference montage used to routinely assess patients this approach was considered both impractical and inappropriate. Thus a two dimensional investigation was initially undertaken using two electrode chains perpendicular to each other which we hoped would enable certain assumptions to be made regarding the position of scalp sources and sinks. Using the 13 channels proposed for this study would require an additional 20 electrodes to provide the ideal requirements for the source derivation as described by Hjorth (1976).

4.3 The Validation of the Source Derivation Technique and the Topographical Investigation of the VEP

Two studies were undertaken in an attempt to establish the usefulness of the proposed source derivation technique.

Each study used the same stimulus and recording equipment.

STUDY 1: The VEP to whole field, right and left half-field stimulation using a pattern reversal stimulus. The distribution was recorded from a transverse electrode montage.

STUDY 2: The VEP to whole field, upper and lower field stimulation using a pattern reversal stimulus. The distribution was recorded from a medial electrode montage.

4.3.1 Method

1 Transverse Montage: Seven electrodes were placed in a transverse row across the occiput. Five of the electrode locations correspond to standard positions (T5, O1, Oz, O2, T6) in the 10-20 system (Jasper 1958). The midway electrodes, between T5 and O1 and between T6 and O2 were labelled O3 and O4 respectively. All electrodes were referred to a common reference at Fz (Figure 4.7).

This montage was used on 20 normal, male subjects with an age range from 19 to 24 years and a visual acuity of 6/6 or better. Each subject was presented with whole field and right and left half-field stimulation to the right eye.

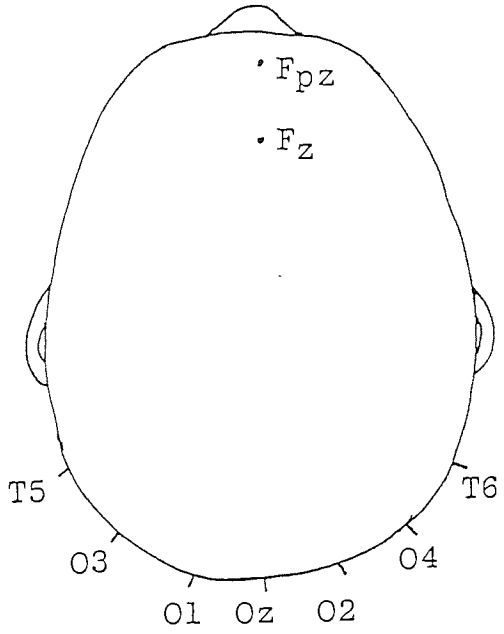


FIGURE 4.7 Transverse Montage

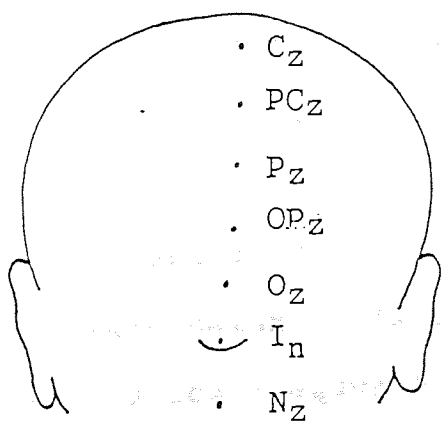


FIGURE 4.8. Medial Montage

11 Medial Montage: Seven electrodes were placed in a medial row on the midline. Three of the electrode locations correspond to standard positions (Oz, Pz, Cz) in the 10-20 system. The midway electrodes, between Oz and Pz and between Pz and Cz were labelled OPz and PCz respectively. The electrode at the inion was called I_N and the electrode 10% below the inion was called N_Z, corresponding to the medial nuchal crest. All electrodes were referred to a common reference at Fz (Figure 4.8).

This montage was used on 18 normal, male subjects with an age range from 19 to 24 years and a visual acuity of 6/6 or better. Each subject was presented with whole field, upper and lower field stimulation to the right eye.

The pattern reversal stimulus was an optically produced twice per second reversing black and white checkerboard with a contrast of 74%. The check was 56 minutes of arc with a field radius of 28^{o}. Half-field stimulation was produced by masking half of the whole field stimulus. One hundred sweeps were recorded for each stimulus and the potentials were averaged using a Nicolet Pathfinder II. Bandpass filters with a low frequency cut-off of 0.5Hz and a high frequency cut-off of 70Hz were used.

The common reference potentials were stored on disc. The

bipolar and source derivation distributions were then computed from the stored data. The bipolar derivation was computed by application of the difference operator:

$$B_n = C_{n+1} - C_n \qquad \text{where}$$

B_n is the nth bipolar channel from the subject's left and C_{n+1} and C_n are the n +1th and nth common reference channels from the subject's left. This bipolar derivation corresponds to a bipolar chain from left to right (Barrett et al. 1976). The source derivation was computed by a repeated application of the difference operator, ie.

$$S_n = B_{n+1} - B_n = (C_{n+2} - C_{n+1}) - (C_{n+1} - C_n)$$

$$= C_{n+2} + C_n - 2C_{n+1} \qquad \text{where}$$

S_n is the nth source derivation channel from the subject's left.

The amplitudes of the responses were measured with respect to the Fz reference. In order to investigate the distribution of the P100 component, the latency of the component on the channel on which it was maximal was determined, and the amplitude was measured on the other channels at this latency.

Hjorth (1975) specified the size of the source derivation as a voltage, whereas Katznelson (ch. 7 Nunez 1981) has related it directly to the physical concept of the Laplacian of the potential field by expressing it in units of uV/cm^2.

In order to facilitate interpretation of the source derivation recordings in terms of sources and sinks in the scalp current flow, the latter units were adopted. The appropriate scaling was achieved by dividing the source derivation by the square of the distance between the electrodes, measured in centimetres. With the sign conventions used in this study, a positive value in the source derivation indicates the presence of a current sink, whilst a negative value indicates the presence of a current source at the electrode.

4.3.2 Full Field, Right and Left Half-field Stimulation

The response to full field stimulation on the midline consisted of an NPN wave form (Blumhardt et al. 1977). The 3 peaks had mean latencies of 63.7, 96.9 and 140.4 msec with standard deviations of 7.0, 8.4 and 15.4 msec respectively. The amplitude of the NP component had a mean of 8.2uV with a standard deviation of 4.2uV, while that of the PN component had a mean of 8.7uV with a standard deviation of 4.4uV. The mean peak amplitude of the P100 component at the O_Z electrode was 7.13 microvolts (S.D. 3.46 microvolts).

An example of the evoked responses to half-field pattern reversal stimulation is shown in Figure 4.9. The common reference recordings show a clear lateralisation ipsilateral to the hemifield stimulated. The source derivation reveals

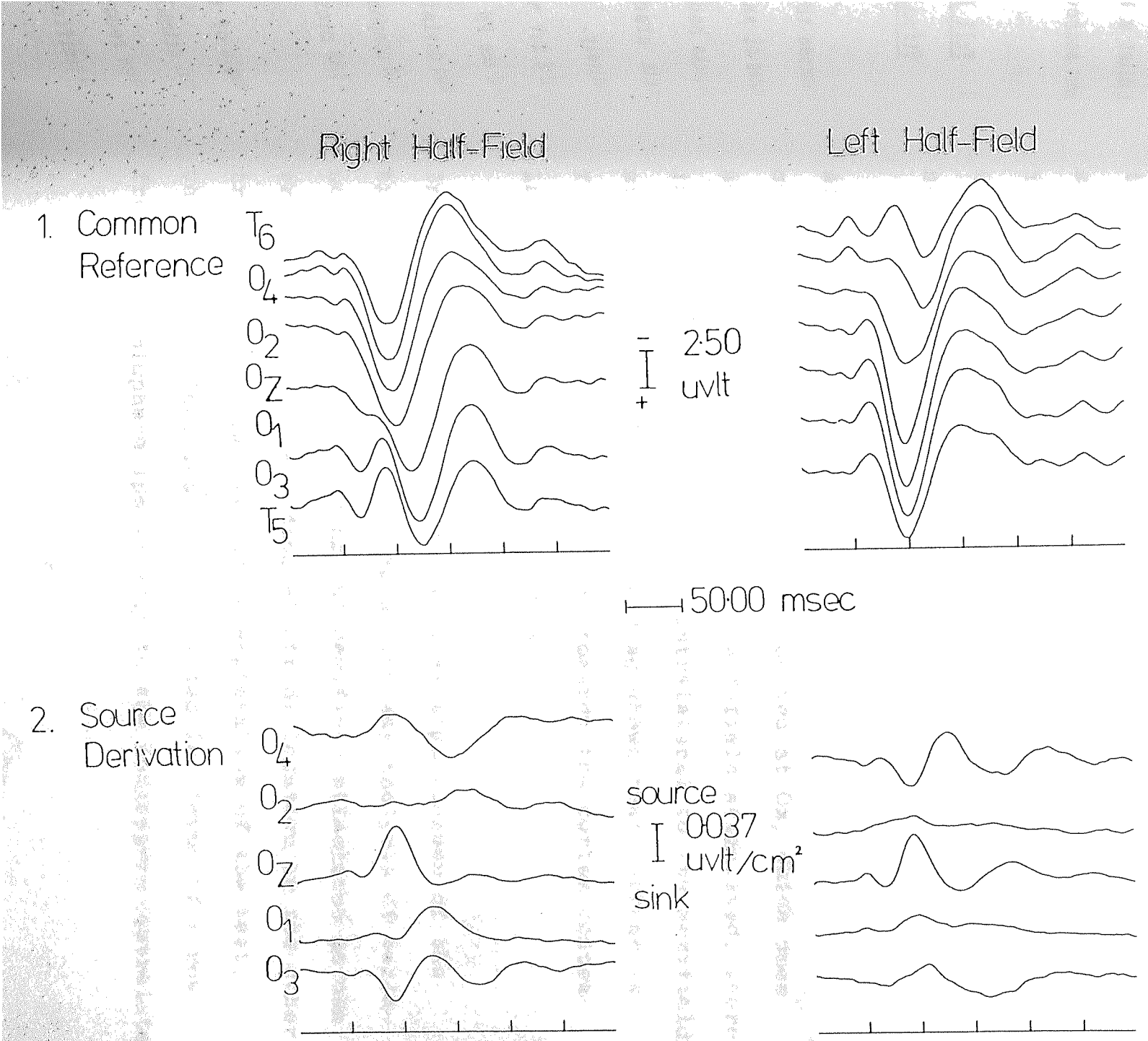


FIGURE 4.9

Visual evoked potentials to half field pattern reversal stimulation. Despite the clear ipsilateral lateralisation of the common reference recordings, the source derivation reveals a source location at Oz, which does not shift with a change in the half-field stimulation.

a source located at Oz, and a sink located at O3 with stimulation of the right half-field and at O4 with stimulation of the left half-field.

The distributions of the amplitude of the major positive component in the group averages of the common reference responses to half-field stimulation, together with the bipolar and source derivation distributions computed at the latency at which the major positive was maximal, are shown in Figure 4.10. In order to emphasise the lateralisation of the distributions, each distribution has been normalised so that its maximum value, be it positive or negative, is unity.

Although the main current generator, as revealed by the source derivation, is a source located at Oz, which does not shift with a change in the half-field stimulated, there is also a sink which appears contralateral to the hemifield stimulated. The bipolar recording shows that current is flowing away from the midline, towards the cortex contralateral to the hemifield stimulated.

In order to test the statistical significance of the trends in the group averages, two-way analysis of variance was carried out, using the hemifield stimulated as one treatment and the recording electrode location as the other treatment. To simplify the interpretation of the test, the electrode location was specified in terms of a row from the hemisphere ipsilateral to the hemisphere contralateral

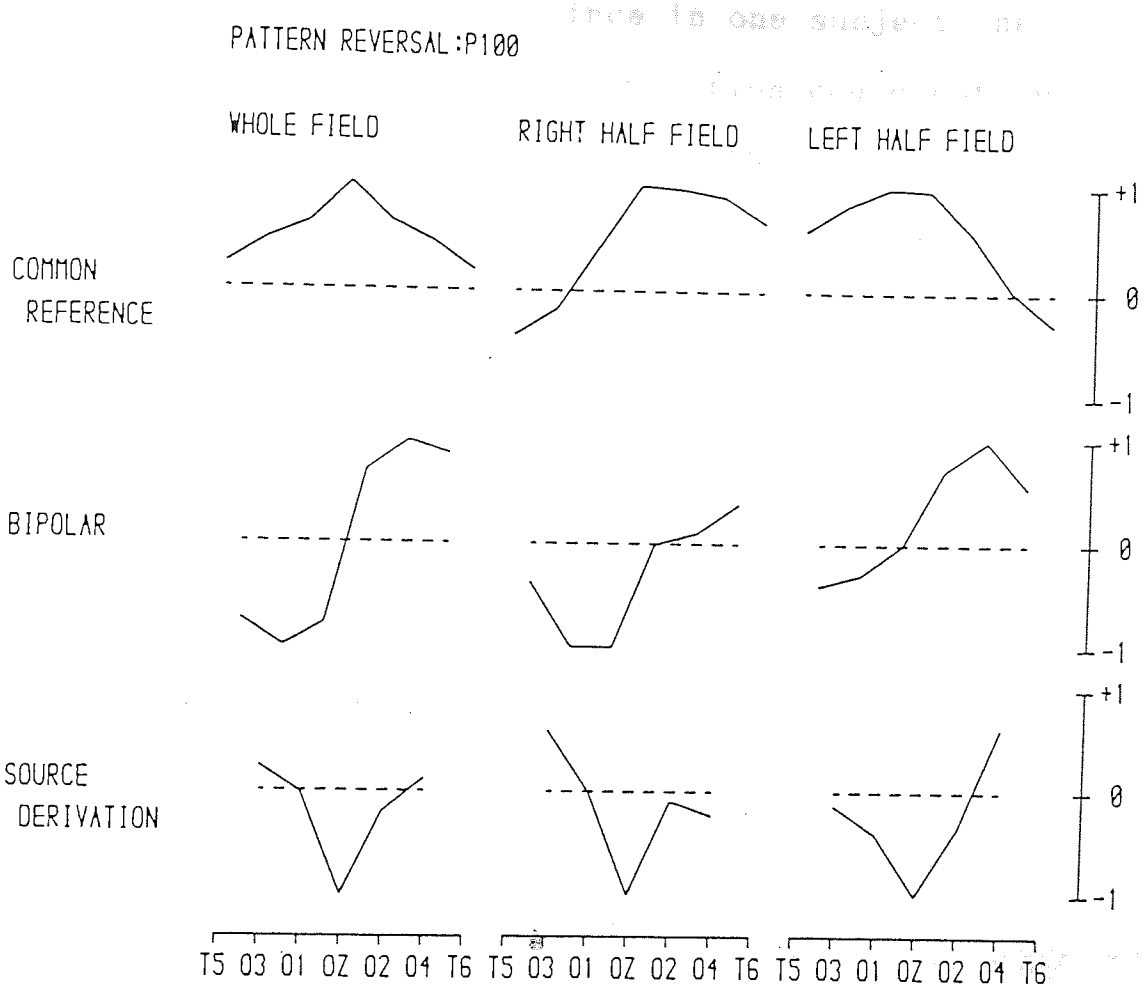


FIGURE 4.10 Distributions of the group average amplitude of the major positive component to whole field, right and left half-field stimulation, plus the bipolar and source derivation distributions computed at the maximal major positivity, each distribution has been normalised so that its maximum value is unity.

to the hemifield stimulated. Only 19 subjects were used for the statistical analysis, since in one subject the P100 component with half-field stimulation could not be reliably identified. The way in which the source derivation changed with recording electrode location was found to be highly significant ($F_{4.72} = 15.1$, $p > 0.001$), demonstrating that the source-sink configuration found in the group average has not arisen by chance. There was no significant difference in the source derivation between the two half-fields stimulated, and the interaction effect was also not significant, showing that the way in which the source derivation changes with recording electrode location does not depend on the half-field stimulated.

4.3.3 Full Field, Upper and Lower Field Stimulation

The response at the Oz electrode to full field pattern reversal stimulation consisted of an NPN waveform. The three major components had mean latencies of N-64.2 msec (S.D. 6.29), P-96.8 msec (S.D. 4.40) and N-147.4 msec (S.D. 12.19). The amplitude of the NP component had a mean of 9.82 microvolts (S.D. 3.67) whilst the PN component had a mean amplitude of 11.60 microvolts (S.D. 6.35). The mean baseline corrected peak amplitude for the P100 component at the Oz electrode was 8.39 microvolts (S.D. 3.75) (Figure 4.11).

The upper field stimulus, ie. lower hemiretinal stimulation, showed an increase in mean latency at 103.56 msec (S.D. 7.37) which is significantly later than the whole

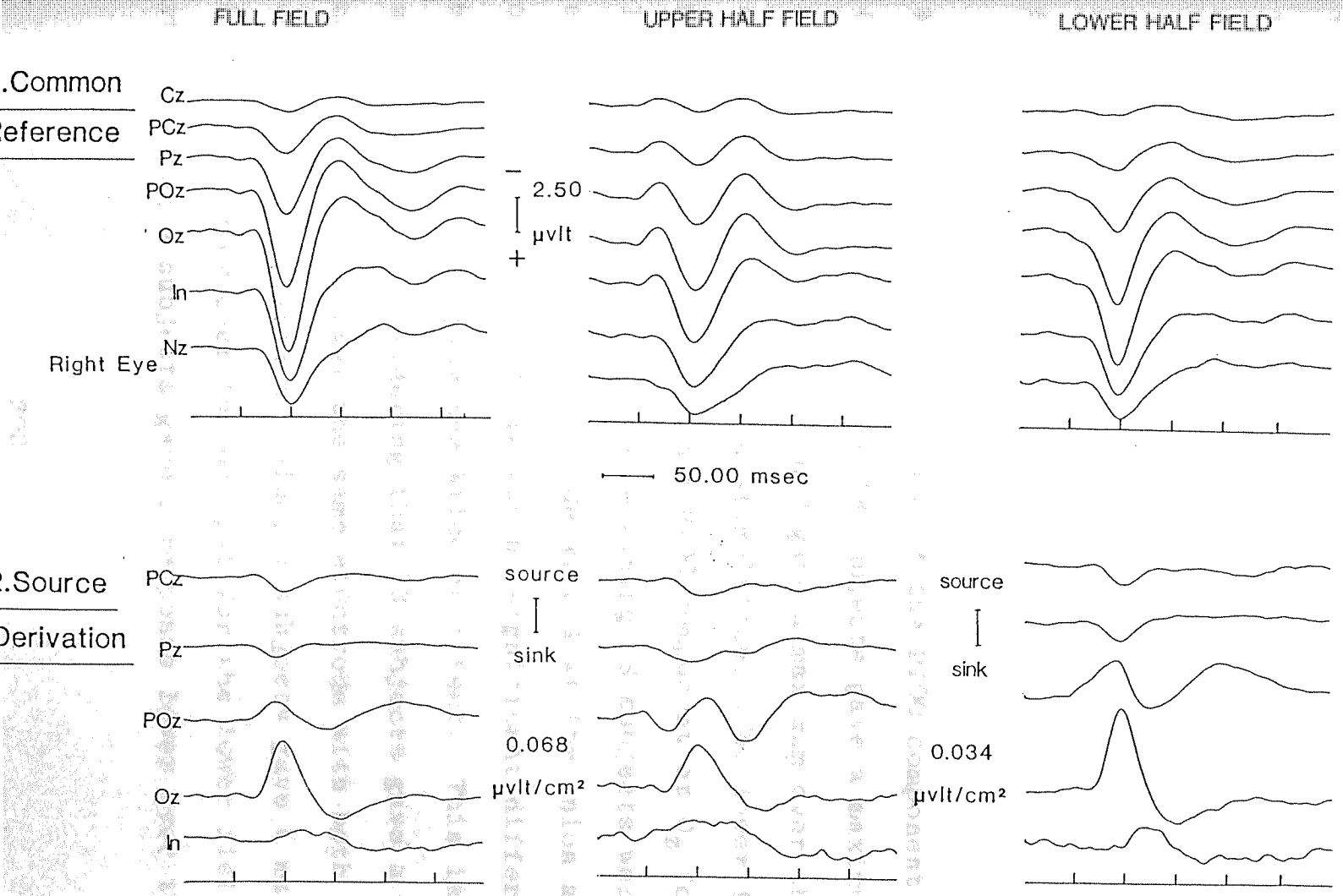


FIGURE 4.11. Group average distributions following pattern reversal stimulation of the full field, upper and lower fields

field response and the lower field stimulus response ($p > 0.01$). There was no significant difference between the lower field stimulus response which had a mean latency of 96.1 msec (S.D. 5.32) and the full field response.

Source derivation reveals a source located at Oz irrespective of whether the upper or lower hemiretina was stimulated. Eleven of the 18 subjects had a source at the same location for both upper and lower field stimulation. Of the remaining 7 subjects, 5 gave a source located approximately 10% more anteriorly over the occiput for the lower field stimulus and 2 gave a source located c10% more posteriorly over the occiput for the lower field stimulus.

When looking at the amplitude of the P100 component (Figure 4.12) seven of the 18 subjects gave a maximum response over the inion and 8 gave a maximum over the O_Z electrode, for upper field stimulation. The lower field stimulus indicated a maximum P100 component at O_Z for 10 of the 18 subjects, the remaining 8 subjects were evenly distributed either side with 4 at the inion and 4 over electrode OPz. There was no significant difference however, when applying the Wilcoxen t-test. This is not surprising when considering that 13 subjects gave a maximum amplitude over the same electrode with both the upper and lower field stimulus, 3 subjects gave a maximum amplitude higher over the occiput for the lower field stimulus but 2 subjects gave a response lower over the

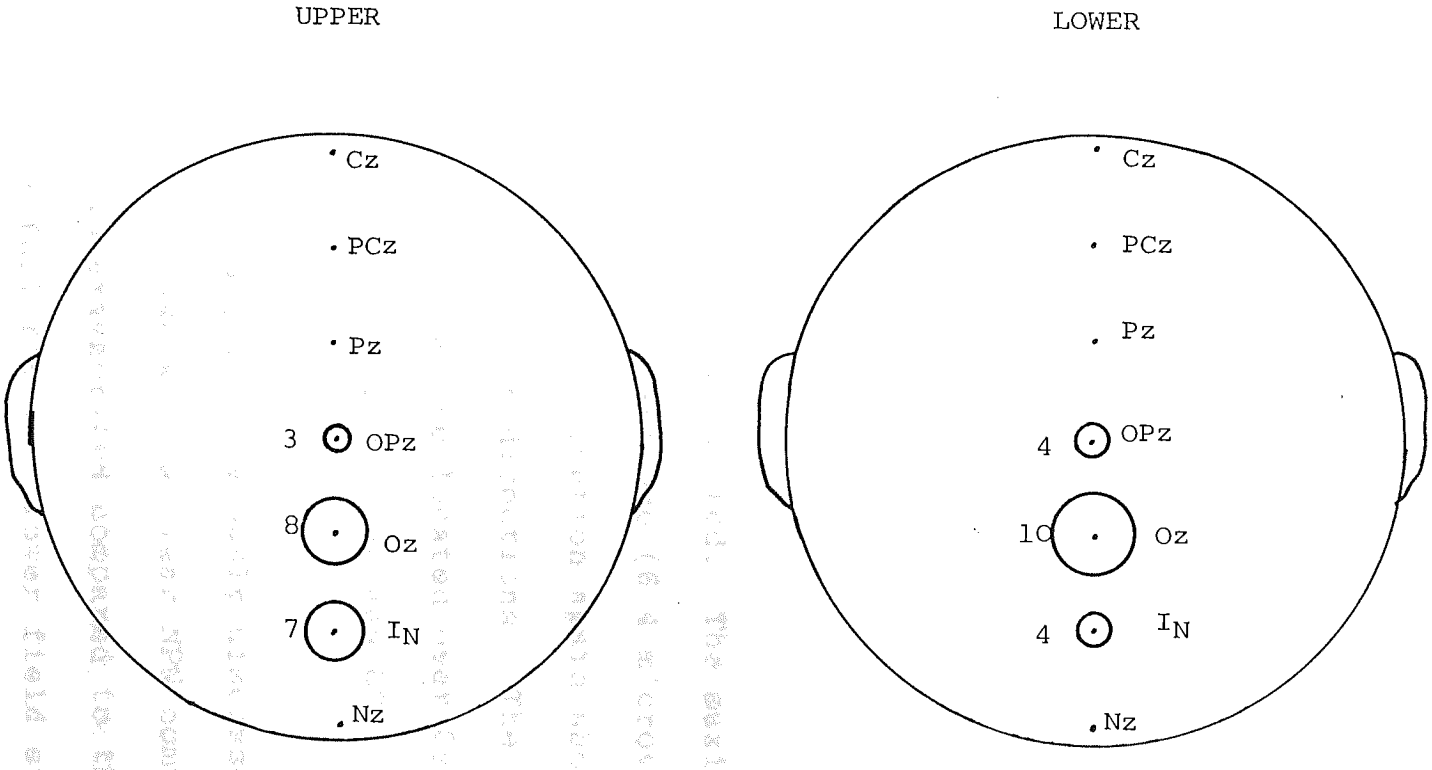


FIGURE 4.12 Position of maximum P100 component

occiput for the lower field stimulus.

When looking at the group average results the full field stimulus results showed the clearly formed NPN complex, discussed earlier, with a maximum amplitude over electrode O_Z (8.39 microvolts). The bipolar distribution showed current flowing away from O_Z in both directions, towards N_Z and C_Z. The main current generator of the P100 component is a source located at O_Z with a sink appearing between P_Z and CP_Z (Figure 4.11).

The lower field stimulus gave a very similar appearance, the main difference being the lack of the earlier N75 component. This is present in most individual traces but is obviously a less consistent component when only the upper hemiretina is stimulated. The maximum amplitude appears over the O_Z electrode (6.4 microvolts, S.D. 3.4). The bipolar distribution again showed current flowing away from Oz in both directions. The main current generator was a source located over Oz with a sink appearing between electrodes P_Z and CP_Z.

Upper field stimulation, as previously discussed, gave a later, broader response with a clear NPN complex. The N75 component is exaggerated compared to the results obtained by either full field or lower field stimulation. The maximum amplitude appeared over the O_Z electrode (4.33 microvolts, S.D. 1.82). The bipolar distribution showed current flowing in both directions over the head

but this time the channel representing the potential gradient between O_Z and PO_Z was relatively flat which may indicate that the current is flowing from an area somewhere above O_Z towards POz. The main current generator, however, was still predominantly a source over the O_Z electrode and the maximum sink appears to be between P_Z and CP_Z in a similar position to both whole field and lower field stimulation.

The source would appear to be generated around O_Z for all three stimuli and the position of the sink between electrode P_Z and CP_Z. When looking at the position of the sink it must be remembered that we are somewhat limited by the number of electrodes and may not in fact be indicating the position of the maximum sink. If the head was covered in a montage of equally spaced electrodes we may find a more diffuse area of current sink rather than the specifically localised areas like that found for the source. It is unlikely, however, that such an approach will ever prove practical for general clinical purposes without considerable technological advances in the recording techniques. The few studies that have looked at equipotential mapping over large areas of the scalp have often been limited to very small subject groups because of the recording problems (eg. Darcey 1979).

Figure 4.13 clearly shows the similarity of the source and sink distributions found by the source derivation technique for the seven electrodes used in our medially orientated montage.

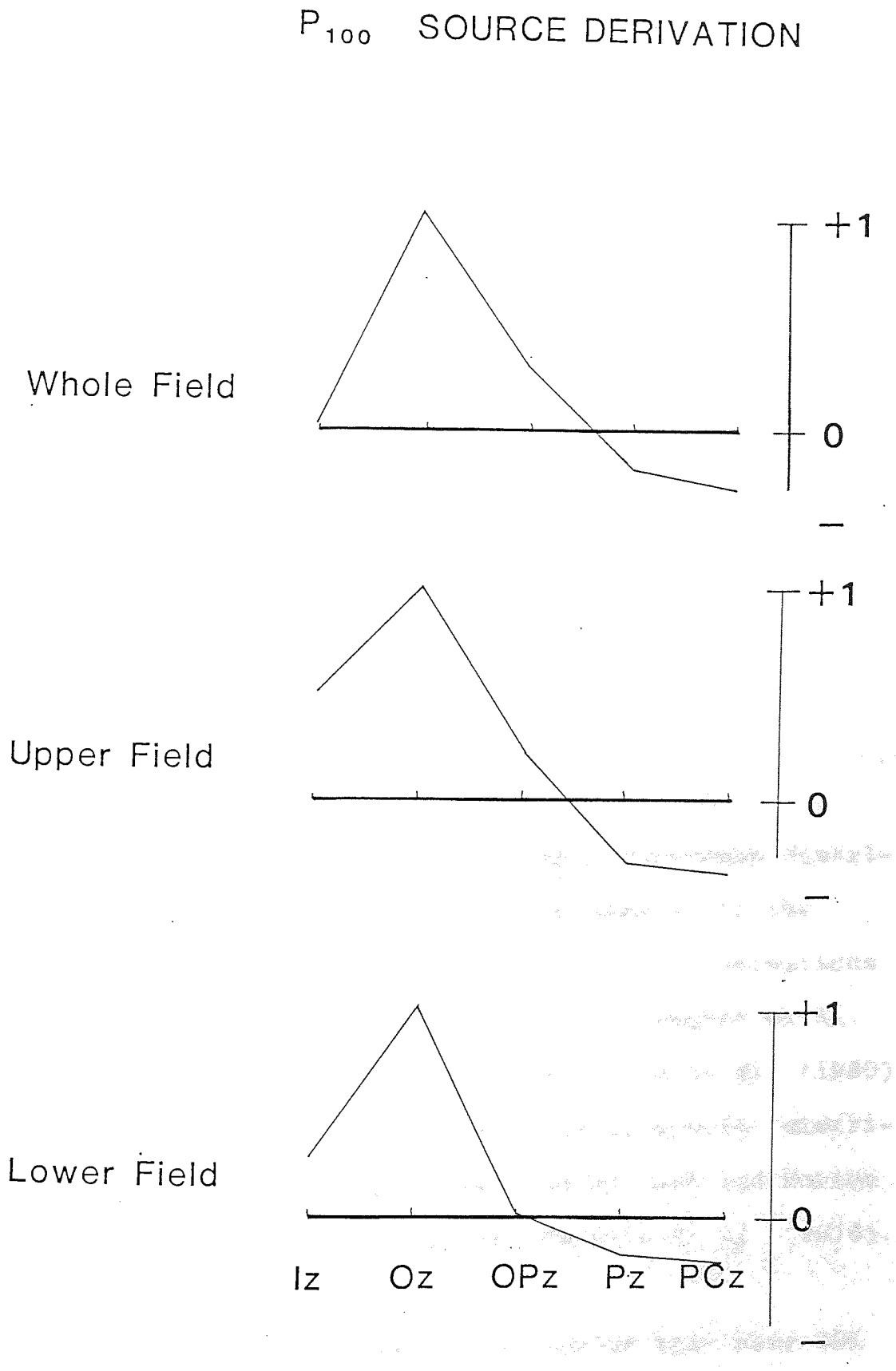


FIGURE 4.13 The source-sink distribution found by the source derivation technique for the seven electrodes used in the medially orientated montage

4.3.4 Discussion

Right and left half-field stimulation showed current flowing away from the same scalp source on the midline towards the cortex contralateral to the hemifield stimulated.

We have already discussed the many paradoxical results in the literature using half-field stimulation and different recording techniques. One of the advantages of the source derivation technique is that it removes many of the problems related to the reference from the interpretation of the VEP. The results presented are implicit within the findings of previous authors in spite of their apparently anomalous results (see Section 1.2.2).

Figure 4.10 illustrates how the common reference distribution gave a response which was ipsilateral to the stimulated hemisphere, thus confirming the observations of, for example, Barrett et al. (1976); Shagass et al. (1976); Blumhardt et al. (1978); Van Lith et al. (1980) and Harding et al. (1980). The computed bipolar distribution predicts the results reported by Cobb and Morten (1970); Shagass et al. (1976) and Barrett et al. (1976).

Upper and lower field stimulation showed that over 60% of the subjects demonstrated a stable source. The lower field stimulus did not give a significantly higher source over the occiput than the upper field stimulus. The

maximum amplitude for the P100 component was not significantly higher over the occiput for the lower field stimulus. When considering the literature (Section 1.2.3) this would appear a little surprising. There were undoubtedly individuals in this study who gave results in accordance with any one of these previous studies, but the overall result showed no significant difference. It must be noted that there is a considerable difference in the degree of asymmetry and phase-reversal in the previously presented results. At one extreme the very early results of Michael and Halliday (1971) show considerable variation in the position of the maximum response accompanied by complete phase reversal of the response to a lower field stimulus. Adachi-Usami and Lehmann (1982) reported no phase-reversal to a lower field stimulus and the difference in peak amplitude, although reported as being significant, was very small. It is likely, considering the orientation of the expected cortical sources for upper and lower field stimulation whether striate, parastriate or extrastriate, that the response to a lower field stimulus is likely to be more variable. Individuals within this study showed similar peak amplitude positions and no phase-reversal to a lower field stimulus; a higher peak amplitude over the head and phase-reversal over most electrodes; and a lower peak amplitude and no phase-reversal. The subject group as a whole did not show either of the latter trends. Kriss and Halliday (1980) published results that appear to be similar. Unfortunately,

they were used to illustrate a different subject area and the results have not been subsequently available with the relevant observations of amplitude and latency.

There was a significant mean average delay in latency of the P100 component of 7.5 milliseconds for lower hemiretinal stimulation, ie. the upper field stimulus. This is in total agreement with previous studies. It is interesting however, that there were a few individuals who showed very little difference between the two stimulus conditions, although no one gave an increased latency for the lower field stimulus. It may be possible that some people within the normal population do not have the "normal" degree of asymmetry between the lower and upper hemiretina and it would be interesting to investigate the reaction time differences and retinal sensitivity in these subjects. The pattern ERG may well give an interesting insight into these subjects with particular regard to retinal ganglion cell density.

Wildberger (1984b) has already illustrated how the asynchrony between the upper and lower field results can give a "PNP" type complex in a normal subject following full field stimulation. Our results confirm this asynchrony which may have serious implications over the scotomatous nature of the PNP complex as proposed by Blumhardt et al. (1978).

By combining the two normative subject groups it can be

seen that pattern reversal stimulation, for the test conditions stated, gives a maximum scalp potential source at O_Z. When stimulating different hemifields of the visual field, only the orientation of the associated scalp potential sink is altered.

The source derivation has proved to be useful clinically but we would advocate that it is always computed from a topographic, common reference potential distribution, which reflects the current flow in the scalp, and not recorded directly. With the new generation of computerised evoked potential equipment such computations are relatively easily performed and instantaneous in execution. The source derivation thus obtained can successfully identify the sources and sinks in the scalp current flow which is associated with the underlying cortical activity (Katznelson 1981).

The aim of using this technique was to add clinically useful information to a standard, clinical, recording technique within the constraints of time and patient fatigue. It is well accepted that the source derivation is a relatively crude approach when attempting to identify the cortical areas that are stimulated but it has never been our intention to introduce a technique which would compete with dipole modelling. We are attempting to establish the position over the scalp of the maximum current sources and sinks and thus help to establish a gross picture of a distant response when a large amount

of the visual cortex is stimulated. It has been estimated that stimulating the central 30^{o} of the visual field will activate some 60% of the striate cortex (Drasdo 1977; Drasdo and Peaston 1980).

4.4 Source Derivation and Evoked Potentials

Since performing these experiments there have been several published reports using source derivation to assist in the analysis of evoked potentials. MacKay (1983) discussed the technical requirements and electrode montage required. He considers that the technique "offers a picture with a higher spatial resolution and has less vulnerability to interferences than conventional monopolar or bipolar derivations, and it solves elegantly the problem of choice of reference electrode, which dogs monopolar recording". Although he does not consider it a true distribution of the scalp sources as the brain is a complex volume conductor. He proposes that the responses should be recorded directly which gives a better rejection of common-mode interference and that "massive computing facilities" would be required to compute the response. This is obviously a point of contention. In 1984, he published three further reports applying the techniques to event related potentials during evaluated action and to "mapping visual receptive fields".

Thickbloom et al. (1984) investigated the source derivation of the visual evoked potential to pattern reversal

stimulation of the left half-field using 30 electrodes over the scalp. They computed the source derivation and compared it to common reference recording, using a neck-chest reference, and average reference recording. They concluded that the source derivation technique was less influenced by the type of reference and that it had a greater spatial specificity for mapping the topography of the VEP.

CHAPTER 5

INVESTIGATION OF THE TOPOGRAPHY OF THE VISUAL EVOKED POTENTIAL

5.1 Introduction

The literature in Chapter 1 outlined the controversy regarding the distribution of the VEP particularly with relationship to patients demonstrating a visual field defect. Chapter 4 has outlined a new techique to assist in the interpretation of the VEP scalp distribution when recorded topographically. The aim of the studies in this Chapter is to provide detailed topographic information about the scalp potential field over a large range of different stimulus conditions. This was considered necessary as although each stimulus type may have been used previously there has not been a reported study using the same subjects and recording techniques and comparing the responses to the different stimuli. Stimulus and recording parameters can seriously affect the responses analysed and lack of standardisation between laboratories make comprehension of the results difficult. Some studies have used more recording sites but usually on fewer subjects (Darcey 1979 used 3 subjects of which one was dismissed for the purposes of analysis) and investigated fewer stimulus parameters.

The aim of the experiments, to be outlined, is to create a model of the topographic scalp distribution with respect to:

i/ the central and peripheral field characteristics by assessing the effect of various field and check sizes.

ii/ the effect of simulated visual field abnormalities and

iii/ the correlation between the scalp topography and the neural representation of the visual field by comparing the normal, full field results to those obtained using simulated field defects.

5.2 Method

The stimulus and recording techniques and instrumentation are those outlined in Chapter 5. It was important to achieve the maximum information from the minimum number of stimulus presentations owing to the vast range of stimulus conditions used. The following parameters were considered.

1. Field Size The largest field size approximated to that most commonly used for clinical assessment of the VEP in the clinic at Aston and has a diameter of 30^{o}. The smallest field size was 3^{o} which corresponds to the maximal foveal response (Drasdo 1982) and ensures, as far as possible, that it is principally the polar occipital projection which is stimulated. It was considered desirable to have an intermediate field size which would

help identify any trends found in the results elicited by the two extreme field sizes. From Drasdo's Graticule it can be estimated that the 30^{o} stimulus would activate c.60% of the striate cortex. The 3^{o} stimulus activates c.10%. Consequently, a field size of 10^{o} was chosen to supplement the experiments as this activates c.30% of the striate cortex, one half of the largest stimulus.

2. Check Size An attempt was made to approximately M-scale the stimuli bearing in mind the spatial tuning characteristics mentioned in Chapter 1. From the equations of Drasdo (1976, 1980), outlined in Chapter 3, the optimum check size for any given field size was calculated to be c.25, as this corresponds to the retinal receptive field size at the mid-point annulus (Drasdo 1982).

The angular subtense of the check used for each field size was therefore:

1/ 30^{o} field: 1.2^{o} or $1^{o}12'$ (actual size $1^{o}7'$)

2/ 10^{o} field: 0.4^{o} or 24' (actual size 22')

3/ 3^{o} field: 0.12^{o} or 7'12"

3. Electrode Montage For the reasons outlined in Chapter 4 it was considered necessary to investigate the source derivation of the scalp potential. Consequently the electrodes were required to be equally spaced and 10% was found to be ideal. MacKay (1983) had suggested an inter-electrode distance of between 1.5cm and 6cm. The standard 10-20 system introduced by Jasper (1958) could

thus be used and still fall within this specification. The other limitation was the number of channels available on the recording equipment. The Nicolet Pathfinder II was used in all experiments and has an 8-channel capacity. It was therefore decided to use the same montages as in Chapter 4 to investigate the topography of the VEP in both the transverse and medial planes.

The most controversial consideration was that of a reference. Although the various problems of reference have been discussed (1.6) it was decided to continue using the mid-frontal Fz electrode. This is ideally placed for the transverse electrode chain being approximately equidistant from all electrodes and is probably the least active cephalic reference being little affected by ERG, eye movement and myogenic artifact. It is not as ideally situated for the medial electrode montage. Nose, soft palate or chin reference would be more symmetrically situated but all have severe artifact restrictions. A non-cephalic site was considered impractical at that time judging from past experience within the Clinical Neurophysiology Unit, although with advancing technology such a reference should be periodically re-assessed. Another consideration was that we would be recording the source derivation which, even with the medial montage, helps to negate the problems of reference.

4. Simulation of Field Defects The aim was to simulate the effect of absolute and relative hemianopic,

altitudinal and central visual field defects. For the absolute scotomas masks were made to use in conjunction with the projection stimulus system which effectively resulted in half-field presentation to each of the four major meridians. Throughout the thesis the results will be discussed in terms of the stimulus rather than the stimulated hemifield, eg. a lower field stimulus would stimulate the upper hemiretina. The central field defect was simulated by masking the central 3^{o} of the visual field. The simulation of the relative scotomas used similar masks but with a 0.6 neutral density filter over the area of field depravation. This effectively reduced the luminance in this area by 60%.

5. Population Sample Owing to the number of stimulus parameters to be examined and the constraints of time, it was proposed to keep the number of subjects to a minimum but still allow for the possibility of statistical evaluation of the results. Consequently, 10 eyes were used. It was also considered important to investigate inter-ocular asymmetry as it has been generally accepted that in the case of a unilateral abnormality the unaffected eye provides a useful clinical comparison. Consequently, we examined both eyes of 5 subjects.

Two additional subjects were initially investigated to safeguard the minimum number of results required but they both failed to complete the full course of investigation. Each subject was male, because of the reported differences between the sexes (1.2.1), and between the ages of 19 and

25. The affect of age on the VEP to pattern-reversal stimulation is detailed in Section 1.2.1 and indicates that results found in this age group will extrapolate well to the population up until an approximate age of 65 years, although small checks and field sizes may restrict the upper age limit. The visual acuity was at least $^{6}/_{6}$ in each eye tested and there was no reported ophthalmological or neurological abnormality. Each subject was examined at the same time on the same day of the week to reduce as much as possible the effect of circadian rhythms. It took no longer than six months to complete each set of results and approximately eighteen months to complete all the investigations.

6. The Visual Field The visual fields were assessed by using the Octopus Automated Perimeter Programme 31 both with and without the 0.6 neutral density filter. Target size was used with a background luminance of 3.15 asb.

5.3 Full Field Stimulation

5.3.1 Transverse Montage Results

Stimulation of the central 30° of the visual field gave a similar response to the results presented in Chapter 4 with a clear NPN-complex which was maximum on the midline. Table 5.1 illustrates the individual latency and amplitudes following common reference recording and Table 5.2 shows the source derivation distributions measured at the same

FULL FIELD STIMULATION (TRANSVERSE MONTAGE)

	MD R.EYE	MD L.EYE	AC R.EYE	AC L.EYE	MW R.EYE	MW L.EYE	RD R.EYE	RD L.EYE	JR R.EYE	JR L.EYE	GROUP AVERAGE
	99msec	98msec	90msec	93msec	98msec	100msec	88msec	89msec	100msec	101msec	95.6msec
T5	1.10	0.83	2.45	2.50	2.57	2.30	0.63	1.92	3.18	0.66	1.81
O3	1.08	1.29	3.14	3.20	5.05	4.72	1.65	2.96	4.68	1.92	2.97
O1	2.59	2.89	5.25	4.86	6.68	6.41	4.89	5.77	5.89	3.48	4.87
30° Oz	3.57	4.15	5.57	4.90	7.48	7.20	5.76	6.58	5.09	3.51	5.38
O2	2.54	3.27	3.85	3.59	5.93	5.94	3.39	4.08	3.03	1.77	3.74
O4	0.98	1.86	3.11	3.29	4.76	5.14	0.70	1.25	1.28	0.16	2.25
T6	0.03	0.82	1.34	1.94	3.43	3.63	0.11	0.84	0.40	-0.34	1.29
	92msec	99msec	101msec	90msec	106msec	103msec	96msec	90msec	100msec	88msec	96.5msec
T5	2.48	1.25	2.97	2.97	-1.96	0.09	0.32	1.08	-0.14	0.90	0.99
O3	3.41	2.11	3.74	2.51	-1.23	1.47	0.49	1.38	1.40	2.16	1.96
O1	4.30	3.06	5.33	4.68	-0.11	2.17	3.37	4.20	2.82	2.91	3.27
10° Oz	4.36	3.23	4.92	4.07	0.07	2.17	4.36	4.86	3.12	2.97	3.41
O2	3.46	2.48	3.55	2.29	0.33	2.38	2.73	3.38	2.02	2.24	2.49
O4	1.97	0.73	3.80	2.33	-0.57	1.69	0.72	1.23	0.70	1.31	1.39
T6	1.06	0.10	1.96	0.68	-1.20	1.05	0.76	1.17	0.41	0.73	0.67
	107msec	102msec	127msec	106msec	102msec	108msec	108msec	97msec	115msec	111msec	110.3msec
T5	0.59	1.59	1.39	0.92	1.96	1.05	0.11	2.54	0.93	-0.30	1.08
O3	1.13	1.98	2.16	1.73	3.15	1.39	0.45	4.04	1.61	0.21	1.79
O1	1.89	2.54	3.27	2.89	3.38	2.05	1.70	4.63	2.07	0.93	2.54
3° Oz	1.85	2.48	3.22	2.95	2.80	1.42	2.04	4.03	2.13	1.32	2.42
O2	1.46	1.98	2.14	1.99	1.66	0.30	2.45	3.37	1.39	0.54	1.73
O4	0.20	0.82	2.22	1.63	0.70	-0.62	1.74	3.07	0.79	-0.08	1.05
T6	-0.40	0.73	1.60	1.13	0.66	-0.48	1.02	2.39	0.36	-0.55	0.65

TABLE 5.1 The individual latencies and amplitudes (microvolts) following common reference recording

FULL FIELD STIMULATION

(TRANSVERSE MONTAGE)

		MD R.EYE	MD L.EYE	AC R.EYE	AC L.EYE	MW R.EYE	MW L.EYE	RD R.EYE	RD L.EYE	JR R.EYE	JR L.EYE	GROUP AVERAGE
	O3	1.54	1.14	1.43	0.95	0.84	0.73	2.21	1.76	0.30	0.30	0.746
	O1	.54	0.35	1.80	1.61	0.84	0.90	2.36	2.00	2.00	1.54	1.394
30^{o}	Oz	2.00	2.13	2.03	1.36	2.34	2.04	3.24	3.30	1.26	1.77	2.147
	O2	.54	0.54	0.97	1.01	0.38	0.46	0.31	0.33	0.30	0.12	0.152
	O4	0.62	0.39	1.02	1.04	0.16	0.72	2.09	2.42	0.88	1.12	0.458
	O3	0.04	0.10	0.82	2.62	0.40	0.68	2.71	2.52	0.13	0.50	0.782
	O1	0.83	0.79	2.00	2.78	0.94	0.70	1.89	2.16	1.11	0.70	1. 39
10^{o}	Oz	0.95	0.91	0.96	1.17	0.09	0.20	2.62	2.14	1.40	0.79	1.065
	O2	0.59	1.00	1.61	1.82	1.16	0.89	0.37	0.67	0.22	0.21	0.168
	O4	0.57	1.12	2.08	1.69	0.27	0.05	2.04	2.09	1.02	0.36	0.375
								L	R			
	O3	0.21	0.16	0.35	0.34	0.96	0.30	0.90	0.92	0.23	0.21	0. 22
	O1	0.79	0.62	1.16	1.09	0.80	1.28	1.19	0.91	0.40	0.33	0.857
3^{o}	Oz	0.35	0.44	1.03	1.02	0.55	0.49	0.07	0.07	0.80	1.16	0.584
	O2	0.87	0.66	1.16	0.60	0.17	0.19	0.37	1.12	0.14	0.15	0.013
	O4	0.67	1.07	0.71	0.14	0.92	1.06	0.39	0.02	0.18	0.15	0.279

TABLE 5.2 The source derivation distribution
(microvolts cm^{-2})

latency. Figure 5.1 plots the group average P100 amplitudes for the common reference and source derivation distributions. Table 5.3 demonstrates the mean and median averages, standard error, range, interocular differences and distribution asymmetries of the group average.

5.3.2 Discussion

The mean latency elicited by stimulation of the central 30^{o} and 10^{o} of the visual field were very similar and in accordance with the results presented in Chapter 4. When compared to the study of Wright et al. (1985) in which the same stimulus equipment was used, the mean latency was earlier, 95.6 msec compared to 101.78 msec, with a smaller standard deviation, 5.06 compared to 7.64. These results were for the same number of subjects within the same age group. Only the overall field and check-size were different to this study being slightly smaller. This alone was unlikely to cause the difference reported as they were the same parameters used in Chapter 4. The recording equipment was, however, considerably different and reaffirms the necessity expressed by Halliday (1982) and discussed in 1.2.1, that each laboratory must define its own normative values.

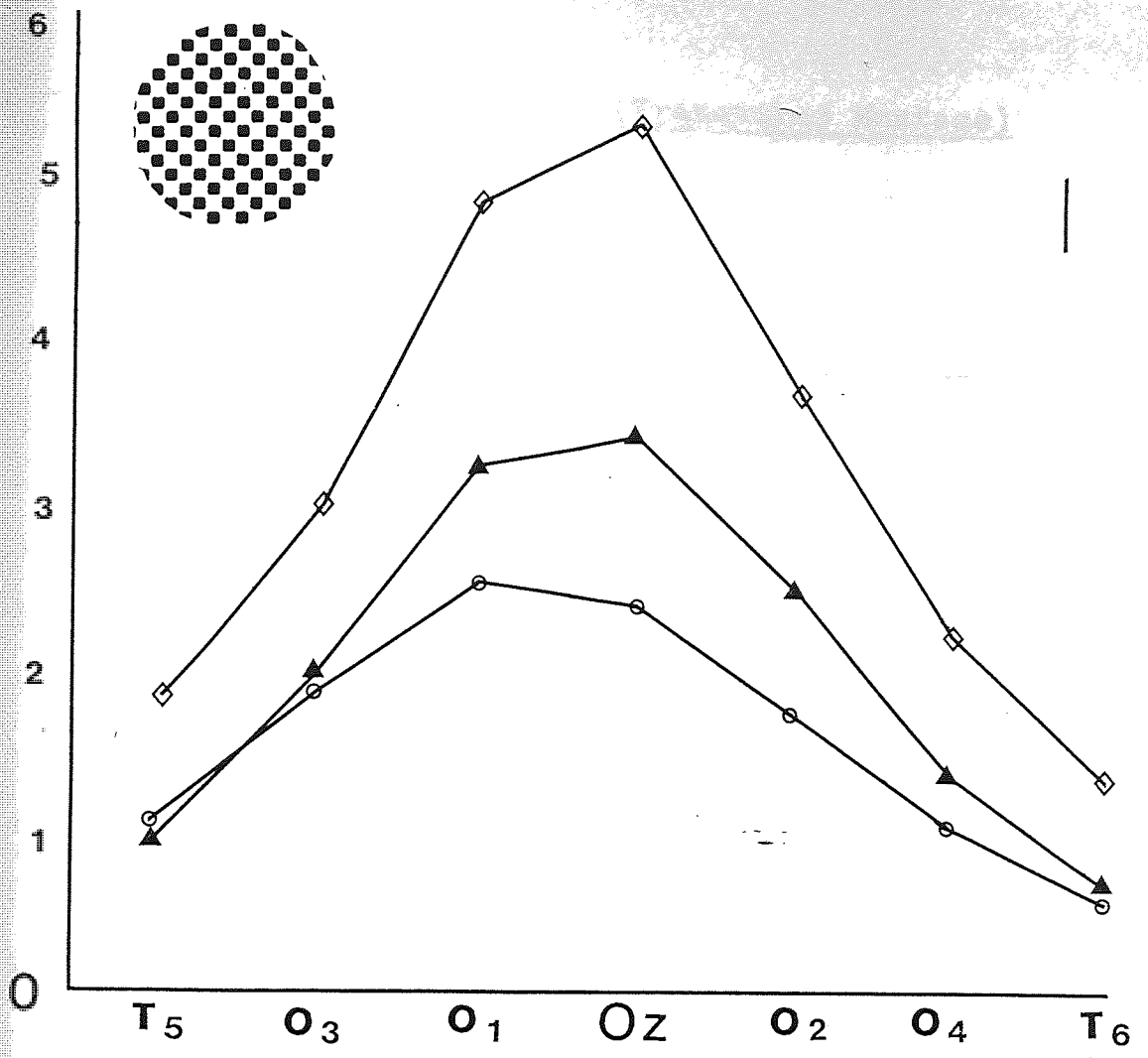
The mean peak latency elicited by stimulation of the central 3^{o} of the visual field was considerably delayed at 110.3 msec with a large standard deviation of 9.90 msec.

A t-test showed a significant difference between the latency obtained by the 30^{o} and 10^{o} stimuli compared to the 3^{o} stimulus ($p<0.01$, in both cases).

FIGURE 5.1

The Group Average Amplitudes for the Common Reference and Source Derivation Distributions Following Full Field Stimulation (transverse montage).

The source derivation distribution has been normalised to the maximum scalp current source.


6
5
4
3
2
1
0
μvlt
T5
O3
O1
Oz
O2
O4
T6

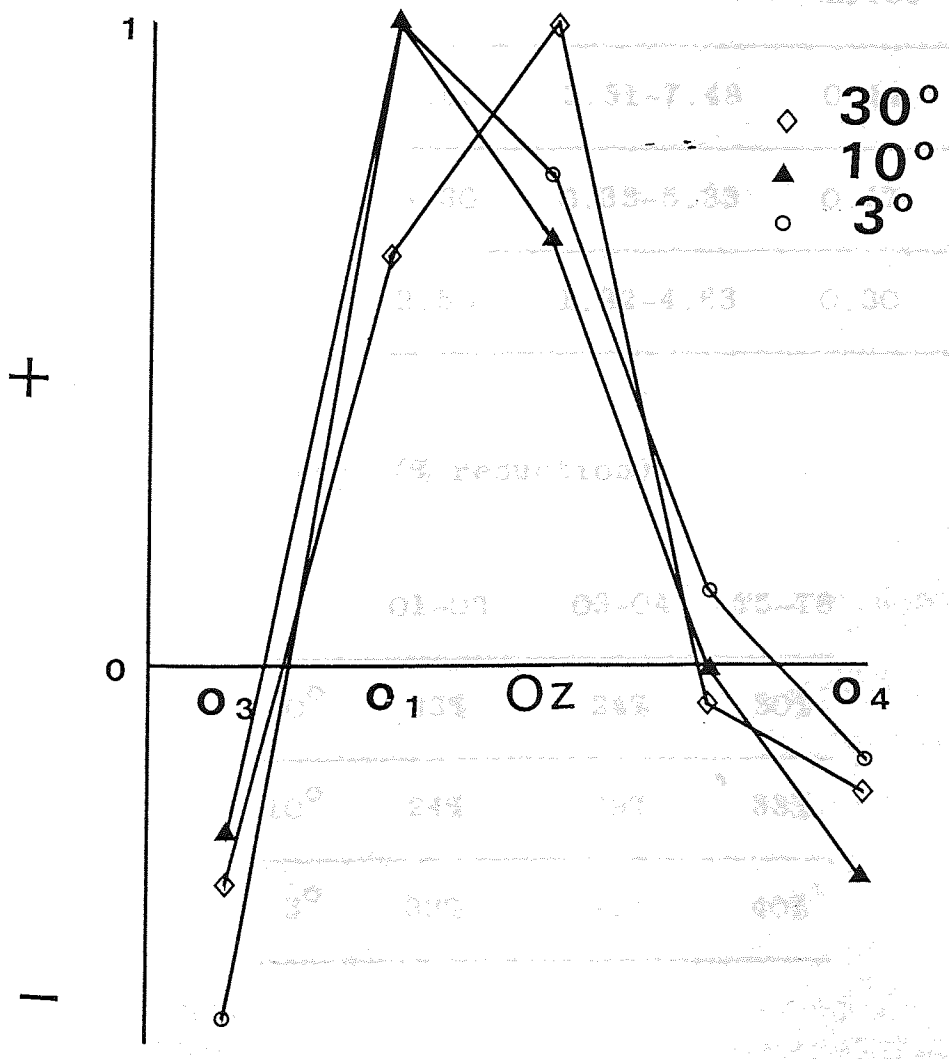

1
0
+
−
O3
O1
Oz
O4
30°
10°
3°

TABLE 5.3 FULL FIELD (Transverse Montage)

Latency (milliseconds)

Field Size	Mean	Median	Range	Standard Error	Intraocular Asynchrony
30°	95.6	98	88-101	1. 6	1.2
10°	96.5	97.5	88-106	1.97	5
3°	110.3	108	97-127	3.13	3

Amplitude (microvolts)

Field Size	Mean	Mean	Range	Standard Error	Intraocular Asymmetry
30°	5.46	5.65	3.51-7.48	0.44	0.22
10°	3.46	3.80	0.33-5.33	0.47	0.09
3°	2.66	2.50	1.32-4.63	0.30	0.03

Amplitude Asymmetry (% reduction)

	O1-O2	O3-O4	T5-T6
30°	23%	24%	30%
10°	24%	29%	33%
3°	32%	41%	40%

This compared favourably with the results discussed by Yiannikas and Walsh (1983) who found a P100 component of 96.2 msec for a 32^{o} field using 55' checks and of 109.2 msec with a greatly increased standard deviation, using a 2^{o} field. This was in spite of the check size remaining at 55'. They considered that the large check size had not been ideal for foveal stimulation. Our own study, by approximately M-scaling the stimulus, had presented much smaller checks, within the limits stated by Harter (1970) for eliciting a maximum response within the central 3^{o}, but still gave a delayed latency. Another possible explanation is the reduction in mean luminance as the field size is reduced. Such an explanation is unlikely considering the nature of the checkerboard stimulus but it is conceivable that a reduction in check size could result in reduced stimulus contrast owing to the modulation transfer function causing blurring on the retina. With the check sizes and high contrast used being above saturation level, this is also unlikely as the effect of blurring, even on the 7'12" check, will be negligible (Drasdo 1985: personal communication). A third possible explanation was that of poor fixation with narrow visual angles. All observers were well trained but it is indisputebly more difficult to maintain accurate fixation with such a small field and check size. This is a more probable explanation of the increased standard deviation rather than the overall trend of a delayed latency, particularly when considering the

response distribution and the indicated trend with decreasing field size.

If we accept that we are genuinely stimulating the foveal retina only, with this smallest field size, then we must also consider the anatomical differences of the central and peripheral retina as an explanation for the observed delay in latency. The increased standard deviation may be due to the large inter-individual variation in the projection of the striate cortex at the polar region of the occipital lobes (Stensaas et al. 1974). When large areas of the striate cortex, within the medial cortical field, are stimulated the affect of this variability would be reduced.

Similarly, when only stimulating the foveal projections, the cones, which dominate this area, tend to be more "sustained" in response. Admittedly the model of a central "sustained" system and peripheral "transient" system is rather simplistic but when stimulating the central 3^{o} of the visual field we are effectively at one extreme, and this may be at least part of the explanation for the observed response characteristics.

When looking at the inter-ocular latency asynchrony the difference is very small for each stimulus paradigm, thus agreeing with Celesia and Daly (1977); Blumhardt and Halliday (1979) and Kriss et al. (1982). Each subject

showed very close agreement for the 30° stimulus and were well within Halliday's (1982) suggested inter-ocular limit of abnormality of 8 msec for similar stimulus parameters. When using the 10° stimulus, although there was no overall trend, two of the subjects indicated a large inter-ocular asynchrony. Subject JR gave a 12 msec difference with the right eye giving the more delayed response. This was not found for either of the other two stimulus conditions and is about twice the standard deviation found for the mid-line electrode. Similarly, subject AC gave an 11 msec asynchrony with the right eye giving the more delayed response. In both cases the small asynchrony that was present was in the opposite direction for the 30° stimulus, ie. the left eye gave the slightly delayed response, but was of a similar direction, if not magnitude, for the 3° stimulus. This would suggest that the stimulus parameters used when eliciting a response from the central 10° of the visual field, are more likely to give rise to an inter-ocular latency difference.

The mean amplitude for the P100 component following stimulation of the central 30° was 5.46 microvolts which was 1.67 microvolts lower than that found using a similar technique in Chapter 4. The standard deviation was considerably lower at 1.40 compared to 3.46. Wright et al. (1985) found a slightly lower mean amplitude of 4.54 microvolts, but again produced a slightly higher standard deviation of 1.98. This simply highlights the large inter-individual variation in amplitude reported in the literature. When looking at the maximum amplitude for

each stimulus paradigm there was a reduction when a smaller field and check size was used, with the 30^{o} stimulus eliciting approximately twice the amplitude of the 3^{o} stimulus. There was a similar but less pronounced reduction in amplitude between the 10^{o} stimulus and the 3^{o} stimulus.

Yiannikas and Walsh (1983) predicted that the central 2^{o} contributed between 25 and 35% of the maximal response elicited by the 32^{o} stimulus. In our study the amplitude of the 3^{o} stimulus is nearly 50% of the maximal response to the 30^{o} stimulus. This clarifies further the affect of spatial tuning and the enhanced response gained by the approximate M-scaling. It would be incorrect to assume that it therefore contributes 50% of the response as the stimulus parameters have changed in both field and check size. Wright et al. (1985) maintained a constant field size but reduced the check size from 56' to 13'. The amplitude elicited by the latter was over 60% of the amplitude elicited by the former.

The average inter-ocular asymmetry is very low for each stimulus paradigm. The maximum individual inter-ocular asymmetry using the 30^{o} stimulus, subject JR, is within two standard deviations of the group mean amplitude. Subject RD, when using the 3^{o} stimulus, provided the only asymmetry which is not within two standard deviations, with a difference of 2.18 microvolts and a group mean standard deviation of 0.94. This is the same subject who gave a large inter-ocular latency asynchrony for the same stimulus parameters resulting in a significantly earlier and larger response from the left eyes. This was

not the case for the other stimulus paradigms.

When looking at the distribution of the response there is a marked hemispheric asymmetry in the group average with the electrodes over the left hemisphere recording the largest responses. Figure 5.1 clearly indicates the trend away from a maximum response on the midline, using the largest field and check size, to a maximum response over electrode O1 using the smallest field and check size. The 10^{o} stimulus provided a distribution lying somewhere between the two. Such an observation has never previously been reported. Even with the 30^{o} stimulus the distribution was not symmetrical around the midline, with a 23% reduction in amplitude when comparing electrode O2 to O1.

A t-test between the amplitudes obtained at electrodes O1 and O2 showed a significant difference for each stimulus condition ($p<0.01$ in each case). Analysis of variance between the 3 stimulus conditions showed a significant difference ($F_{12, 162} = 4.35$; $p<0.01$). Although a maximum response over electrode O1 has been identified for the 3^{o} stimulus a t-test showed no significant difference between the amplitudes at O1 and Oz. This was similar for the 10^{o} stimulus. Only the 30^{o} stimulus gave a significant difference ($p<0.01$).

Consequently we can predict that for all 3 stimulus conditions the scalp potential will be asymmetrical with a bias towards the left scalp. The 30^{o} stimulus will give a maximum response on the midline but the 10^{o} and

3^{o} stimulus will give a maximum over the Ol electrode or the midline, with no signficant difference between the two.

There are several possible reasons for such an asymmetry. First let us consider anatomical hemispheric asymmetry. If the right hemisphere was larger it would distort the expected midline symmetry by pushing past the midline towards the left hemisphere which would result in a maximum response over the left occiput. Three of the five subjects indicated a preference, or "dominance" towards using their right eye for simple observation tasks and were both right handed and right footed. One subject showed a left eye preference but was right handed and right footed. The remaining subject indicated a preference for using his left eye and was left handed and left footed. If we were to assume that the "dominant" hemisphere was the largest only the latter subject would completely support the hypothesis for a larger right hemisphere. Dimond (1972) in his book "The Double Brain" observed that the left hemisphere, if any, was usually the largest. By removing the results obtained from the left "sided" subject the trend was still present and would suggest that this hypothesis does not warrant further consideration.

Another possible anatomical variable is the skull. If this was generally thinner over the left hemisphere it may give rise to a larger amplitude recordable over the left occiput owing to reduced resistance. The author

has been unable to locate any reference to this in the literature. Simple measurements in three human skulls, using a caliper, also failed to indicate any support for this hypothesis. Similarly, asymmetry of bony landmarks in the occipital region, most notably the inion, could also contribute to the relative asymmetry of the VEP scalp topography. Again no conclusive evidence could be found to suggest a consistent skull asymmetry which would result in a "symmetrical" evoked potential distribution being distorted to give the asymmetrical scalp topography recorded.

The most likely explanation has already been discussed, although for different reasons, in Chapter 1. Smith (1907); Brodmann (1918); Polyak (1957) and Stensaas et al. (1974) have all noted considerable hemispheric asymmetry in anatomical studies of the human striate cortex. Wolfe (1944) discussed the inter-individual variation of the polar striate projections being dependent on the development of the parietal and temporal association areas. In later editions, however, this statement was retracted. They found that the striate area did not always reach the occipital pole but that if it did the amount of exposed striate was often larger on the left occipital lobe. This would adequately explain the group average results. When a large amount of the striate cortex is stimulated this asymmetry would be relatively masked but become increasingly apparent as the stimulus decreases in size to selectivity elicit a response from the foveal region. These

observations would support the discussion of Celesia et al. (1983). It must be remembered that although the stimulus conditions are M-scaled to give a maximum response over a known percentage of striate cortex they are not equally weighted. Consequently we have the added complication, if diffuse stimulation does not exist, of depth as discussed by Young (1981). He states that "in principle, the closer a generator site is to an electrode, the greater its contribution is to that electrode" but that "a large far-field potential cannot be readily distinguished from a small near-field potential". Such a principle would clearly distort our results but help explain why the suspected foveal asymmetry, at its polar occipital projection, still appears to influence even the largest field and check size used as a stimulus.

The source derivation distribution, which gives us a finer spatial mapping of the scalp potential, also supports this hypothesis with the maximum scalp current source switching from the midline, following the 30^{o} stimulus, to electrode O1 when the 10^{o} and 3^{o} stimuli were used.

If we go back to the results discussed in Chapter 4 in which the response of 20 right eyes were recorded using the same equipment and electrode montage but with slightly different stimulus parameters, the amplitude distribution was far more symmetrical with the O1 amplitude being only 0.02 microvolts larger than the O2

amplitude. By looking at the individual results, 9 of the 20 subjects showed a significant bias over the left occiput as we have discovered in this study; 4 gave an approximately symmetrical result; and 7 subjects gave a bias over the right occiput. These results must, however, be taken in context. We have already discussed how the asymmetry is relatively masked when a large amount of cortex is stimulated and without the results from the two smaller field sizes we would have struggled to identify an asymmetrical trend. What is clear is that it is important to perform a much more extensive study using larger subject groups to determine whether or not the trend we have observed from the 10 eyes and 5 subjects of this detailed study can be corroborated. If the subject group used in this study is found to be unrepresentative then the results at least demonstrate the severe problems associated with inter-individual variability when recording the VEP.

5.3.3 Medial Montage Results

Stimulation of the central 30^{o} of the visual field gave an NPN-complex which was maximum over the Oz electrode. Table 5.4 illustrates the individual latency and amplitudes following common reference recording and Table 5.5 shows the source derivation distribution measured at the same latency. Figure 5.2 plots the group average P100 amplitudes for the common reference and source derivation distributions. Table 5.6 demonstrates the mean and median averages, standard error, range

FULL FIELD STIMULATION (MEDIAL MONTAGE)

	MD R.EYE	MD L.EYE	AC R.EYE	AC L.EYE	MW R.EYE	MW L.EYE	RD R.EYE	RD L.EYE	JR R.EYE	JR L.EYE	GROUP AVERAGE
	96msec	96msec	91msec	97msec	95msec	100msec	92msec	91msec	94msec	100msec	95.2msec
Cz	0.16	0.19	0.71	0.34	0.86	0.67	-0.10	0.35	0.18	0.41	0.377
CP2	0.64	0.78	1.72	0.94	1.80	1.29	-0.20	0.79	0.37	0.88	0.901
Pz	1.71	2.30	3.91	2.24	3.23	2.61	0.47	1.86	1.05	1.73	2.111
30^{o} POz	4.06	5.01	7.68	5.55	5.07	4.20	2.82	5.02	2.52	2.74	4.467
Oz	3.88	4.59	6.66	4.91	6.00	4.68	5.69	7.54	4.79	3.76	5. 25
I_N	3.54	4.09	4.50	3.89	4.57	2.54	5.73	5.17	4.43	2.92	4.138
Nz	2.77	3.72	3.55	3.63	2.17	0.45	4.00	3.07	3.14	1.84	2.834
	104msec	99msec	101msec	96msec	100msec	104msec	90msec	90msec	93msec	95msec	97.2msec
Cz	-0.15	0.32	0.27	0.76	0.54	-0.01	0.55	-0.04	0.06	0.20	0.255
CP2	0.19	1.32	0.79	1.50	0.79	0.27	0.76	-0.17	0.04	0.63	0.646
Pz	0.77	2.48	2.07	2.71	1.11	0.62	1.41	0.58	0.73	1.52	1. 40
10^{o} POz	2.07	4.52	5.32	5.92	2.39	1.91	3.26	2.38	2.30	3.11	3.318
Oz	2.67	4.27	5.00	5.58	3.11	2.44	5.73	4.82	4.78	5.08	4.348
I_N	2.37	3.71	3.33	3.98	2.06	2.46	4.46	3.84	4.55	4.68	3.544
Nz	2.17	3.23	1.96	3.30	1.19	2.35	4.18	3.02	3.75	3.54	2.869
	109msec	108msec	120msec	112msec	100msec	113msec	98msec	100msec	119msec	107msec	108.6msec
Cz	-0.55	-0.45	0.01	0.98	-0.29	0.95	-0.44	0.46	-1.01	0.69	-0.035
CP2	-0.59	-0.27	0.04	1.09	-0.32	1.50	-0.37	0.54	-0.75	0.81	-0.133
Pz	-0.41	0.04	0.08	1.46	-0.26	1.55	-0.32	0.80	-0.41	1.21	-0.374
3^{o} POz	0.74	0.51	1.48	3.25	0.46	2.34	0.02	1.55	0.12	1.77	1.224
Oz	1.74	0.82	2.42	4.28	1.00	2.89	1.26	2.63	1.02	3.45	2.151
I_N	1.43	0.77	1.36	3.39	1.44	2.98	1.34	2.20	1.54	3.73	2.018
Nz	1.13	0.50	0.80	2.72	1.58	2.38	0.80	1.30	0.99	3.13	1.533

TABLE 5.4 The individual latencies and amplitudes (microvolts) following common reference recording

FULL FIELD STIMULUS

(Medial Montage)

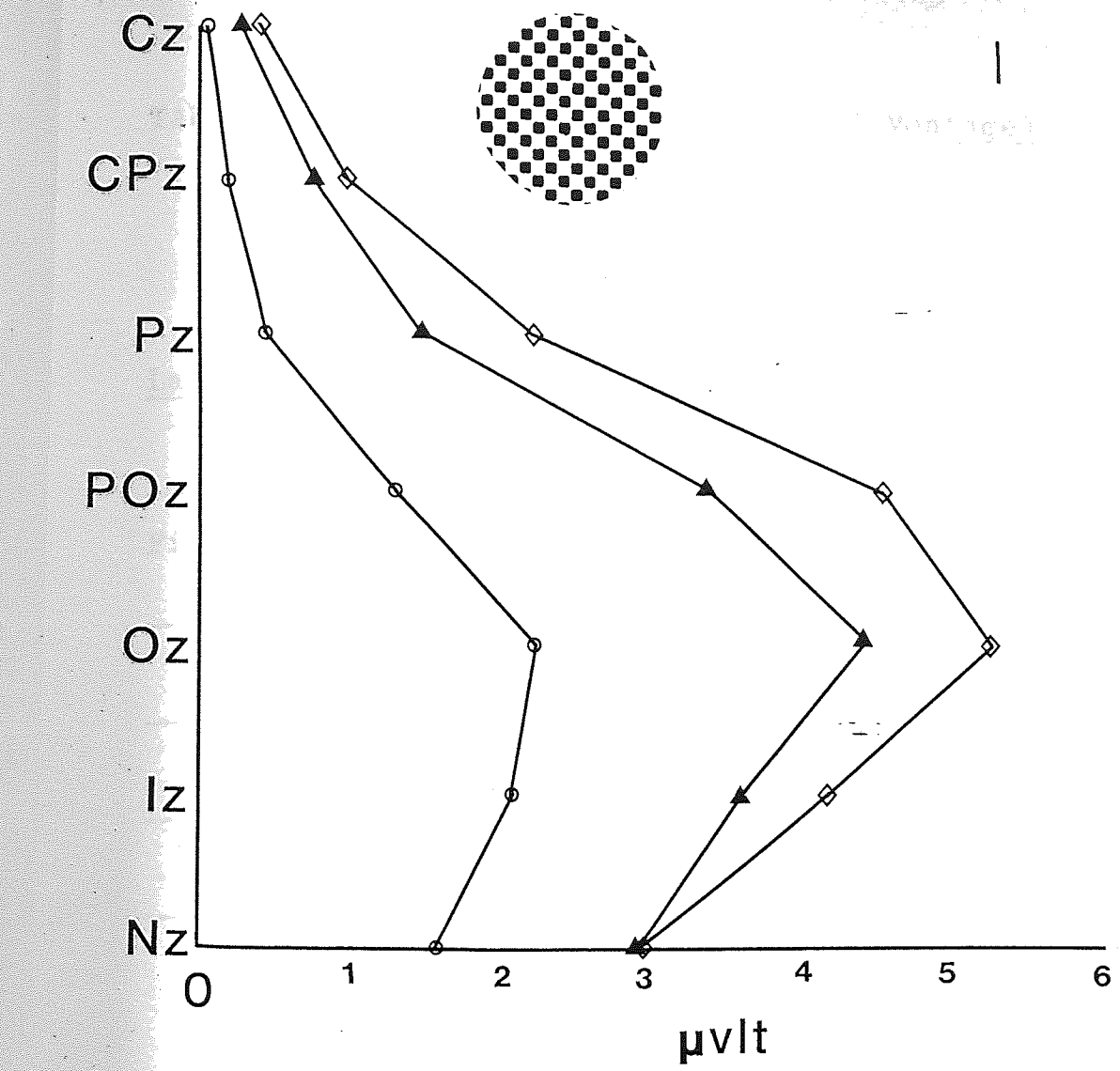
		MD R	MD L	AC R	AC L	MW R	MW L	RD R	RD L	JR R	JR L	GROUP AVERAGE
	CPz	0.60	0.94	1.18	0.71	0.48	0.70	0.39	0.63	0.48	0.38	0.649
	Pz	1.27	1.18	1.58	2.00	0.42	0.28	1.88	2.09	0.79	0.15	1.164
30^{o}	POz	2.53	3.13	4.79	3.95	0.91	1.12	0.15	0.64	0.81	0.01	1. 64
	Oz	0.16	0.09	1.13	0.37	2.36	2.61	4.25	4.89	2.64	1.85	2.035
	IN	0.43	0.14	1.21	0.75	0.98	0.05	0.14	0.28	0.92	0.25	0.001
	CPz	0.23	0.07	0.76	0.46	0.07	0.06	0.44	0.21	0.71	0.46	0.347
	Pz	0.73	0.30	1.96	2.00	0.95	0.95	1.20	1.38	0.88	0.69	1.044
10^{o}	POz	0.71	2.28	3.57	3.55	0.55	0.77	0.63	0.65	0.91	0.39	0.885
	Oz	0.90	0.86	1.35	1.26	1.78	0.50	3.75	3.41	2.71	2.38	1.718
	IN	0.11	0.22	0.30	0.93	0.18	0.14	0.99	0.15	0.57	0.75	0.142
	CPz	0.23	0.13	0.01	0.25	0.09	0.20	0.01	0.18	0.07	0.28	0.143
	Pz	0.96	0.16	1.37	1.43	0.66	0.38	0.30	0.48	0.20	0.16	0. 61
3^{o}	POz	0.15	0.16	0.47	0.76	0.18	0.22	0.89	0.34	0.36	1.12	0.077
	Oz	1.32	0.36	1.99	1.92	0.10	0.47	1.15	1.51	0.37	1.40	1.059
	IN	0.02	0.23	0.49	0.22	0.30	0.69	0.63	0.48	1.07	0.88	0.355

TABLE 5.5 The source derivation distribution

(microvolts cm^{-2})

FIGURE 5.2

The Group Average Amplitudes for the Common Reference and Source Derivation Distributions Following Full Field Stimulation (medial montage).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CPz
Pz
POz
Oz
Iz
Nz
0
1
2
3
4
5
6
µvlt

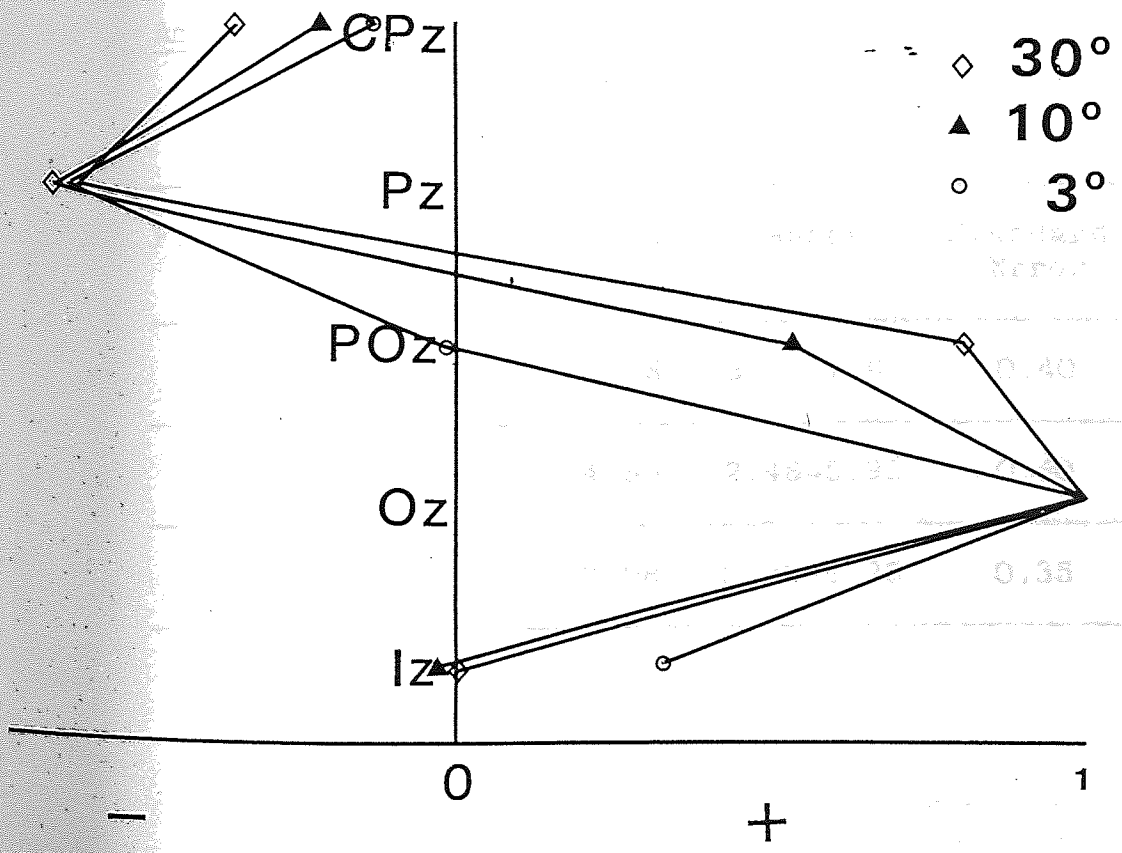

CPz
Pz
POz
Oz
Iz
30°
10°
3°
0
1
−
+

TABLE 5.6 FULL FIELD (Medial Montage)

Latency (milliseconds)

Field Size	Mean	Median	Range	Standard Error	Interocular Asynchrony
30°	95.2	95.5	91-100	0.99	3.2
10°	97.2	97.5	90-104	1.65	0.8
3°	108.6	108.5	98-120	2.43	1.2

Amplitude (microvolts)

Field Size	Mean	Median	Range	Standard Error	Interocular Asymmetry
30°	5.48	5.28	3.76-7.68	0.40	0.3
10°	4.44	4.80	2.46-5.92	0.40	0.18
3°	2.31	2.08	0.82-4.28	0.35	1.32

and inter-ocular differences of the group average.

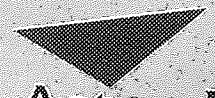
5.3.4 Discussion

The mean latencies and inter-ocular latency asynchronies for the 3 stimulus paradigms, were very similar to those found using the transverse montage. A t-test showed no significant difference between the latencies found for the 30^{o} and 10^{o} stimuli; a highly significant difference between the 30^{o} and 3^{o} stimuli ($p<0.001$); and a highly significant difference between the 10^{o} and 3^{o} stimuli ($p<0.001$). Neither of the subjects who had demonstrated a large inter-ocular asynchrony for the 10^{o} stimulus gave the same result, thus further demonstrating the innate variability of the VEP. When using the 3^{o} stimulus subject RD did not reaffirm the asynchrony indicated when using the transverse montage but subjects AC, MW and JR all gave asynchronies of 8, 13 and 12 msec respectively which were not present previously. Such differences are still within two standard deviations of the mean latency and indicate the further variability of the small field and check response.

The mean amplitudes and inter-ocular asymmetries for the 30^{o} and 10^{o} stimulus were very similar, on the midline, to that using the transverse montage. The inter-ocular asymmetry found when using the 3^{o} stimulus is very much larger than any of the other results so far discussed. There would also appear to be a vast morphological difference with the right eyes giving a phase-reversed PNP-complex over the more anterior electrodes which is

not present on left eye stimulation. Unfortunately the numbers are insufficient to draw any conclusions but would certainly warrant further investigation.

When we stimulate the right eye we are activating the nasal upper and lower projections at the polar occipital region of the left cortical hemisphere and the temporal upper and lower projections at the right cortical hemisphere and vice-versa for the left eye. The lower hemiretinal projection is orientated in such a way as to most likely produce a response which is maximal, for small check and field sizes, at a position lower over the scalp than the upper hemiretinal projection (Figure 5.3 after Holmes 1945). Similarly, we might expect a more anteriorly phase-reversed response. We have also discussed the relative dominance of the nasal hemiretina (Celesia and Meredith 1982). Consequently, if the left, occipital, polar projections are more exposed, as suggested in the previous Section, then we might expect a response which is influenced more noticeably when the right eye is stimulated as this involves stimulation of the right, nasal, lower hemiretina which is the most likely projection, in isolation, to give a PNP-complex over the more anterior electrodes. It is tempting to suggest therefore that the responses recorded may further support the idea of a more exposed foveal striate at the left hemisphere, but we have insufficient data, at present, to state this with confidence. Analysis of variance comparing the amplitude distributions of the two eyes



Aston University

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showed no significant difference ($F_{6,48} = 0.46$).

The distribution of the group average results showed a maximum response, for the P100 component, over the Oz electrode for all stimulus conditions. On more careful examination, however, there is a trend for the maximum amplitude to range from Oz to POz for the 30° stimulus and to switch below Oz for the 3° stimulus. There is a small 7% reduction in amplitude when comparing POz to the inion for the 30° stimulus; a 13% switch to a 6% reduction at POz when compared to the inion for the 10° stimulus; and a 39% reduction in the amplitude of POz compared to the inion for the 3° stimulus. The difference in the distribution between the three stimulus conditions was confirmed using analysis of variance comparing the amplitude of each stimulus condition at the seven electrodes used. The interaction variance ratio was significant with p 0.01 ($F_{12,162} = 6.99$).

This slight difference in the distribution is again most likely to be explained in terms of the polar striate activity, when the foveal retina is stimulated, eliciting a smaller, more localised response between Oz and the inion, compared to the larger cortical activity generated by the 30° stimulus, which is influenced by the peripheral striate projections within the medial fold, orientating the maximum response towards POz rather than the inion.

The source derivation distribution indicated a maximum

source-sink configuration between Oz and Pz for each stimulus used.

5.4 Half Field Stimulation

5.4.1 Right Half Field Results

Table 5.7 illustrates the individual latencies and amplitudes following common reference recording and Table 5.8 shows the source derivation distribution measured at the same latency. Figure 5.4 plots the group average P100 amplitudes for the common reference and source derivation distributions. Table 5.9 demonstrates the mean and median averages, standard error, range, inter-ocular differences and distribution asymmetries of the group average.

5.4.2 Left Half Field Stimulation

Table 5.10 illustrates the individual latencies and amplitudes following common reference recording and Table 5.11 shows the source derivation distribution measured at the same latency. Figure 5.5 plots the group average P100 amplitudes for the common reference and source derivation distributions. Table 5.12 demonstrates the mean and median averages, standard error, range, inter-ocular differences and distribution asymmetries of the group average.

RIGHT HALF FIELD STIMULATION

	MD R.EYE	MD L.EYE	AC R.EYE	AC L.EYE	MW R.EYE	MW L.EYE	RD R.EYE	RD L.EYE	JR R.EYE	JR L.EYE	GROUP AVERAGE
	92msec	99msec	94msec	95msec	98msec	100msec	90msec	93msec	92msec	96msec	94.9msec
T6	0.06	0.86	0.36	1.88	0.11	0.73	-1.42	-1.24	-0.52	-1.09	-0.211
O4	0.30	0.63	2.08	3.55	1.70	2.55	-1.31	-1.04	0.49	0.04	0.713
O2	1.85	1.20	2.63	4.81	3.56	4.17	1.72	1.54	1.81	1.95	2.524
30° Oz	3.11	2.71	3.43	5.17	4.57	4.80	3.15	2.34	2.27	3.13	3.468
O1	3.07	2.47	2.71	3.98	3.95	4.48	2.88	1.82	2.14	3.04	3.054
O3	2.45	2.23	2.16	3.63	3.18	3.97	2.54	1.81	2.55	3.32	2.784
T5	2.06	1.70	1.75	2.83	2.79	3.28	2.12	1.50	2.54	2.74	2.331
	92msec	95msec	92msec	100msec	108msec	100msec	88msec	95msec	83msec	91msec	94.4msec
T6	0.66	1.38	0.71	0.75	2.35	0.53	-0.88	-0.45	2.28	0.72	0.805
O4	1.21	2.04	1.25	1.53	3.52	1.14	-0.71	-0.37	2.83	1.84	1.428
O2	2.41	3.04	2.38	2.28	4.00	1.51	2.09	1.81	2.81	2.68	2.502
10° Oz	2.83	3.31	2.13	2.25	3.59	1.33	2.71	4.00	2.29	1.51	2.559
O1	2.61	2.86	1.37	1.67	3.38	1.15	2.32	1.77	2.08	2.93	2.214
O3	2.17	1.80	1.28	1.55	2.99	1.36	1.83	1.59	2.14	2.63	1.931
T5	1.74	1.18	0.23	0.61	2.50	1.19	1.40	0.88	1.56	1.88	1.317
	112msec	93msec	123msec	106msec	109msec	108msec	96msec	91msec	110msec	110msec	105.8msec
T6	0.96	0.54	1.16	1.33	-0.98	0.49	0.06	0.46	1.62	-0.32	-0.532
O4	0.93	1.33	1.86	1.60	-0.57	1.35	0.79	1.64	2.06	0.00	1.099
O2	1.61	1.57	2.66	2.45	0.19	1.21	1.21	3.03	2.27	0.70	1.735
3° Oz	1.38	1.29	2.37	2.55	0.04	1.22	1.01	2.52	2.31	1.11	1. 58
O1	0.95	1.39	1.51	1.84	-0.16	1.18	0.70	1.69	1.89	0.88	1.187
O3	0.03	1.05	1.84	1.67	-0.33	0.68	0.45	1.36	1.55	0.38	0.869
T5	-0.41	1.16	1.34	1.13	-0.43	0.49	0.25	0.95	1.26	0.43	0.567

TABLE 5.7 The individual latencies and amplitudes (microvolts) following common reference recording

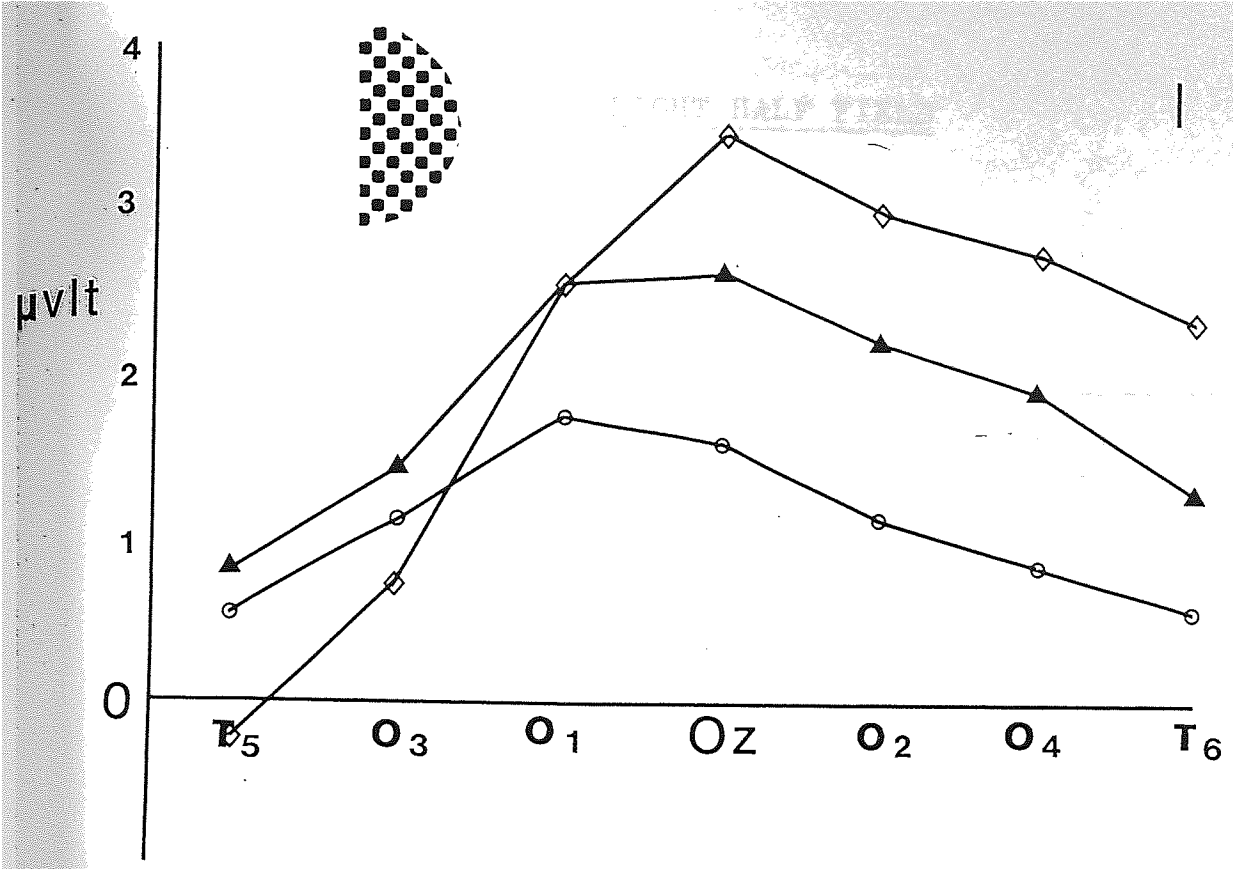
RIGHT HALF FIELD STIMULUS

		MD R	MD L	AC R	AC L	MW R	MW L	RD R	RD L	JR R	JR L	GROUP AVERAGE
	O3	2.39	1.60	1.17	0.42	0.28	0.20	2.93	2.36	0.31	0.79	0.887
	O1	0.89	0.32	0.25	0.89	0.86	1.00	1.61	1.76	0.87	0.72	0.867
30°	Oz	1.31	1.75	1.52	1.55	1.62	0.95	1.70	1.33	0.57	1.28	1.358
	O2	0.57	0.01	0.17	0.84	0.14	0.19	0.07	0.50	0.52	0.38	0.143
	O4	0.22	0.29	0.13	0.45	0.37	0.18	0.08	0.30	0.41	0.87	0. 26
	O3	0.63	0.34	0.59	0.04	0.69	0.23	2.64	2.10	0.57	0.28	0.449
	O1	0.77	0.74	1.38	0.78	0.89	0.55	2.18	1.76	0.50	0.56	1.011
10°	Oz	0.65	0.71	0.50	0.54	0.20	0	1.02	0.89	0.31	0.30	0. 41
	O2	0.21	0.61	0.66	0.45	0.17	0.38	0.10	0.29	0.27	0.27	0.069
	O4	0.01	0.44	0.96	0.81	0.11	0.37	0.06	0.53	0.63	0.45	0.335
	O3	0.71	0.55	0.11	0.59	0.36	0.54	0.21	0.30	0.23	0.37	0.073
	O1	0.91	0.52	1.11	0.75	0.91	0.76	1.89	0.63	0.17	0.27	0.792
3°	Oz	0.21	0.38	0.56	0.82	0.05	0.40	0.32	0.11	0.46	0.65	0. 24
	O2	0.54	0.43	1.18	0.55	0.03	0.46	0.51	0.05	0.08	0.27	0. 07
	O4	0.60	0.45	0.82	0.37	0.07	0.32	0.09	0.43	0.05	0.55	0.033

TABLE 5.8 The source derivation distribution
(microvolts cm^{-2})

FIGURE 5.4

The Group Average Amplitudes for the Common Reference and Source Derivation Distributions Following Stimulation of the Right Half Field


4
3
µvlt
2
1
0
T5
O3
O1
Oz
O2
O4
T6

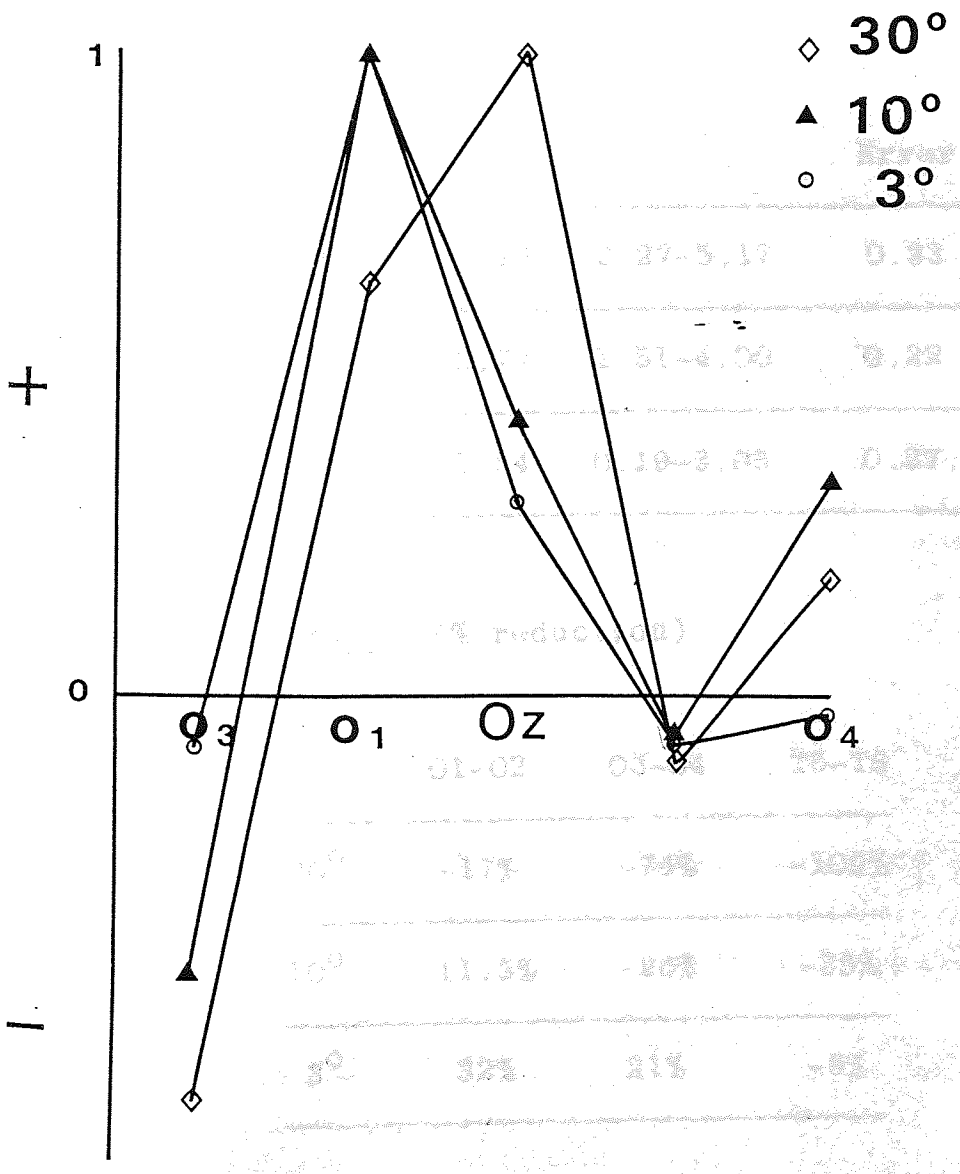

30°
10°
3°
1
+
0
−
O3
O1
Oz
O4

TABLE 5.9 RIGHT HALF FIELD

Latency (milliseconds)

Field Size	Mean	Median	Range	Standard Error	Interocular Asynchrony
30°	94.9	95.5	90-100	1.05	3.4
10°	94.4	93.5	83-108	2.22	3.6
3°	105.8	107	91-123	3.10	8.4

Amplitude (microvolts)

Field Size	Mean	Median	Range	Standard Error	Interocular Asymmetry
30°	3.47	3.14	2.27-5.17	0.33	0.32
10°	2.7	2.77	1.51-4.00	0.22	0.3
3°	1.79	1.64	0.19-3.03	0.27	0.32

Amplitude Asymmetry (% reduction)

	O1-O2	O3-O4	T5-T6
30°	-17%	-74%	-109%
10°	11.5%	-26%	-39%
3°	32%	21%	-6%

LEFT HALF FIELD STIMULUS

		MD R.EYE	MD L.EYE	AC R.EYE	AC L.EYE	MW R.EYE	MW L.EYE	RD R.EYE	RD L.EYE	JR R.EYE	JR L.EYE	GROUP AVERAGE
		98msec	116msec	90msec	89msec	98msec	106msec	95msec	89msec	101msec	102msec	98.4msec
	T5	1.93	2.41	4.11	1.62	2.08	0.97	1.75	1.53	1.90	1.28	1.958
	O3	2.43	3.02	4.28	0.97	2.50	2.02	2.86	2.34	2.62	2.20	2.524
	O1	2.51	3.32	6.75	2.93	2.33	2.32	3.48	2.86	3.07	2.55	3.212
30°	Oz	2.38	3.27	6.79	3.34	2.26	2.21	3.38	2.72	2.03	1.75	3.613
	O2	1.04	2.80	4.60	1.65	1.55	0.86	0.95	1.24	0.11	0.21	1.501
	O4	-0.75	1.64	4.07	0.98	0.40	-0.21	-1.01	-0.43	-1.47	-1.25	0.197
	T6	-1.33	0.75	1.66	-0.38	-0.10	-0.62	-0.91	-0.87	-1.87	-1.61	-0.528
		94msec	103msec	94msec	100msec	104msec	103msec	87msec	86msec	89msec	100msec	96msec
	T5	1.53	1.10	1.01	2.86	-0.28	1.59	1.25	1.16	1.27	1.68	1.317
	O3	2.32	1.53	1.09	3.89	0.27	2.48	1.58	1.88	2.30	2.23	1.957
	O1	2.13	1.73	3.03	5.28	0.41	2.72	2.59	2.46	2.57	2.30	2.522
10°	Oz	2.01	1.40	3.27	5.45	0.48	2.55	3.06	2.92	2.81	1.84	2.579
	O2	1.22	0.64	1.76	4.15	0.15	2.73	2.50	2.32	2.43	0.82	1.872
	O4	0.09	-0.98	0.93	4.02	-0.50	1.91	1.27	1.06	1.89	-0.26	0.943
	T6	-0.39	-1.58	-0.20	2.47	-0.39	1.56	0.62	0.52	1.66	-0.40	0.387
		102msec	97msec	115msec	118msec	98msec	117msec	92msec	106msec	103msec	109msec	105.7msec
	T5	-0.22	0.50	0.52	1.12	0.70	0.77	1.16	1.74	0.80	0.65	0.774
	O3	-0.22	1.52	0.65	0.77	0.90	1.13	1.70	2.80	1.13	1.03	1.141
	O1	0.39	1.82	1.36	1.77	0.63	1.13	1.80	2.61	1.16	1.03	1. 37
3°	Oz	0.48	2.05	1.71	1.64	0.93	1.09	1.92	2.76	1.10	0.91	1.459
	O2	0.37	2.26	1.23	0.65	1.80	0.84	1.95	3.14	0.86	0.29	1.339
	O4	-0.91	1.18	0.68	0.86	2.05	0.47	1.91	2.98	0.33	-0.38	0.917
	T6	-1.34	0.58	0.54	0.02	1.57	0.49	1.32	1.89	-0.04	-0.81	0.422

TABLE 5.10 The individual latencies and amplitudes (microvolts) following common reference recording

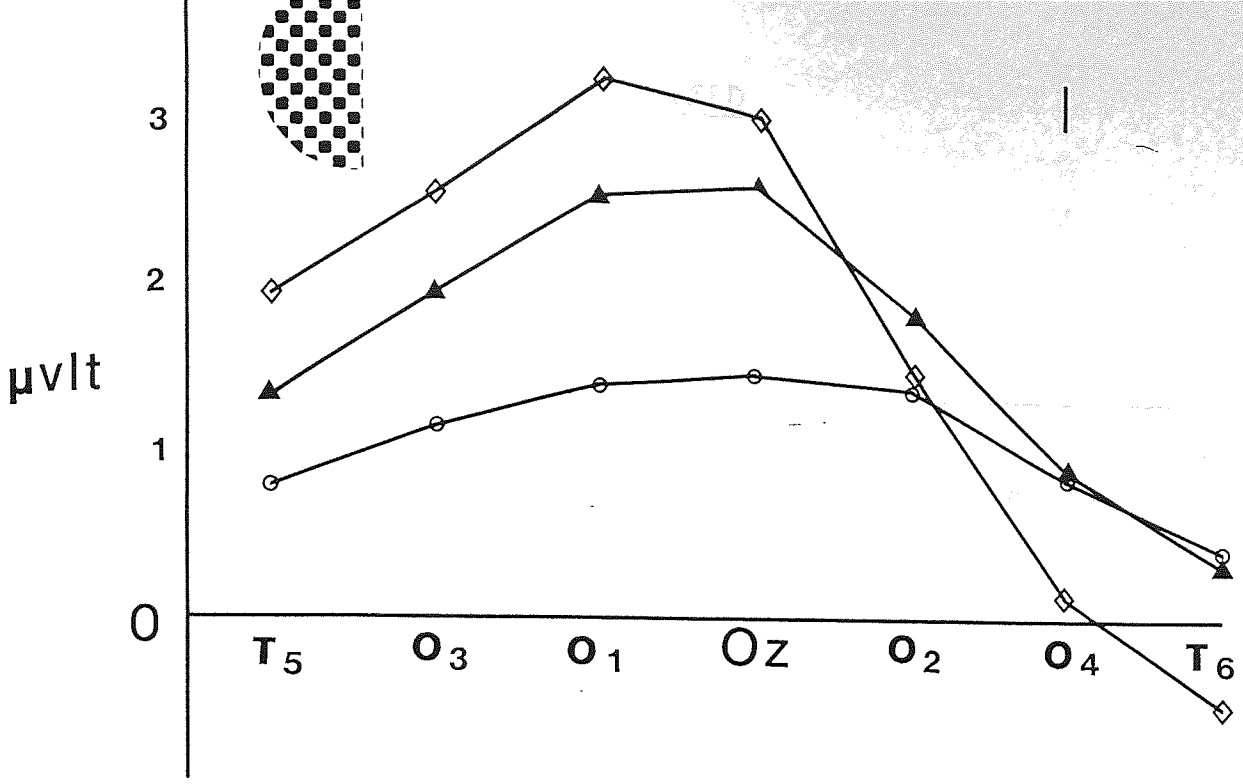
LEFT HALF FIELD STIMULUS

		MD R	MD L	AC R	AC L	MW R	MW L	RD R	RD L	JR R	JR L	GROUP AVERAGE
	O3	0.41	0.32	2.31	2.61	0.58	0.75	0.49	0.29	0.58 L	0.27 R	0.123
	O1	0.21	0.34	2.44	1.54	0.10	0.40	0.73	0.66	1.14	1.49	0.885
30°	Oz	1.22	0.43	2.22	2.10	0.64	1.25	2.32	1.35	0.73	0.88	1.314
	O2	0.43	0.69	1.66	1.02	0.45	0.27	0.47	0.19	0.08	0.35	0.209
	O4	1.20	0.27	1.89	0.70	0.65	0.68	2.06	1.23	1.09	1.18	0.577
	O3	0.99	0.23	1.86	0.36	0.41	0.66	0.68	0.14	0.76	0.49	0.078
	O1	0.07	0.52	1.71	1.22	0.06	0.40	0.55	0.13	0.04	0.52	0.508
10°	Oz	0.66	0.43	1.74	1.47	0.41	0.34	1.02	1.05	0.62	0.55	0.761
	O2	0.35	0.86	0.68	1.17	0.31	0.99	0.68	0.67	0.16	0.07	0.224
	O4	0.66	1.02	0.30	1.43	0.76	0.46	0.57	0.71	0.30	0.94	0.277
	O3	0.61	0.71	0.58	1.35	0.47	0.37	0.44	1.24	0.30	0.37	0.136
	O1	0.52	0.06	0.35	1.12	0.57	0.05	0.01	0.33	0.09	0.11	0.139
3°	Oz	0.21	0.04	0.84	0.86	0.57	0.20	0.09	0.23	0.18	0.51	0.213
	O2	1.17	1.28	0.06	1.19	0.62	0.12	0.06	0.54	0.28	0.05	0.299
	O4	0.85	0.48	0.41	1.04	0.73	0.39	0.57	0.93	0.15	0.24	0.075

TABLE 5.11 The source derivation distribution
(microvolts cm^{-2})

FIGURE 5.5

The Group Average Amplitudes for the Common Reference and Source Derivation Distributions Following Stimulation of the Left Half Field


3
2
µvlt
1
0
T5
O3
O1
Oz
O2
O4
T6

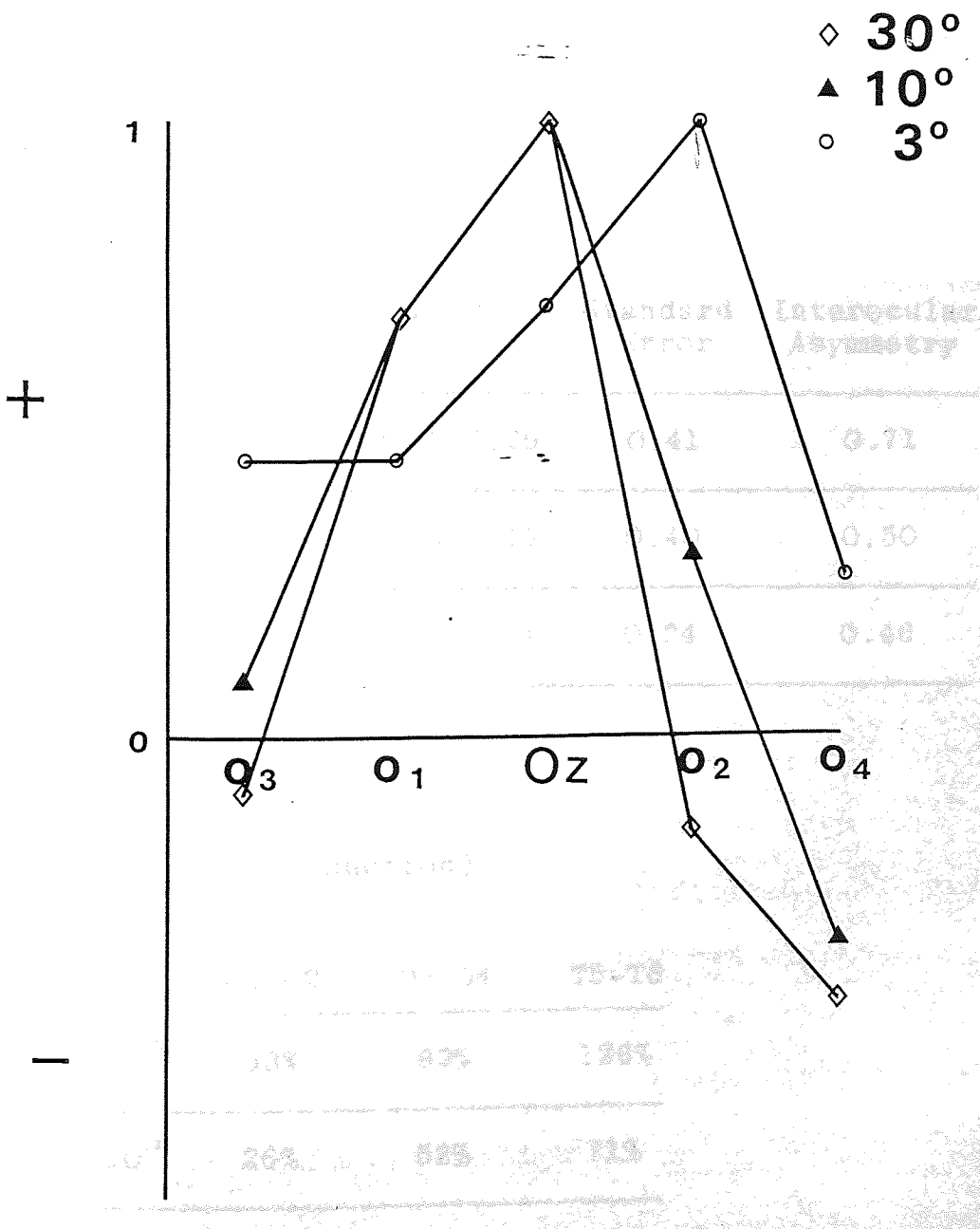

30°
10°
3°
1
+
0
O3
O1
Oz
O2
O4
−

TABLE 5.12 LEFT HALF FIELD

Latency (milliseconds)

Field Size	Mean	Median	Range	Standard Error	Interocular Asynchrony
30°	98.4	98	89-116	2.68	4.0
10°	96	97	86-104	2.19	4.8
3°	105.7	105	92-118	2.83	7.4

Amplitude (microvolts)

Field Size	Mean	Median	Range	Standard Error	Interocular Asymmetry
30°	3.27	2.97	2.32-6.79	0.41	0.71
10°	2.7	2.77	0.48-5.45	0.40	0.50
3°	1.67	1.74	0.48-3.14	0.24	0.46

Amplitude Asymmetry (% reduction)

	O1-O2	O3-O4	T5-T6
30°	53%	92%	126%
10°	26%	52%	71%
3°	2%	19.5%	45%

5.4.3 Discussion

The mean latency on the midline, using the O-15° stimulus, was similar to that following full field stimulation when the right half field stimulus was used. The left half field stimulus gave a slightly later mean latency with a far larger standard deviation of 8.47 msec and exhibited a maximum amplitude over the O1 electrode. The inter-ocular asynchrony was much the same for all three stimulus conditions. When the O-5° stimulus was used the peak latency and inter-ocular asynchrony was similar for all three stimulus conditions with the maximum amplitude on the midline. When the O-1½° stimulus was used the mean latency was c.5 msec earlier following half field stimulation compared to full field stimulation. The inter-ocular asynchrony was far larger following half field stimulation with the nasal hemiretina giving a later response which may suggest that it is dominant in deciding the latency and morphology of the full field response. This observation is supported by the results of Todd Meredith and Celesia (1982) who found the superior and nasal hemiretinae gave "better" results than the inferior and temporal hemiretinae. A t-test comparing the latencies elicited from the nasal hemiretina of each eye compared to the temporal hemiretina indicated a significant difference ($p < 0.02$). The maximum amplitude following the left half field stimulus was over the midline rather than the O1 electrode as it was for the right half field and full field stimuli.

The mean amplitude of the P100 component showed a similar reduction for both half field stimuli compared to full field stimulation. The O-15° stimulus gave a 36% reduction on the midline for the right half field stimulus and a 44% reduction for the left half field stimulus. The inter-ocular asymmetry was similar for all three stimuli. The O-5° stimulus gave a 25% reduction on the midline for the right half field and a 24% reduction for the left half field. The O-1½° stimulus gave a 32% reduction on the midline for the right half field and a 40% reduction for the left half field although the latter gave a maximum amplitude over the O1 electrode.

There was, however, a striking difference in the distribution asymmetry for the two half field results. The O-15° stimulus gave an amplitude distribution which was clearly ipsilateral to the stimulated hemifield for both stimulus conditions. When compared to the full field results there was a 40% difference between the O1 and O2 electrodes following the right half field stimulus but only a 21% difference following the left half field stimulus. Similarly between electrodes O3 and O4 there was a 98% difference for the right half field but only a 51% difference for the left half field.

The O-5° stimulus gave an amplitude distribution which was rather misleading on first inspection. The right half-field results appeared contralateral to the stimulated hemifield and the left half field result clearly ipsilateral. When we compare the amplitude

asymmetries between the O1 and O2 electrodes to the full field distribution asymmetry the right half field result was 12.5% more ipsilateral whereas the left half field result showed only a 2% change and cannot be considered significantly different. The right half field result was more ipsilateral by 58% at the O3 and O4 electrodes but the left half field result was more ipsilateral by 23%.

The amplitude distribution following stimulation of the O-1½° right half field appeared even more contralateral to the hemifield stimulated when observed in isolation. Indeed, this would be in accordance with the literature (1.2.2) which states quite categorically that the half field response to small fields and small checks is contralateral to the stimulated hemifield. When comparing the amplitude reduction between electrodes O1 and O2 the asymmetry was identical to the full field response and therefore showed no evidence of lateralisation. The reduction between electrodes O3 and O4 was 21% which is only 20% different from the full field response but in an ipsilateral direction to the stimulated hemifield. Electrode T5 was reduced by 6% when compared to the amplitude at T6 which is a 46% more ipsilateral response. The distribution is therefore more ipsilateral to the stimulated hemifield but can only be considered conclusive at a laterality 30% from the midline.

The amplitude distribution following stimulation of the O-1½° left half field appeared, in isolation, to be symmetrical around the midline. When compared to the full

field distribution the reduction between electrodes O1 and O2 was 30% less and in a direction which was contralateral to the stimulated hemiretina and as such was the first stimulus condition discussed to give a contralateral response. Similarly, the reduction between electrodes O3 and O4 was 21.5% more contralateral to the stimulated hemiretina when compared to the full field response. The asymmetry at the T5 and T6 electrodes is very similar to that found for full field stimulation and therefore displays no clear lateralisation.

The difference in the distribution between the three stimulus conditions was confirmed using analysis of variance comparing the amplitude of each stimulus condition at the seven electrodes used. The right half field results gave an interaction variance ratio which demonstrated a highly significant difference with $p < 0.001$ ($F_{12,162} = 13.26$). The left half field results showed a similar level of significance with $p < 0.001$ ($F_{12,162} = 12.28$).

The source derivation distribution confidently revealed a contralateral source-sink configuration for the $0\text{-}15^{o}$ and $0\text{-}5^{o}$ stimuli. The $0\text{-}1\frac{1}{2}^{o}$ stimuli elicited a maximum scalp current source over the contralateral hemisphere but did not exhibit a scalp current sink. This was not surprising as the source derivation technique only allowed an evaluation of the scalp potentials to electrodes 20% lateral to the midline.

In summary, if we chose an optimistic definition of abnormality as an inter-hemispheric reduction in amplitude of 40% we would be confident of detecting an absolute left homonymous hemianopic defect, from a good observer, at a 10% laterality for the 30^{o} full field stimulus; a 20% laterality for the 10^{o} full field stimulus; and only a 30% laterality for the 3^{o} full field stimulus. For a right homonymous hemianopia the situation appeared far less reliable with only the 30^{o} full field stimulus at a 20-30% laterality capable of confidently predicting the defect. If, however, we chose the more commonly accepted level of abnormality as a 50% reduction in amplitude we would only be confident of discovering the extreme left hemianopia at a 20% laterality for the 30^{o} and 10^{o} full field stimulus and would never be confident, within a 30% laterality of the midline, for a 3^{o} full field stimulus. For a right hemianopia we would again only be confident at a 20% laterality for the 30^{o} full field stimulus.

These observations are confirmed by using analysis of variance. The interaction variance ratio when comparing the amplitude for the full field and right half field 30^{o} stimuli, at each of the seven electrodes, showed a significant difference in the distribution ($F_{6,108} = 13.49$, $p < 0.01$). When comparing the full field and left half field results the difference in the distribution was also significant ($F_{6,108} = 12.77$; $p < 0.01$). The 3^{o} full field and right half field results gave an interaction variance ratio which was not significant

($F_{6,108} = 2.28$). Similarly, the 3^{o} full field and left half field results gave a ratio which was not significant ($F_{6,108} = 2.41$).

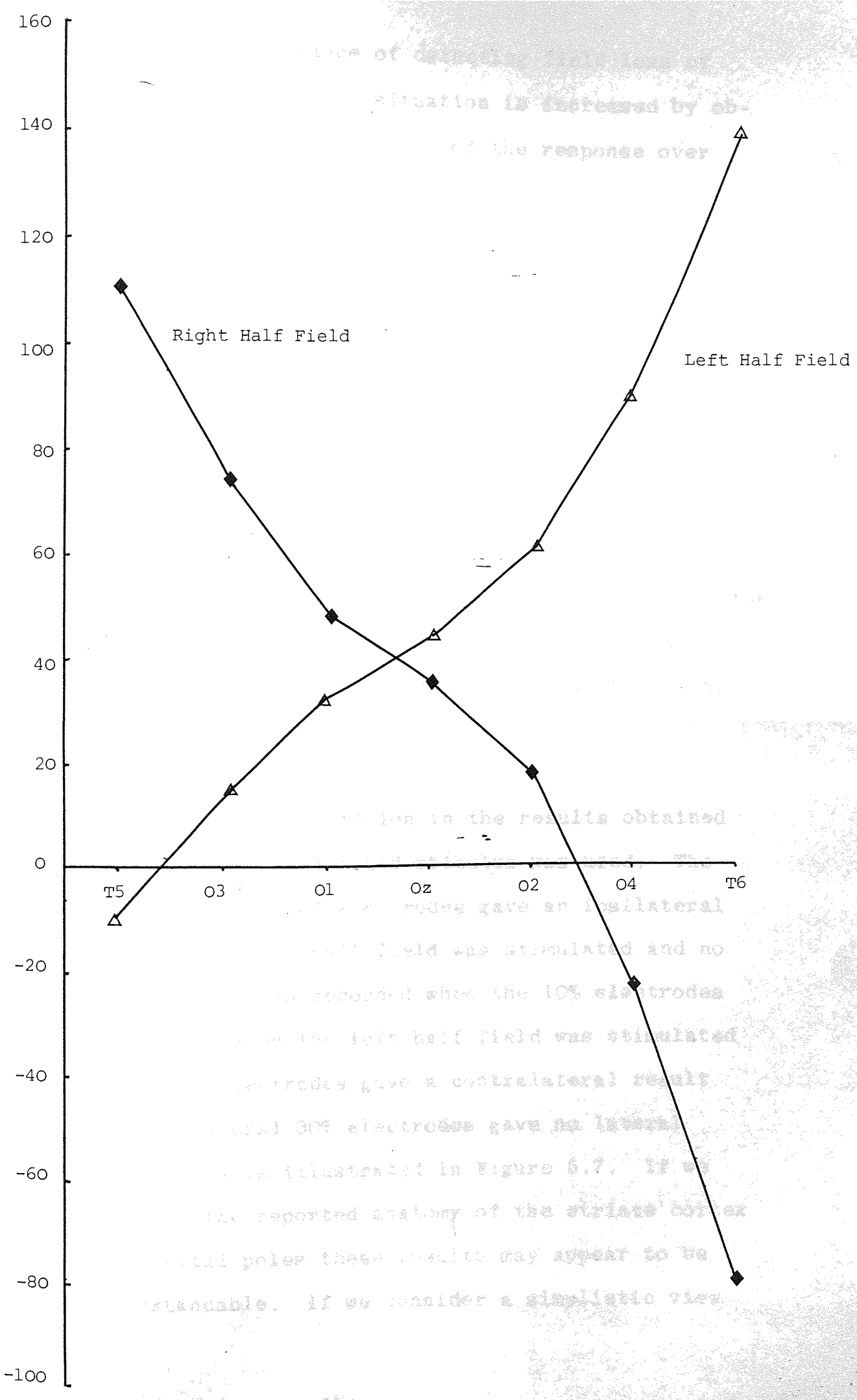
These results were unexpected and rather surprising. It has been common practise, in the literature, to pool the right and left half field results as we have done in Chapter 4. This is clearly incorrect and will distort the results. It also helps to explain why full field stimulation of patients with suspected hemianopic defects has led to such controversy. In isolation, results, particularly when using electrodes close to the midline, may appear contralateral when in fact they are considerably ipsilateral to the stimulated hemifield. Doubt has been raised as to the relevance of predicting a classical hemianopic result from normal half field results (Section 1.5 and 1.6). Again this is more understandable when we realise the topography of the full field result is not necessarily symmetrical around the midline and thus complicates the half field result. Unfortunately, as expected from the anatomy studies discussed earlier, there are individuals who do give a relatively symmetrical result on full field stimulation. Two of the 10 eyes examined did not show the degree of asymmetry demonstrated in the group average giving the more "traditional" symmetrical distribution around the midline. Interestingly, these 2 eyes demonstrated the "normal" half field response found in the group average results and discussed above.

If we re-examine the results from Chapter 4 the left half field stimulus (Figure 1.20) showed a maximum over electrode O1 as found in this study. This would appear to confirm that the majority of the population would demonstrate a bias towards an exaggerated scalp potential recordable over the left hemisphere.

Rather than further denigrating the use of normal half field stimulation as a model for hemianopic visual field loss the results may prove to reaffirm the relationship and if examined carefully may help clarify some of the problems involved. The importance of the more lateral electrodes may also help provide further understanding of the results obtained from different montages. In 1.6 we discussed at length the problems of comparing the widely spaced occipital-rolandic bipolar montage to a common reference montage. It is likely that the relative activity of the C3 and C4 electrodes on half field stimulation help to exaggerate the contralateral response following full field stimulation of a hemianopic subject. Common reference recording would only be reliable if electrodes are at least 20% from the midline and large field and check sizes are used. Full field stimulation of the foveal region in patients with macula splitting may not prove particularly beneficial. Figure 5.6 illustrates the percentage reduction at each electrode for the half field results compared to the full field result. These observations are based purely on amplitude asymmetry which is the only available method of quantification and as such demands the attention it

FIGURE 5.6

The Percentage Reduction for the Half Field Results Compared to the Full Field Results (30^{o} stimulation)


160
140
120
100
80
60
40
20
0
-20
-40
-60
-80
-100
Right Half Field
Left Half Field
T5
O3
O1
Oz
O2
O4
T6

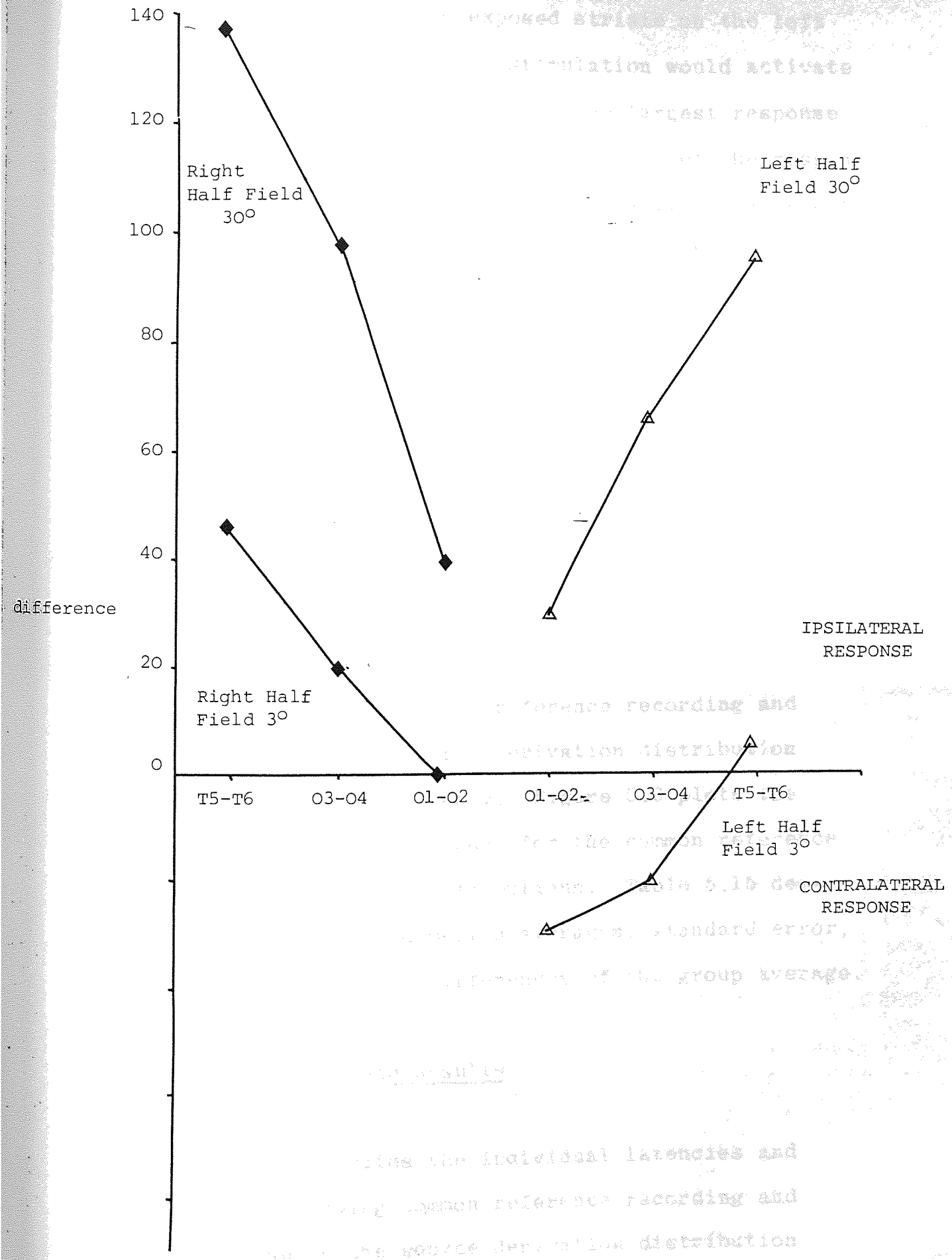
has received. The chance of detecting field loss of this kind in the clinical situation is increased by observing the relative morphology of the response over each occiput.

The results highlight the clinical usefulness of the half field stimulus. Even in the last example of using a foveal stimulus on a patient with macula splitting the distribution of the preserved half field becomes relatively unimportant if the opposite half field result is absent. It is the relative hemianopic defects which may still present a major problem in interpretation of the results obtained. It would also appear that only the largest field and check sizes should be used clinically if full field presentation is the only available means of stimulation.

The most obvious contradiction in the results obtained was when the 0-1½° half field stimulus was used. The more lateral 20 and 30% electrodes gave an ipsilateral result when the right half field was stimulated and no lateral dominance was recorded when the 10% electrodes were examined. When the left half field was stimulated the 10 and 20% electrodes gave a contralateral result and the most lateral 30% electrodes gave no lateral dominance. This is illustrated in Figure 5.7. If we again look at the reported anatomy of the striate cortex at the occipital poles these results may appear to be more understandable. If we consider a simplistic view

FIGURE 5.7

The Amplitude Distribution Asymmetry for the Half Field Results Compared to the Full Field Result


140
120
100
80
60
40
20
0
difference
Right
Half Field
30°
Left Half
Field 30°
IPSILATERAL
RESPONSE
Right Half
Field 3°
T5-T6
O3-O4
O1-O2
O1-O2
O3-O4
T5-T6
Left Half
Field 3°
CONTRALATERAL
RESPONSE

of the cortex with a more exposed striate on the left hemisphere, right half field stimulation would activate this hemisphere. This would give the largest response over the contralateral hemisphere at O1, yet the response over the right hemisphere would be relatively large compared to the full field stimulus results, where there is likely to be an inter-reaction with the response generated by the right hemisphere. The less exposed striate over the right hemisphere would result in a more contralateral response compared to the full field stimulus but would be relatively even over the scalp.

5.4.4 Upper Field Results

Table 5.13 illustrates the individual latencies and amplitudes following common reference recording and Table 5.14 shows the source derivation distribution measured at the same latency. Figure 5.8 plots the group average P100 amplitudes for the common reference and source derivation distributions. Table 5.15 demonstrates the mean and median averages, standard error, range and inter-ocular differences of the group average.

5.4.5 Lower Field Results

Table 5.16 illustrates the individual latencies and amplitudes following common reference recording and Table 5.17 shows the source derivation distribution measured at the same latency. Figure 5.9 plots the

UPPER FIELD STIMULUS

		MD R.EYE	MD L.EYE	AC R.EYE	AC L.EYE	MW R.EYE	MW L.EYE	RD R.EYE	RD L.EYE	JR R.EYE	JR L.EYE	GROUP AVERAGE
		105msec	106msec	111msec	108msec	102msec	108msec	102msec	103msec	115msec	113msec	107.3msec
	Cz	0.15	-0.49	0.39	0.70	0.22	0.53	0.47	1.38	0.90	0.57	0.482
	CPz	0.21	-0.09	0.88	1.09	0.20	1.14	0.46	1.34	1.34	1.12	0.769
	Pz	1.11	0.79	1.90	1.44	1.14	1.94	0.84	2.31	1.40	1.43	1. 43
30°	POz	3.07	2.14	4.01	2.77	1.84	3.04	1.79	3.94	1.23	1.48	2.531
	Oz	2.96	3.01	3.26	3.16	2.94	3.41	2.76	4.76	1.38	2.00	2.964
	IN	3.09	3.03	1.73	3.16	3.07	2.22	2.42	4.68	1.60	2.10	2. 71
	Nz	3.14	2.53	1.14	3.12	1.82	0.70	1.18	3.79	1.47	1.77	2.006
		102msec	113msec	98msec	93msec	113msec	105msec	100msec	100msec	88msec	90msec	100.2msec
	Cz	-0.32	-0.38	-0.23	-0.08	0.48	1.02	-0.55	0.18	2.12	0.15	-0.215
	CPz	-0.52	-0.32	0.10	-0.13	0.88	1.35	-0.16	-0.12	2.91	0.47	-0.136
	Pz	-0.14	0.14	1.01	0.52	1.19	1.57	0.35	0.03	2.83	0.65	0.249
10°	POz	0.97	1.17	2.91	2.14	1.78	1.81	1.41	1.27	1.58	1.20	1.308
	Oz	2.05	1.65	3.11	2.71	2.17	2.20	2.62	2.43	0.71	1.98	2.163
	IN	2.84	1.54	1.91	2.62	0.93	2.05	2.83	2.57	1.32	2.35	2.096
	Nz	2.86	1.21	1.18	2.04	0.33	1.64	2.44	2.08	1.25	2.02	1.705
		98msec	105msec	125msec	129msec	100msec	100msec	102msec	89msec	116msec	114msec	107.8msec
	Cz	-0.15	-0.03	1.01	0.18	0.38	0.21	-0.05	0.20	-1.02	-0.57	-0.016
	CPz	-0.05	-0.05	1.10	0.37	0.35	0.54	0.07	0.24	-0.73	-0.71	0.113
	Pz	0.16	-0.25	1.01	0.81	0.43	0.84	0.16	0.58	-1.01	-0.88	0.185
3°	POz	0.57	0.30	1.55	1.99	0.91	1.04	0.94	0.70	-0.94	-1.02	0.604
	Oz	1.42	0.96	2.04	2.26	1.96	1.15	1.86	1.05	-0.06	-0.13	1.263
	IN	2.04	1.36	1.95	2.20	2.39	1.12	2.10	1.04	0.68	0.29	1.517
	Nz	2.19	1.61	2.24	2.14	1.89	0.74	2.03	0.80	0.12	-0.07	1.369

TABLE 5.13 The individual latencies and amplitudes (microvolts) following common reference recording

UPPER FIELD STIMULUS

		MD R	MD L	AC R	AC L	MW R	MW L	RD R	RD L	JR R	JR L	GROUP AVERAGE
	CPz	0.83	0.48	0.53	0.04	0.96	0.13	0.37	1.02	0.39	0.34	0.423
	Pz	1.07	0.48	1.09	0.98	0.25	0.08	0.58	0.66	0.22	0.19	0.466
30°	POz	1.07	0.49	0.86	0.94	0.41	0.24	0.02	0.82	0.31	0.06	0.326
	Oz	0.25	0.85	1.29	0.40	0.98	0.75	1.31	0.89	0.07	0.57	0.558
	IN	0.09	0.52	0.95	0.03	1.37	1.04	0.91	0.82	0.34	0.74	0.491
	CPz	0.59	0.40	0.57	0.69	0.10	0.12	0.13	0.46	0.88	0.14	0.336
	Pz	0.73	0.56	0.99	0.98	0.29	0.03	0.55	1.08	1.17	0.37	0.675
10°	POz	0.04	0.55	1.71	1.06	0.20	0.14	0.16	0.07	1.03	0.23	0.207
	Oz	0.29	0.58	1.39	0.65	1.62	0.53	1.01	1.02	1.68	0.41	0.918
	IN	0.77	0.23	0.47	0.50	0.63	0.27	0.60	0.63	0.67	0.71	0.328
	CPz	0.10	0.18	0.19	0.25	0.12	0.02	0.02	0.23	0.04	0.03	0.024
	Pz	0.21	0.76	0.63	0.75	0.40	0.10	0.68	0.36	0.12	0.04	0.313
3°	POz	0.43	0.10	0.05	0.91	0.57	0.09	0.14	0.22	1.04	1.02	0.247
	Oz	0.23	0.26	0.58	0.33	0.62	0.14	0.68	0.21	0.38	0.46	0.389
	IN	0.46	0.15	0.38	0	0.93	0.34	0.31	0.30	0.75	0.79	0.285

TABLE 5.14. The source derivation distribution (microvolts cm^{-2})

FIGURE 5.8

The Group Average Amplitudes for the Common Reference and Source Derivation Distributions Following Stimulation of the Upper Field

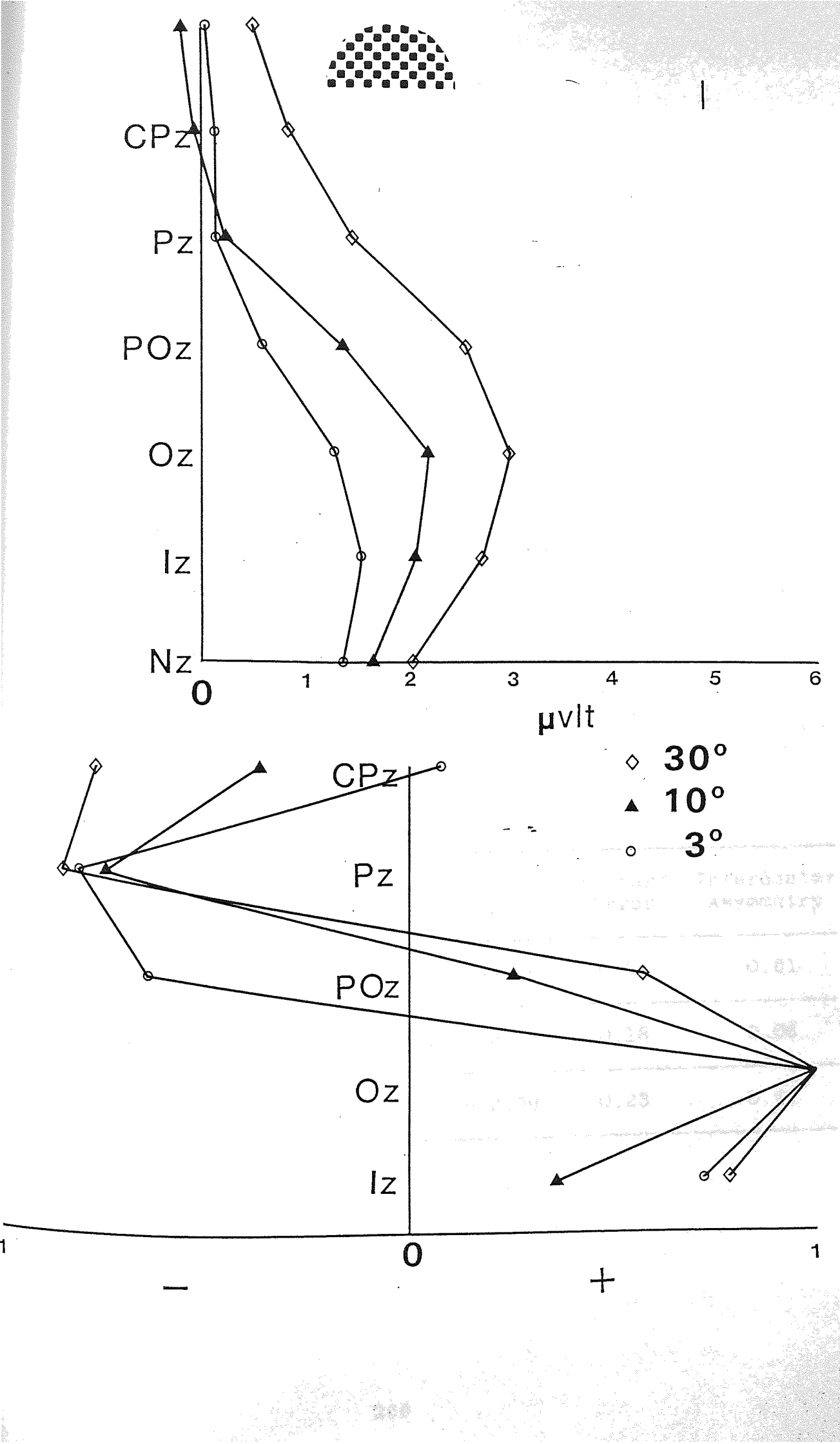

CPz
Pz
POz
Oz
Iz
Nz
0
1
2
3
4
5
6
µvlt
30°
10°
3°
CPz
Pz
POz
Oz
Iz
1
0
1
−
+

TABLE 5.15 UPPER FIELD

Latency (milliseconds)

Field Size	Mean	Median	Range	Standard Error	Interocular Asynchrony
30°	107.3	107	102-115	1.45	0.6
10°	100.2	100	88-113	2.72	0
3°	107.8	101	89-129	3.91	0.8

Amplitude (microvolts)

Field Size	Mean	Median	Range	Standard Error	Interocular Asymmetry
30°	3.10	3.07	1.60-4.76	0.28	0.61
10°	2.38	2.46	1.32-3.11	0.18	0.06
3°	1.56	1.85	0.29-2.39	0.23	0.41

LOWER FIELD STIMULUS

		MD R.EYE	MD L.EYE	AC R.EYE	AC L.EYE	MW R.EYE	MW L.EYE	RD R.EYE	RD L.EYE	JR R.EYE	JR L.EYE	GROUP AVERAGE
		95msec	95msec	91msec	91msec	100msec	102msec	90msec	92msec	94msec	92msec	94.2msec
	Cz	0.63	0.50	-0.07	1.02	0.59	0.33	1.59	1.12	0.40	0.46	0.707
	CPz	1.42	1.06	0.49	2.14	0.48	1.43	1.44	1.63	1.04	0.94	1.207
	Pz	2.75	2.48	2.44	4.01	0.98	2.15	1.91	3.63	1.88	1.73	2.397
30°	POz	4.64	4.16	5.68	7.31	1.99	2.96	4.20	5.36	2.84	3.21	4.235
	Oz	1.72	3.49	4.62	5.75	3.15	4.00	5.45	4.57	3.95	5.61	4.431
	IN	3.04	1.55	1.97	2.60	2.93	4.30	4.18	3.41	4.17	4.55	3. 27
	Nz	2.63	1.06	1.11	1.23	2.50	3.55	2.41	1.85	2.16	3.45	2.295
		96msec	95msec	96msec	101msec	98msec	94msec	93msec	86msec	86msec	89msec	93.6msec
	Cz	0.55	0.45	0.78	0.84	0.37	0.26	0.38	0.39	0.16	-0.14	0.404
	CPz	1.41	1.61	1.86	1.08	0.39	0.96	1.08	1.00	0.31	0.15	0.985
	Pz	2.87	3.02	3.22	1.73	0.26	1.35	3.00	2.07	0.24	0.54	1. 83
10°	POz	4.16	4.44	5.80	3.72	0.75	2.16	5.35	4.20	1.21	1.50	3.389
	Oz	3.33	3.28	4.61	2.36	1.18	2.23	4.80	3.79	2.39	2.11	3.008
	IN	1.54	2.04	2.69	0.29	-0.33	1.29	3.73	2.82	1.75	0.76	1.658
	Nz	0.90	1.10	1.89	-0.46	-0.51	0.63	2.10	1.60	0.62	0.03	0.790
		106msec	98msec	104msec	111msec	104msec	102msec	98msec	98msec	109msec	110msec	104msec
	Cz	-0.06	0.11	1.43	0.93	0.14	0.95	0.50	-0.59	0.33	0.23	0.397
	CPz	0.09	0.04	2.14	1.40	0.30	1.06	0.86	-0.34	0.29	0.40	0.624
	Pz	0.40	0.17	2.34	1.76	0.39	1.44	1.57	0.20	-0.03	0.87	0.911
3°	POz	1.65	1.42	3.09	2.89	0.98	1.45	2.24	0.75	0.36	1.54	1.636
	Oz	2.14	2.06	3.40	3.45	1.29	1.72	2.53	0.75	1.63	2.71	2.168
	IN	2.24	1.55	3.00	2.94	0.75	1.76	2.07	0.45	1.24	2.22	1.822
	Nz	2.02	1.52	2.43	2.41	0.20	1.14	1.04	-0.04	0.86	1.75	1.353

TABLE 5.16 The individual latencies and amplitudes (microvolts) following common reference recording

LOWER FIELD STIMULUS

		MD R	MD L	AC R	AC L	MW R	MW L	RD R	RD L	JR R	JR L	GROUP AVERAGE
	CPz	0.54	0.86	1.39	0.76	0.60	0.20	0.62	1.48	0.21	0.51	0.717
	Pz	0.56	0.26	1.29	1.43	0.52	0.29	1.81	0.26	0.12	0.79	0.681
30^{o}	POz	2.81	3.34	4.89	5.36	0.14	0.73	1.03	2.52	0.14	0.64	2.104
	Oz	0.23	0.73	0.40	0.60	1.38	1.56	2.51	0.37	0.88	2.54	0.928
	IN	0.28	0.44	1.20	1.29	0.20	0.34	0.51	0.40	1.23	0.35	0.088
	CPz	0.59	0.25	0.27	0.41	0.14	0.32	1.21	0.46	0.22	0.09	0. 26
	Pz	0.44	0.02	1.23	1.34	0.62	0.43	0.44	1.06	1.05	0.58	0.721
10^{o}	POz	3.32	2.58	3.79	3.35	0.06	0.74	2.89	2.54	0.20	0.34	1.941
	Oz	0.36	0.09	0.72	0.71	1.94	1.01	0.54	0.56	1.80	1.97	0. 97
	IN	1.15	0.31	1.12	1.31	1.34	0.28	0.55	0.25	0.50	0.63	0.484
	CPz	0.16	0.20	0.52	0.11	0.06	0.27	0.36	0.29	0.28	0.29	0. 06
	Pz	0.93	1.12	0.54	0.77	0.50	0.37	0.04	0	0.71	0.21	0.437
3^{o}	POz	0.75	0.61	0.43	0.57	0.29	0.27	0.38	0.52	0.88	0.50	0. 19
	Oz	0.40	1.16	0.72	1.07	0.86	0.24	0.75	0.32	1.66	1.67	0.885
	IN	0.31	0.48	0.17	0.18	0	0.65	0.56	0.19	0.01	0.02	0.119

TABLE 5.17 The souce derivation distribution (microvolts cm^{-2})

FIGURE 5.9

The Group Average Amplitudes for the Common Reference and Source Derivation Distributions Following Stimulation of the Lower Field

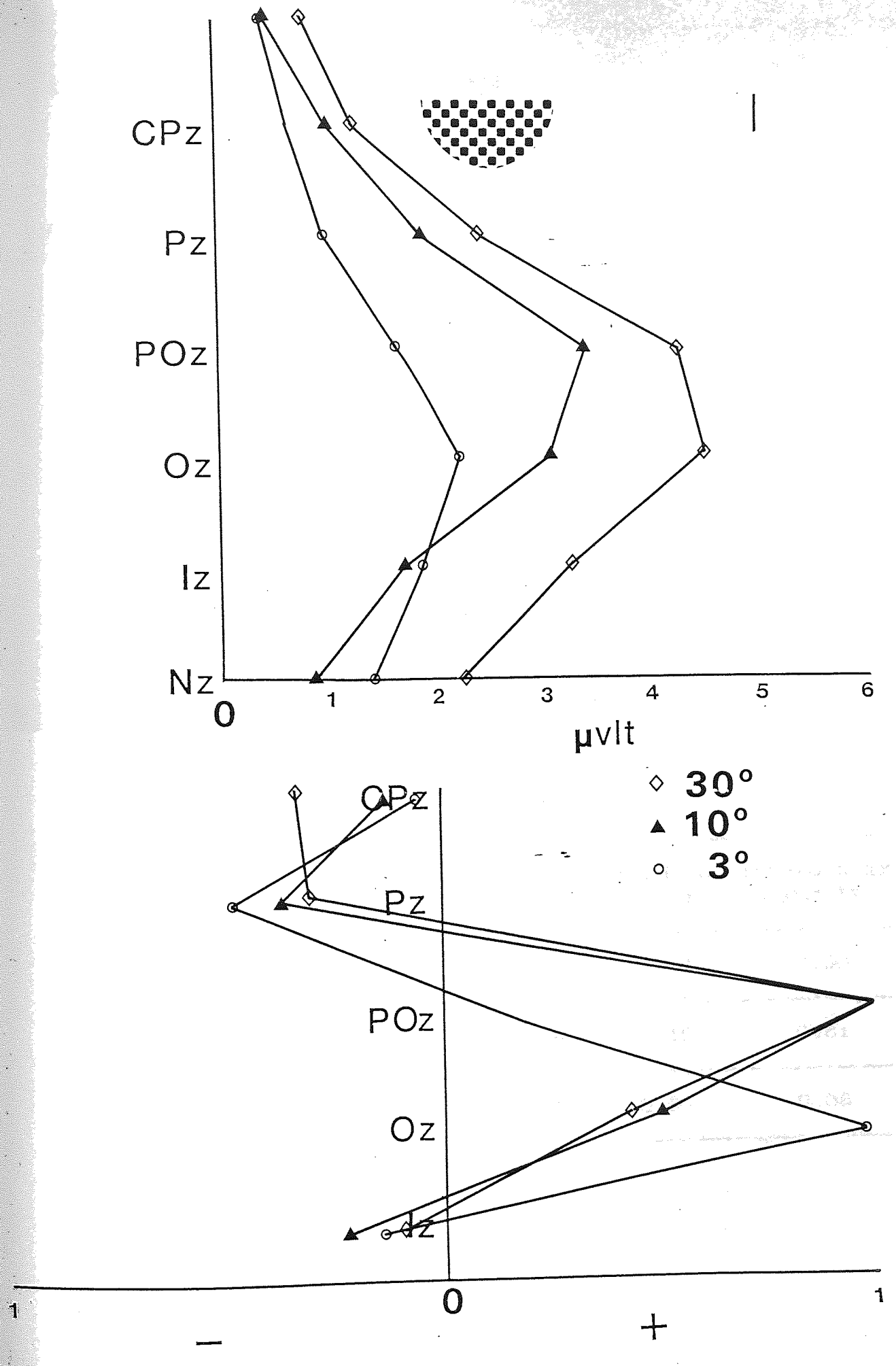

CPz
Pz
POz
Oz
Iz
Nz
0
1
2
3
4
5
6
µvlt
30°
10°
3°
CPz
Pz
POz
Oz
Iz
1
0
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TABLE 5.18 LOWER FIELD

Latency (milliseconds)

Field Size	Mean	Median	Range	Standard Error	Interocular Asynchrony
30°	94.2	93	90-102	1.26	0.4
10°	93.6	94.5	86-101	1.49	0.4
3°	104	104	98-111	1.58	0.4

Amplitude (microvolts)

Field Size	Mean	Median	Range	Standard Error	Interocular Asymmetry
30°	4.98	5.00	3.15-7.31	0.36	0.50
10°	3.62	3.96	1.18-5.80	0.49	0.51
3°	2.18	2.15	0.75-3.45	0.28	0.06

group average P100 amplitudes for the common reference and source derivation distributions. Table 5.18 demonstrates the mean and median averages, standard error, range and inter-ocular differences of the group average.

5.4.6 Discussion

The mean latency following an upper field stimulus of $0\text{-}15^{o}$ was 107.3 msec, 12.1 msec more delayed than the full field response and 13.1 msec more delayed than the lower field response. T-tests confirmed that this difference was highly significant, $p<0.001$ in each case. There was no significant difference, however, between the full field and lower field latencies. The observed delay was expected and has been extensively reported in the literature as discussed in Chapter 1 and 4. The delay found in the earlier study was only 7.5 msec but it is apparent from the literature that there is a large degree of variability in the response delay (1.2.3).

The mean latency following an upper field stimulus of $0\text{-}5^{o}$ demonstrated a much smaller delay when compared to the full field results. A t-test indicated no significant difference between the two. There was, however, a significant difference between the $0\text{-}15^{o}$ and $0\text{-}5^{o}$ upper field stimulus results (t-test: $p<0.1$). The mean latency following a lower field stimulus of $0\text{-}5^{o}$, was 3.6 msec earlier than that for full field stimulation. A t-test showed a significant difference between the two ($p<0.05$).

When compared to the upper field results there was a 6.6 msec delay which was also significant (t-test: $p<0.05$).

The $0\text{-}1\frac{1}{2}^{o}$ upper field stimulus gave a mean latency which was slightly earlier than the full field results but a t-test showed no significant difference. There was also no significant difference between the $0\text{-}15^{o}$ and $0\text{-}1\frac{1}{2}^{o}$ upper field stimulus results. The $0\text{-}1\frac{1}{2}^{o}$ lower field stimulus results gave a mean latency which was 4.6 msec earlier than the full field results. The difference was just significant, at the 10% level, by t-test ($p<0.1$). When compared to the $0\text{-}1\frac{1}{2}^{o}$ upper field stimulus the results were not significantly different.

We have already discussed the possible reasons behind the later latency found on full field foveal stimulation and it is not surprising that the upper field foveal stimulus showed a similar delay. From the literature we would also expect the latencies found for the large $0\text{-}15^{o}$ field stimulus which has been attributed to the reduction in human retinal cells within this hemifield (Osterberg 1935). What is surprising is the lack of delay found for the $0\text{-}5^{o}$ upper field stimulus when compared to the full field response. This may suggest that the delay found at the two extreme field sizes is attributable to two separate mechanisms of the visual pathway. The foveal stimulus might be delayed by the preponderance of cone activity in this region of the retina or by transmission factors, as discussed earlier. When the peri and para-foveas are also stimulated such factors, which may cause a delay of

the central foveal response, are no longer dominant and we get a much earlier response which is not dissimilar to the full field result. When a large proportion of peripheral retina is stimulated the observations of Osterberg (1935), discussed earlier in Chapter 1, may influence the response and cause a similar delay to that found for the foveal stimulus. Although such a proposition is purely speculative there is a considerable amount of literature to support the two extreme mechanisms mentioned (see Chapter 1).

More recently Nakayama (1982; in discussion with Bodis-Wollner) mentioned the idea of a "Y-ganglion cell" type response. For whatever reason the results stress the importance of considering these latency changes when a stimulus of large field and check size is used clinically or if a patient has an upper altitudinal visual field loss (Lesevre 1973; Halliday et al. 1973; Lehmann and Skandries 1977 and Wildberger 1984).

The 0-15^{o} lower field results showed no difference when compared to the full field results and would support the physiological factors discussed above for the delay of the upper field result. The 0-5^{o}, peri and para-foveal lower field stimulus however, gave a significant difference when compared to both the full field and upper field results being earlier in each case. In isolation there appeared to be little difference between the full field and upper field latencies but when considered in conjunction with the lower field results the full field

the full field latency appeared approximately mid-way between the two. This would suggest that the peri and para-fovea is somewhat affected by the physiological factors considered earlier. It is unlikely to be the influence of the foveal mechanism as this would be just as likely to affect the lower field results.

It is interesting that the full field result was similar to the upper hemiretinal response for the O-15° stimulus; is between the two for the O-5° stimulus; and more similar to the lower hemiretinal response for the O-1½° stimulus.

The mean amplitude elicited by the O-15° stimulus was maximum over the Oz electrode but was reduced by 44% for the upper field response and 16% for the lower field response when compared to the full field results. Stimulation of the O-5° gave a maximum amplitude over the Oz electrode following an upper field stimulus but there was a reduction of 50% compared to the full field response. The lower field stimulus gave a maximum over electrode POz and gave a reduction in amplitude of 31%, at the Oz electrode, when compared to the full field results. The O-1½° upper field stimulus gave a maximum over the inion which was reduced in amplitude by 25%. Unlike the full field results the inter-ocular asymmetry was negligible. The O-1½° lower field stimulus gave a maximum over the Oz electrode which was slightly larger than the full field amplitude. The inter-ocular asymmetry was also negligible. The lower field stimulus therefore gave a consistently earlier and larger response than for

the upper field stimulus.

The maximum response was over electrode Oz in all stimulus conditions, as reported in Chapter 4. There was, however, a clear switch in the bias of the response, or skew in the distribution, from the inion when the lower hemiretina was stimulated, to electrode POz when the upper hemiretina was stimulated. This skew was much more obvious when the smaller field and check sizes were used.

For the upper field 0-15^{o} stimulus the amplitude at POz was reduced by 7% when compared to the inion. This represents a 14% change when compared to the full field results. The lower field stimulus gave a reduction in amplitude of 23% at the inion compared to electrode POz. This was 16% greater than the reduction following full field stimulation and showed a 30% difference in distribution skew to the upper field results. There was no indication of an anterior PNP-complex in the upper field response thus confirming the results discussed in Chapter 4. Only one of the ten eyes demonstrated an anterior PNP-complex.

The amplitude distribution for the 0-5^{o} upper field stimulus revealed a maximum over the Oz electrode with electrode POz being reduced in amplitude by 38% when compared to the inion. This constituted a 32% greater reduction than the full field results showing a skew towards the inion. Seven of the ten eyes demonstrated an anterior PNP-complex which was reflected in the group

average over electrodes PCz and Cz. The lower field stimulus elicited a maximum over the POz electrode, 10% higher over the occiput than for the upper and full field responses. There was no evidence of an anterior PNP-complex as found for the upper field results.

The amplitude distribution for the O-1½° upper field stimulus revealed a maximum over the inion and showed a reduction in amplitude of 61% at electrode POz. This was 22% greater than the distribution skew following full field stimulation. Five of the ten eyes showed a slight PNP-complex over the more anterior electrodes but this was not reflected in the group average. The lower field stimulus elicited a maximum over electrode Oz. This was similar to the full field response but 10% higher over the occiput than the upper field response. POz was reduced in amplitude by 10% when compared to the inion which was 51% less than the distribution skew following stimulation of the upper field.

These observations were confirmed using analysis of variance. The interaction variance ratio when comparing the amplitudes for the three stimulus conditions at each of the seven electrodes used showed a significant difference in the distribution (Upper Field: $F_{12,162} = 3.30$, $p<0.005$; Lower Field: $F_{12,162} = 5.99$, $p<0.01$). When comparing the 30° full field and upper field distributions the interaction variance ratio was also significant ($F_{6,108} = 6.90$, $p<0.05$) but there was no significant difference when comparing the 30° full field and lower

field distributions. The interaction variance ratio was, however, significant when comparing the 3^{o} stimuli (Upper Field: $F_{6,108} = 4.31$, $p<0.05$; Lower Field: $F_{6,108} = 3.84$; $p<0.05$).

The results for the largest field and check size agree with those reported in Chapter 4. The smaller field and check size results confirm the observations of some previous authors (see 1.2.3 and 4.3.4) that an upper field stimulus produces a response lower over the occiput. The change in the topography was small compared to the dramatic changes elicited by Michael and Halliday (1971). The stimulus parameters were, however, quite different and comparison a little unrealistic. There was no evidence to support the argument, tentatively proposed when discussing [illegible] field results that the inferior nasal retina is more likely to give a PNP-complex over the more anterior electrodes.

The largest change in the amplitude distributions was elicited by the $0\text{-}5^{o}$ stimulus. Such a stimulus provided results which agree with the work of Lesevre (1973); Lehmann et al. (1977, 1982) and Adachi-Usami and Lehmann (1982). This demonstrates once again how the stimulus parameters can so greatly affect the VEP and its topography and that care must be taken in making generalised statements as to the effect that a particular area of the visual field will create without considering the type of stimulus used.

The results elicited by the smaller field demonstrated further the surprising specificity of the pattern-reversal response once free of the complicating cortical orientation found within the medial folds of the occipital cortex. This specificity of the pattern-reversal response often appears neglected in the literature and, even if the results prove uncomfortably variable in the clinical situation, they nevertheless help to establish a deeper understanding of the results obtained when larger amounts of the cortex are stimulated.

The source derivation distribution demonstrated a source-sink configuration between Oz and Pz for each of the upper field stimulus conditions. This was similar to the full field distribution. The 0-15° lower field stimulus gave a source-sink configuration between POz and CPz. This was 10% more anterior over the occiput than that reported in Chapter 4, although the difference in the two group averages is very small with the source being almost equal between electrodes Oz and POz in both cases. The 0-5° stimulus gave a source-sink configuration between POz and Pz and the 0-1½° stimulus was between Oz and Pz.

5.5 Simulated Relative Right Hemianopia

5.5.1 Results Following Full Field Stimulation

The relative hemianopia was simulated using a 0.6 neutral density filter to mask the right half field. Table 5.19

illustrates the individual latencies and amplitudes following common reference recording and Table 5.20 shows the source derivation distribution measured at the same latency. Figure 5.10 plots the group average P100 amplitudes for the common reference and source derivation distributions. Table 5.21 demonstrates the mean and median averages, standard error, range, inter-ocular differences and distribution asymmetries of the group average. Figures 5.11, 5.12 and 5.13 compare the group average distributions with the full field and left half field distributions.

5.2.2 Discussion

The mean latency of the P100 component following stimulation of the central 30^{o}, with a simulated relative scotoma covering the right half field, was closer to the left half field result, a simulated absolute right hemianopic scotoma, than the full field result. The standard deviation, however, was similar to that found for full field stimulation and considerably less than that for the left half field stimulus. A t-test showed no significant difference between the latencies for the simulated relative and absolute hemianopic defects but did indicate a small difference ($p<0.2$) when comparing the relative scotoma to the full field result. A similar level of significance was found comparing the simulated absolute scotoma, ie. the left half field result, to the full field result ($p<0.2$). There was no significant inter-ocular asynchrony.

FULL FIELD STIMULATION WITH SIMULATED RELATIVE RIGHT HEMIANOPIA

	MD R.EYE	MD L.EYE	AC R.EYE	AC L.EYE	MW R.EYE	MW L.EYE	RD R.EYE	RD L.EYE	JR R.EYE	JR L.EYE	GROUP AVERAGE
	98msec	103msec	93msec	95msec	107msec	108msec	98msec	97msec	95msec	94msec	98.8msec
T5	1.48	1.28	1.24	1.12	2.21	1.78	-0.17	2.12	1.14	1.81	1.40
O3	2.20	2.38	1.76	2.05	4.49	3.42	-0.06	2.96	1.83	2.53	2.36
O1	4.25	4.10	3.92	3.75	6.48	5.13	2.14	5.35	3.08	3.84	4.20
30° Oz	4.97	5.03	5.39	3.82	8.04	6.23	4.90	8.62	5.08	5.95	5.80
O2	3.62	3.92	4.11	2.85	6.49	4.49	4.88	7.84	3.75	4.82	4.68
O4	3.24	3.42	2.02	1.40	5.02	3.00	2.23	5.41	2.08	2.04	2.99
T6	2.33	2.57	0.42	0.42	2.59	1.54	0.45	3.27	0.93	1.23	1.58
	96msec	100msec	101msec	95msec	108msec	109msec	91msec	89msec	91msec	95msec	97.5msec
T5	1.52	1.66	2.06	2.47	0.96	1.48	1.72	2.44	2.35	1.54	1.82
O3	2.36	2.59	3.02	2.93	2.20	2.52	2.18	2.68	2.52	2.34	2.53
O1	3.21	3.49	6.36	2.98	3.27	3.11	3.91	4.19	3.27	3.62	3.74
10° Oz	3.37	3.27	5.75	1.96	3.78	2.83	6.93	6.39	4.41	5.09	4.39
O2	2.22	2.00	4.37	3.70	2.41	2.25	6.56	6.15	3.63	4.22	3.75
O4	1.53	1.37	1.98	2.94	0.83	1.37	4.48	4.12	2.34	2.55	2.35
T6	0.93	0.97	0.56	1.27	0. 0	1.23	3.05	2.91	1.37	1.40	1.37
	101msec	105msec	119msec	110msec	103msec	109msec	100msec	96msec	105msec	111msec	105.9msec
T5	1.27	0.93	0.71	0.81	0.45	0.72	-0.20	1.30	1.61	1.96	0.96
O3	1.57	1.37	1.22	1.47	0.98	1.50	0.05	2.12	2.09	2.62	1.50
O1	1.98	1.68	1.78	4.76	1.37	2.06	0.63	2.44	2.66	3.35	2.27
3° Oz	2.11	1.39	2.97	2.33	0.87	1.81	1.08	2.74	3.19	4.57	2.31
O2	1.62	0.56	1.97	1.86	0.05	1.06	1.20	1.89	2.71	3.94	1.69
O4	1.46	0.03	0.86	1.21	-1.09	0.46	0.76	1.17	1.95	3.22	1.00
T6	1.17	-0.36	0.09	0.59	-0.73	0.27	0.45	0.64	1.12	2.52	0.58

TABLE 5.19 The individual latencies and amplitudes (microvolts) following common reference recording

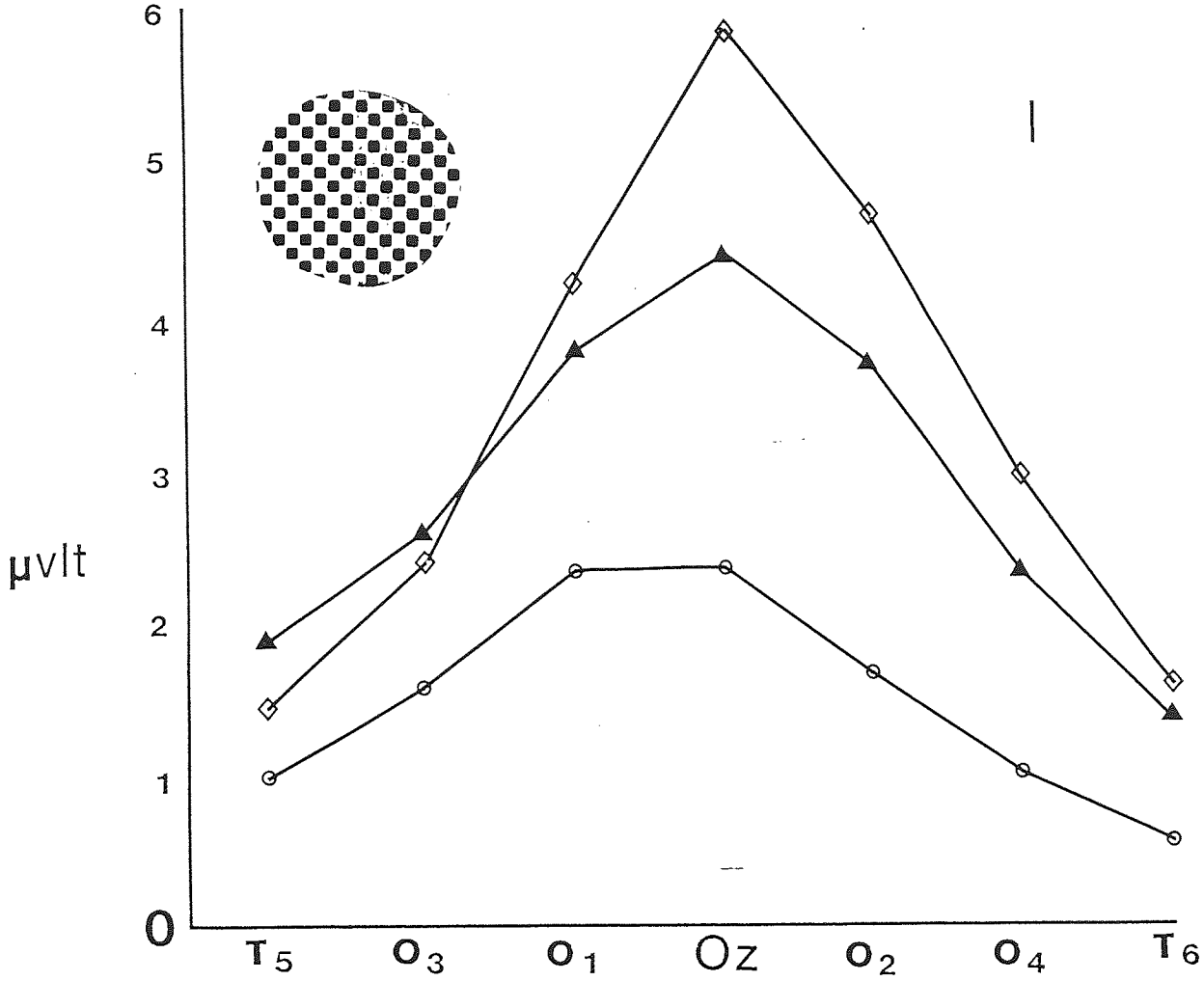
FULL FIELD STIMULATION WITH SIMULATED
RELATIVE RIGHT HEMIANOPIA

		MD R	MD L	AC R	AC L	MW R	MW L	RD R	RD L	JR R	JR L	GROUP AVERAGE
30°	O3	1.33	0.63	1.65	0.79	0.28	0.08	2.09	1.54	0.56	0.60	0.899
	O1	1.34	0.79	0.70	1.64	0.44	0.61	0.55	0.89	0.75	0.79	0.412
	Oz	2.06	2.05	2.75	1.05	3.10	2.84	2.77	4.06	3.33	3.23	2.724
	O2	0.97	0.62	0.82	0.47	0.08	0.25	2.62	1.65	0.33	1.65	0.562
	O4	0.53	0.36	0.50	0.47	0.96	0.03	0.86	0.30	0.51	1.96	0.278
10°	O3	0	0.03	2.39	0.41	0.16	0.46	1.27	1.27	0.58	0.48	0.493
	O1	0.69	1.12	3.96	1.07	0.57	0.86	1.28	0.70	0.39	0.19	0.571
	Oz	1.31	1.04	0.76	2.75	1.87	0.30	3.38	2.45	1.91	2.34	1.261
	O2	0.45	0.64	1.01	2.49	0.21	0.30	1.71	1.78	0.52	0.80	0.773
	O4	0.09	0.22	0.97	0.91	0.75	0.73	0.64	0.81	0.34	0.51	0.415
3°	O3	0.12	0.14	0.05	2.63	0.14	0.21	0.31	0.50	0.10	0.07	0.229
	O1	0.29	0.59	0.63	5.72	0.89	0.82	0.12	0.02	0.05	0.49	0.738
	Oz	0.61	0.55	2.18	1.96	0.32	0.50	0.34	1.15	1.01	1.84	0.654
	O2	0.32	0.30	0.12	0.18	0.32	0.15	0.55	0.12	0.27	0.09	0.064
	O4	0.13	0.14	0.35	0.02	1.51	0.41	0.13	0.20	0.07	0.01	0.257

TABLE 5.20 The source derivation distribution
(microvolts cm^{-2})

FIGURE 5.10

The Group Average Amplitudes for the Common Reference and Source Derivation Distributions Following Full Field Stimulation with a Simulated Relative Right Hemianopia


6
5
4
3
2
1
0
μvlt
T5
O3
O1
Oz
O2
O4
T6

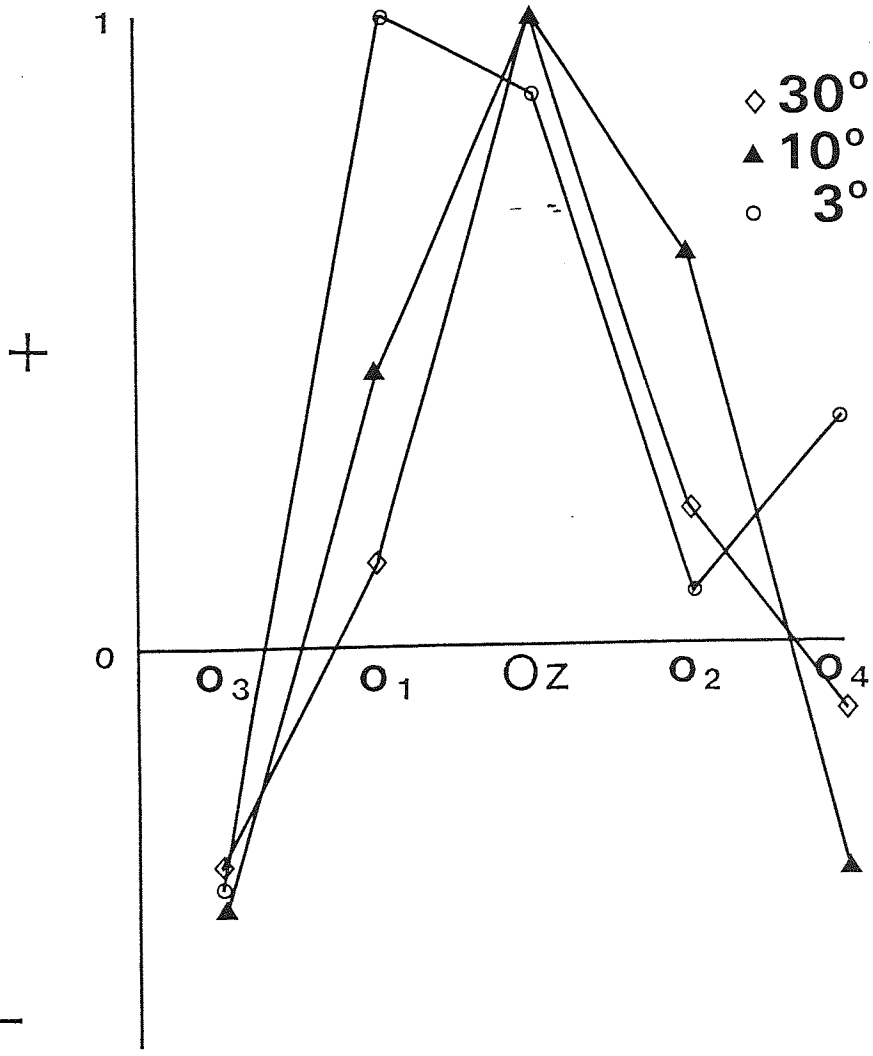

1
0
+
−
30°
10°
3°
O3
O1
Oz
O2
O4

TABLE 5.21. FULL FIELD STIMULATION WITH SIMULATED RELATIVE RIGHT HEMIANOPIA

Latency (milliseconds)

Field Size	Mean	Median	Range	Standard Error	Interocular Asynchrony
30^{o}	98.8	97.5	93-108	1.70	1.2
10^{o}	97.5	95.5	89-109	2.19	0.2
3^{o}	105.9	105	96-119	1.98	0

Amplitude (microvolts)

Field Size	Mean	Median	Range	Standard Error	Interocular Asymmetry
30^{o}	5.8	5.27	3.82-8.62	0.47	0.25
10^{o}	4.66	4.05	3.11-6.93	0.48	0.94
3^{o}	2.67	2.43	1.20-3.79	0.39	0.53

Amplitude Asymmetry (% reduction)

	O1-O2	O3-O4	T5-T6
30^{o}	-10%	-20%	-11%
10^{o}	0%	7%	25%
3^{o}	26%	33%	40%

The mean latency following stimulation of the central 10^{o} gave a very similar latency and standard deviation for full field, simulated relative right hemianopia and simulated absolute right hemianopia. These observations were confirmed when using a t-test, which found no significant differences between the 3 stimulus conditions. There was no significant inter-ocular asynchrony.

The mean latency following stimulation of the central 3^{o} was similar for the two simulated field defects both being c.4.5 msec earlier than the full field response. This was confirmed using a t-test which showed no significant difference between the latencies of the two simulated field defects but both were significantly different ($p<0.05$) to the full field results. Unlike the left half field results, discussed earlier, the simulated relative scotoma did not give a significant inter-ocular asynchrony.

The mean amplitude for the 30^{o} stimulus was similar for the full field and relative scotoma. Both were between 2 and 2.5 microvolts larger than the mean peak amplitude for the simulated absolute scotoma. The standard deviations and inter-ocular asymmetries were very similar for all three stimulus conditions. The mean amplitude for the 10^{o} stimulus was largest for the simulated relative scotoma, followed by the full field stimulus and the smallest response was from the simulated absolute scotoma. The only difference which was greater than one standard deviation of the mean was between the two simulated

defects. The standard deviations and inter-ocular asymmetries were similar for all three stimulus conditions. The mean amplitude for the 3^{o} stimulus was identical for the full field and simulated relative scotoma, on the midline, but reduced, by more than one standard deviation, for the simulated absolute scotoma. The standard deviations and inter-ocular asymmetries were very similar for the three stimulus conditions.

It would appear therefore that the simulated half field defect, which reduced the luminance by c.60%, had little effect on the amplitude of the VEP but does seem to affect the latency. The amplitude distribution, however, was considerably affected as illustrated in Figures 5.11, 5.12 and 5.13.

The response following stimulation of the central 30^{o} appeared far more symmetrical around the midline and when compared to the full field response would appear to be considerably contralateral to the normally stimulated hemiretina. The expected result would have been somewhere between the full field response and the ipsilateral, left half field response. Once again the topographical investigation of the scalp potential revealed an unexpected result which demands further investigation. Analysis of variance showed no significant difference between the distributions of the 30^{o} relative hemianopic stimulus compared to the 30^{o} full field

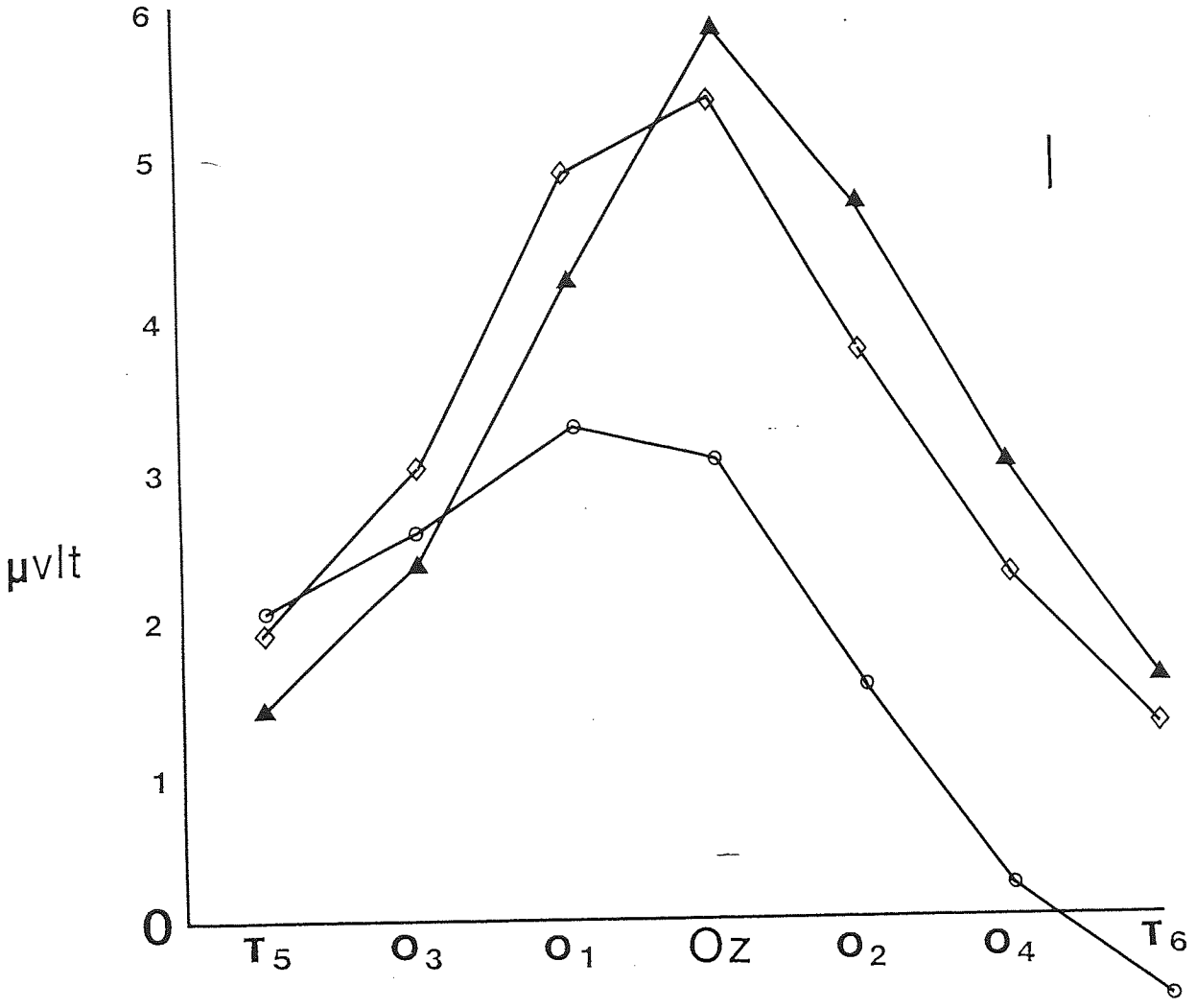
FIGURE 5.11

Comparison between the Group Average Distribution and the Full Field and Left Half Field Distributions (30^{o} stimulus)

◇ - Simulated Relative Right Hemianopia

▲ - Full Field

o - Simulated Absolute Right Hemianopia (Left Half Field)


6
5
4
3
2
1
0
µvlt
T5
O3
O1
OZ
O2
O4
T6

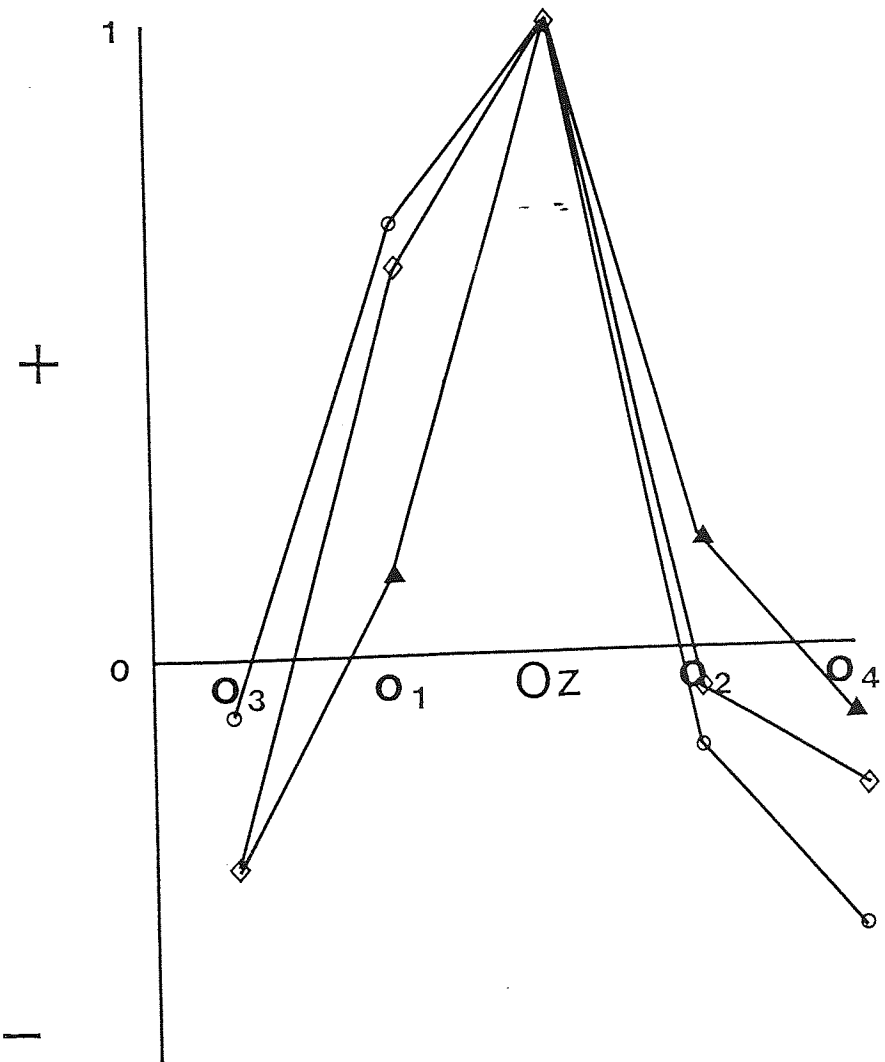

1
0
O3
O1
OZ
O2
O4

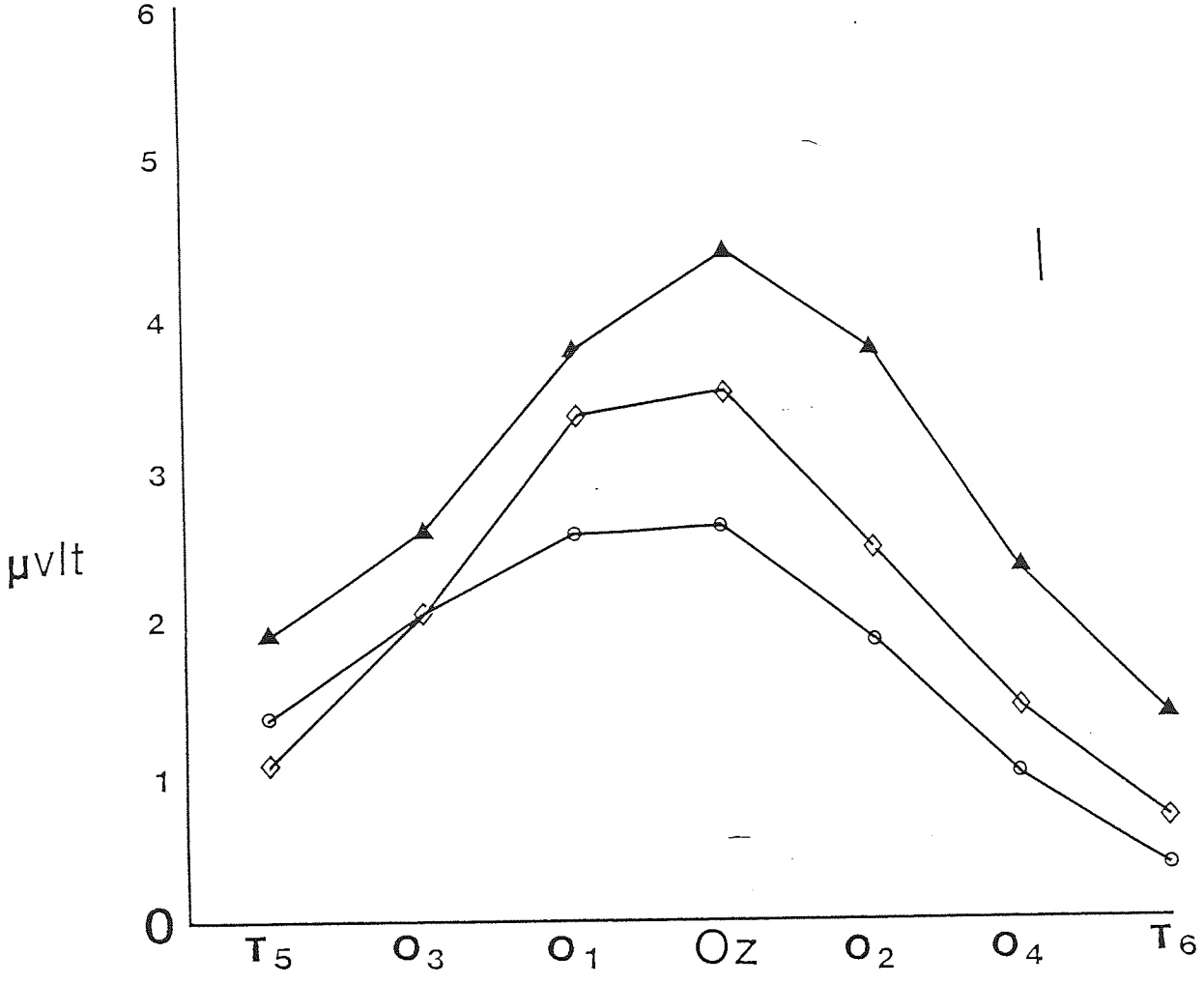
FIGURE 5.12

Comparison between the Group Average Distributions and the Full Field and the Left Half Field Distributions (10^{o} stimulus)

▲ - Simulated Relative Right Hemianopia

◇ - Full Field

o - Simulated Absolute Right Hemianopia (Left Half Field)


6
5
4
3
2
1
0
μvlt
T5
O3
O1
Oz
O2
O4
T6

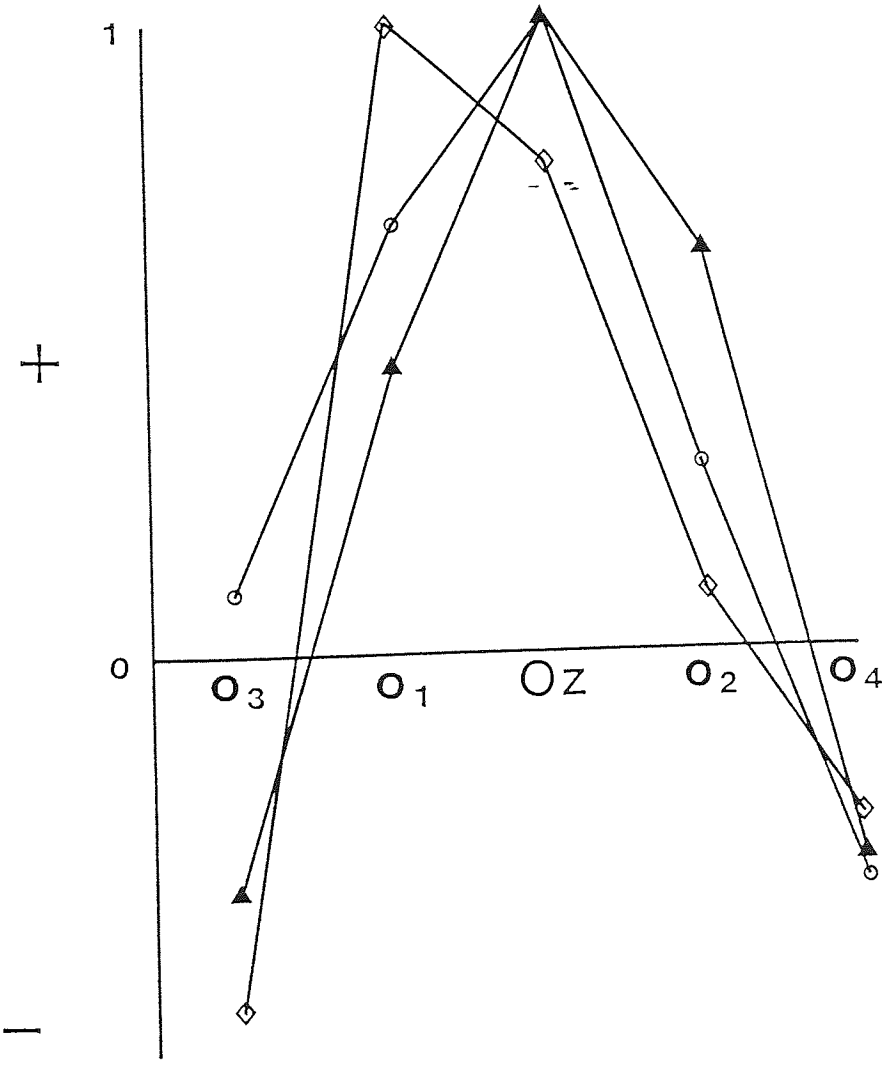

1
+
0
—
O3
O1
Oz
O2
O4

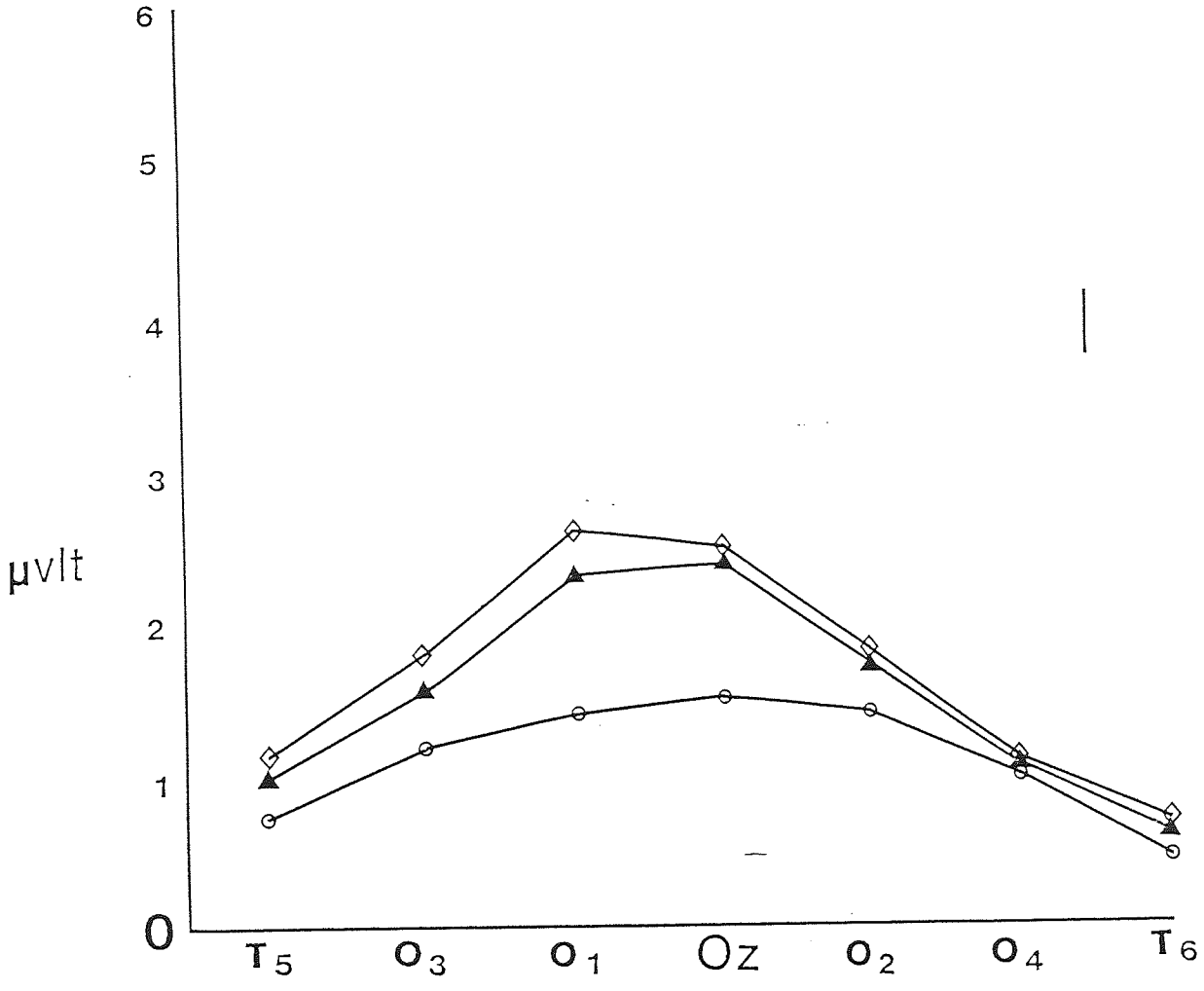
FIGURE 5.13

Comparison between the Group Average Distribution and the Full Field and Left Half Field Distributions (3^{o} stimulus)

▲ - Simulated Relative Right Hemianopia

◇ - Full Field

o - Simulated Absolute Right Hemianopia (Left Half Field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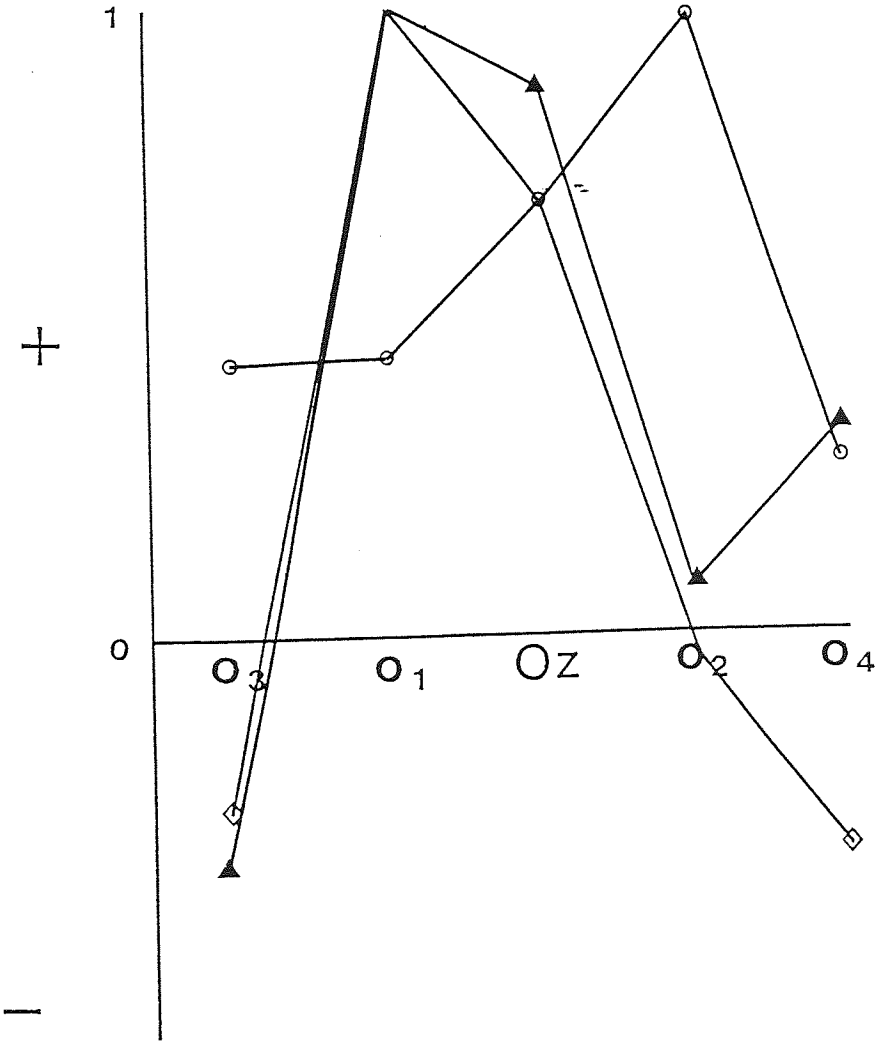
5
4
3
µvlt
2
1
0
T5
O3
O1
Oz
O2
O4
T6


1
+
0
O3
O1
Oz
O2
O4
—

stimulus ($F_{6,108} = 0.49$). There was however, a highly significant interaction variance ratio ($F_{6,108} = 22.07$, $p<0.01$) when comparing the 30^{o} relative and absolute hemianopic stimuli. It would appear, therefore, that although the amplitude is little affected by the filter the latency and scalp topography are. When the absolute scotoma was simulated only the right hemisphere was stimulated which resulted in a scalp potential which was ipsilateral to the stimulated hemifield, as discussed earlier. The full field response is asymmetrical due to the projection of the foveal, occipital, polar striate cortex on the left hemisphere. When the filter was used to simulate the relative scotoma the right hemisphere was fully stimulated but the left hemisphere, which causes the asymmetry, was not. Although this does not seem to affect the amplitude it may, however, slightly reduce the distribution asymmetry caused by the left hemisphere. This would explain the symmetry of the distribution and the reason for the relative scotomatous result not depicting a half-way stage between the two extreme stimulus conditions. This explanation is again rather tenuous and will only be substantiated by further research.

The amplitude distribution following stimulation of the central 10^{o} of the visual field again showed a remarkable degree of symmetry around the midline rather than a slightly ipsilateral result somewhere between the full field and simulated absolute scotoma.

The amplitude distribution for the 3^{o} stimulus finally gave a result which is somewhere between the full field and simulated absolute scotoma results. The full field stimulus gave a maximum over electrode O1 and a bias over the left hemisphere. The simulated relative scotoma gave a maximum result on the midline and a similar distribution over the right hemisphere. Over the left hemisphere, however, the response was marginally reduced giving the appearance of a slightly contralateral result to the normally stimulated hemifield. The simulated absolute scotoma gave a more obviously contralateral result to the stimulated hemiretina, as discussed earlier. Even with this distribution the relative scotoma results mimick the full field result far more closely than the absolute scotoma results and may predict the problems of trying to detect a relative hemianopic defect by full field stimulation alone.

Analysis of variance showed no significant difference between the distribution of the 3^{o} relative hemianopic results and the 3^{o} full field and absolute hemianopic results. With the 3^{o} stimulus the foveal, polar projection was isolated. The results obtained appear to give further evidence of the highly complex interactions between the two hemispheres which cause the scalp distribution. The relative scotomatous results are only reduced over the left occiput due, presumably, to the reduction in stimulus to the left hemisphere. When the stimulus was reduced completely, ie. by left half field stimulation, the response was not only

further reduced over the left occiput but was also reduced to between 10 and 15% of the midline over the right occiput. The literature (see 1.2.2) has discussed the ipsilateral response, by common reference recording of the medially orientated cortex and the contralateral response of the polar orientated cortex. We have already discussed the way in which the latter appears to affect the former by investigating the full field, right and left half field results. The results demonstrated in Figure 5.13 appear to further compound this relationship as it appears that each hemispheres polar projection helps contribute to the response over each occiput with an overlap of at least 15% laterality when the right hemisphere is involved. The 30^{o} full field results similarly show how the polar projection of the left hemisphere can influence the potential recorded over the left occiput in spite of the majority of that occiputs scalp potential being generated within the medial projection of the right hemisphere. It is clear, once again, that the relationship between the scalp potential and the depth and orientation of the cortical generators is not a simple one.

The source derivation distributions revealed a maximum scalp current source on the midline for each stimulus condition when the central 30^{o} are stimulated. Only the absolute scotoma revealed a scalp current sink. When the central 10^{o} are stimulated there was a midline source after the relative and absolute scotomata but a source over electrode O1 for the full field stimulus. Again

only the absolute scotoma revealed a contralateral sink over electrode O4. Stimulation of the central 3^{o} revealed a maximum source over electrode O1 for the full field and relative scotoma results with a source over electrode O2 for the absolute scotoma results.

5.5.3 Results Following Stimulation of the Right Half Field

Table 5.22 illustrates the individual latencies and amplitudes following common reference recording and Table 5.23 shows the source derivation distribution measured at the same latency. Figure 5.14 plots the group average P100 amplitudes for the common reference and source derivation distributions. Table 5.24 demonstrates the mean and median averages, standard error, range, inter-ocular differences and distribution asymmetries of the group average. Figures 5.15, 5.16 and 5.17 compare the group average distributions with the right half field distributions.

5.5.4 Discussion

Stimulation of the $0\text{-}15^{o}$ right half field, with a simulated relative hemianopic defect, gave a mean latency of 98.2 msec compared to the normally stimulated half field result of 94.9 msec. A t-test indicated that this delay was significant when comparing the two stimulus conditions ($p<0.1$). This would appear to support the observations of Halliday et al. (1973a) that a reduction

RIGHT HALF FIELD STIMULATION WITH SIMULATED RELATIVE RIGHT HEMIANOPIA

	MD R.EYE	MD L.EYE	AC R.EYE	AC L.EYE	MW R.EYE	MW L.EYE	RD R.EYE	RD L.EYE	JR R.EYE	JR L.EYE	GROUP AVERAGE
	102msec	101msec	105msec	98msec	105msec	103msec	89msec	95msec	93msec	91msec	98.2msec
T5	-0.69	-0.43	-0.41	-1.96	0.73	0.53	-1.30	-0.62	-1.93	-0.63	-0.67
O3	-0.26	0.30	0.18	-1.28	1.91	0.97	-1.52	-0.04	-2.05	-0.88	-0.27
O1	1.39	1.32	1.77	0.06	2.99	2.80	0.16	1.51	-0.81	-0.37	1.08
30^{o} Oz	2.39	2.09	2.65	0.76	4.16	3.13	3.11	3.98	0.93	0.78	2.40
O2	1.67	1.67	2.53	0.41	3.41	2.60	3.67	4.11	1.68	0.92	2.27
O4	1.43	1.31	2.67	1.73	2.90	2.73	3.30	3.83	1.03	0.97	2.19
T6	1.21	1.13	1.30	0.40	2.11	1.93	2.48	2.76	1.57	1.29	1.63
	97msec	100msec	100msec	89msecs	110msec	109msec	91msec	91msec	92msec	93msec	97.2msec
T5	1.27	1.92	-0.07	2.46	-0.40	0.07	-0.80	0.75	0.99	0.62	0.68
O3	1.80	2.51	0.23	3.18	0.37	0.83	-1.20	1.13	1.43	1.26	1.15
O1	2.50	3.05	1.83	4.18	0.82	1.46	-0.18	2.29	1.91	2.71	2.06
10^{o} Oz	2.52	2.96	1.73	4.19	1.59	1.62	2.12	4.18	2.71	3.41	2.70
O2	2.09	1.99	1.41	2.99	0.96	0.66	2.46	3.94	2.46	2.51	2.15
O4	2.06	1.77	0.94	2.50	0.63	0.07	2.07	3.61	2.77	2.71	1.91
T6	1.70	1.46	-0.07	1.40	0.52	0.15	1.94	3.15	2.52	2.00	1.48
	101msec	108msec	104msec	96msec	103msec	99msec	104msec	99msec	107msec	119msec	104msec
T5	1.55	1.06	1.28	1.48	1.48	0.62	-0.40	1.44	1.84	1.00	1.14
O3	1.75	1.24	1.81	1.84	1.77	1.37	-0.27	1.92	2.16	1.36	1.50
O1	1.64	1.48	3.20	3.77	1.84	1.98	0.11	2.55	2.89	1.36	2.08
3^{o} Oz	1.37	1.42	3.36	2.63	0.89	1.86	0.56	2.62	3.06	1.86	1.96
O2	1.25	1.47	2.96	2.62	0.59	1.41	0.38	1.99	2.79	1.77	1.72
O4	1.34	1.52	2.64	2.46	0.07	1.83	0.41	1.94	3.06	1.73	1.70
T6	1.41	1.37	1.92	1.75	0.54	0.97	0.29	1.52	2.32	1.12	1.32

TABLE 5.22 The individual latencies and amplitudes (microvolts) following common reference recording

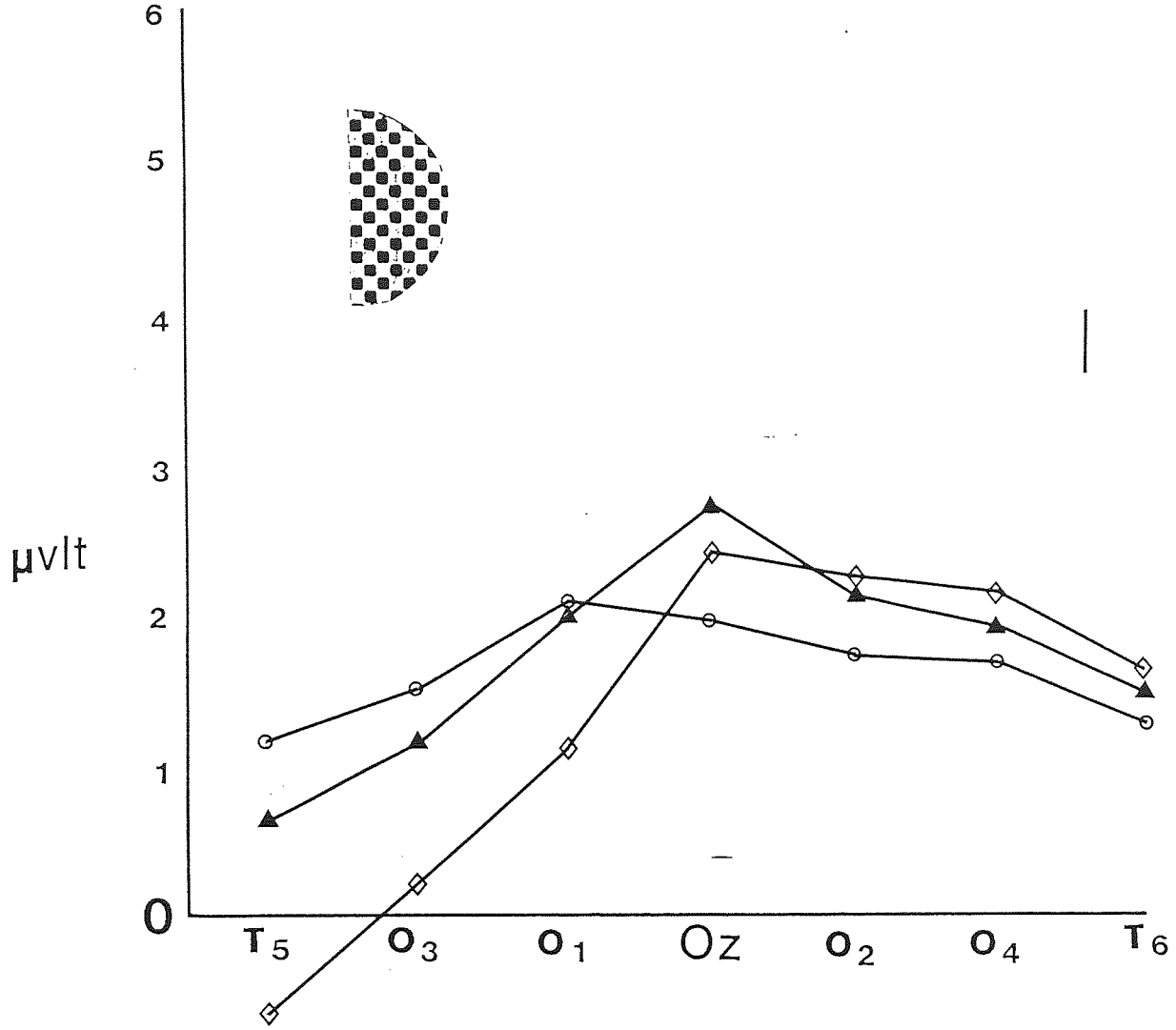
RIGHT HALF FIELD STIMULATION WITH SIMULATED
RELATIVE RIGHT HEMIANOPIA

		MD R	MD L	AC R	AC L	MW R	MW L	RD R	RD L	JR R	JR L	GROUP AVERAGE
	O3	1.23	0.29	0.99	0.67	0.09	1.38	1.91	0.96	1.35	0.75	0.944
	O1	0.66	0.26	0.70	0.65	0.09	1.50	1.26	0.93	0.51	0.65	0.033
30°	Oz	1.73	1.18	1.01	1.05	1.91	0.86	2.38	2.35	1.00	1.01	1.448
	O2	0.49	0.06	0.26	1.68	0.23	0.67	0.93	0.41	1.39	0.09	0.057
	O4	0.02	0.18	1.51	2.59	0.29	0.94	0.44	0.79	1.18	0.27	0.491
	O3	0.18	0.05	1.30	0.28	0.32	0.12	1.43	0.78	0.04	0.81	0.433
	O1	0.69	0.63	1.70	1.00	0.32	0.48	1.27	0.73	0.31	0.76	0.263
10°	Oz	0.45	0.88	0.22	1.20	1.40	1.12	1.95	2.13	1.04	1.59	1.198
	O2	0.40	0.75	0.14	0.71	0.30	0.37	0.74	0.09	0.56	1.10	0.322
	O4	0.34	0.09	0.54	0.61	0.21	0.66	0.27	0.13	0.57	0.91	0.205
	O3	0.31	0.06	0.86	1.57	0.23	0.15	0.26	0.16	0.43	0.37	0.228
	O1	0.16	0.30	1.24	3.06	1.01	0.73	0.06	0.56	0.57	0.51	0.706
3°	Oz	0.14	0.12	0.55	1.12	0.64	0.32	0.63	0.70	0.43	0.59	0. 12
	O2	0.22	0.01	0.08	0.15	0.21	0.86	0.21	0.59	0.53	0.06	0.218
	O4	0.03	0.20	0.39	0.54	0.99	1.28	0.14	0.37	1.00	0.58	0.354

TABLE 5.23 The source derivation distribution
(microvolts cm^{-2})

FIGURE 5.14

The Group Average Amplitudes for the Common Reference and Source Derivation Distributions Following Stimulation of the Right Half Field with a Simulated Relative Right Hemianopia


6
5
4
3
µvlt
2
1
0
T5
O3
O1
Oz
O2
O4
T6

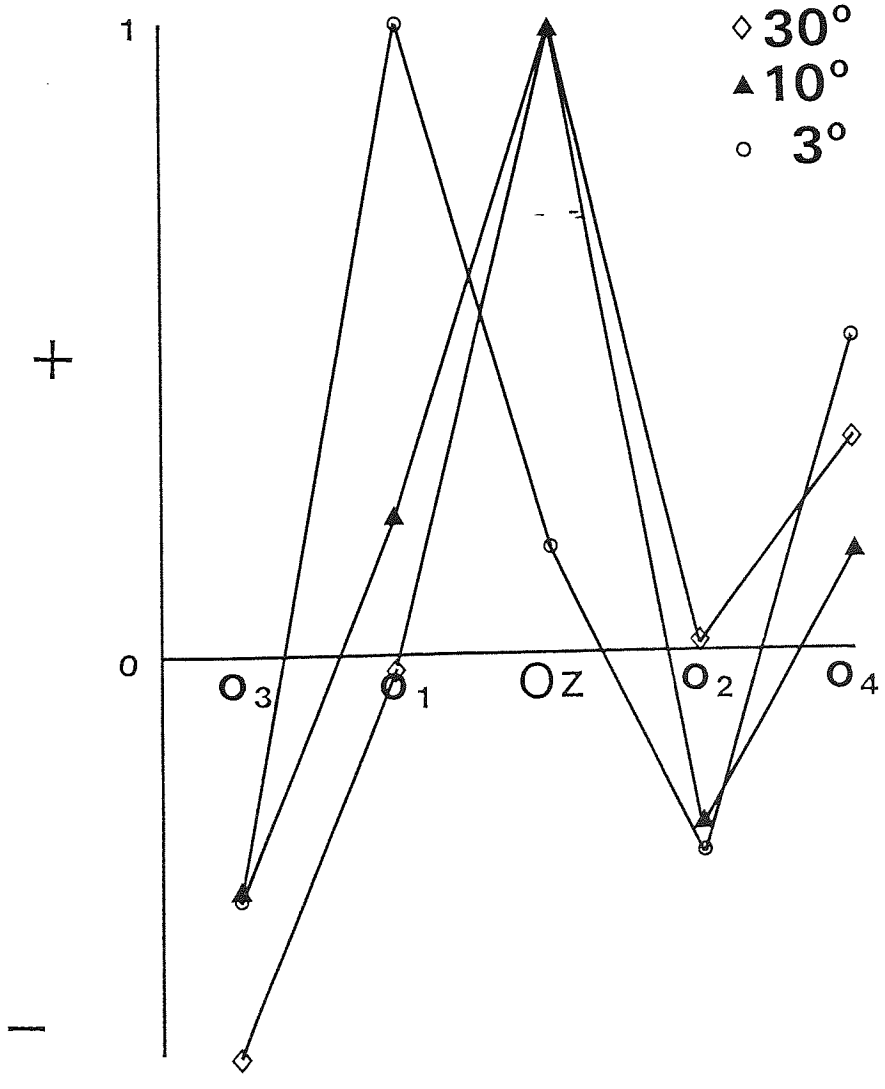

1
30°
10°
3°
+
0
O3
O1
Oz
O2
O4
–

TABLE 5.24 RIGHT HALF FIELD WITH SIMULATED RELATIVE RIGHT HEMIANOPIA

Latency (milliseconds)

Field Size	Mean	Median	Range	Standard Error	Interocular Asynchrony
30^{o}	98.2	99.5	89-105	1.86	1.2
10^{o}	97.2	95	89-110	2.37	1.6
3^{o}	104	103.5	96-119	2.04	0.4

Amplitude (microvolts)

Field Size	Mean	Median	Range	Standard Error	Interocular Asymmetry
30^{o}	2.69	2.53	1.29-4.16	0.33	0.50
10^{o}	2.76	2.65	1.59-4.19	0.30	1.14
3^{o}	2.23	1.92	0.56-3.77	0.30	0.24

Amplitude Asymmetry (% reduction)

	O1-O2	O3-O4	T5-T6
30^{o}	-52%	-112%	-141%
10^{o}	-4%	-40%	-54%
3^{o}	17%	-12%	-14%

in the mean luminance causes a delay in latency of the p100 component. There was no significant inter-ocular asynchrony for either stimulus. Stimulation of the 0-5° right half field for the two stimulus conditions also showed a very slightly significant delay (t-test: $p < 0.2$). The 0-1½° stimulus, however, showed no significant difference.

The mean amplitude for the 0-15° stimulus was reduced by 31% when compared to the normally stimulated half field. This confirms Halliday et al's. (1973a) other observation that a reduction in mean luminance also causes a reduction in amplitude. The 0-5° stimulus however, gave an approximately equal mean peak amplitude on the midline and the 0-1½° stimulus gave an increased amplitude with the normal half field result being reduced by 17%.

It would appear, therefore, that Halliday's observations are only valid for large field stimulation. When the foveal stimulus was used the latency remains the same but the amplitude increases slightly when the mean luminance is reduced. This may be further evidence that we have isolated the extreme "sustained" system when stimulating the fovea, as discussed earlier in this Chapter. The cones seem to react more efficiently with a less saturated stimulus, although the contrast is similar. Further research would be necessary to establish at what level of saturation this response peaks.

The amplitude distribution for the O-15° stimulus showed a very similar topography but with a reduced amplitude over the whole scalp potential field. The laterality of the response was more exaggerated when the simulated scotoma was used and there was an increase of the peripheral PNP-complex contralateral to the stimulated hemifield (Figure 5.15). Analysis of variance confirmed these observations as, in spite of the reduction in amplitude, there was no significant difference in the distributions ($F_{6,108} = 3.55$).

The O-5° stimulus gave an amplitude distribution which was almost identical over the right occiput but the scalp potential over the left occiput showed a slight reduction in amplitude giving the result a more ipsilateral appearance with the simulated scotoma (Figure 5.16).

The O-1½° stimulus gave an amplitude distribution which was very similar in topography, with the peak amplitude being over the O1 electrode for both stimulus conditions, but was slightly greater in amplitude. The scotomatous result was slightly more ipsilateral than the normally stimulated half field result. Half field stimulation of a simulated relative hemianopic defect would seem, therefore, to give a more clearly lateralised scalp distribution.

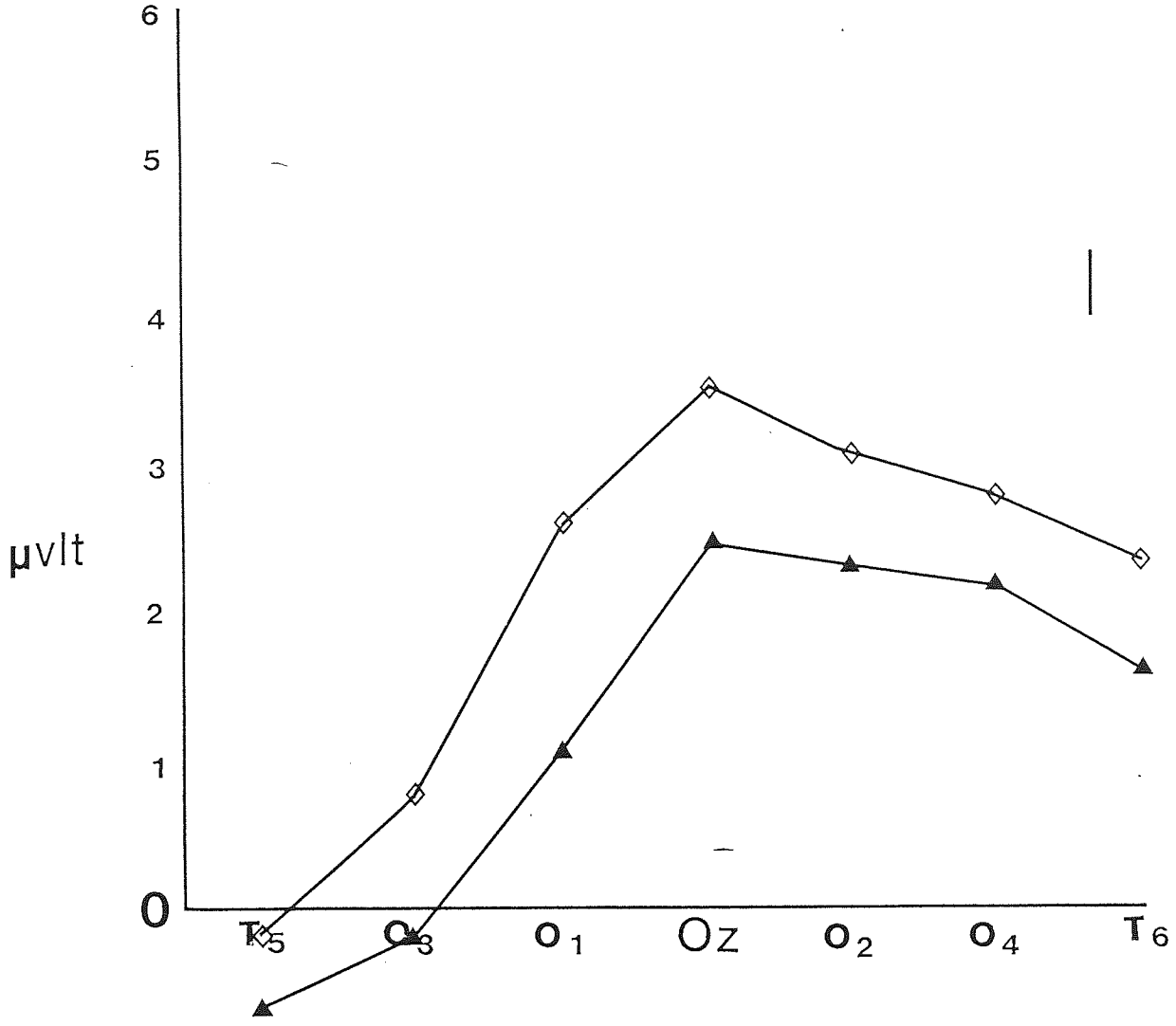
The source derivation distribution corresponded to these

FIGURE 5.15

Comparison between the Group Average Distribution and the Right Half Field Distribution (30^{o} stimulus)

▲ - Simulated Relative Right Hemianopia with Absolute Left Hemianopia

◇ - Simulated Absolute Left Hemianopia (Right Half Field)


6
5
4
3
μvlt
2
1
0
T5
O3
O1
Oz
O2
O4
T6

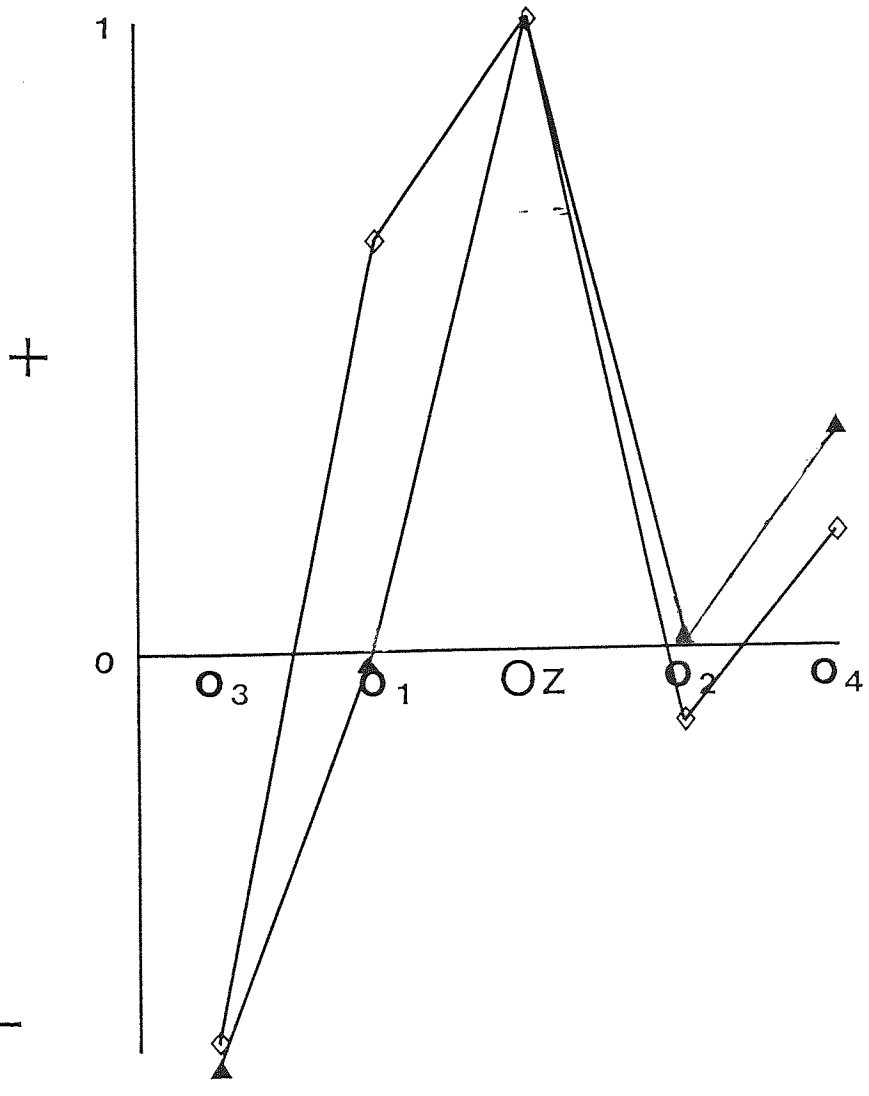
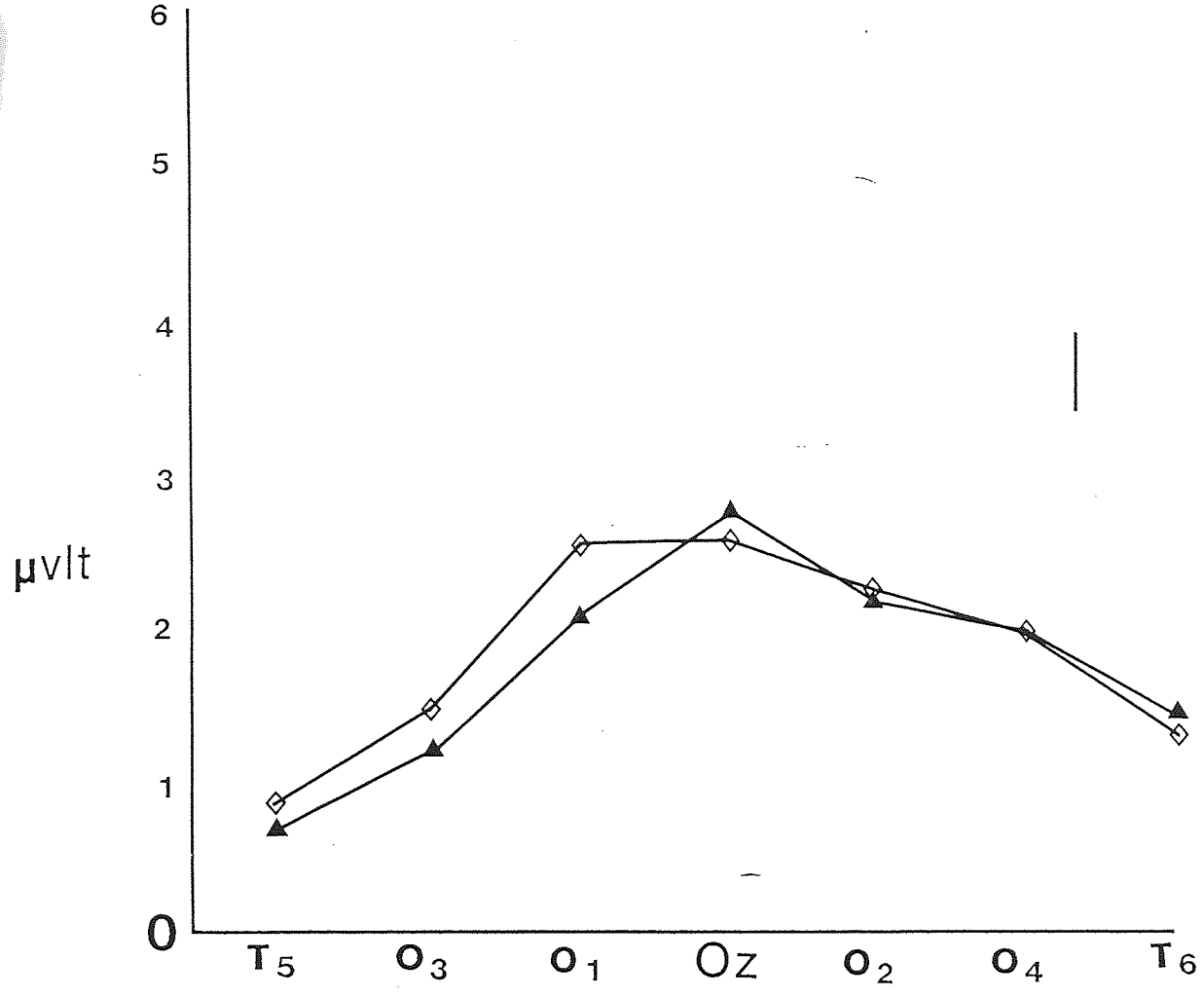

1
+
0
O3
O1
Oz
O2
O4
−

FIGURE 5.16

Comparison between the Group Average Distribution and the Right Half Field Distribution (10^{o} stimulus)

▲ - Simulated Relative Right Hemianopia with Absolute Left Hemianopia

◇ - Simulated Absolute Left Hemianopia (Right Half Field)


6
5
4
3
µvlt
2
1
0
T5
O3
O1
Oz
O2
O4
T6

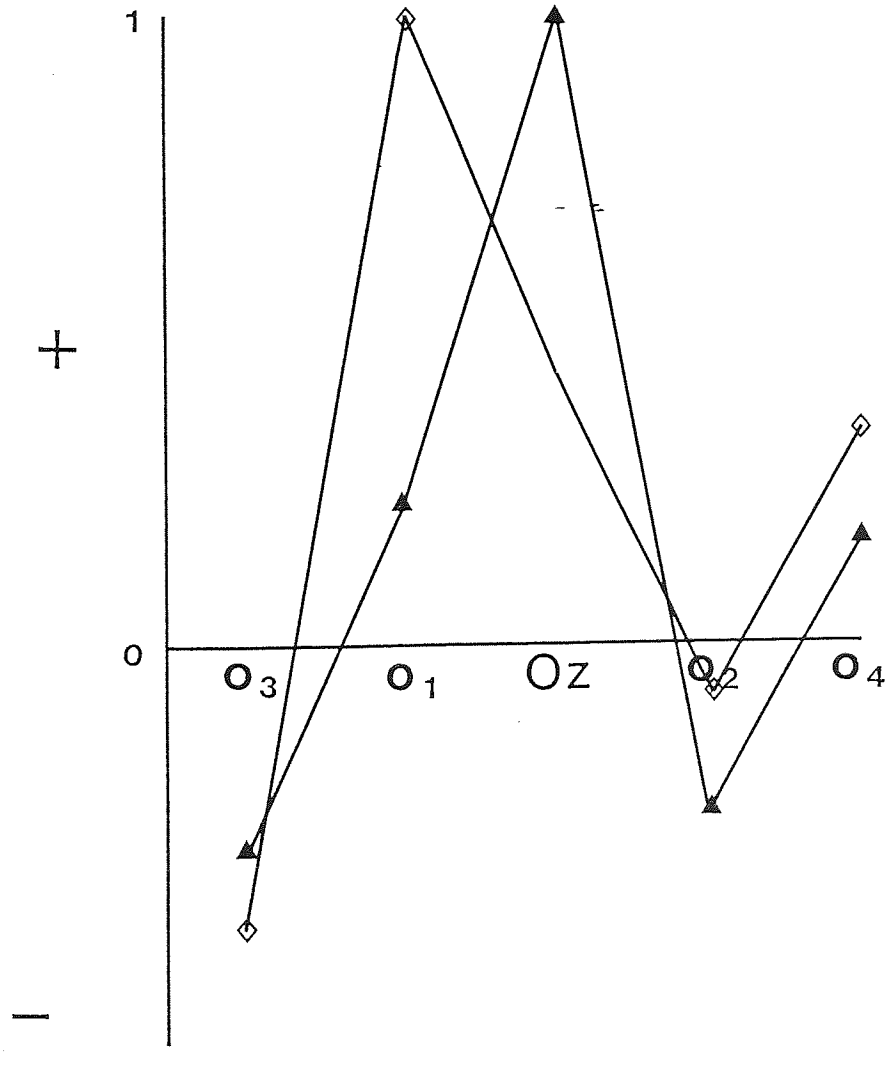
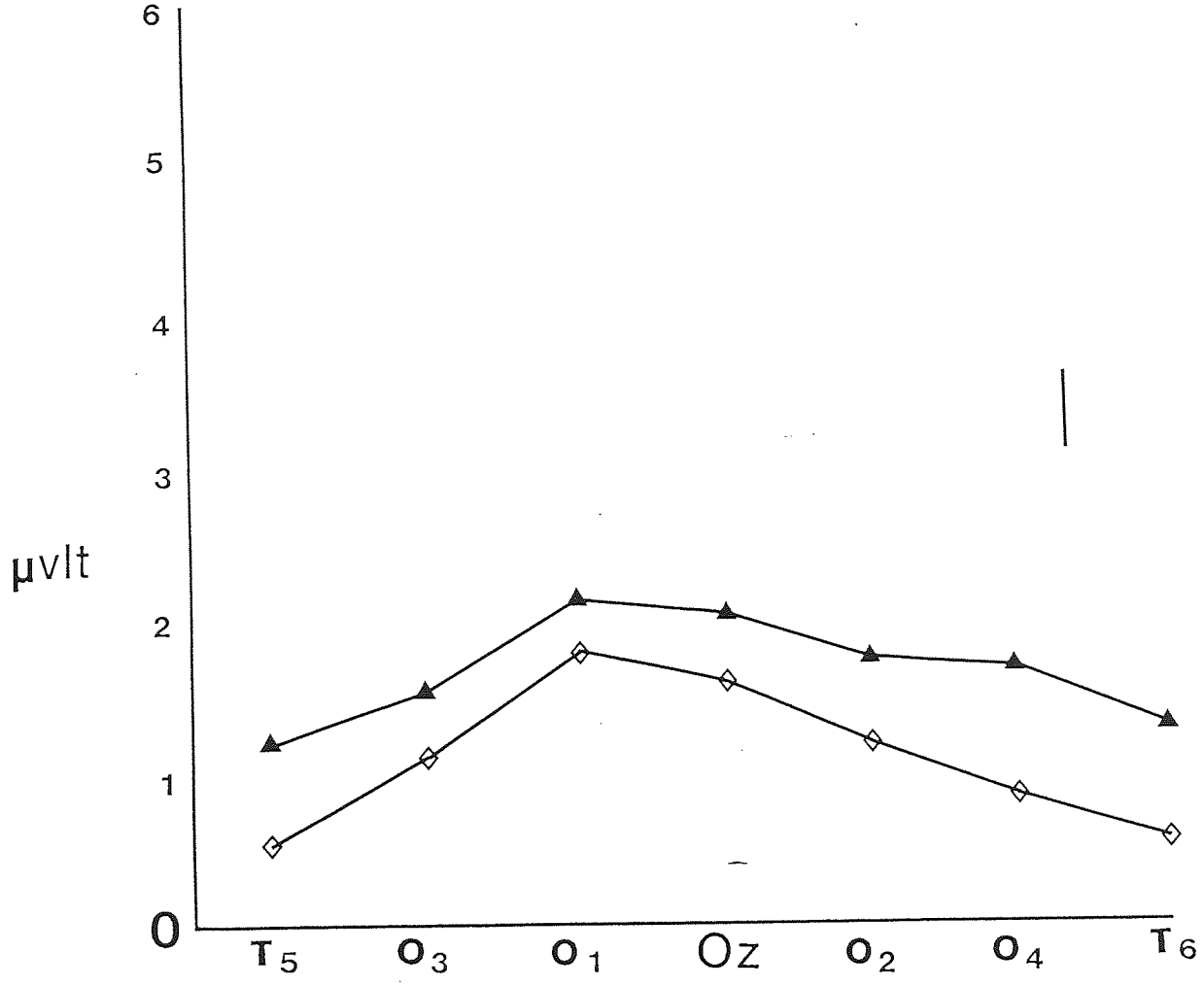

1
+
0
O3
O1
Oz
O2
O4
–

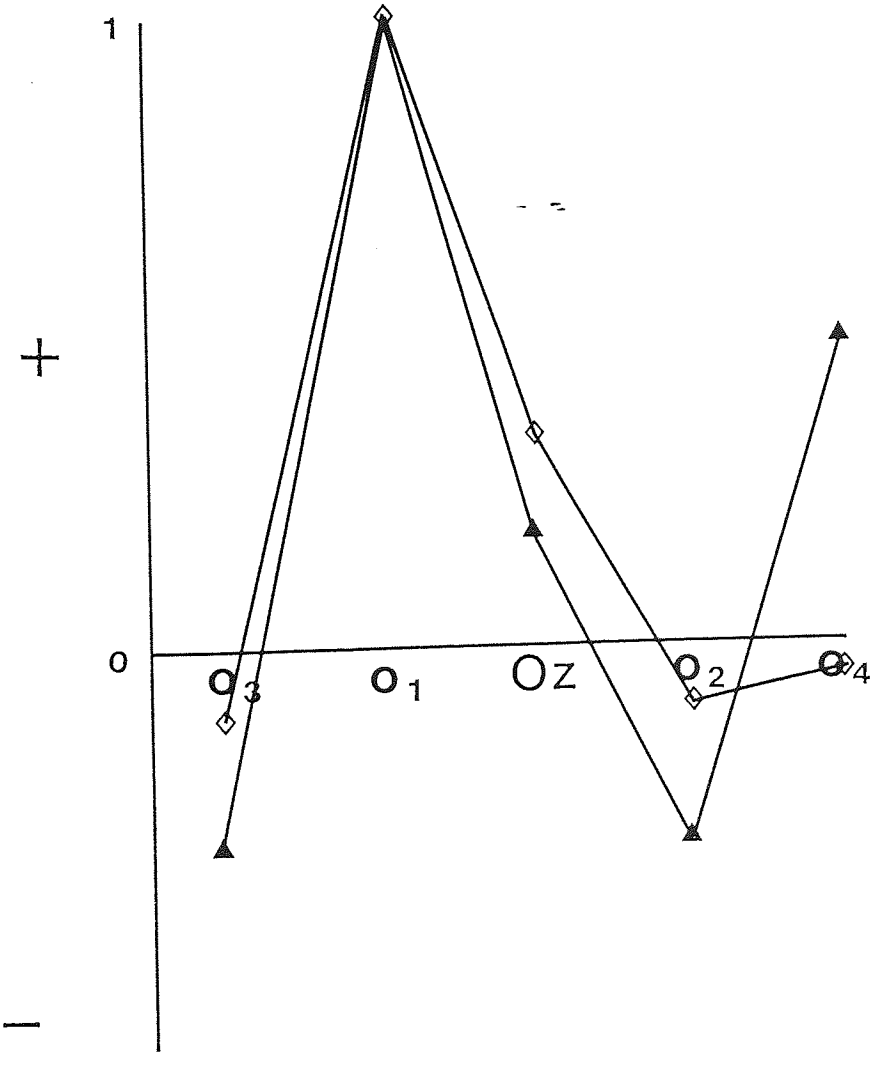
FIGURE 5.17

Comparison between the Group Average Distribution and the Right Half Field Distribution (3^{o} stimulus)

▲ - Simulated Relative Right Hemianopia with Absolute Left Hemianopia

◇ - Simulated Absolute Left Hemianopia (Right Half Field)


6
5
4
3
μvlt
2
1
0
T5
O3
O1
Oz
O2
O4
T6


1
+
0
O3
O1
Oz
O2
O4
—

observations exactly. For the 0-15° field size both stimulus conditions gave a maximum scalp current source over the midline with a sink over electrode O3, contralateral to the stimulated hemifield. The 0-5° stimulus gave a similar source-sink configuration for the more ipsilateral scotomatous result but the normally stimulated half field gave a maximum scalp current source over the O1 electrode but with a similar sink over electrode O3. The 0-1½° stimulus showed a maximum scalp current source over electrode O1 for both stimulus conditions with no clear scalp current sink.

5.6 Simulated Relative Altitudinal Scotoma

5.6.1 Results Following Full Field Stimulation with a Simulated Relative Lower Altitudinal Scotoma

The relative scotoma was simulated using a 0.6 neutral density filter to mask the lower hemifield. Table 5.25 illustrates the individual latencies and amplitudes following common reference recording and Table 5.26 shows the source derivation distribution measured at the same latency. Figure 5.18 plots the group average P100 amplitudes for the common reference and source derivation distributions. Table 5.27 demonstrates the mean and median averages, standard error, range and inter-ocular differences of the group average. Figures 5.19, 5.20 and 5.21 compare the group average distributions to the full field and upper field distributions.

FULL FIELD STIMULATION WITH SIMULATED LOWER FIELD DEFECT

		MD R.EYE	MD L.EYE	AC R.EYE	AC L.EYE	MW R.EYE	MW L.EYE	RD R.EYE	RD L.EYE	JR R.EYE	JR L.EYE	GROUP AVERAGE
		96msec	102msec	95msec	99msec	104msec	108msec	94msec	91msec	104msec	103msec	99.6msec
	Cz	0.38	-0.54	-0.12	0.57	0.99	1.44	0.16	1.03	0.28	0.12	0.351
	CPz	1.07	-0.33	1.05	1.85	1.45	2.23	0.37	1.64	0.18	0.17	0.968
	Pz	1.84	0.70	3.44	3.81	2.51	2.93	1.63	2.53	0.79	0.75	2.093
30°	POz	4.15	3.02	5.25	6.28	4.29	4.60	4.98	6.10	2.47	2.75	4.389
	Oz	4.80	4.09	4.47	5.42	4.59	4.83	7.81	7.61	3.61	4.47	5. 17
	IN	3.73	2.79	3.62	4.34	3.07	3.73	5.45	5.73	1.81	2.21	3.648
	Nz	3.26	2.14	2.89	3.72	1.73	3.04	4.20	3.42	0.96	1.50	2.686
		100msec	98msec	103msec	103msec	95msec	102msec	100msec	93msec	101msec	100msec	99.5msec
	Cz	0.22	0.77	0.55	-0.05	0.54	0.14	0.81	0.21	-0.54	0.32	0.297
	CPz	0.52	1.13	1.34	0.68	0.77	0.16	1.25	0.43	-0.27	0.88	0.689
	Pz	1.12	1.68	2.58	2.54	1.25	0.44	2.76	0.55	0.32	1.39	1.463
10°	POz	3.00	3.91	4.11	4.16	1.94	1.05	6.80	2.51	2.34	3.40	3.052
	Oz	3.78	4.12	2.54	2.50	2.04	0.57	7.64	5.94	4.06	6.46	3.965
	IN	2.00	3.57	1.34	1.50	1.73	0.13	6.46	4.98	2.14	5.29	2.914
	Nz	1.64	3.11	0.84	1.48	1.21	0.01	5.17	4.09	0.96	5.14	2.365
		103msec	117msec	116msec	118msec	112msec	108msec	105msec	101msec	112msec	116msec	110.8msec
	Cz	0.04	0.65	0.18	0.68	0.81	0.25	0.12	-0.25	0.36	-0.29	0.255
	CPz	0.27	1.31	1.16	0.68	1.34	0.48	0.43	-0.24	0.56	-0.52	0.547
	Pz	0.55	1.46	2.36	0.62	1.86	1.04	0.70	0.19	0.54	-0.45	0.849
3°	POz	1.52	2.45	3.41	1.02	3.04	1.86	1.37	0.25	1.00	0.59	1. 65
	Oz	2.50	3.67	3.02	1.45	3.83	2.02	2.64	1.37	2.23	3.63	2.636
	IN	2.18	3.23	2.34	1.51	3.30	1.30	2.73	1.66	2.13	3.60	2.348
	Nz	1.66	2.99	1.87	1.54	2.56	0.87	2.59	1.46	1.57	3.09	2. 02

TABLE 5.25 The individual latencies and amplitudes (microvolts) following common reference recording

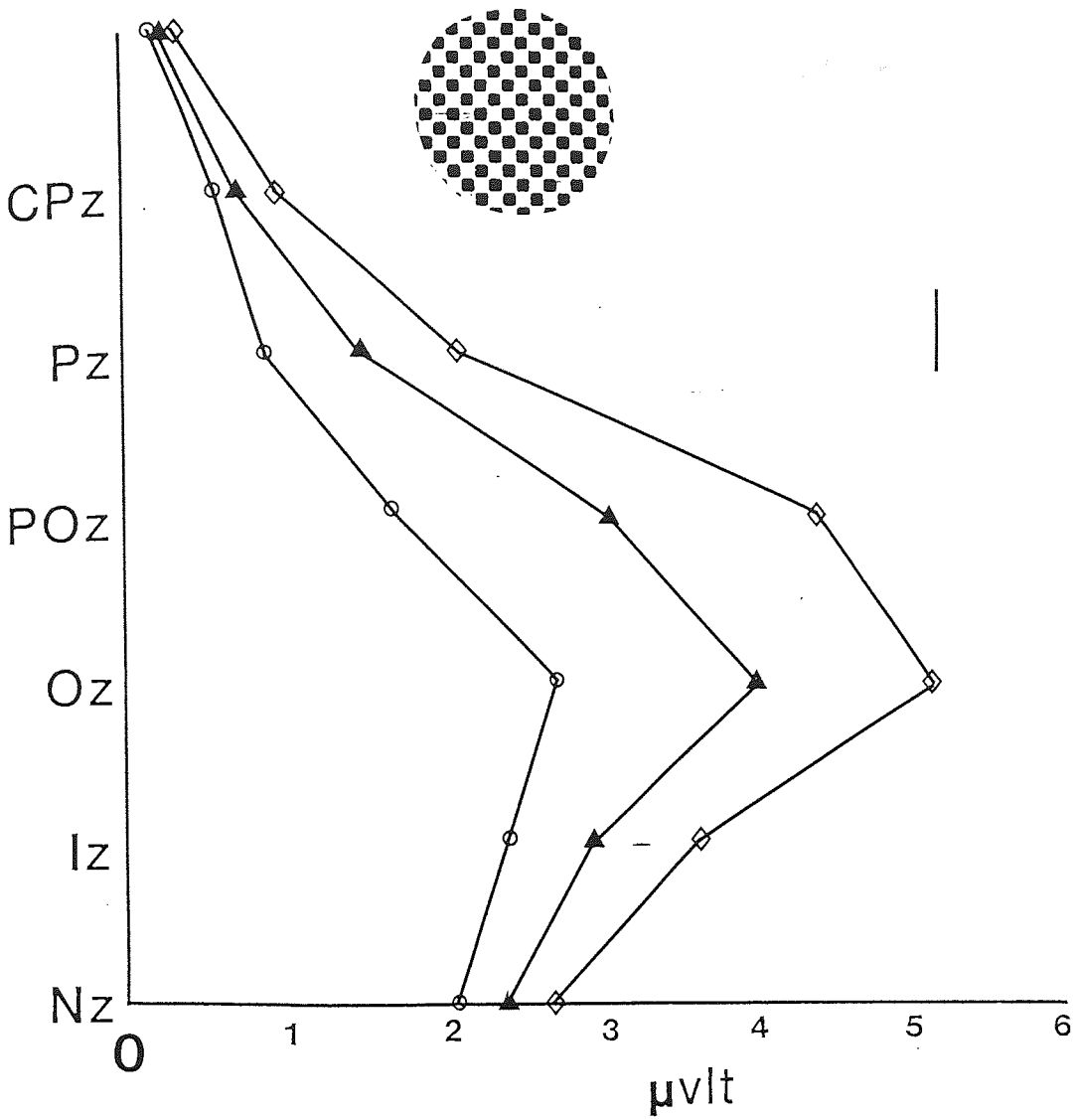
FULL FIELD STIMULATION WITH SIMULATED LOWER FIELD DEFECT

		MD R	MD L	AC R	AC L	MW R	MW L	RD R	RD L	JR R	JR L	GROUP AVERAGE
	CPz	0.07	0.83	1.22	0.69	0.61	0.08	1.05	0.28	0.14	0.29	0.51
	Pz	1.55	1.29	0.58	0.51	0.71	0.96	2.09	2.68	1.08	1.42	1.17
30°	POz	1.66	1.26	2.59	3.33	1.47	1.43	0.51	2.05	0.55	0.27	1.51
	Oz	1.73	2.36	0.08	0.22	1.82	1.34	5.20	3.39	2.93	3.98	2.31
	IN	0.60	0.66	0.12	0.47	0.18	0.41	1.11	0.42	0.94	1.54	0.56
	CPz	0.30	0.18	0.45	1.12	0.24	0.27	1.08	0.09	0.31	0.04	0.38
	Pz	1.29	1.68	0.29	0.23	0.22	0.33	2.53	2.13	1.44	1.50	1.12
10°	POz	1.11	2.02	3.11	3.29	0.60	1.10	3.21	0.88	0.30	1.04	1.28
	Oz	2.55	0.75	0.38	0.67	0.40	0.05	2.01	4.09	3.63	4.23	1.66
	IN	1.41	0.08	0.68	0.98	0.20	0.31	0.12	0.06	0.73	1.02	0.49
	CPz	0.06	0.50	0.21	0.05	0.02	0.32	0.04	0.02	0.23	0.29	0.002
	Pz	0.69	0.83	0.14	0.46	0.67	0.26	0.41	1.05	0.49	0.98	0.57
3°	POz	0.01	0.23	1.45	0.04	0.40	0.64	0.59	0.42	0.77	2.00	0.07
	Oz	1.30	1.65	0.29	0.37	1.32	0.89	1.18	1.50	1.33	3.07	1.29
	IN	0.19	0.20	0.21	0.02	0.21	0.29	0.23	0.13	0.47	0.47	0.10

TABLE 5.26 The source derivation distribution (microvolts cm^{-2})

FIGURE 5.18

The Group Average Amplitudes for the Common Reference and Source Derivation Distributions Following Full Field Stimulation with a Simulated Relative Lower Altitudinal Scotoma


CPz
Pz
POz
Oz
Iz
Nz
0
1
2
3
4
5
6
µvlt

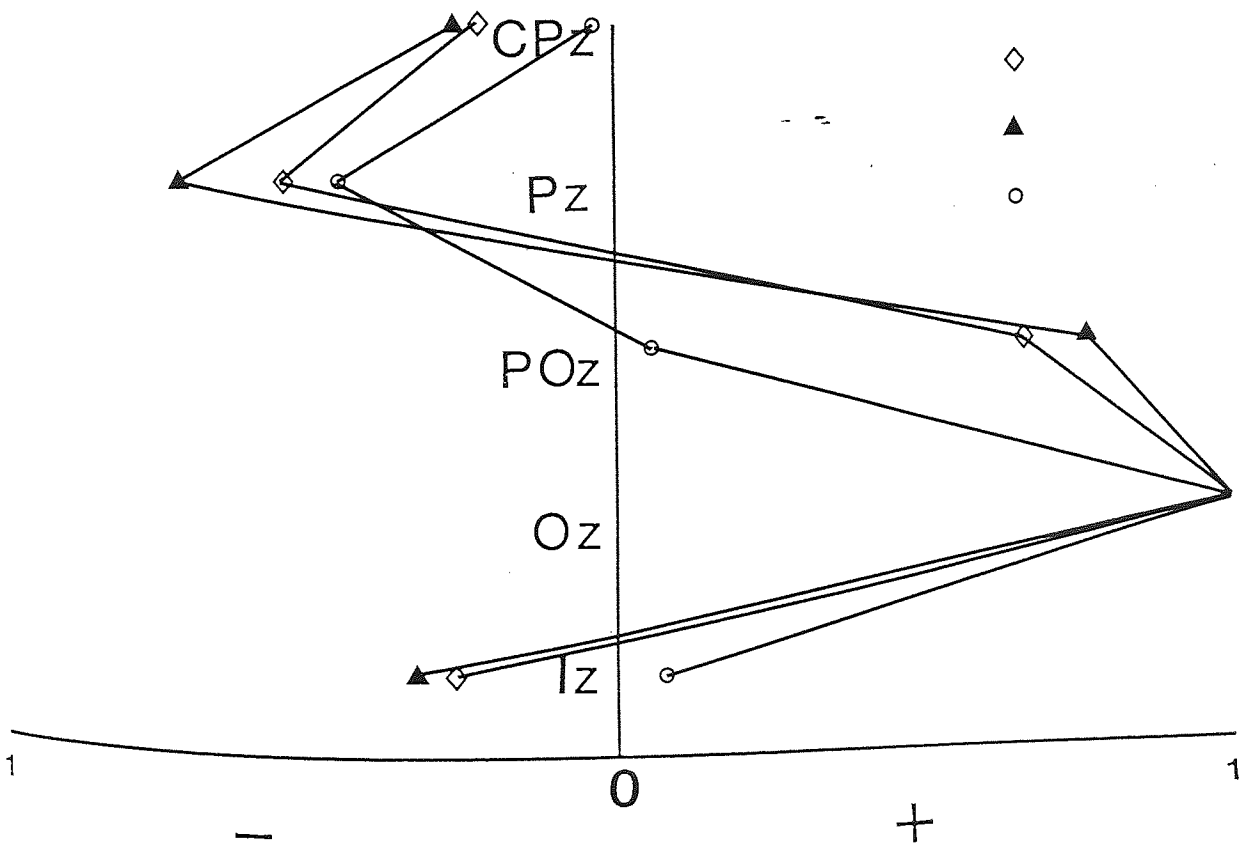

CPz
Pz
POz
Oz
Iz
1
0
1
–
+

TABLE 5.27 FULL FIELD WITH SIMULATED RELATIVE LOWER ALTITUDINAL SCOTOMA

Latency (milliseconds)

Field Size	Mean	Median	Range	Standard Error	Interocular Asynchrony(Oz)
30°	99.6	97.5	91-108	1.72	2.0
10°	99.5	100	93-103	1.04	0.6
3°	110.8	112	101-118	0.85	2.4

Amplitude (microvolts)

Field Size	Mean	Median	Range	Standard Error	Interocular Asymmetry(Oz)
30°	5.33	4.82	3.61-7.81	0.46	0.22
10°	4.34	4.12	1.05-7.64	0.62	0.09
3°	2.70	2.62	1.46-3.83	0.28	0.41

5.6.2 Discussion

When comparing these results to those obtained by full field stimulation and stimulation of the upper field, a simulated absolute lower altitudinal scotoma, the affect on the mean latency was negligible for the 10^{o} and 3^{o} stimuli. The 30^{o} stimulus, however, elicited a significant delay between the full field result and the relative scotoma (t-test: $p<0.01$), which was in turn significantly earlier than the results for the absolute scotoma (t-test: $p<0.01$).

The mean amplitude for the P100 component was very similar for the 30^{o} and 10^{o} full field and relative scotoma stimuli but was reduced for the simulated absolute scotoma. The 3^{o} stimulus again showed a very similar full field and relative scotoma result but the amplitude was slightly higher for the latter stimulus. This may support the observation mentioned in the previous Section that a partial reduction in the mean luminance of the foveal stimulus gives an increased amplitude although we must be wary as there was no statistically significant difference between the two.

The amplitude distributions (Figures 5.19 to 5.21) are little affected by the relative scotoma compared to the full field stimulus. Analysis of variance supported these observations as there was no significant interaction variance ratio for any of the 3 stimulus conditions. There was, however, a significant difference

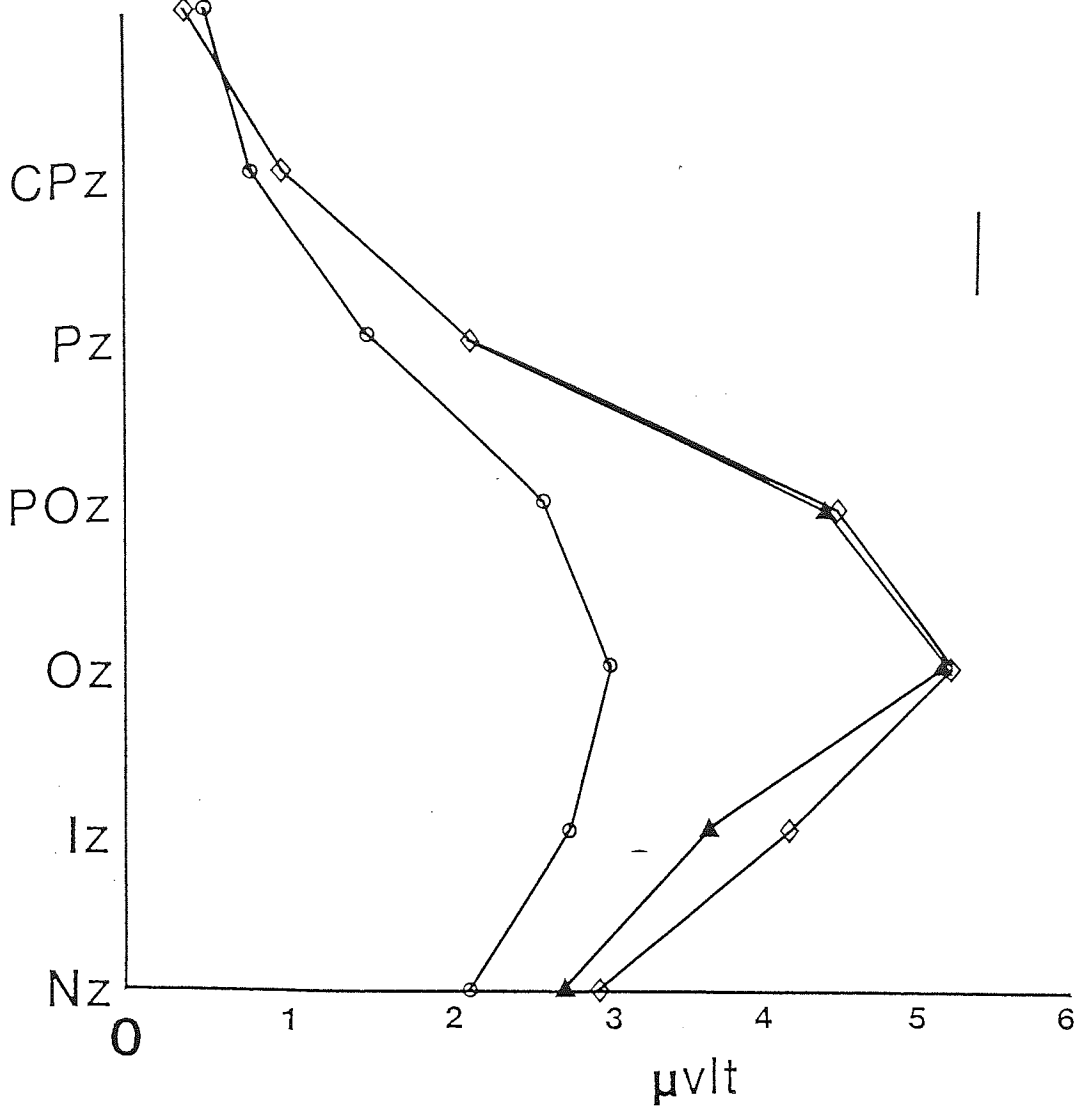


FIGURE 5.19

Comparison between the Group Average Distribution and the Full Field and Upper Field Distributions (30^{o} stimulus)

▲ - Simulated Relative Lower Altitudinal Defect

◇ - Full Field

o - Simulated Absolute Lower Altitudinal Defect

(Upper Field)

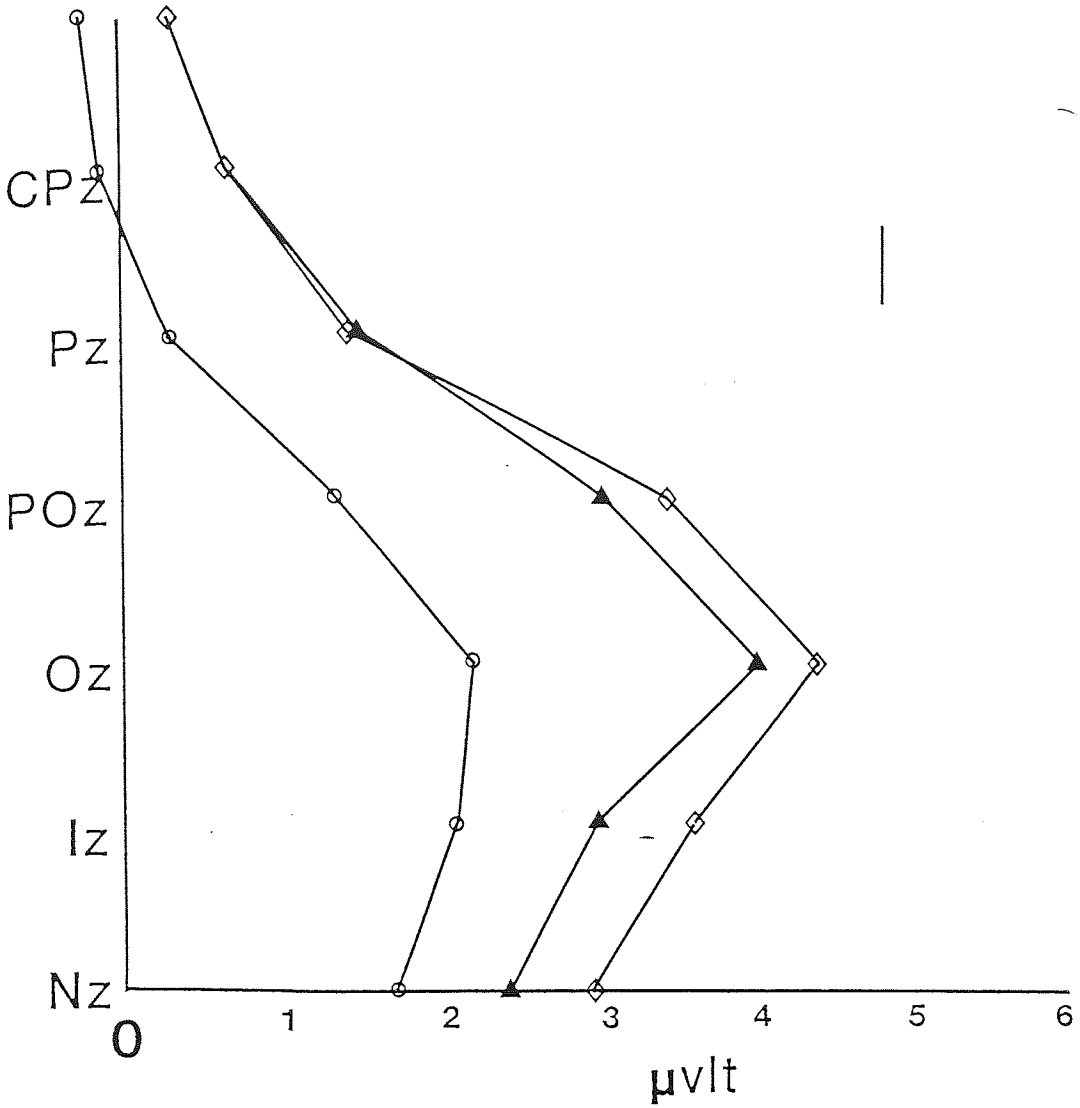


FIGURE 5.20

Comparison between the Group Average Distribution and the Full Field and Upper Field Distributions (10^{o} stimulus)

▲ - Simulated Relative Lower Altitudinal Defect

◇ - Full Field

o - Simulated Absolute Lower Altitudinal Defect

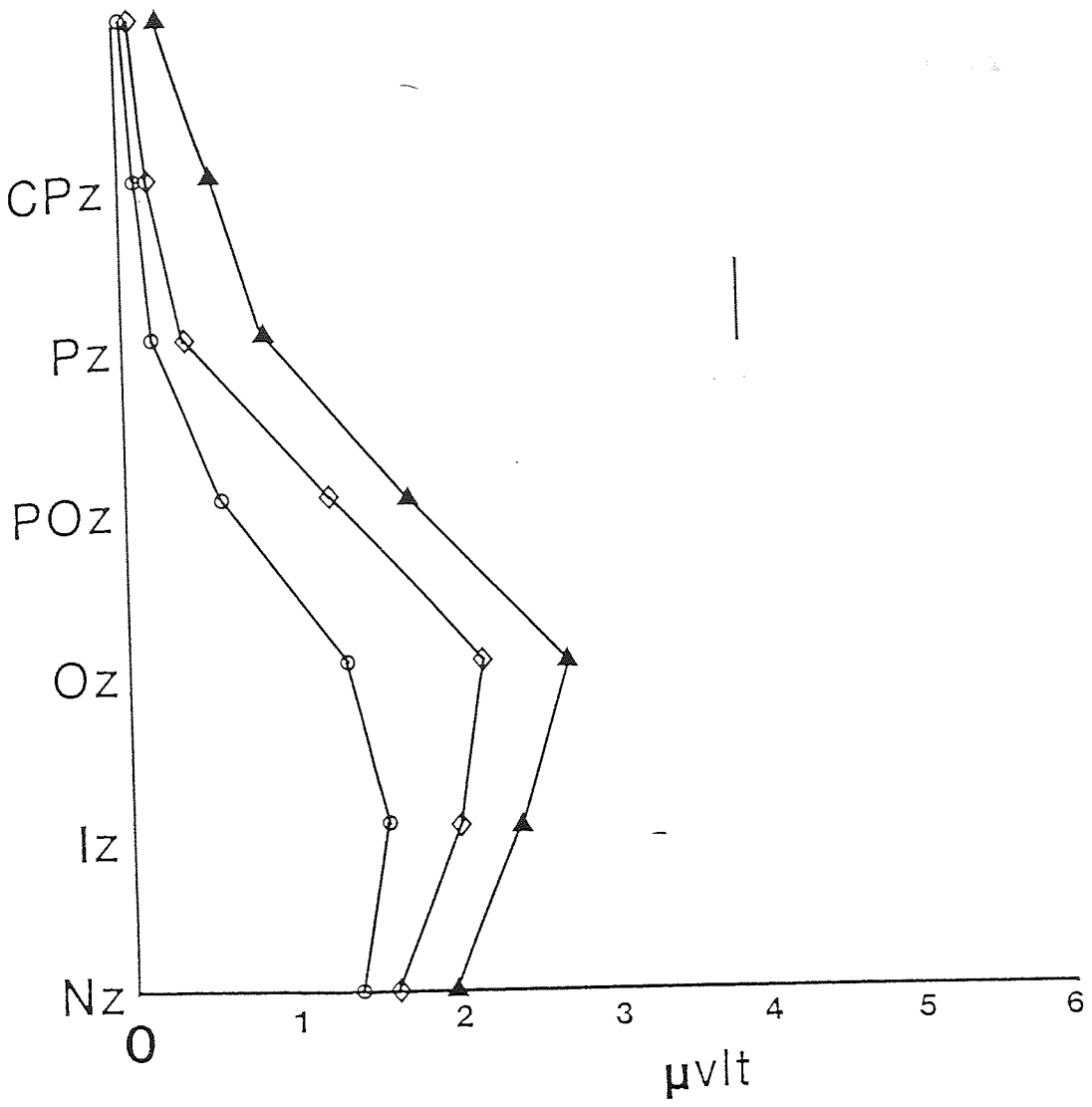


FIGURE 5.21

Comparison between the Group Average Distribution and the Full Field and Upper Field Distributions (3^{o} stimulus)

▲ - Simulated Relative Lower Altitudinal Defect

◇ - Full Field

o - Simulated Absolute Lower Altitudinal Defect

(Upper Field)

between the amplitude distributions following stimulation by the relative and absolute scotomas for the 30^{o} field size ($F_{6,108} = 8.02$: $p<0.01$). Analysis of variance for the 3^{o} stimulus showed no significant interaction variance ratio.

We must therefore conclude that a relative, lower, altitudinal field defect may be very difficult to distinguish from the normal full field result even when touching the midline.

5.6.3 Results Following Full Field Stimulation with a Simulated Relative Upper Altitudinal Scotoma

The relative scotoma was simulated using a 0.6 neutral density filter to mask the upper hemifield. Table 5.28 illustrates the individual latencies and amplitudes following common reference recording and Table 5.29 shows the source derivation distribution measured at the same latency. Figure 5.22 plots the group average P100 amplitudes for the common reference and source derivation distributions. Table 5.30 demonstrates the mean and median averages, standard error, range and inter-ocular differences of the group average. Figures 5.23, 5.24 and 5.25 compare the group average distributions to the full field and lower field distributions.

FULL FIELD STIMULATION WITH SIMULATED UPPER FIELD DEFECT

		MD R.EYE	MD L.EYE	AC R.EYE	AC L.EYE	MW R.EYE	MW L.EYE	RD R.EYE	RD L.EYE	JR R.EYE	JR L.EYE	GROUP AVERAGE
		92msec	95msec	106msec	92msec	105msec	99msec	92msec	94msec	100msec	93msec	96.8msec
	Cz	1.05	-0.28	-0.69	0.91	1.50	1.18	0.80	0.64	0.04	-0.13	-0.502
	CPz	0.70	-0.02	-1.05	2.32	2.44	1.97	1.34	1.29	0.25	0.05	0.929
	Pz	1.55	1.01	-0.60	4.07	3.55	2.47	1.84	2.34	0.84	0.76	1.783
30°	POz	3.70	3.55	1.61	5.93	5.17	3.97	5.02	5.71	2.84	2.71	4.021
	Oz	3.89	3.55	2.88	5.35	4.54	4.20	6.73	7.82	5.26	3.76	4.798
	IN	2.73	3.43	2.86	4.53	2.82	3.11	4.86	6.40	4.30	2.26	3. 73
	Nz	2.09	2.66	2.46	3.96	2.07	2.60	3.52	4.46	4.20	1.66	2.968
		92msec	94msec	102msec	104msec	96msec	102msec	95msec	91msec	96msec	100msec	97.2msec
	Cz	0.53	-0.01	0.27	1.43	-0.07	0.36	0.62	-0.16	-0.03	0.18	0.312
	CPz	1.23	0.28	1.30	2.43	0.45	0.50	0.70	-0.02	0.39	0.79	0.805
	Pz	1.87	0.55	2.91	3.64	0.95	0.61	1.02	0.54	0.96	1.25	1. 43
10°	POz	4.50	2.81	4.71	5.50	1.78	1.50	2.46	2.67	2.52	3.23	3.168
	Oz	5.23	3.50	2.53	3.90	1.58	1.93	4.65	5.95	3.85	5.55	3.867
	IN	4.09	2.28	0.77	2.10	1.00	1.43	3.82	4.91	1.79	4.46	2.665
	Nz	3.74	1.79	0.00	1.21	1.52	0.58	3.70	3.14	0.79	3.47	1.994
		97msec	96msec	108msec	124msec	105msec	103msec	96msec	94msec	105msec	114msec	104.2msec
	Cz	0.17	-0.01	0.86	0.86	0.43	0.74	0.47	0.00	0.25	-0.89	0.288
	CPz	0.00	0.24	0.69	1.35	0.89	0.61	0.96	4.08	0.20	-0.84	0.418
	Pz	0.01	0.56	0.25	1.65	1.11	0.65	1.43	0.41	0.25	-0.41	0.591
3°	POz	1.13	1.48	0.60	1.98	1.87	1.60	2.95	2.54	0.55	0.64	1.534
	Oz	2.26	2.20	-0.10	1.67	2.69	1.71	4.06	5.57	1.94	3.11	2.511
	IN	2.30	1.79	-0.66	1.11	2.37	0.95	3.67	4.75	1.90	3.09	2.127
	Nz	2.13	1.31	-1.01	0.98	2.09	0.13	3.14	3.81	0.98	2.61	1.617

TABLE 5.28 The individual latencies and amplitudes (microvolts) following common reference recording

FULL FIELD STIMULATION WITH SIMULATED
UPPER FIELD DEFECT

		MD R	MD L	AC R	AC L	MW R	MW L	RD R	RD L	JR R	JR L	GROUP AVERAGE
	CPZ	1.19	0.78	0.81	0.35	0.17	0.30	0.04	0.40	0.37	0.53	0.43
	Pz	1.30	1.51	1.76	0.11	0.52	1.00	2.68	2.32	1.42	1.25	1.39
30°	POz	1.96	2.54	0.94	2.44	2.26	1.27	1.47	1.27	0.42	0.91	1.46
	Oz	1.35	0.12	1.29	0.25	1.08	1.31	3.57	3.52	3.38	2.55	1.84
	IN	0.52	0.65	0.38	0.26	0.96	0.58	0.53	0.52	0.86	0.89	0.31
	CPz	0.07	0.01	0.58	0.22	0.02	0.03	0.24	0.41	0.14	0.15	0.13
	Pz	1.99	1.98	0.19	0.66	0.34	0.79	1.13	1.57	0.99	1.52	1.12
10°	POz	1.90	1.56	3.99	3.47	1.04	0.47	0.73	1.16	0.22	0.35	1.04
	Oz	1.87	1.91	0.43	0.20	0.37	0.92	3.02	4.33	3.39	3.42	1.90
	IN	0.80	0.74	0.98	0.91	1.10	0.35	0.71	0.73	1.05	0.11	0.53
	CPz	0.17	0.07	0.27	0.20	0.24	0.18		0.05	0.09	0.39	0.01
	Pz	1.11	0.60	0.79	0.03	0.54	0.91		0.38	0.26	0.62	0.58
3°	POz	0.02	0.20	1.05	0.64	0.06	0.84		0.68	1.09	1.42	0.06
	Oz	1.09	1.13	0.13	0.25	1.14	0.86		1.32	1.43	2.49	1.06
	IN	0.21	0.07	0.22	0.43	0.04	0.07		0.50	0.88	0.46	0.06

TABLE 5.29. The source derivation distribution (microvolts cm^{-2})

FIGURE 5.22

The Group Average Amplitudes for the Common Reference and Source Derivation Distributions Following Full Field Stimulation with a Simulated Relative Upper Altitudinal Scotoma

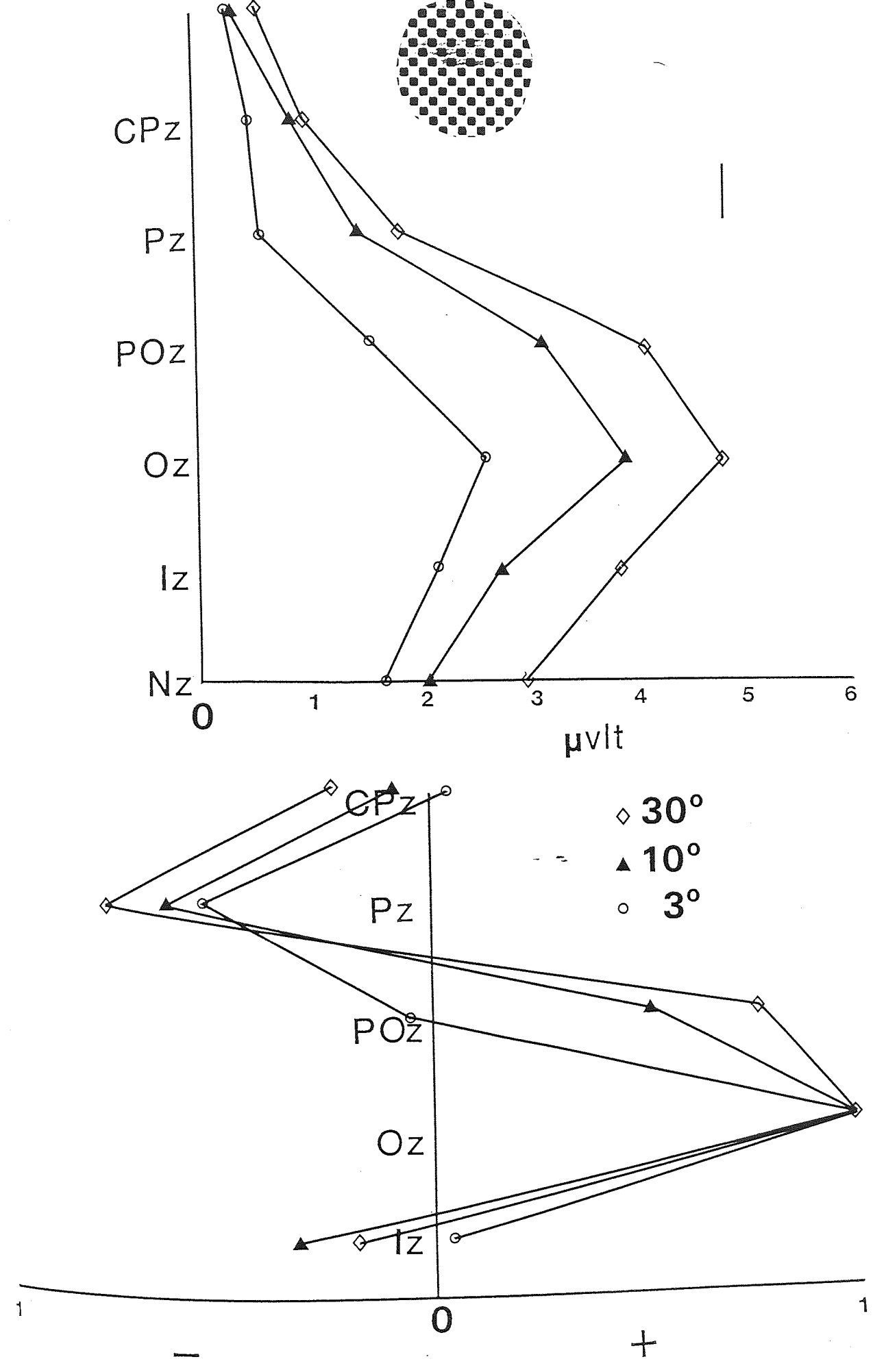

CPz
Pz
POz
Oz
Iz
Nz
0
1
2
3
4
5
6
µvlt
CPz
Pz
POz
Oz
Iz
30°
10°
3°
1
0
1
–
+

TABLE 5.30 FULL FIELD WITH SIMULATED RELATIVE UPPER ALTITUDINAL SCOTOMA

Latency (milliseconds)

Field Size	Mean	Median	Range	Standard Error	Interocular Asychrony(Oz)
30°	96.8	94.5	92-105	1.71	4.4
10°	97.2	96	91-104	1.43	2.0
3°	104.2	104	94-124	2.97	4.0

Amplitude (microvolts)

Field Size	Mean	Median	Range	Standard Error	Interocular Asymmetry(Oz)
30°	4.90	4.69	2.88-7.82	0.50	0.28
10°	4.27	4.68	1.78-5.95	0.47	0.64
3°	2.62	2.25	0.86-5.57	0.44	0.68

5.6.4 Discussion

When comparing these results to those obtained by full field stimulation and stimulation of the lower field, a simulated absolute upper altitudinal scotoma, the effect on the mean latency was negligible for the 30^{o} and 10^{o} stimuli. The 3^{o} stimulus resulted in a significantly earlier latency when the 2 scotomatous results were compared to the full field results (t-test: $p<0.05$).

The mean amplitude of the P100 component was very similar for all stimulus conditions at each field size. Interestingly, the 3^{o} relative scotomatous result gave a slightly higher amplitude than the full field result as noted for the simulated relative lower altitudinal scotoma. Figures 5.23, 5.24 and 5.25 compare the amplitude distributions for the 3 stimulus conditions. The distribution for the relative scotoma was very similar to the full field and absolute scotoma distributions for the 30^{o} and 3^{o} stimuli. The 10^{o} stimulus again showed the most exaggerated range of responses for the medial montage. There was a slight reduction in the amplitude of the relative scotoma results below the Oz electrode giving a distribution which appeared somewhere between the full field and lower field results. Analysis of variance, however, showed no significant interaction between the relative scotoma results and the other two stimulus conditions for any of the 3 field sizes. These results illustrate further the difficulty

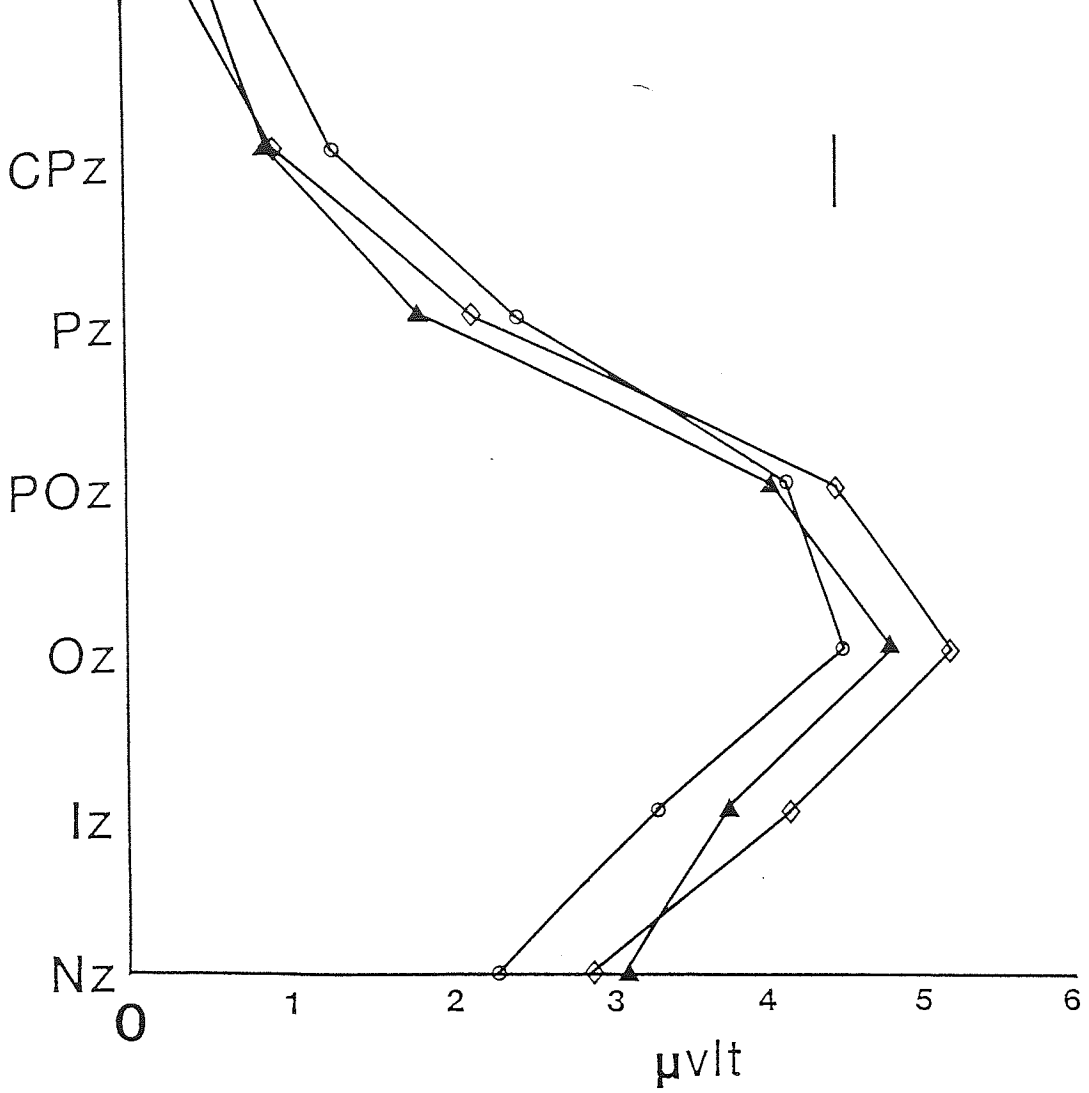


FIGURE 5.23

Comparison between the Group Average Distribution and the Full Field and Lower Field Distributions (30° stimulus)

▲ - Simulated Relative Upper Altitudinal Defect

◇ - Full Field

o - Simulated Absolute Upper Altitudinal Defect

(Lower Field)

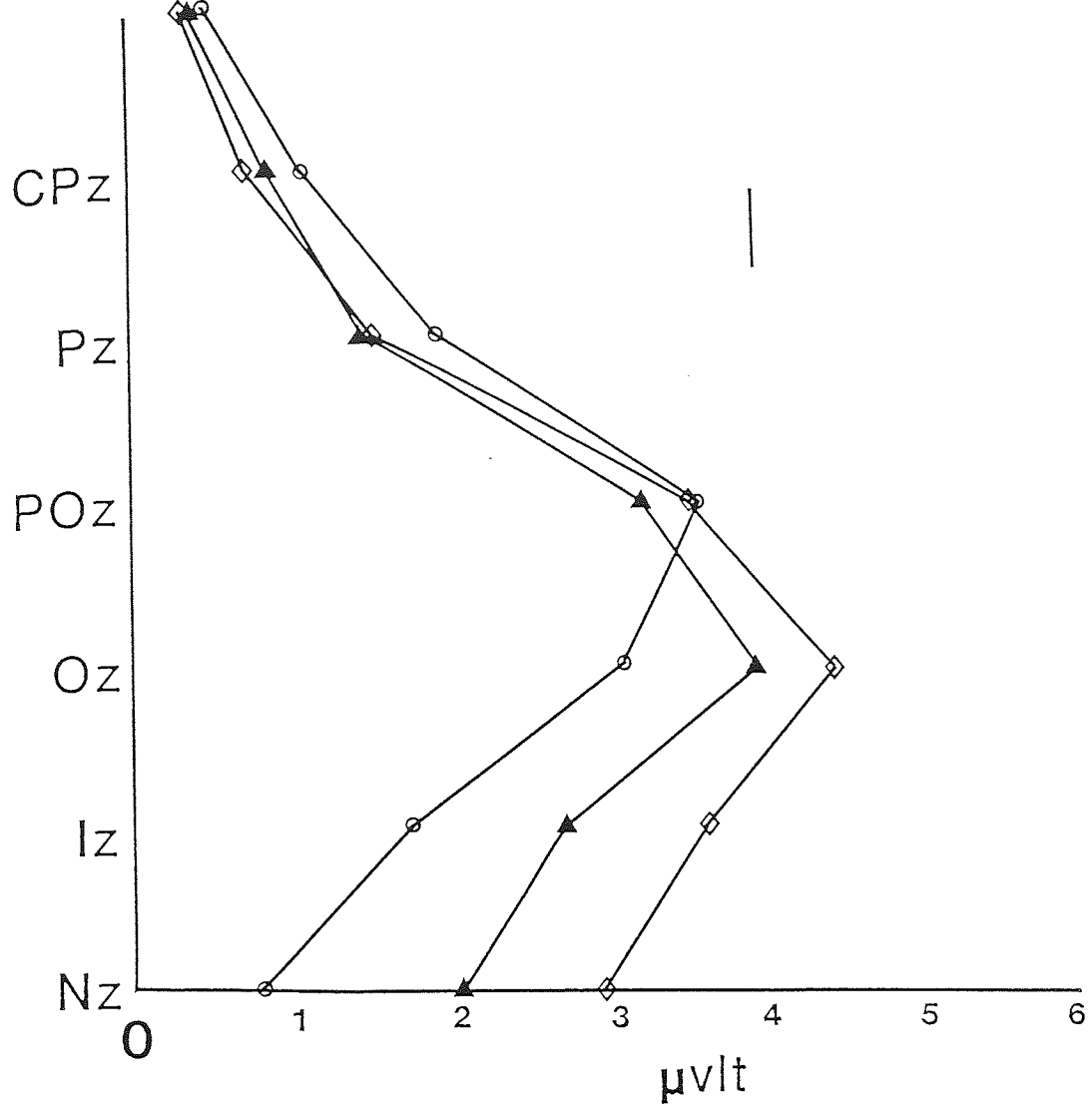


FIGURE 5.24

Comparison between the Group Average Distribution and the Full Field and Lower Field Distributions (10^{o} stimulus)

▲ - Simulated Relative Upper Altitudinal Defect

◇ - Full Field

o - Simulated Absolute Upper Altitudinal Defect

(Lower Field)

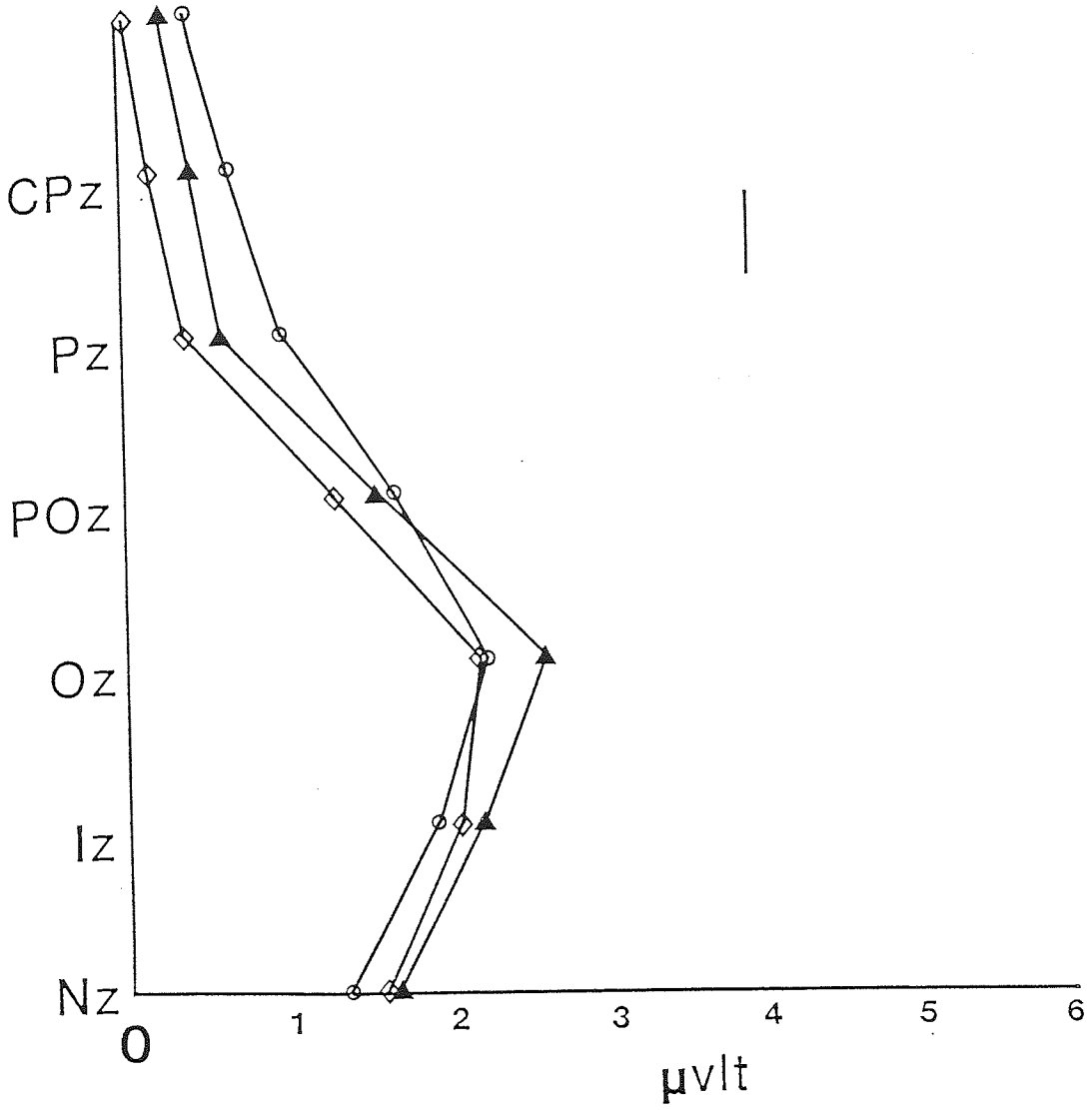


FIGURE 5.25

Comparison between the Group Average Distribution and the Full Field and Lower Field Distributions (3^{o}) stimulus)

▲ - Simulated Relative Upper Altitudinal Defect

◇ - Full Field

o - Simulated Absolute Upper Altitudinal Defect

(Lower Field)

we may encounter distinguishing altitudinal scotoma following full field stimulation.

5.7 Simulated Central Scotoma

5.7.1 Results

1. 3^{o} Relative Central Scotoma

Table 5.31 illustrates the individual latencies and amplitudes following common reference recording and Table 5.32 shows the source derivation distribution measured at the same latency. Figure 5.26 plots the group average P100 amplitudes for the common reference and source derivation distributions. Table 5.33 demonstrates the mean and median averages, standard error, range, inter-ocular differences and distribution asymmetries of the group average.

11. 3^{o} Absolute Central Scotoma

Table 5.34 illustrates the individual latencies and amplitudes following common reference recording and Table 5.35 shows the source derivation distribution measured at the same latency. Figure 5.27 plots the group average P100 amplitudes for the common reference and source derivation distributions. Table 5.36 demonstrates the mean and median averages, standard error, range, inter-ocular differences and distribution asymmetries for the group average. Figures 5.28, 5.29

FULL FIELD STIMULATION WITH SIMULATED 3° RELATIVE CENTRAL SCOTOMA

	MD R.EYE	MD L.EYE	AC R.EYE	AC L.EYE	MW R.EYE	MW L.EYE	RD R.EYE	RD L.EYE	JR R.EYE	JR L.EYE	GROUP AVERAGE
	100msec	99msec	99msec	97msec	109msec	108msec	91msec	91msec	96msec	102msec	99.2msec
T5	-0.36	0.59	2.77	2.77	2.91	2.17	1.82	1.77	1.71	1.38	1.75
03	0.11	0.93	3.98	3.32	5.11	4.39	4.05	3.37	2.75	2.33	3.03
01	2.26	2.37	5.49	3.88	6.59	5.97	6.08	5.43	4.58	3.71	4.64
30° Oz	3.71	3.07	6.26	4.05	7.01	6.21	7.66	7.06	5.08	4.90	5.50
02	2.55	1.90	4.90	2.99	4.79	3.75	5.92	5.09	3.07	3.29	3.83
04	1.92	0.80	3.32	2.15	3.29	2.49	3.78	2.37	1.17	1.80	2.31
T6	1.27	0.46	1.56	1.30	2.06	1.28	2.09	1.03	0.22	1.25	1.25
	108msec	93msec	105msec	94msec	110msec	109msec	93msec	93msec	97msec	100msec	100.2msec
T5	1.68	1.25	1.38	1.46	0.76	0.27	-0.23	1.16	2.07	1.37	1.15
03	2.00	1.52	1.88	3.04	2.04	0.78	0.56	2.26	3.43	2.47	2.05
01	2.76	2.37	3.04	4.55	3.06	1.07	2.55	3.82	5.38	3.90	3.32
10° Oz	3.02	3.23	3.50	4.78	2.94	1.00	4.55	5.20	6.14	4.56	3.89
02	1.67	3.04	3.59	4.20	1.84	0.55	3.62	4.04	4.55	3.37	2.98
04	0.09	2.06	1.72	3.15	1.09	0.02	2.07	2.29	2.97	2.49	1.74
T6	-0.49	1.59	0.67	1.83	0.62	-0.26	1.04	1.25	1.99	1.39	0.93
	125msec	107msec	113msec	109msec	110msec	116msec	101msec	101msec	111msec	106msec	109.9msec
T5	0.73	0.76	2.06	0.74	1.00	0.23	-0.68	1.29	0.65	0.30	0.71
03	1.03	1.11	3.31	1.08	1.94	0.58	-0.20	2.14	0.84	0.88	1.27
01	1.99	1.46	4.60	1.65	2.27	0.69	0.73	2.57	1.66	1.68	1.93
3° Oz	2.02	1.64	4.83	2.21	2.13	0.65	0.34	2.39	2.23	2.16	2.06
02	1.32	1.32	3.90	1.55	1.96	0.54	-0.29	1.70	1.55	1.34	1.49
04	0.96	0.64	3.17	0.24	1.20	0.61	-0.41	1.48	1.10	1.28	1.03
T6	0.43	0.34	2.35	-0.18	0.51	0.46	-0.53	0.71	0.59	0.83	0.55

TABLE 5.31 The individual latencies and amplitudes (microvolts) following common reference recording

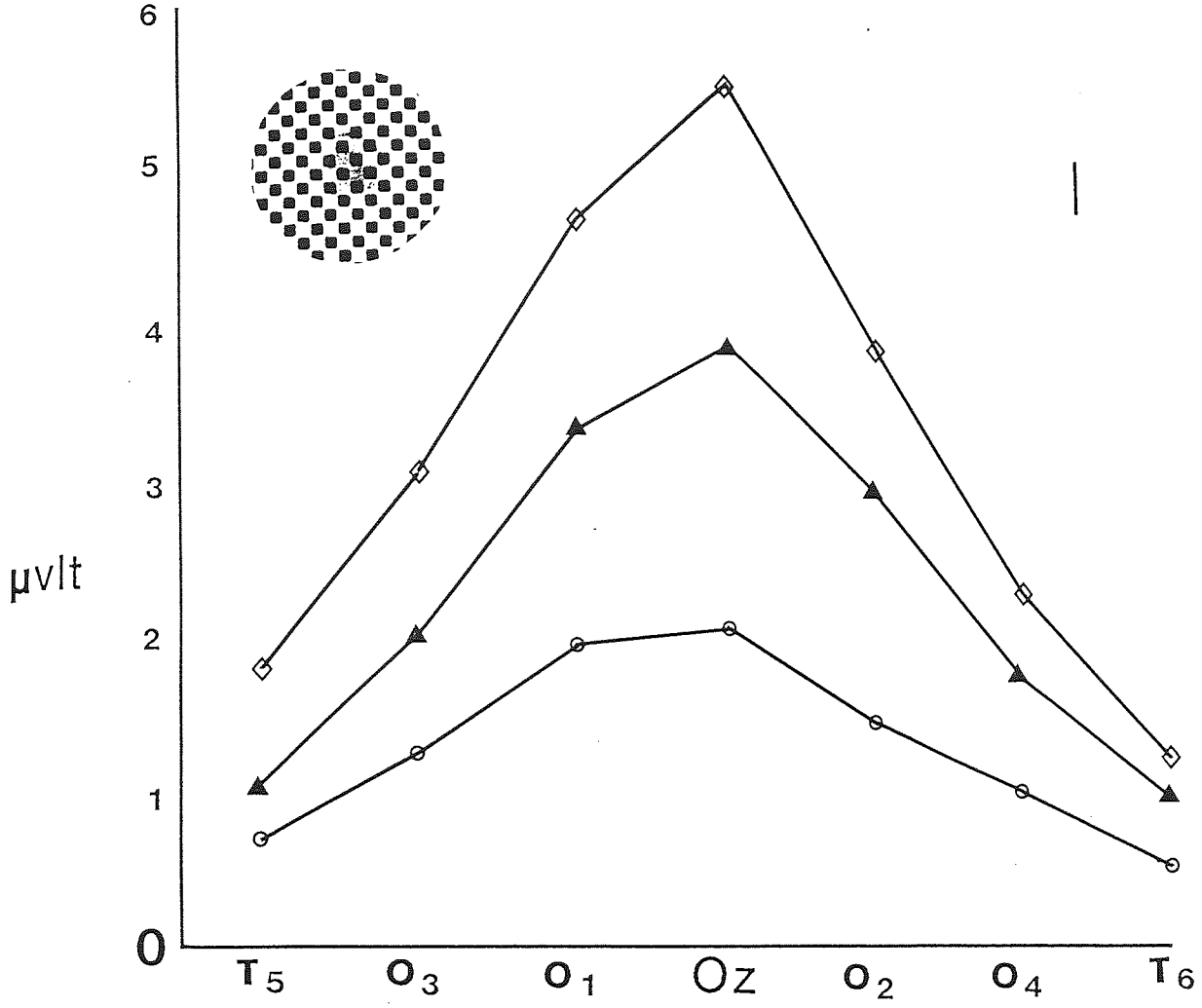
FULL FIELD STIMULATION WITH SIMULATED
3° RELATIVE CENTRAL SCOTOMA

		MD R	MD L	AC R	AC L	MW R	MW L	RD R	RD L	JR R	JR L	GROUP AVERAGE
	03	1.67	1.09	0.29	0.01	0.72	0.64	0.21	0.46	0.78	0.43	0.316
	01	0.70	0.73	0.74	0.40	1.05	1.35	0.45	0.43	1.32	0.19	0.736
30°	Oz	2.60	1.88	2.13	1.22	2.64	2.69	3.32	3.60	2.51	2.80	2.539
	02	0.52	0.07	0.23	0.22	0.73	1.19	0.40	0.75	0.11	0.12	0.158
	04	0.02	0.75	0.17	0.01	0.27	0.05	0.45	1.39	0.95	0.94	0. 31
	03	0.43	0.51	0.66	0.05	0.26	0.22	1.20	0.45	0.59	0.33	0.364
	01	0.49	0.80	0.70	1.30	1.14	0.36	0.02	0.18	1.19	0.77	0.691
10°	Oz	1.62	1.04	0.37	0.80	0.99	0.37	2.95	2.55	2.34	1.86	1.489
	02	0.23	0.01	1.95	0.47	0.36	0.09	0.61	0.58	0	0.32	0.324
	04	1.00	0.57	0.81	0.28	0.28	0.25	0.52	0.72	0.61	0.22	0.426
	03	0.66	0	0.04	0.24	0.61	0.25	0.45	0.43	0.64	0.22	0.096
	01	0.94	0.18	1.06	0.02	0.47	0.15	1.32	0.61	0.27	0.32	0.534
3°	Oz	0.71	0.50	1.16	1.21	0.03	0.07	0.23	0.52	1.23	1.29	0.695
	02	0.32	0.35	0.20	0.66	0.59	0.19	0.50	0.48	0.21	0.75	0.105
	04	0.16	0.37	0.09	0.90	0.06	0.22	0	0.55	0.05	0.38	0.012

TABLE 5.32. The source derivation distribution
(microvolts cm^{-2})

FIGURE 5.26

The Group Average Amplitudes for the Common Reference and Source Derivation Distributions Following Full Field Stimulation with a Simulated 3^{o} Relative Central Scotoma


6
5
4
3
µvlt
2
1
0
T5
O3
O1
Oz
O2
O4
T6

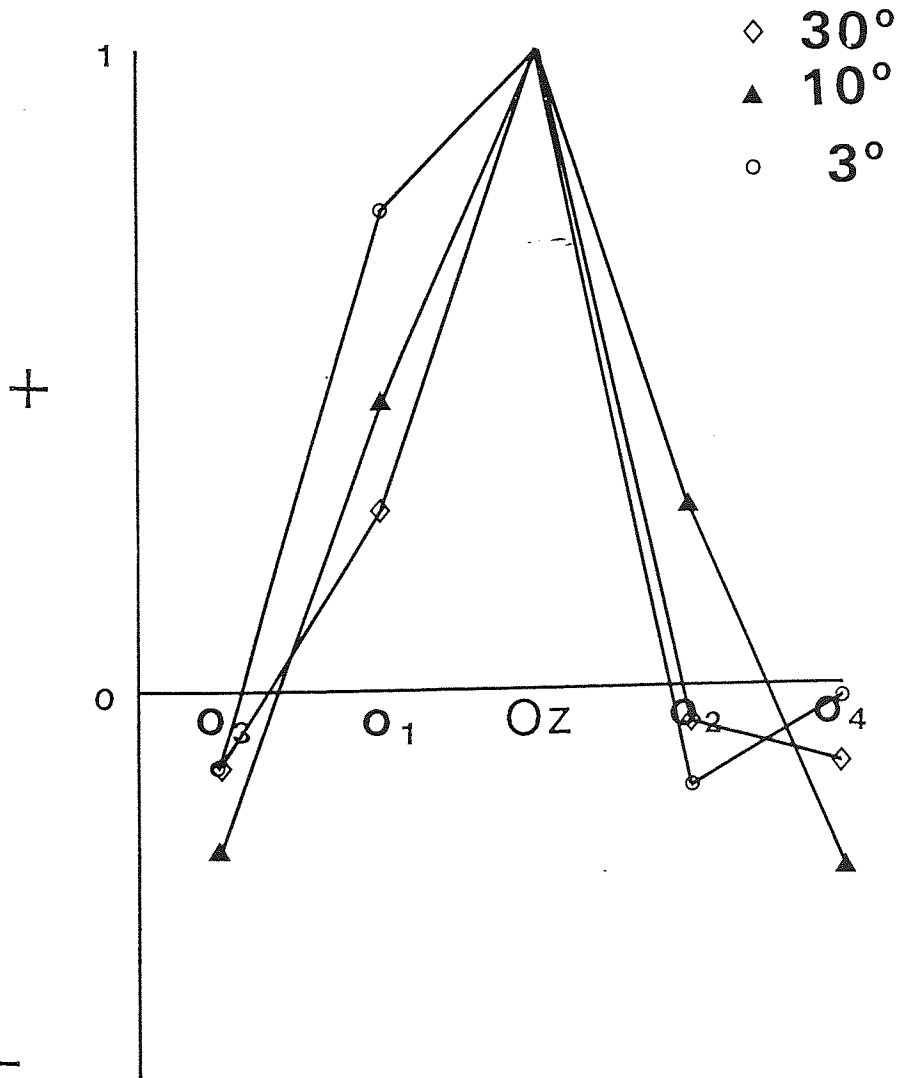

30°
10°
3°
1
+
0
O1
Oz
O2
O4
−

TABLE 5.33 FULL FIELD WITH SIMULATED 3^{o}

RELATIVE CENTRAL SCOTOMA

Latency (milliseconds)

Field Size	Mean	Median	Range	Standard Error	Interocular Asynchrony
30^{o}	99.2	99	91-109	1.92	0.4
10^{o}	100.2	95.5	93-110	2.26	4.8
3^{o}	109.9	109.5	101-125	2.26	4.2

Amplitude (microvolts)

Field Size	Mean	Median	Range	Standard Error	Interocular Asymmetry
30^{o}	5.5	4.62	3.07-7.66	0.47	0.88
10^{o}	3.92	4.07	1.07-6.14	0.45	0.28
3^{o}	2.14	2.22	0.69-4.83	0.36	0.50

Amplitude Asymmetry (% reduction)

	O1-O2	O3-O4	T5-T6
30^{o}	17%	24%	29%
10^{o}	10%	5.5%	19%
3^{o}	22%	19%	22%

FULL FIELD STIMULATION WITH SIMULATED 3^{O} ABSOLUTE CENTRAL SCOTOMA

		MD R.EYE	MD L.EYE	AC R.EYE	AC L.EYE	MW R.EYE	MW L.EYE	RD R.EYE	RD L.EYE	JR R.EYE	JR L.EYE	GROUP AVERAGE
		97msec	90msec	94msec	85msec	95msec	105msec	89msec	87msec	98msec	101msec	94.1msec
	T5	0.32	0.04	1.35	1.04	0.84	2.18	-0.09	1.87	1.54	1.43	1.05
	O3	0.41	0.52	1.96	1.86	2.14	3.39	0.89	2.82	3.01	2.14	1.91
	O1	1.59	1.74	2.84	2.55	2.96	3.89	2.96	4.43	5.77	3.69	3.24
30^{O}	Oz	2.35	2.62	3.47	2.79	3.36	4.09	4.51	5.99	6.01	5.63	4.08
	O2	1.78	1.79	3.11	2.29	2.24	3.21	3.81	4.71	3.98	3.45	3.04
	O4	1.20	1.54	2.58	1.73	0.97	2.66	1.34	2.91	1.78	2.03	1.87
	T6	0.88	0.95	1.52	0.45	0.15	1.53	0.61	1.83	0.32	1.23	0.95
		94msec	112msec	99msec	100msec	97msec	105msec	86msec	84msec	100msec	100msec	97.9msec
	T5	-0.57	1.51	2.27	2.67	1.04	0.18	1.12	0.22	4.43	-0.54	1.23
	O3	-0.32	1.62	2.96	3.32	0.83	0.55	1.07	0.12	5.20	0.34	1.57
	O1	0.68	2.10	3.74	3.98	0.94	1.01	1.97	0.78	6.31	1.66	2.32
10^{O}	Oz	1.04	2.52	4.16	4.30	1.02	1.06	2.80	1.46	6.08	1.90	2.63
	O2	0.54	1.75	3.55	4.20	0.49	0.55	2.55	1.04	4.77	1.00	2.04
	O4	0.16	1.72	2.69	3.11	0.40	-0.01	2.35	0.57	3.53	0.28	1.48
	T6	0.16	1.51	1.93	2.41	0.28	-0.02	1.79	0.06	2.50	-0.20	1.04

TABLE 5.34 The individual latencies and amplitudes (microvolts) following common reference recording

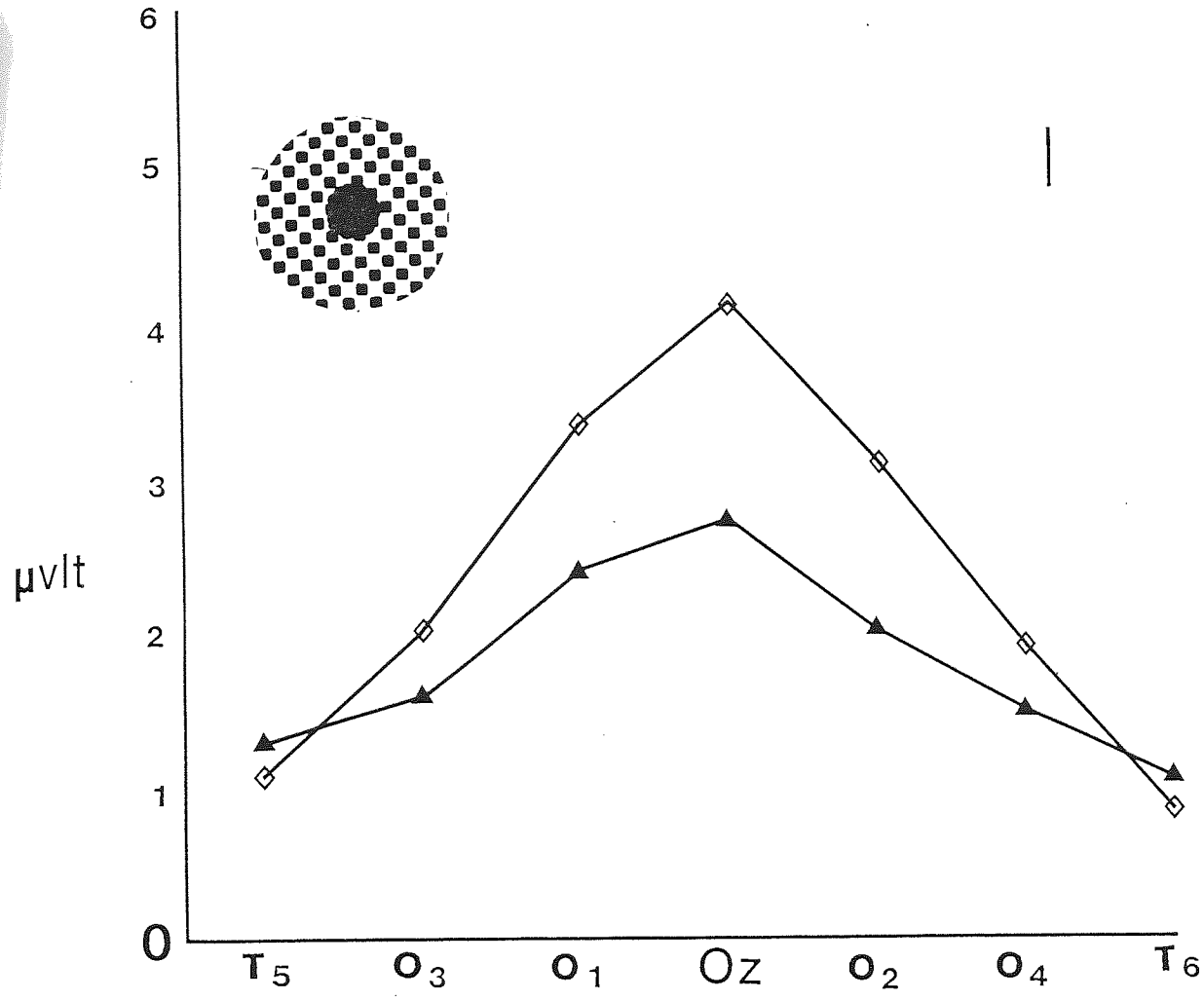
FULL FIELD STIMULATION WITH SIMULATED
3^{o} ABSOLUTE CENTRAL SCOTOMA

		MD R	MD L	AC R	AC L	MW R	MW L	RD R	RD L	JR R	JR L	GROUP AVERAGE
	O3	1.08	0.73	0.27	0.13	0.49	0.70	1.10	0.66	0.91	0.71	2. 72
	O1	0.41	0.34	0.25	0.46	0.42	0.30	0.52	0.05	0.83	0.54	0.412
30^{o}	Oz	1.33	1.71	0.99	0.73	1.51	1.09	2.88	2.84	2.12	1.49	1.669
	O2	0.02	0.58	0.17	0.06	0.16	0.34	0.51	0.52	0.35	0.51	0.036
	O4	0.27	0.34	0.53	0.72	0.45	0.57	1.11	0.71	0.85	0	0.123
	O3	0.75	0.30	0.09	0.02	0.32	0.09	0.96	0.75	0.34	0.44	0.406
	O1	0.63	0.05	0.35	0.34	0.04	0.41	0.07	0.03	1.35	1.07	0.428
10^{o}	Oz	0.88	1.20	1.04	0.43	0.60	0.57	1.09	1.10	1.08	1.14	0.913
	O2	0.13	0.75	0.25	1.00	0.43	0.04	0.05	0.05	0.07	0.17	0.026
	O4	0.37	0.18	0.11	0.40	0.03	0.55	0.36	0.04	0.21	0.25	0.128

TABLE 5.35. The source derivation distribution
(microvolts cm^{-2})

FIGURE 5.27

The Group Average Amplitudes for the Common Reference and Source Derivation Distributions Following Full Field Stimulation with a Simulated 3^{o} Absolute Central Scotoma


6
5
4
3
2
1
0
μvlt
T5
O3
O1
OZ
O2
O4
T6

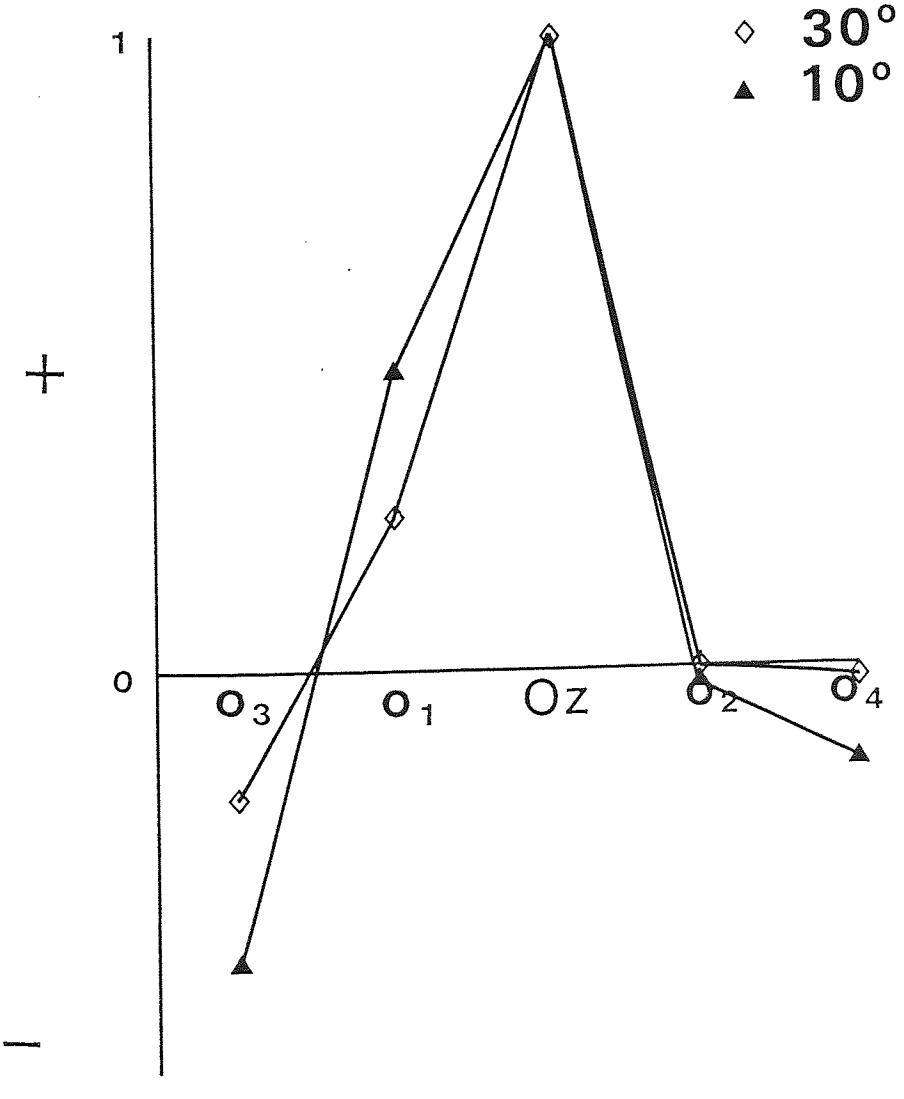

30°
10°
1
+
0
−
O3
O1
OZ
O2
O4

TABLE 5.36 FULL FIELD WITH SIMULATED 3^{o} ABSOLUTE CENTRAL SCOTOMA

Latency (milliseconds)

Field Size	Mean	Median	Range	Standard Error	Interocular Asynchrony
30^{o}	94.1	94.5	85-105	2.02	1.0
10^{o}	97.9	99.5	84-112	2.52	4.6

Amplitude (microvolts)

Field Size	Mean	Median	Range	Standard Error	Interocular Asymmetry
30^{o}	4.08	3.78	2.35-6.01	0.44	0.28
10^{o}	2.66	2.21	1.02-6.31	0.56	0.77

Amplitude Asymmetry (% reduction)

	O1-O2	O3-O4	T5-T6
30^{o}	6%	2%	10%
10^{o}	12%	5.5%	15%

and 5.30 compare the distributions for the two simulated central scotomas with the full field distribution.

5.7.2 Discussion

The mean latency following stimulation of the central 30^{o} was earliest when the central 3^{o} was completely occluded, although there was no significant difference when compared to the full field results. This would seem to further support the hypothesis that the scalp potential is an attenuated response of a summated cortical potential which is influenced by the synchrony, depth and orientation of the various generator areas. The foveal area, in isolation, gives a later response which, when its influence is removed, gave rise to an earlier P100 component. In which case the result obtained is also supportive of a relatively "sustained" foveal response, as discussed earlier in the Chapter. When the 3^{o} relative scotoma was simulated the response was significantly later (t-test: $p<0.05$) than the full field response and the 3^{o} absolute scotoma results (t-test: $p<0.02$). This is not as surprising as it may at first seem. The "sustained" foveal mechanism, as discussed earlier, can give a larger amplitude when the mean stimulus luminance is reduced and the isolated fovea appears to give a delayed latency. Consequently, when we simulate the 3^{o} relative central scotoma we may be increasing the proportional effect of the polar projections on the scalp potential. Obviously, further research would be required to fully substantiate any such theory but it would appear to be consistent with

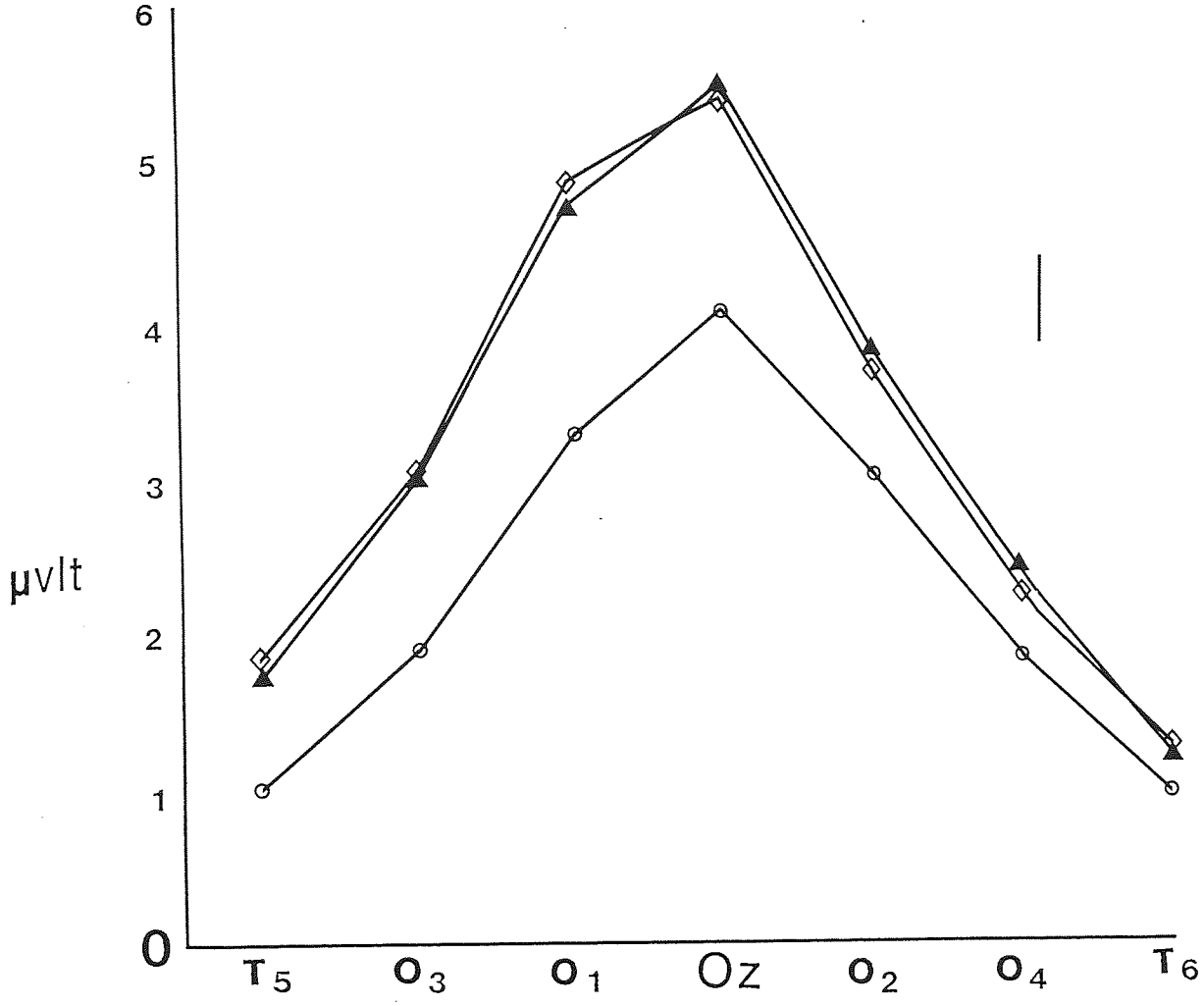
FIGURE 5.28

Comparison between the Simulated Central Scotoma Distributions and the Full Field Distributions (30^{o} Stimulus)

◇ - Full Field

▲ - Simulated Relative 3^{o} Central Scotoma

o - Simulated Absolute 3^{o} Central Scotoma


6
5
4
3
μvlt
2
1
0
T5
O3
O1
OZ
O2
O4
T6

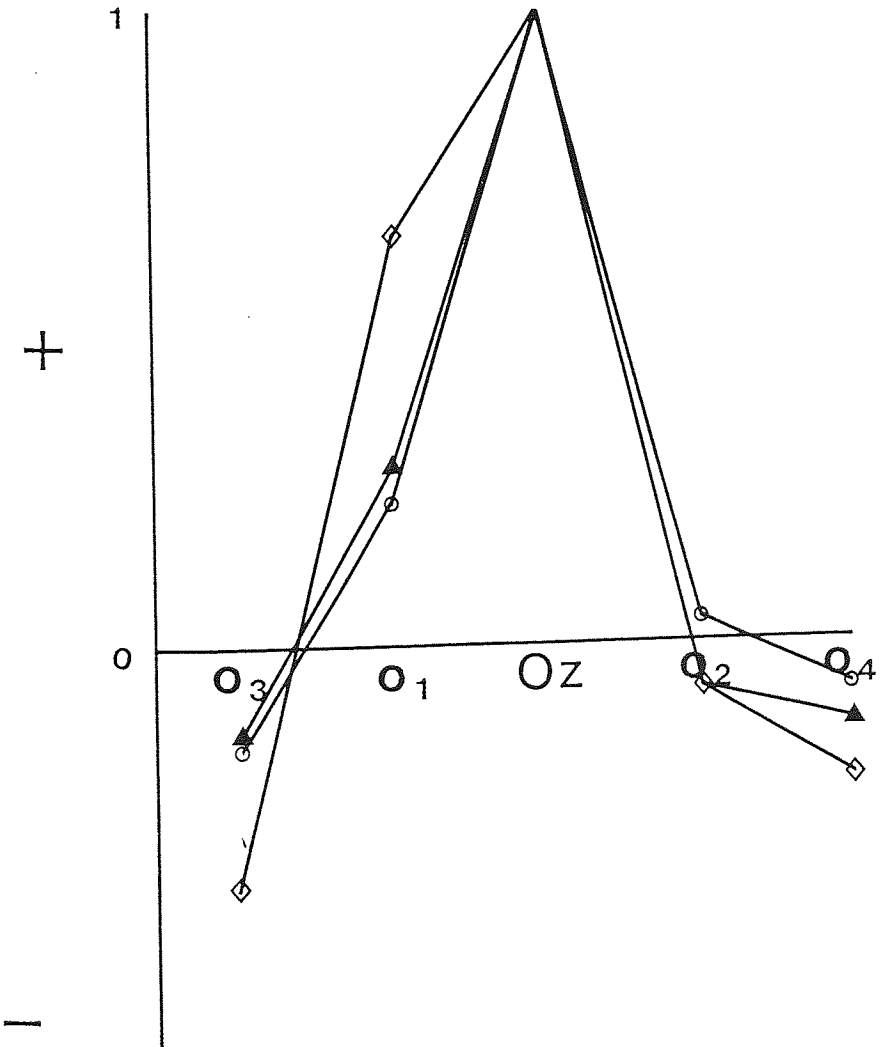

1
+
0
O3
O1
OZ
O2
O4
−

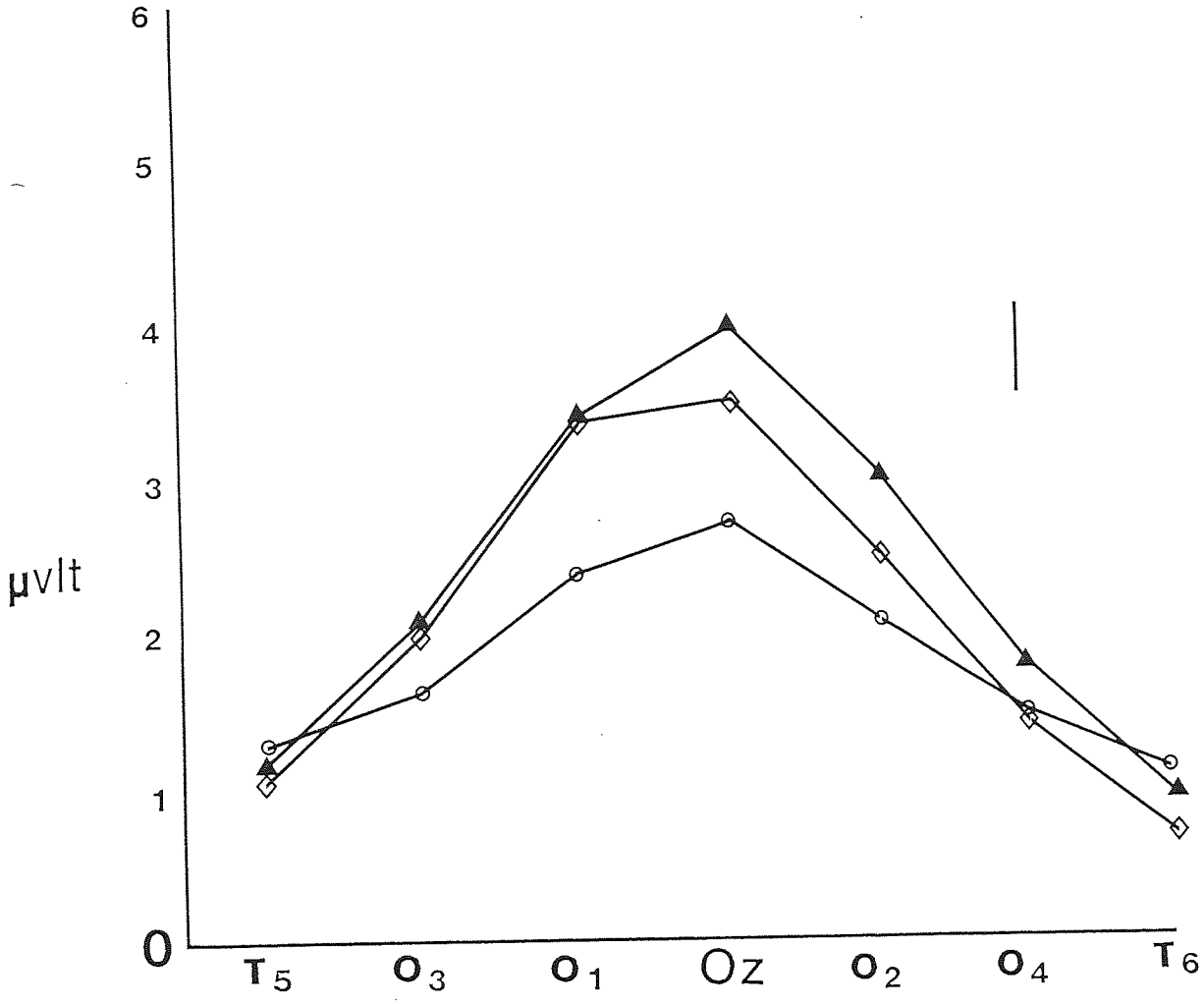
FIGURE 5.29

Comparison between the Simulated Central Scotoma Distributions and the Full Field Distribution (10^{o} Stimulus)

◇ - Full Field

▲ - Simulated Relative 3^{o} Central Scotoma

o - Simulated Absolute 3^{o} Central Scotoma


6
5
4
3
2
1
0
µvlt
T5
O3
O1
OZ
O2
O4
T6

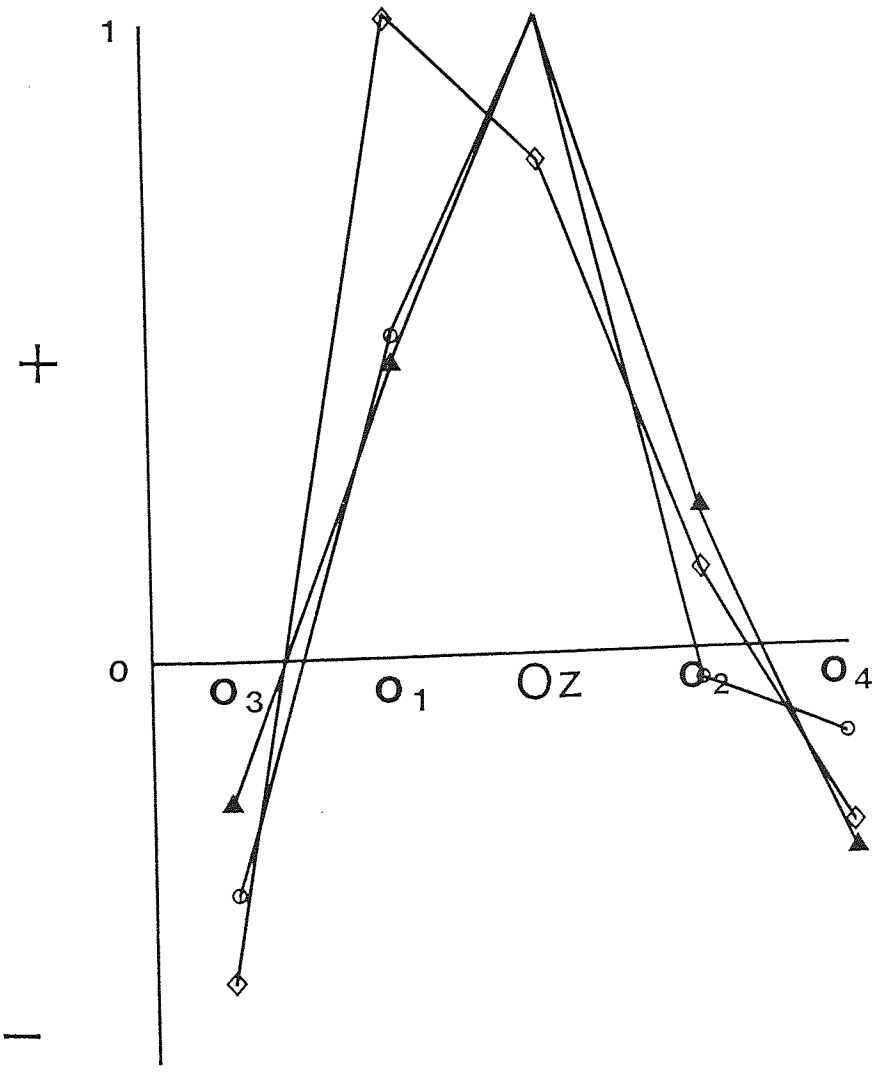
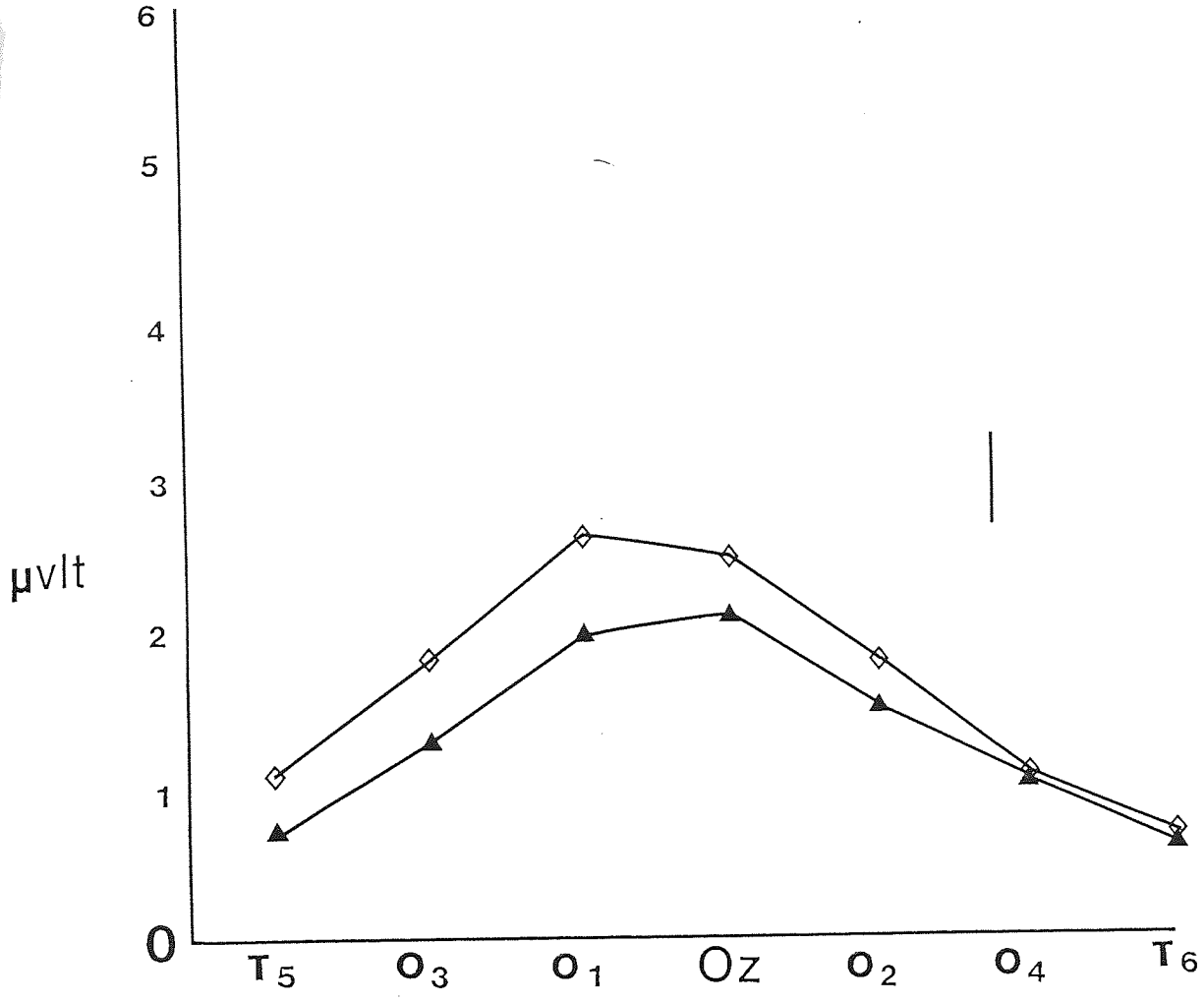

1
+
0
O3
O1
OZ
O2
O4
—

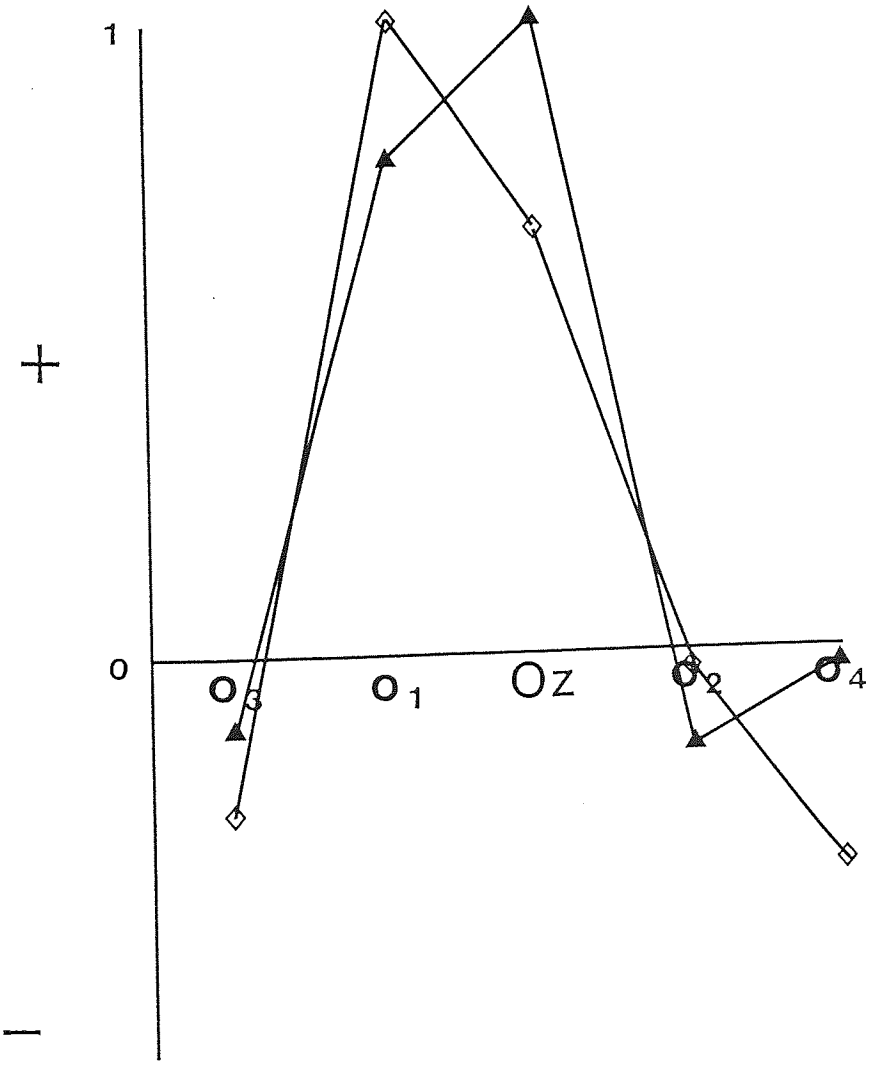
FIGURE 5.30

Comparison between the Simulated Central Scotoma Distributions and the Full Field Distribution (3^{o} Stimulus)

◇ - Full Field

▲ - Simulated Relative 3^{o} Central Scotoma


6
5
4
3
2
1
0
μvlt
T5
O3
O1
OZ
O2
O4
T6


1
+
0
O3
O1
OZ
O2
O4
—

the results found throughout the study. The validity of simulating relative scotomas must be questioned as in a real, relative central scotoma the effects on the VEP can be quite dramatic probably due to the nature of the disease rather than the presence of a reduced stimulus. This will be considered further in the proceeding Chapter. The standard deviation and inter-ocular asynchronies were not significantly different between the 3 stimulus conditions.

The mean latency following 10^{o} stimulation showed a similar trend. There was no significant difference between the full field and the absolute scotoma results or between the two scotomatous responses. There was, however, a small significant difference between the full field and relative scotoma result (t-test: $p<0.2$). The 3^{o} stimulus can only be considered for the full field and relative scotoma, as an absolute scotoma would be the same as a blank field and offer no stimulus. There was no significant difference in the mean peak latencies for these two stimulus conditions.

The mean peak amplitude, following stimulation of the central 30^{o}, was maximum on the midline for all 3 stimulus conditions. The full field and relative scotomatous results were almost identical. The simulated absolute scotoma showed a significant reduction in amplitude. The

10^{o} stimulus gave a mean amplitude which was slightly greater for the relative scotoma stimulus and reduced for the absolute scotoma stimulus when compared to the full field results. The 3^{o} stimulus demonstrated a slight reduction in the mean amplitude when the relative scotoma was simulated. The full field stimulus gave a maximum over electrode Ol whereas the relative scotoma elicited a maximum on the midline. It would appear, therefore, that the simulated relative scotoma caused little effect on the amplitude for any of the stimulus conditions and only a slight delay in latency was recorded for the largest stimulus. The simulated absolute scotoma caused little effect on the latency but produced a slight, but significant, reduction in amplitude. This would suggest a poor diagnostic value for using VEPs to investigate a small central scotoma which is clearly not the case when we consider the literature (see 1.2.4). We must therefore attribute our clinical findings principally to the disease rather than the simple loss of stimulus caused by an associated scotoma. This would support the conclusions of Asselman et al. (1975) and Yiannikas and Walsh (1983) but disagree with those of Halliday (1976) and Blumhardt et al. (1978).

The amplitude distribution was of greater interest. When the 30^{o} stimulus was used the relative scotoma gave a distribution which was very similar to the full field with only a slight reduction in the asymmetry between

electrodes O1 and O2 (Figure 5.28). The absolute scotoma, however, gave a distribution which was not only reduced in amplitude but was far more symmetrical around the midline showing very little lateral asymmetry. This clearly supports the arguments that the 'normal' full field asymmetry is caused by the unequal projection of the foveal striate cortex at the occipital poles observed anatomically by Polyak (1975) and Stensaas (1974) and discussed at length earlier in the Chapter. Using analysis of variance there was no overall difference between the amplitude distribution when comparing the full field and absolute scotoma results ($F_{6,108} = 1.11$). There was, however, a significant difference when comparing the lateral asymmetry at the 10% electrodes using a t-test. The 30^{o} full field stimulus gave a significant asymmetry ($p<0.01$) whereas the 30^{o} stimulus with an absolute scotoma did not. The results obtained when simulating a 3^{o} relative scotoma also gave a significant asymmetry although the level of significance was slightly reduced when compared to the full field result ($p<0.02$) (Figure 5.30).

The amplitude distributions following stimulation of the central 10^{o} of the visual field further supports these observations (Figure 5.29). Both the simulated relative and absolute scotomata gave distributions which were far more symmetrical around the midline than the full field stimulus. Analysis of variance showed a significant

interaction variance ratio when comparing the full field with the absolute scotoma results ($F_{6,108} = 3.72 : p<0.05$).

The amplitude distribution following stimulation of the central 3^{o} showed a reduction in the lateral asymmetry when the simulated relative scotoma was used (Figure 5.30) with the maximum response being over the midline rather than the O1 electrode. Analysis of variance, however, did not demonstrate a significant difference ($F_{6,108} = 0.32$).

Figures 5.28 and 5.29 clearly demonstrate the presence of a slight lateral asymmetry when the relative scotoma was simulated but a very clear symmetry around the midline when the absolute scotoma was simulated. The source derivation distributions help clarify the results by demonstrating a maximum scalp current source on the midline for all stimulus field and check sizes when a scotoma was simulated. When compared to the full field results (Figures 5.28, 5.29 and 5.30) the maximum scalp current source switched to the O1 electrode for 10^{o} and 3^{o} stimulation.

At no time was there any evidence of the so called "scotomatous negativity" of Halliday (1976) discussed in 1.2.4 and 1.3. There is little doubt that the PNP-complex can be found in many pre-chiasmal lesions but to attribute its presence to a simple manipulation of stimulus parameters would seem a little naive. Lack of

central stimulus obviously contributes to the resultant evoked potential but the morphology of the waveform recorded at the scalp is clearly far more complex than that due to the scotoma itself and can be elicited without a measurable central scotoma (Harding and Crews 1982). Asselman et al. (1975) had predicted a 50% reduction in amplitude of the P100 component when the central 5-6^{o} were occluded. We have recorded a 25% reduction in amplitude when the central 3^{o} were occluded. Yiannikas and Walsh (1983) stated that the central 2^{o} contributed 25% of the maximal response and the central 4^{o}, 35%. Our own findings are surprisingly similar. They also experienced problems confirming Halliday's "scotomatous negativity". They simulated absolute central scotoma to as large as 15^{o} but could still only elicit a PNP-complex from 2 of the 5 subjects and only then at the most extreme scotoma where the response was reduced by over 50% or, in 2 of the 5 subjects, could no longer be identified.

5.8 The Scalp Topography of the VEP and its Neural Representation

5.8.1 Introduction

The theory behind the neural representation of the visual field and its application to the way in which we might analyse the mapped visual field and M-scale the stimuli for eliciting the VEP has been outlined in

Chapter 3. Todd Meredith and Celesia (1982) had concluded that there was evidence to suggest some form of diffuse summation between the amount of cortex stimulated and the recorded scalp potential. Earlier in this Chapter the way in which the three stimulus conditions used have an M-scaling which predicts a 6:3:1 ratio in terms of the amount of cortex that is expected to be activated has been discussed.

There are two hypotheses which must be considered:

1. That there is a form of diffuse summation in which the scalp potential reflects, in a linear form, the amount of cortex stimulated or
2. That the problems of cortical generator depth, synchrony and orientation, discussed by Regan (1972); Darcey (1979); Young (1981) and Vaughan (1982), would so distort and attenuate the scalp potential that the relationship between cortical activity and the recorded VEP is complex.

5.8.2 Results

1. Comparison of Amplitudes Recorded at the Oz Electrode

Table 5.37 illustrates the ratios obtained for each

TABLE 5.37

Ratio of the Amplitudes for Each Stimulus Condition Recorded at the Oz Electrode

	30^{o}	10^{o}	3^{o}
Theoretical Ratio	6	3	1
Full Field (Trans.)	2.2	1.4	1
Full Field (Med.)	2.4	2	1
Right Half Field	2.2	1.6	1
Left Half Field	2.1	1.8	1
Upper Field	2.3	1.7	1
Lower Field	2	1.4	1

TABLE 5.38

Ratio of the Amplitudes Recorded at the Oz Electrode Comparing the Half Field and Full Field Results for Each Field and Check Size

Amplitude at Oz (Normalised to full field 3^{o} response)		Full Field	Half Field	Actual Ratio	Theoretical Ratio
Right Half Field	30^{o}	2.2	1.43	1.5:1	2:1
	10^{o}	1.4	1.06	1.3:1	2:1
	3^{o}	1	0.65	1.5:1	2:1
Left Half Field	30^{o}	2.2	1.24	1.8:1	2:1
	10^{o}	1.4	1.06	1.3:1	2:1
	3^{o}	1	0.60	1.7:1	2:1
Upper Field	30^{o}	2.4	1.38	1.7:1	2:1
	10^{o}	2.0	1.01	2:1	2:1
	3^{o}	1	0.59	1.7:1	2:1
Lower Field	30^{o}	2.4	2.06	1.2:1	2:1
	10^{o}	2.0	1.40	1.4:1	2:1
	3^{o}	1	1.01	1:1	2:1

stimulus condition and compares them to the expected theoretical ratio. The ratios were calculated by considering only the amplitude at the Oz electrode thus ignoring the asymmetries recorded in the scalp topography.

Table 5.38 illustrates the ratios obtained by comparing the half field results to the full field results for each field and check size. The ratios were obtained by normalising each Oz amplitude to the 3^{o} full field amplitude.

11. Comparison of Integrated Amplitudes

Table 5.39 illustrates the ratios obtained for each stimulus condition and compares them to the expected theoretical ratio. The ratios were calculated by integrating the amplitudes recorded over all the electrodes used, ie. the sum of the six mid-point amplitudes between the seven electrodes.

Table 5.40 illustrates the ratios obtained by comparing the half field results to the full field results for each field and check size. The ratios were obtained by normalising each integrated amplitude to the 3^{o} full field amplitude.

5.8.3 Discussion

1. Comparison Between the Three Different Field and Check Sizes

Considering the results obtained from the 3 field sizes

TABLE 5.39

Ratio of the Integrated Amplitudes

for Each Stimulus Condition

	30^{o}	10^{o}	3^{o}
Theoretical Ratio	6	3	1
Full Field (Trans.)	2.0	1.3	1
Full Field (Med.)	2.9	2.4	1
Right Half Field	1.9	1.7	1
Left Half Field	1.6	1.6	1
Upper Field	2.6	1.5	1
Lower Field	2.1	1.4	1

TABLE 5.40

Ratio of the Integrated Amplitudes Comparing the Half Field and Full Field Results for Each Field and Check Size

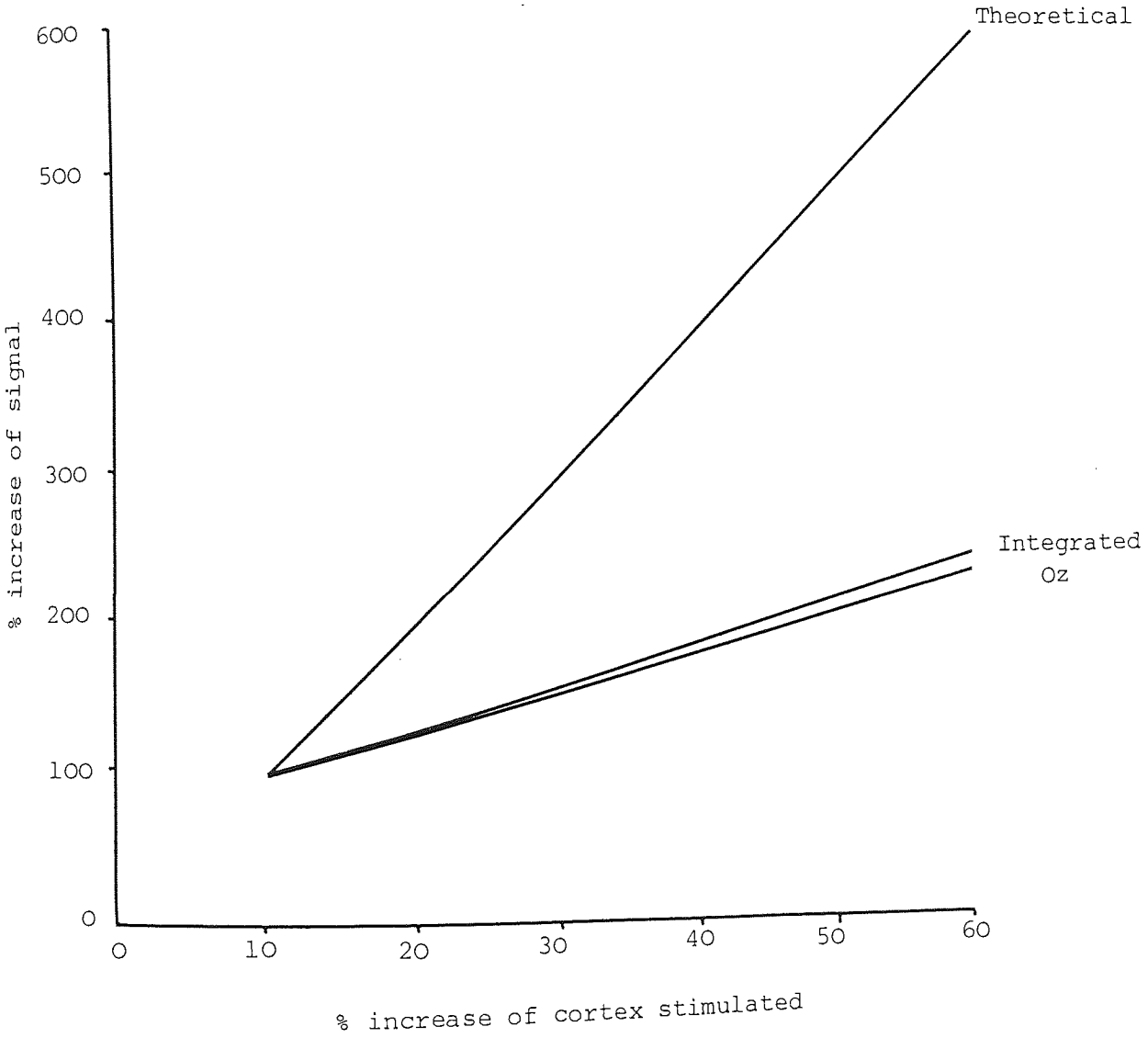
Integrated Amplitude (Normalised to full field 3^{o} response)		Full Field	Half Field	Actual Ratio	Theoretical Ratio
Right Half Field	30^{o}	2.0	1.30	1.5:1	2:1
	10^{o}	1.3	1.12	1.1:1	2:1
	3^{o}	1	0.67	1.5:1	2:1
Left Half Field	30^{o}	2.0	1.06	1.9:1	2:1
	10^{o}	1.3	1.02	1.3:1	2:1
	3^{o}	1	0.65	1.5:1	2:1
Upper Field	30^{o}	2.9	1.80	1.6:1	2:1
	10^{o}	2.4	0.99	2.4:1	2:1
	3^{o}	1	0.68	1.5:1	2:1
Lower Field	30^{o}	2.9	2.62	1.1:1	2:1
	10^{o}	2.4	1.76	1.4:1	2:1
	3^{o}	1	1.24	0.8:1	2:1

for each different stimulus condition it was clear that the relationship between the neural representation, ie. the amount of cortex expected to be stimulated, and the scalp potential was no where near the expected ratio. This would indicate that the power of the cortically generated signal, providing we assume our calculations were correct, was attenuated by the depth, orientation, and possibly asynchrony of the activated cortical areas.

What was remarkable was the almost identical ratio found for all stimulus conditions, whether full field or half field, for both the integrated amplitude ratios and the Oz amplitude ratios. The principles of summation (Halliday 1982) would suggest that the right and left half field results, even if attenuated by depth and orientation factors, would be closer to the expected, theoretical ratio than the full field (transverse) results. This was evidently not the case which would imply that depth and orientation of the cortical generators is a more important attenuating factor. By plotting the expected scalp potential increase if it was related directly to the cortical power of the signal, and the actual percentage increase found in this study, which is surprisingly linear, we have a quantification of the percentage attenuation of any M-scaled field and check size for the stimulus and recording parameters used in our laboratory (Figure 5.31). The implications of this relationship being linear, between the foveal 3^{o} and relatively peripheral 30^{o} stimuli, are immense. It would

FIGURE 5.31

Graph Comparing the Theoretical Scalp Potential Increase and the Actual Increase Found at the Oz Electrode and by Integrating the Scalp Potential Recorded


Theoretical
Integrated
Oz
600
500
400
300
200
100
0
% increase of signal
0
10
20
30
40
50
60
% increase of cortex stimulated

suggest that depth and orientation are the principle factors involved in scalp potential attenuation. We can predict from the graph that an M-scaled check size for a field size which would stimulate 45% of the cortex, but including the fovea, would give a scalp potential which is c.85% greater in amplitude than the result obtained for the 3^{o} foveal stimulus for the P100 component. The latency and relative synchrony of the different cortical generators obviously has a far more complex relationship which has been discussed earlier in the Chapter.

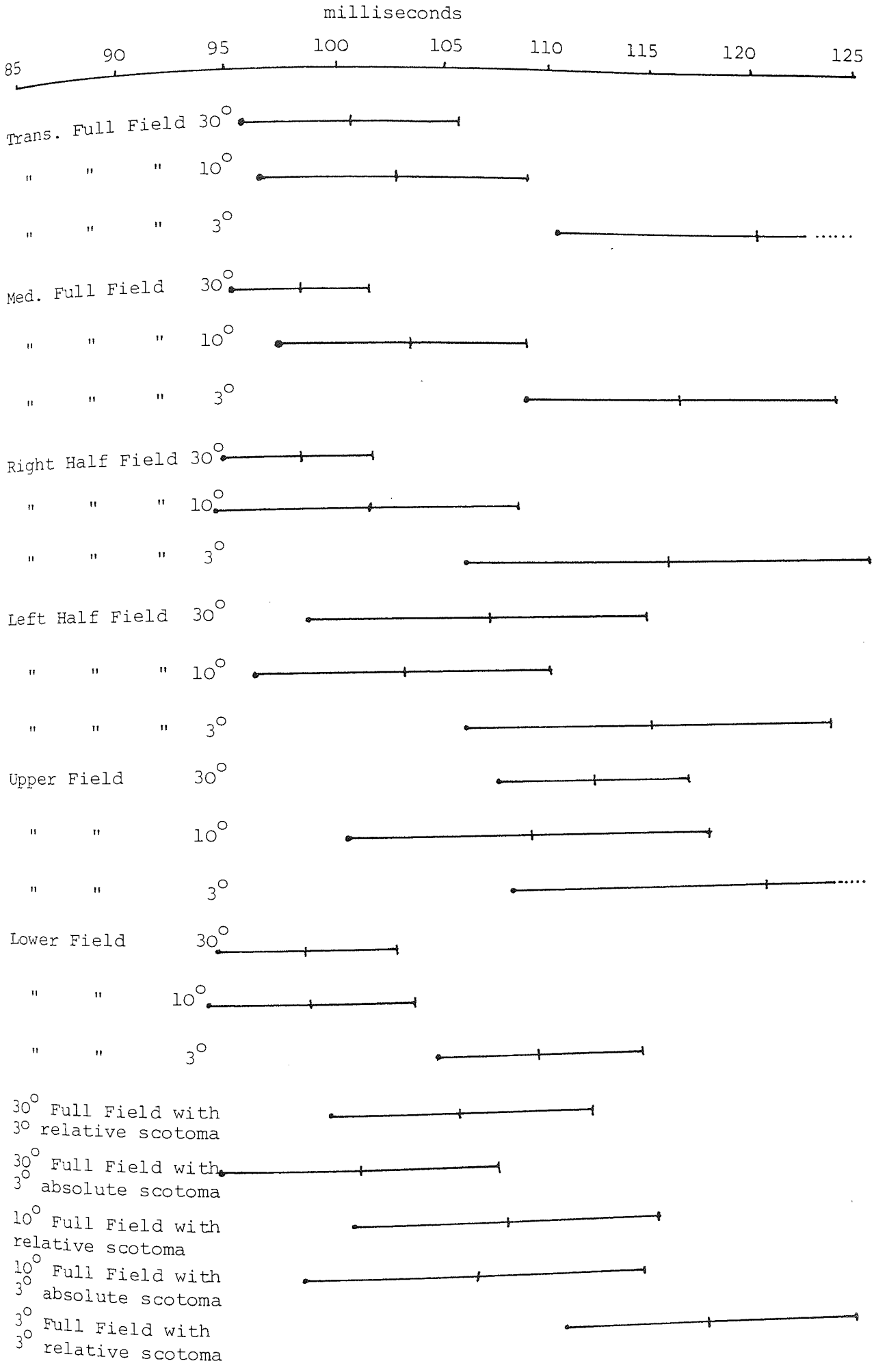
The synchrony of the cortical potential deserves further consideration as it may also play a large part in the difference between the cortical power and the scalp potential. Vaughan (1969) has stated that synchronous activity generated in a small cortical area is much more attenuated at the scalp than is synchronous activity which is generated over a wide area of cortex. From the results obtained it would appear that the only relatively synchronous response is that from a foveal stimulus and even then there are some relatively asynchronous half field components, (see Figure 5.32). The results of Yiannikas and Walsh (1983) have shown that the delay in latency between large and small fields is found for large checks as well as for the small M-scaled checks used in this study. Consequently, the 30^{o} stimulus would have a very asynchronous signal which may contribute to the ratio found. This was

FIGURE 5.32

The Latencies and Standard Deviations for Each Stimulus Condition

• mean

⟷ One standard deviation


milliseconds
85
90
95
100
105
110
115
120
125
Trans. Full Field 30°
" " " 10°
" " " 3°
Med. Full Field 30°
" " " 10°
" " " 3°
Right Half Field 30°
" " " 10°
" " " 3°
Left Half Field 30°
" " " 10°
" " " 3°
Upper Field 30°
" " 10°
" " 3°
Lower Field 30°
" " 10°
" " 3°
30° Full Field with 3° relative scotoma
30° Full Field with 3° absolute scotoma
10° Full Field with relative scotoma
10° Full Field with 3° absolute scotoma
3° Full Field with 3° relative scotoma

supported by the fact that the 30° stimulus, with the central 3° occluded, gave an earlier latency than that without. Such an observation would appear to denigrate the argument for signal transmission factors discussed earlier although the differences in latency with and without the central scotoma were small and of little statistical significance. Vaughan (1969) also stated that the spatial parameter which determines the degree of attenuation was not simply the superficial area of the synchronously active cortex but the orientation.

Cooper, Winter, Crow and Walter (1965) discussed how the scalp potential depends not only on the amplitude of the cerebral activity in microvolts, which we have weighted in terms of neural representation, but on the area of cortex involved in synchronous activity. Thus implying that depth, orientation and synchronicity are all important factors on the influence of the scalp potential. Heath and Galbraith (1966) showed that VEPs to flash stimulation have different waveforms at cortical electrodes situated in the primary visual cortex and in the temporal cortex. They demonstrated how the scalp potential recorded over the primary visual area showed a different waveform at cortical and scalp electrodes with the early P1 component being evident in both cortical and scalp recordings in the occipital region but the later components showing a disparity. They considered that temporal cortical activity influenced the occipital scalp potential but that the

current did not spread to the occipital cortical electrode.

Vaughan and Gross (1969) came to the opposite conclusion following work on the Rhesus monkey. They recorded EPs to flash stimulation with electrodes over the striate cortex both under and on the dura and found the waveforms generated to be identical, and similar to the recorded scalp potential with a small attenuation of c.50% for bipolar recordings and 25% for reference recordings. They concluded that the scalp potential recorded over the occipital pole "reflects in detail the configuration of the evoked cortical response beneath, with little contribution from anterior portions of striate cortex". Regan (1972) has criticised these findings as the cortical potentials and the scalp potentials were recorded from different subjects and that there are possible dangers of interspecies differences between man and monkey. The positioning of the cortical electrode was also considered critical as Geisler and Gerstein (1961) had demonstrated that the major attenuation was due to the dura and the cerebrospinal fluid under the dura. Regan (1972) thus considered that responses from small areas of cortex would show little difference between the scalp potential and the potential recorded on the dura unlike recordings from the cortical surface and the scalp.

The effect of the surrounding media was further in dispute when considering the way in which it affects

the scalp potential. Geisler and Gerstein (1961) calculated from a theoretical model that the scalp potential would be both attenuated and spread, and supported this argument by recording auditory EPs from monkeys whilst successively removing the surrounding layers of the brain. Vaughan (1969), however, claimed that the scalp potential was attenuated only and that there was little spreading or smearing. The similarity between our Oz and "integral" ratios would tend to support the observations of Vaughan, as there is little evidence to suggest that the more lateral electrodes are influenced by a "smearing" or spread of the potential generated within the cortex.

Nakayama (1982) also commented on the effects of attenuation stating that; "the surface VEP records only a fraction of the cortical neurones which might be thought to respond to the stimulus and which could be expected to be involved in perception". Vaughan (1982) in a later publication summarised the factors which we have been able to quantify, although we have been unable to attribute the relative importance of each contributing factor. He stated that the "field potential at any one point in the brain or at the surface represents the algebraic sum of the fields produced by each generator. The primary and secondary cortical regions that contribute to externally recorded EP fields exhibit complex patterns of summation because of the presence of evoked activity that differs somewhat in its timing and waveshape,

as well as in the orientation of the respective generators". Young (1981) discussed the problems of scalp recordings. He felt that the closer a generator site is to an electrode the greater its contribution and that far field potentials should be attenuated at the scalp but that a large far field potential cannot be readily distinguished from a small near field potential. "If the generator sites of surface potentials are not discrete in either spatial or temporal distribution, demonstrating the origin of the surface potentials becomes exceedingly difficult".

The effect, therefore, of depth, orientation and synchronicity of the cortical generators is both complex and at present little resolved. Regan (1972), in a review article, considers many of these problems. What is clear from the results obtained in this study, is that a linear relationship exists between, in single-unit neurophysiological terms, 3 large stimuli and the way in which they are increasingly attenuated and/or smeared by depth, orientation and synchrony of the cortex involved.

It is necessary to consider possible complications and inaccuracies involved in the neural representation calculations. M-scaling of the stimuli, by definition, relates to the primary visual cortex. Pattern reversal is more likely to relate to the primary visual cortex than either pattern appearance-disappearance or flash stimulation (see Chapter 1). It is unlikely, however, that the higher association areas are totally unaffected

by such a stimulus. Zeki (1978) has demonstrated the presence of multiple projection on the surrounding cortical areas in primates and other mammals, each tending to mirror the image of the previous adjacent projection (Daniel and Whitteridge 1961). Drasdo (1984) believes that they are "explicable on the principle of the most economic arrangement of neural connections" and that such an arrangement is believed to exist in humans in the circumstriate area. Obviously any such projections could degrade the relationship between striate neural representation and the recorded scalp potential. This could be further compounded when considering the relative orientation of the higher projections compared to the striate projections particularly for the lower and upper hemifield.

Regan (1972) has demonstrated the considerable controversy over the relationship between gross slow waves recorded at the surface of the cortex and the electrical activity of individual nerve cells. He concludes that there appears to be no fixed relationship and that the paradoxical results obtained by different authors (eg. Adrian and Matthews 1934a, b; Purpura 1959; Creutzfeldt and Kuhnt 1967 and Elul 1962) may be influenced by various factors including state of anaethesia, whether the slow waves recorded are evoked potentials or "spontaneous" EEG and whether the animal was alert or drowsy. There is also evidence that the glial cells may make important contributions to the surface slow waves as they are linked to form a low resistance

pathway which can behave like a single long conductor (Cohen 1970). Consequently, the resultant surface slow waves can have waveforms which bear little resemblance to the waveforms of the active neurones.

Such observations have only been made on necturus and cat, but the implications to higher species are clear. If glial cell activity can contribute to the scalp potential, as the above discussion involves only cortical recordings, then it will be a further inaccuracy in the M-scaling equation used in our experiments.

Young (1981) also discussed the possibility that glial cell activity may generate potentials but in this case stated that they may contribute to the scalp potential. He considered that ionic gradients in the extracellular space and changes in static charge distribution may also alter the scalp potential.

Regan concludes that the "relative values of the single-cell and gross-recording methods (both cortical recordings) cannot be assessed in the present primitive state of understanding of brain function". This can be further extrapolated to scalp potential recordings. We can imply the reasons for our results, ie. depth. orientation and synchrony, but can provide little or no evidence for the relative contributions of each.

Drasdo (1984) has discussed the problems of fissures in

the cortex and the way in which results to small stimuli may be affected. This would imply that any inaccuracy in the ratios found would be in the opposite direction as they are less likely to be influenced by fissures when a large amount of the cortex is stimulated. It is not surprising that our results do not conform to this theory as in terms of fissures our smallest field size, 3^{o}, must be considered as large.

11. Comparison Between the Full Field and Half Field Results

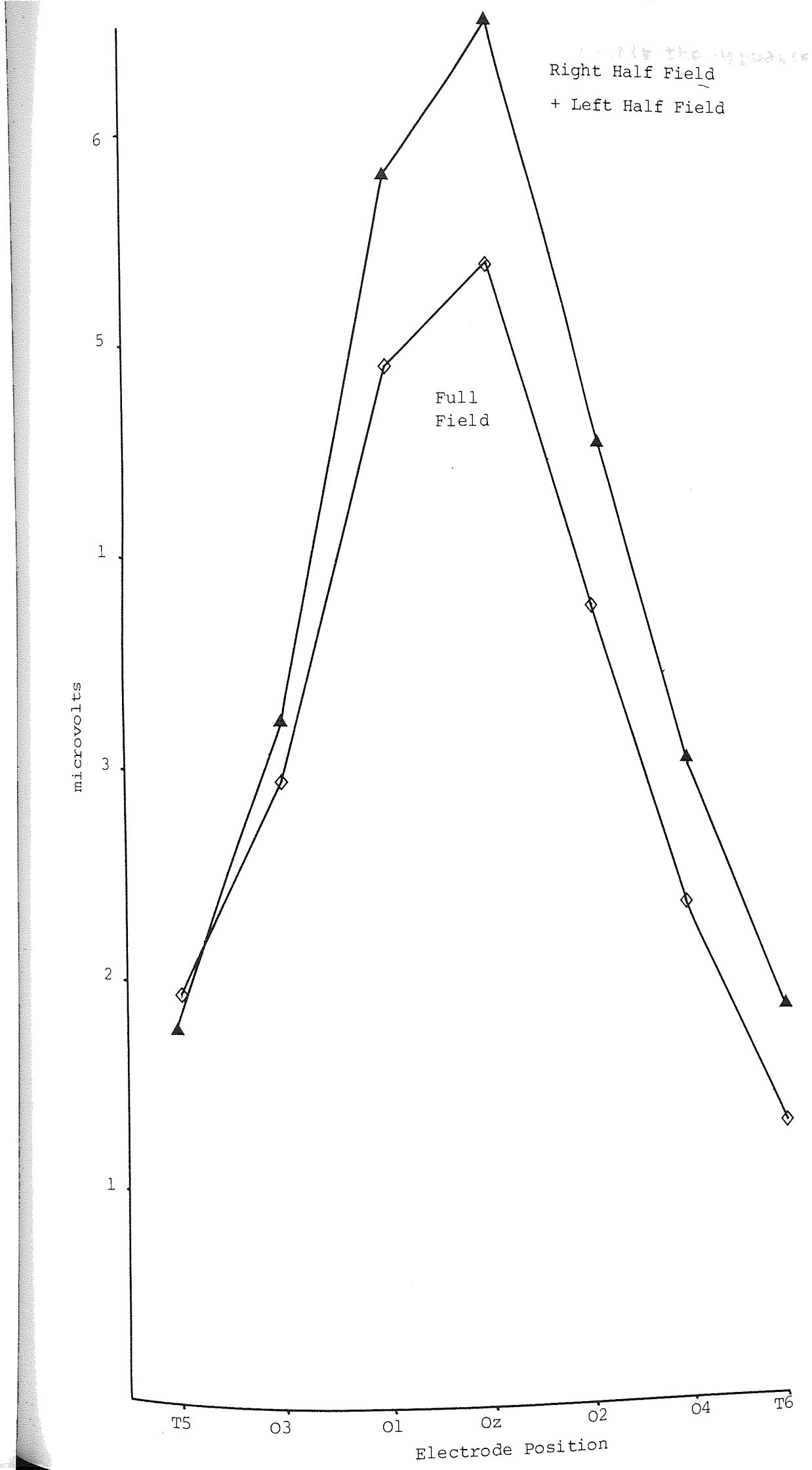
Considering the ratios obtained when comparing full field to half field stimulation there was again a remarkable similarity between the ratios obtained from the Oz electrode and those obtained from an integration of amplitudes recorded topographically across the scalp. This would seem to support the observations of Vaughan (1969) that the scalp potential is simply attenuated and is not smeared as suggested by Geisler and Gerstein (1961). When comparing a half field result to the full field it is a very different relationship to that discussed previously. In terms of depth and orientation of cortex stimulated the comparison is more consistent as the check size and field radius is the same. Consequently, many of the potential inaccuracies in the M-scaling calculations can be ignored whether this be due to ganglion cell density counts, glial cell activity and/or, to some extent, higher cortical projections. With

the right and left half field results the activation of one hemisphere can be compared to the activation of both. Accepting a ratio which is within 25% of the expected, theoretical ratio, as being significant then there would appear to be some support of the invariance principal from the scalp potential field for the 30^{o} and 3^{o} stimuli for both right and left half field stimulation. The full field response is always slightly less than expected which would imply that the principle of summation, as stated by Halliday (1982), in which the full field is said to be equal to the sum of its parts, is not strictly accurate. Figure 5.33 shows the sum of the right and left half field results compared to the full field result. Clearly the sum of the parts gives appreciably more than the whole.

This would appear to have little to do with depth as the area of cortex stimulated is at a similar depth in each case. The asynchrony may be similarly dismissed as any resultant asynchrony would be similar for each stimulus condition. It may, however, be due to the orientation and asymmetry of the cortical projection as discussed earlier in the Chapter. It can also imply a degree of cancellation between the two hemispheres caused by either asynchrony, which is unlikely due to the similarity of the scalp potential latencies, or due to an interaction of the potentials generated by the two hemispheres. At first dismissing summation and considering cancellation may appear to be a contradiction, but Halliday's principle of summation implies no loss of signal,

FIGURE 5.33

Comparison between the Full Field Distribution and the Summation of the Right and Left Half Field Distributions (30^{o} Stimulation)


Right Half Field
+ Left Half Field
Full
Field
6
5
1
3
2
1
microvolts
T5
O3
Ol
Oz
O2
O4
T6
Electrode Position

cancellation, as discussed here, is exactly the opposite.

Looking at the ratios of the upper and lower field stimuli compared to the full field, is rather more complex as a single hemisphere cannot be isolated. The altitudinally separated nasal and temporal quadrants are activated. The upper field stimulus gave results for all 3 field sizes which were closest to the expected ratio, particularly for the 10^{o} stimulus which is not significant for any other half field used. The lower field stimulus, however, gave very poor ratios and was the only hemifield not to exhibit any form of significant result. In terms of synchrony the lower field result was far closer to the full field result. It would seem, therefore, that orientation is the primary influencing factor. Summation of the upper and lower field results (Figure 5.34) showed an even greater disparity than the right and left half field results when compared to the full field results.

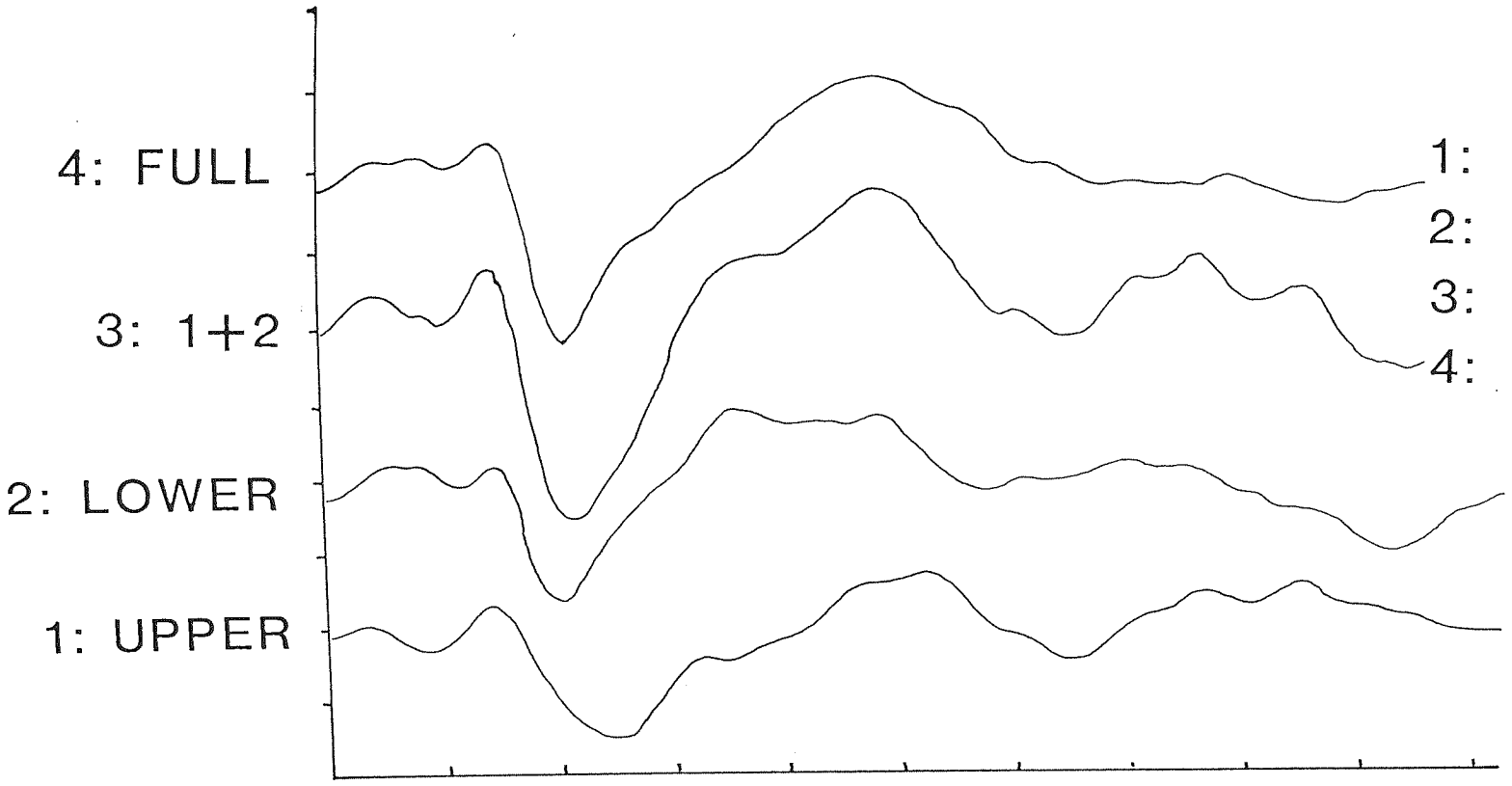
5.8.4 Conclusions

We must dismiss the first hypothesis, based on the work of Celesia and Todd Meredith (1982), which stated that there was a form of diffuse summation between the scalp potential and the cortical generators. We have been able to quantify the degree of scalp potential attenuation for full field stimuli between 3^{o} and 30^{o}. Reasons for this attenuation have been proposed as depth, orientation and synchrony of the generating cortical

FIGURE 5.34

Comparison between the Full Field Response and the Summation of the Upper and Lower Field Responses at the Oz Electrode (30^{o} Stimulation)

5.00μvlt/div



	Amp. (P_{100})	Lat.
1:	7.01	120
2:	7.78	101
3:	13.32	105
4:	10.35	105

50.00msec/div

sources but we have been unable to define the effect of any one factor in isolation. By comparing the ratios obtained from the P100 amplitude at the Oz electrodes to the integral of amplitude recorded over a much larger scalp area we would tend to support Vaughan (1969) that the scalp potential is attenuated but is little affected by "smearing".

The half field results present some tenuous support for the invariance principle but all results suggest that the principle of summation is an over simplification of our interpretation of the scalp potential. There does, however, appear to be a considerable interaction of cortical potentials resulting in the cancellation of at least part of the signal generated.

5.9 Summary

The scalp topography of the visual evoked potential was not symmetrical around the midline but showed a bias towards the left occiput on common reference recording. The foveal projection elicited a response which was both variable and delayed in latency and suggest that great care is taken if such a stimulus is used for clinical purposes. The half field responses were distorted in accordance with this asymmetry and did not summate to give the full field response. It would appear easier to detect a left homonymous hemianopia than a right homonymous hemianopia and large fields and check sizes

should be used clinically with electrodes of at least 20% laterality from the midline in order to best recognise such visual field defects with common reference recording. Half field stimulation should further assist clinical techniques.

There was little or no inter-ocular difference for both amplitude and latency which would suggest that in unilocular abnormalities the use of the healthy eye as a control is justified. As the field and check size was reduced the amplitude was similarly reduced. This did not relate directly to the amount of cortex activated by a given stimulus but was nevertheless linear and implies potential attenuation which may be due to depth, orientation and synchrony of the cortical sources. An upper field stimulus gave a reduction in amplitude with an increased latency and was generally maximum at a position lower over the scalp than for a lower field stimulus. This difference was most exaggerated when the intermediate 10^{o} field size was used. The lower field stimulus elicited a response which appeared to dominate the full field response and as such illustrated the importance of examining the upper and lower field. The nasal hemiretina similarly seems to dominate over the temporal hemiretina. A reduction in the mean luminance of the stimulus caused a delay in latency and reduction in amplitude when a large field and check size was used but when a small field and check size was used the amplitude may increase but the latency was little affected. The results obtained using a simulated

relative scotoma gave interesting scientific results but, rather like the 3^{o} full field results, would suggest a limited value for VEPs in detecting shallow, relative scotomas clinically. This may prove an inappropriate observation when examining patients with central scotomas as the disease itself may cause severe distortion of the VEP rather than the field defect. There was no evidence to suggest a purely scotomatous nature for the PNP-complex.

CHAPTER 6

CLINICAL EVALUATION OF THE INTER-RELATIONSHIP BETWEEN THE VISUAL EVOKED POTENTIAL AND THE VISUAL FIELD

6.1 Introduction

Several areas of controversy in the methods of recording and evaluating the visual evoked potential have been established (Chapters 1, 4 and 5) and new methods of examining the visual field investigated (Chapters 2 and 3). In the preceding Chapter the effects of simulated visual field defects on the scalp topography of the VEP have been evaluated. The aim of this Chapter is to examine patients with conditions which have given rise to classic visual field defects particularly those affecting the central visual field and causing hemianopias.

Wherever possible the patients were examined using the Octopus Programme 31 and the Sargon programmes developed to enable a computation of the Depression Profile and the percentage information loss as outlined in Chapter 3. Visual evoked potentials were recorded topographically using the stimulus and recording techniques established in Chapter 5. Some patients were unable to perform all tests. There were sometimes limits as to the amount of time we could diplomatically demand from the volunteer group. Similarly there were clinical limits on the number of tests required for some of the non-voluntary patients. Unfortunately, two patients died before completing all examinations.

The study was divided into three sections:

1 Pre-chiasmal lesions

11 Chiasmal lesions and

111 Post-chiasmal lesions

A brief clinical report for each patient will be included and followed by a comment on the relationship between the visual field, the visual evoked potentials and the patient diagnosis.

Thankfully, all of the conditions investigated are rare and as such it was difficult to pre-plan the exact number of patients to be examined in each category. The results presented are a precursor to the establishment of a long-term research programme to investigate patients with particular visual field abnormalities. The patients reported in this Chapter were all examined over a two and a half year period from the summer of 1982 to the end of 1984.

6.2 Pre-Chiasmal Lesions

6.2.1 Results

Table 6.1 outlines the diagnoses of the 15 subjects investigated.

TABLE 6.1

PATIENT DIAGNOSIS

SUBJECT	DIAGNOSIS
ADa	Vitteliform Dystrophy (Bests Disease)
CS	Macula Degeneration
JP	Optic Nerve Compression
EM	Granulomatous Optic Neuritis Secondary to Nematode Larvi
EB	Ischaemic Optic Neuropathy
JS	Sectoral Retinitis Pigmentosa
AD	Autosomal Recessive Retinitis Pigmentosa (Invers
RG	" " " " "
RPG	" " " " "
DW	" " " " "
MG	Autosomal Dominant Hereditary Optic Atrophy
JG	" " " " "
PB	" " " " "
KS	" " " " "
DR	Lebers Optic Atrophy

FIGURE 6.1

SUBJECT: ADa DOB: 14.3.'28

EYE: Left VA: $^{6}/_{12-2}$

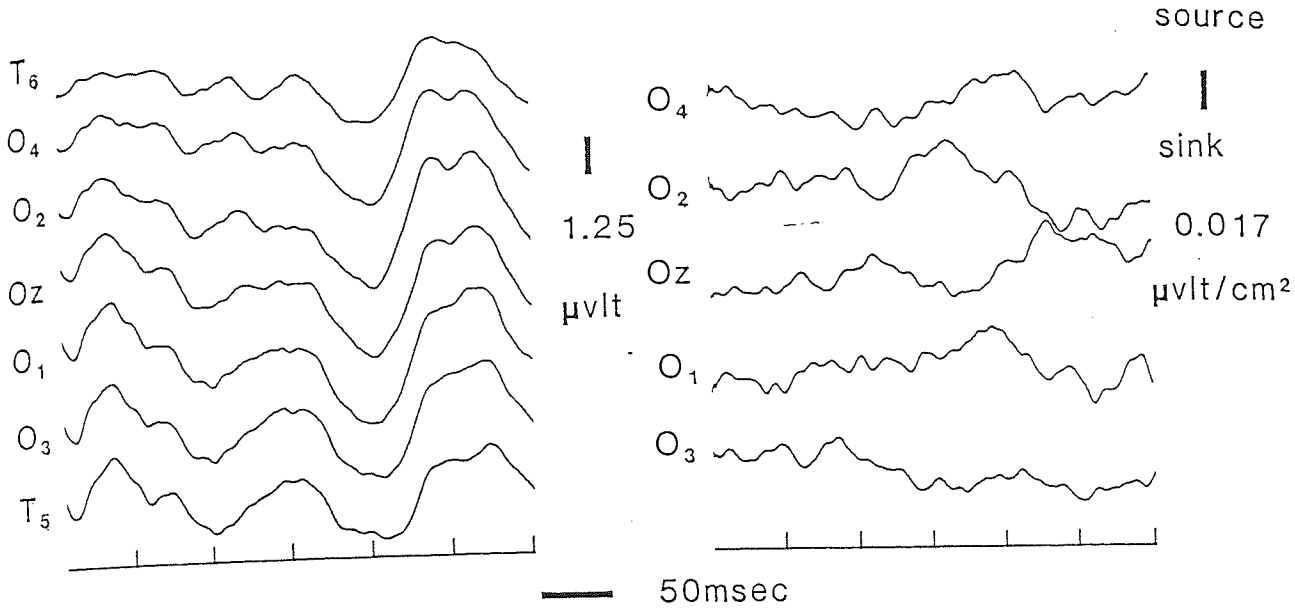
Diagnosis: Vitelliform Dystrophy
(Best's Disease)

1. The visual evoked potential to full field stimulation.
   (Common Reference and Source Derivation)

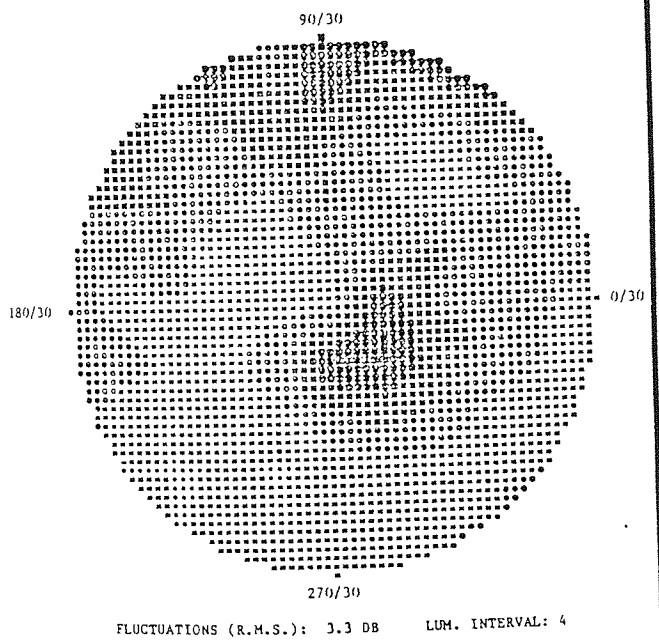
2. The visual field using the Octopus Programme 31

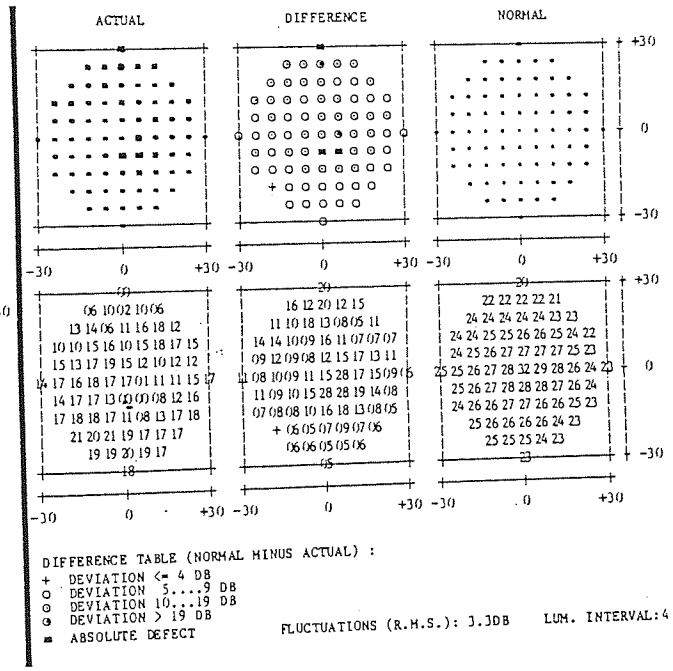
SUBJECT ADa EYE LEFT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD





Information Loss

48.35 %

Subject ADa (Left Eye)

Visual Field

Examination using the Octopus Programme 31 showed a deep, large central scotoma and a generalised reduction in sensitivity. The central 15^{o} was severely affected but the left half field was better preserved.

The Depression Profile quantified an information loss of 48.35% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

The response was poor with a small P100 component at 92msec present over all channels but slightly larger over the left occiput with a maximum amplitude over the Oz electrode (0.71 microvolts).

11. 30^{o} Right Half Field

The response was very poor with a possible PNP-complex over the right occiput at 92msec.

111. 30^{o} Left Half Field

The response was poor with a PNP-complex over both occiputs but clearer over the right at 92msec.

IV. 10^{o} Full Field Stimulation

The response was poor with no easily identifiable components although there may possibly be a small PNP-complex on all channels at 97msec.

V. 10^{o} Right Half Field

There was a small PNP-complex on all channels at 102msec.

VI. 10^{o} Left Half Field

The response was clearer with a P100 component on all channels at 104 msec.

Comment

Vitelliform dystrophy of the fovea, or Best's disease, is a diffuse abnormality of the pigment epithelium and is autosomal, dominant. Visual acuity remains good until the neuro-epithelium is affected. When this occurs it leads to a polymorphous foveal dystrophy which seriously affects the central vision giving an often dense central scotoma. Subject ADa was considered atypical as the central reduction in sensitivity is accompanied by a peripheral reduction in sensitivity.

The visual evoked potential was severely affected although there was a small P100 component which was clearer over the left occiput on full field stimulation.

This would tend to suggest better preservation of the left, temporal field an observation which is confirmed by the slightly better left half field response particularly for the 10^{o} stimulus. There was no evidence of the "scotomatous negativity" following full field stimulation which would support the observations in Chapter 5.

The VEP results must be considered grossly abnormal indicating severe visual field loss within the central 15^{o} which was deeper in the right, nasal field. The visual field results confirm this showing an information loss of 48.35% within the central 30^{o}. The source derivation technique was of little additional value as the common reference result was poor.

EYE LEFT

FIGURE 6.2

SUBJECT: CS DOB: 27. 5. '26

EYE: Left VA: $^{6}/_{24}$

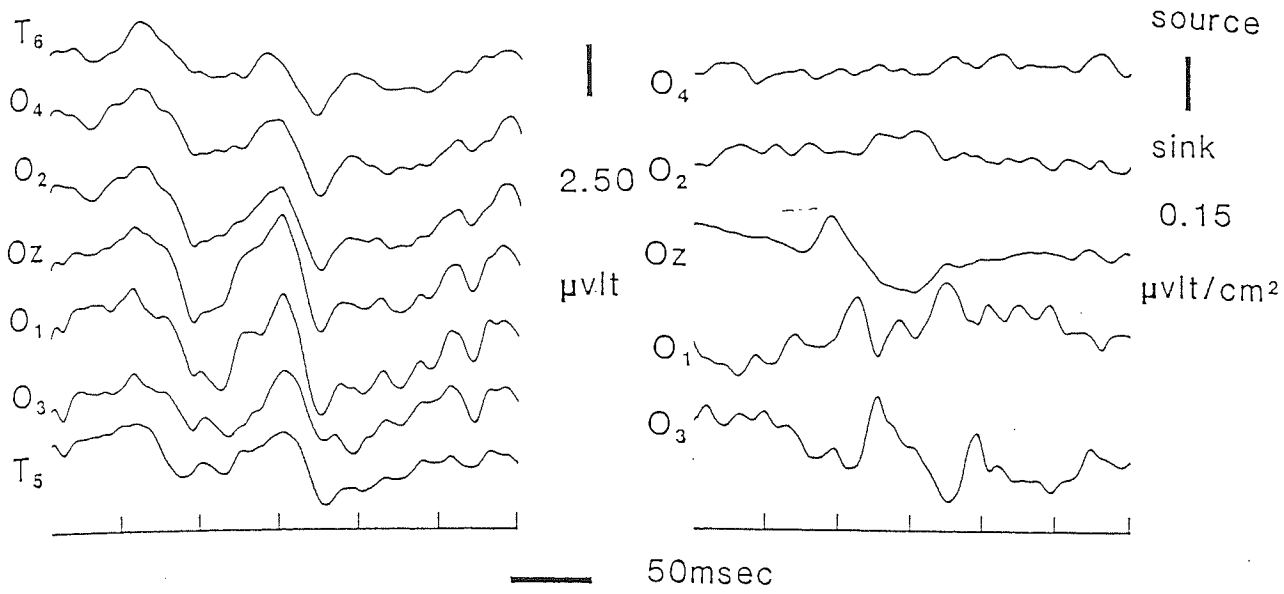
Diagnosis: Macula Degeneration

1. The visual evoked potential to full field stimulation
(Common Reference and Source Derivation)

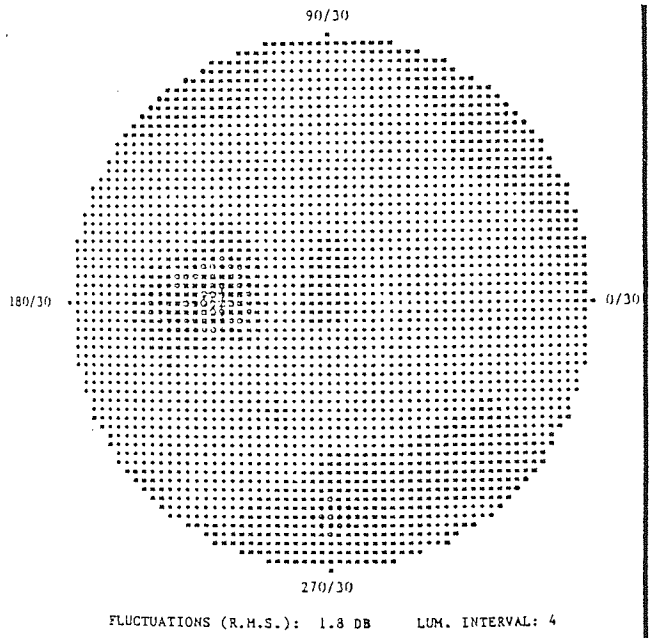
2. The visual field using the Octopus Programmes 31 and 21

SUBJECT CS EYE LEFT

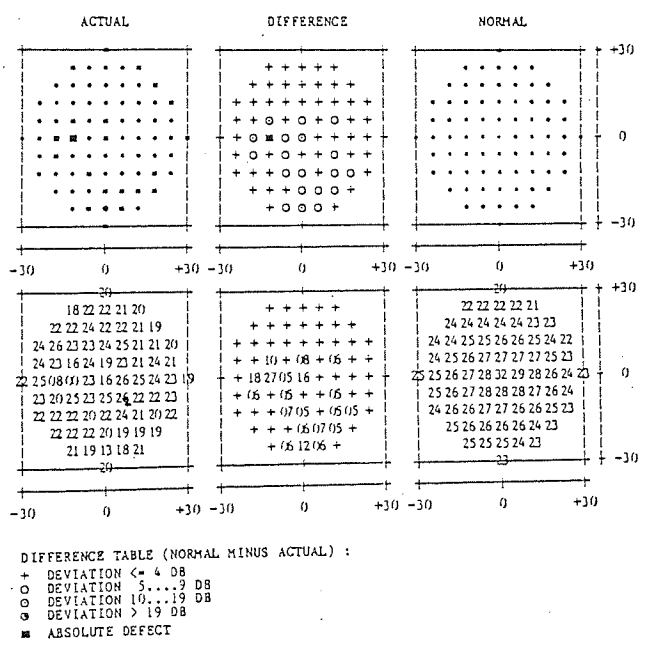
1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD

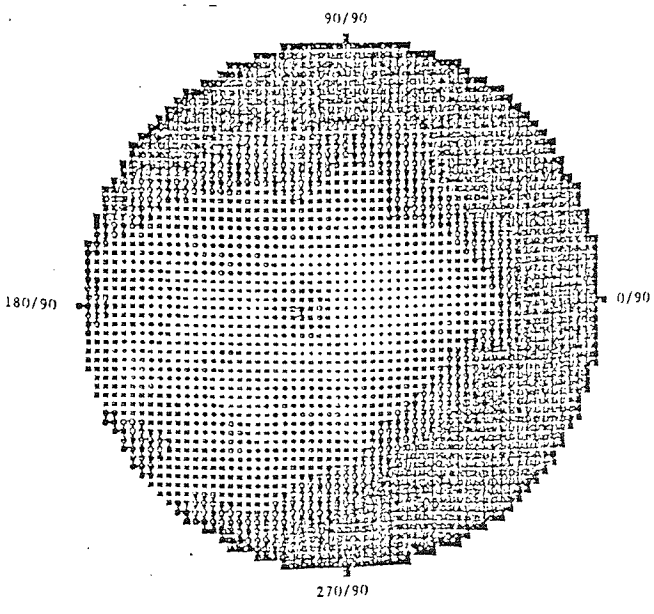


FLUCTUATIONS (R.M.S.): 1.8 DB LUM. INTERVAL: 4



DIFFERENCE TABLE (NORMAL MINUS ACTUAL) :

+ DEVIATION <= 4 DB
○ DEVIATION 5...9 DB
◎ DEVIATION 10...19 DB
● DEVIATION > 19 DB
■ ABSOLUTE DEFECT



FLUCTUATIONS (R.M.S.): 2.5 DB LUM. INTERVAL: 4

Information Loss

6.23 %

Subject CS (Left Eye)

Visual Field

Examination using the Octopus Programme 31 showed an enlargement of the blind spot, a central scotoma and a loss of sensitivity in the lower field. The central 15^{o} was considerably affected with the right half field being more preserved than the left half field.

The Depression Profile quantified an information loss of 6.23% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

The response was small but there was a clear P100 component at 102 msec on all channels although it was contaminated with a small 'bifid' component over the left occiput. The maximum response was on the midline (1.84 microvolts). The source derivation distribution gave a source on the midline with a sink over the left occiput.

11. 30^{o} Right Half Field

Demonstrated a P100 component at 100 msec which was larger over the right occiput, ipsilateral to the

stimulated hemifield. The maximum response was over the O2 electrode at 2.27 microvolts.

III. 30^{o} Left Half Field

The response was small with a large preceding negative component but there was a clear P100 component at 105 msec which was larger over the left occiput, ipsilateral to the stimulated hemifield. The maximum response was over the O1 and Oz electrodes at 1.90 microvolts.

IV. 10^{o} Full Field Stimulation

There was no identifiable response.

V. 10^{o} Right Half Field

Demonstrated a small P100 component over all channels at 120 msec.

VI. 10^{o} Left Half Field

There was no identifiable response.

The 3^{o} stimulus only gave a small response when the right half field was stimulated. This gave a P100 component at 118 msec.

Comment

In spite of the central reduction in sensitivity there was no PNP-complex, the "scotomatous negativity". Half field stimulation proved useful indicating better preservation of the right, nasal half field, with a response which appeared ipsilateral to the hemifield stimulated. When the smaller stimuli were used only the right half field stimulus gave a P100 component which was not lateralised but appeared over each channel although the full field stimulus did not elicit any identifiable components. In spite of the small degree of information loss the visual field results confirmed a small central scotoma and an enlargement of the blind spot affecting the left, temporal field. The source derivation distribution to full field stimulation (30^{o}) was consistent with this observation.

FIGURE 6.3

SUBJECT: JP DOB: 31. 12.'21

EYE: Right VA: 6/36

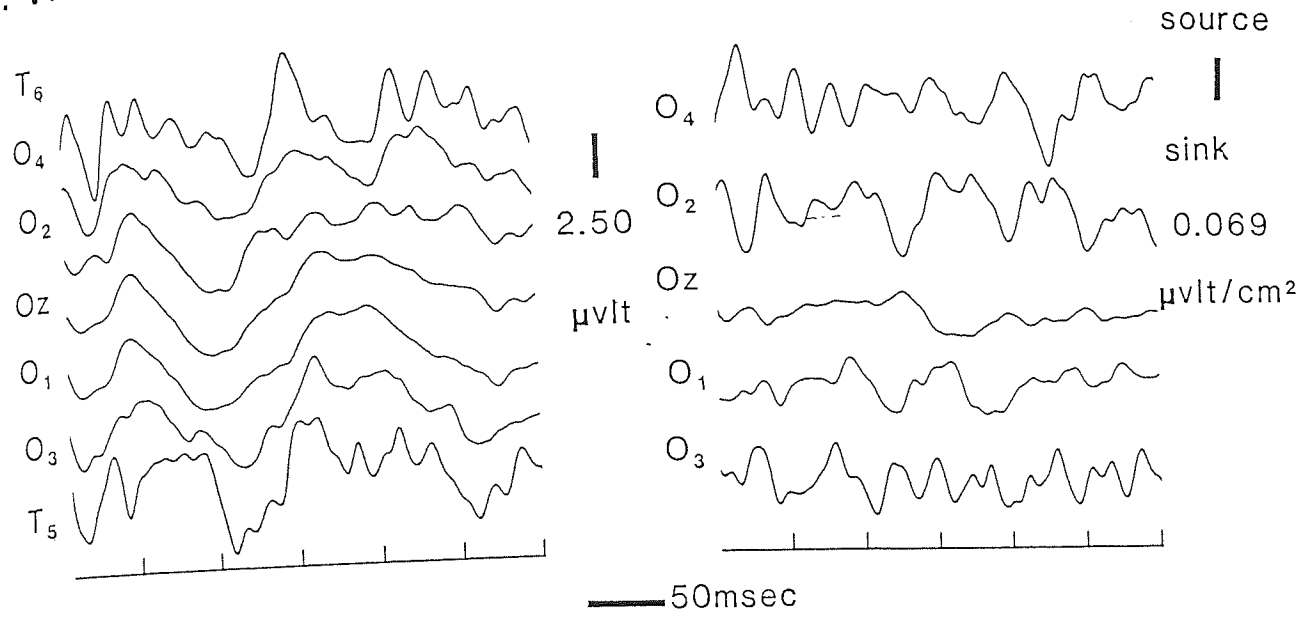
Diagnosis: Optic Nerve Compression

1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

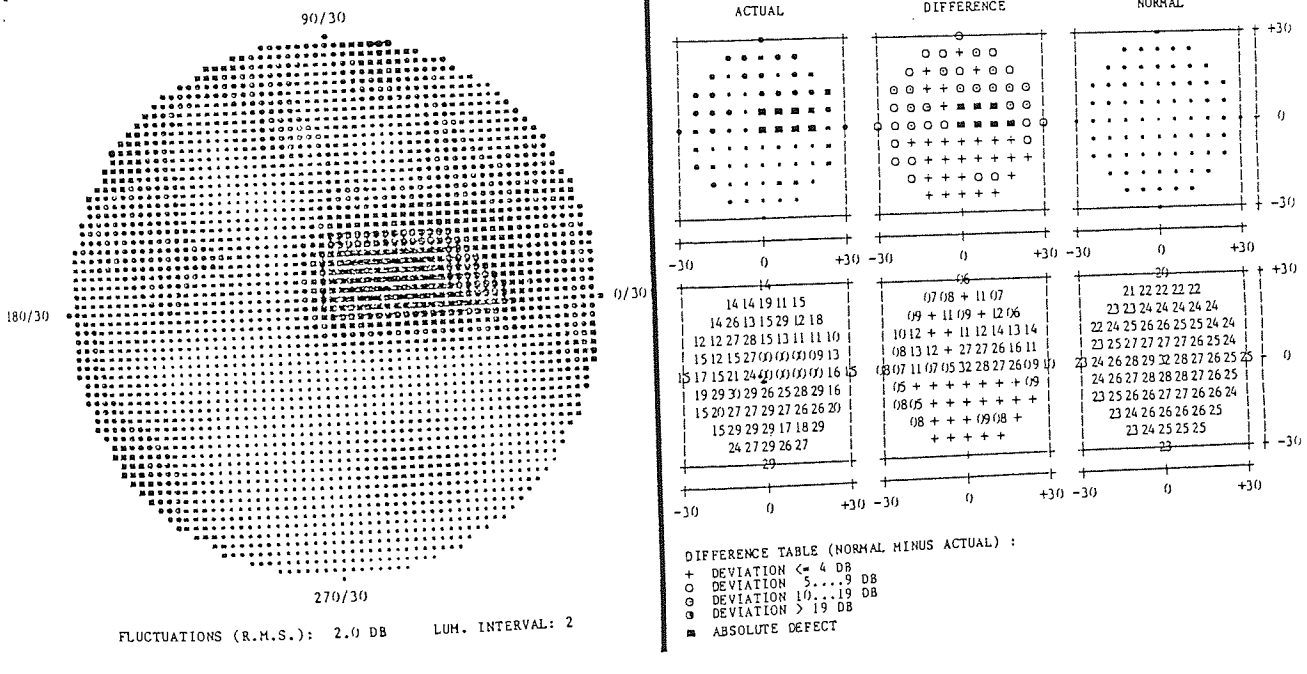
2. The visual field using the Octopus Programme 31

SUBJECT JP EYE RIGHT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



Information Loss

43.64 %

Subject JP (Right Eye)

Visual Field

Examination using the Octopus Programme 31 showed a deep, central scotoma extending from an enlarged blind spot with a generalised reduction of sensitivity in the superior quadrants and a peripheral reduction in sensitivity in the lower temporal quadrant. The field defect was caused by compression of the optic nerve. The central 15^{o} was severely affected with the right half field worse than the left half field.

The Depression Profile quantified an information loss of 43.64% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

The response was surprisingly good considering the extent of the visual field loss. There was a broad, flat P100 component at 97 msec which was maximum on the midline (2.76 microvolts). There was no evidence of a PNP-complex.

11. 30^{o} Right Half Field

The response was poor but there was a P100 component at 111 msec over the T5 and O3 electrodes.

111. 30° Left Half Field

The response was poor with no identifiable components.

1V. 10° Full Field Stimulation

There was a small P100 component identifiable at 96 msec over the three central electrodes only. There was no identifiable response after stimulation of the central 3°.

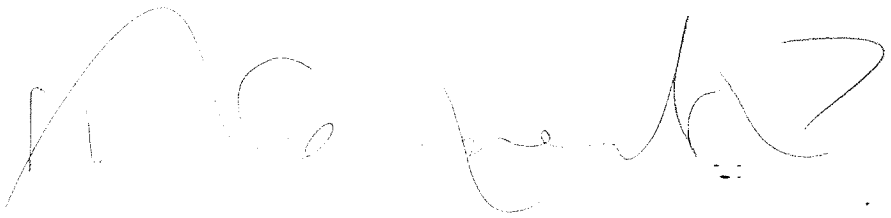


FIGURE 6.4

SUBJECT: JP DOB: 31.12.'21

EYE: Left VA: $^{6}/_{6-1}$

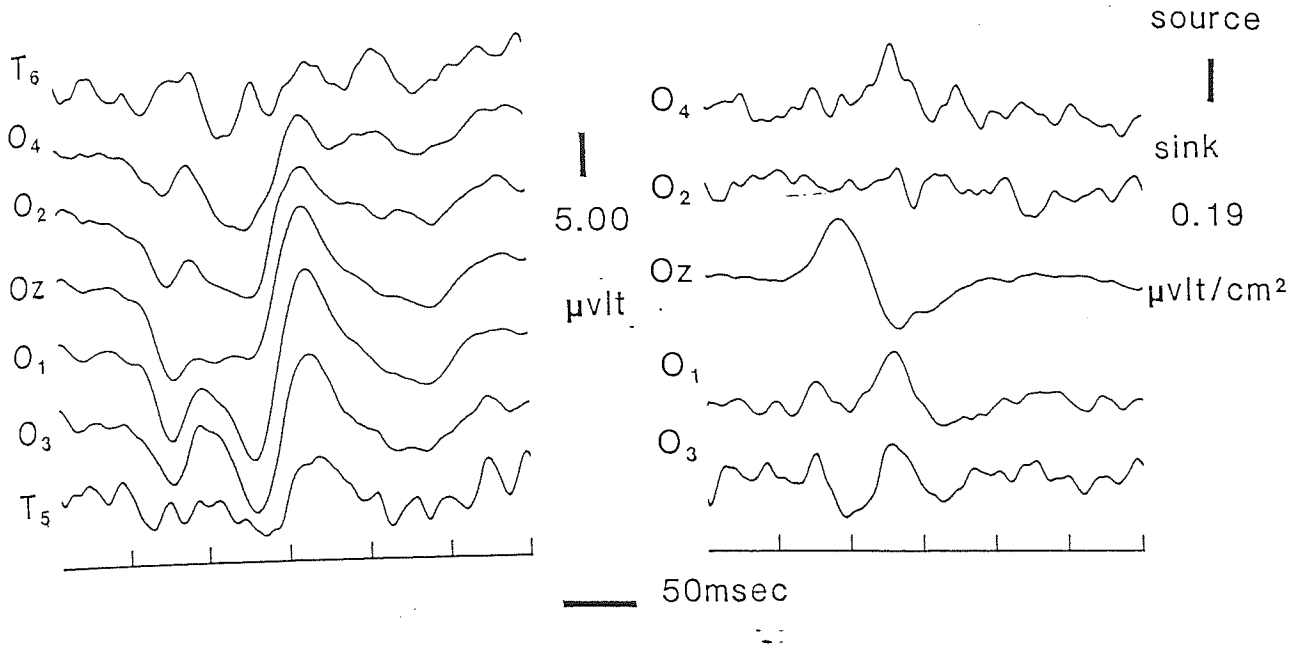
Diagnosis: Optic Nerve Compression

1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

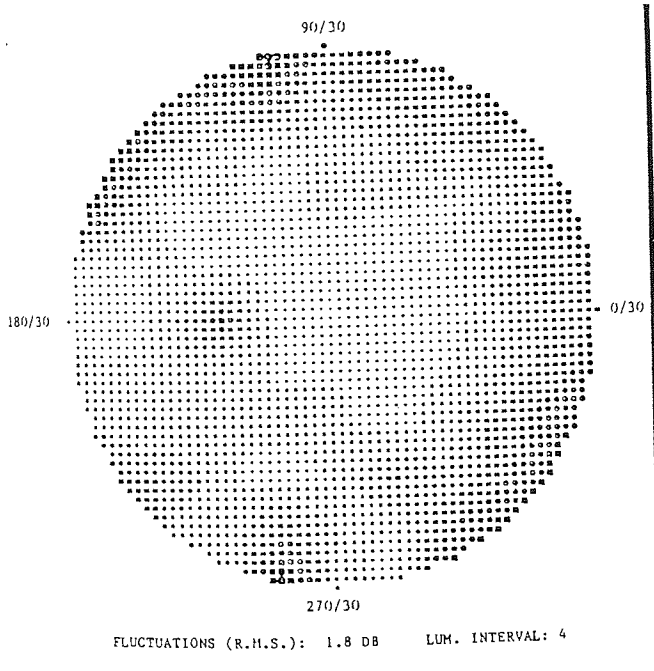
2. The visual field using the Octopus Programme 31

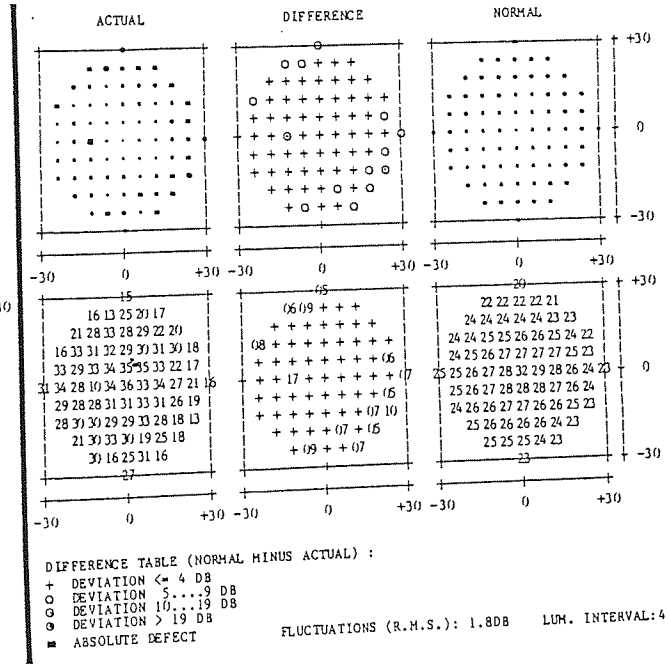
SUBJECT JP EYE LEFT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD





Information Loss

1.99 %

Subject JP (Left Eye)

Visual Field

Examination using the Octopus Programme 31 showed a slight peripheral reduction in sensitivity particularly in the lower, temporal quadrant. The central 15^{o} was not affected.

The Depression Profile quantified an information loss of 1.99% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Demonstrated a PNP-complex with the negative component at 94 msec. It is possible that this complex was actually a grossly delayed NPN-complex with the P100 at 128 msec.

11. 30^{o} Right Half Field

The response appeared to show a PNP-complex over the left occiput with a negativity at 97 msec. Again the results could be described as a delayed P100 component at 128 msec which was best over the right occiput, ie. ipsilateral to the stimulated hemifield.

111. 30^{o} Left Half Field

Demonstrated a P100 component at 126 msec over the

right occiput, maximum over the O2 electrode (4.23 microvolts).

1V. 10^{o} Full Field Stimulation

Demonstrated a central P100 component at 106 msec, which was maximum over the Oz electrode (5.67 microvolts).

There was no identifiable response after stimulation of the central 3^{o}.

Comment

Subject JP was believed to be suffering from optic nerve compression although the exact aetiology is still under investigation. The unilateral nature of the visual field defect suggested an intraorbital pressure. The deep, superior temporal loss which is limited by the horizontal meridian is most likely to be caused by pressure on the lower, nasal portion of the nerve.

The VEP results from the right eye do not exhibit a PNP-complex in spite of the absolute central scotoma. There was a large level of information loss but this was restricted to the upper field. The P100 component present over the three central channels must be mainly attributable to the preserved lower field but as such the morphology was rather poor, not giving the early, sharp P100 component normally associated with upper hemiretinal

stimulation.

The left eye, although exhibiting very little information loss, gave VEP results of poor morphology. The major components were difficult to identify. If we follow the recommendations of Blumhardt et al. (1979) in which he establishes the major component by identifying the ipsilateral components following half field stimulation, it would appear that there is a grossly delayed P100 component at 128 msec.

It has been suggested in the literature (see Chapter 1) that the VEP is particularly sensitive to compressive lesions. The gross abnormality of the VEP from the left eye in spite of an apparently normal visual field within the central 15^{o} may suggest a lesion which is intracranial rather than intraorbital. The slight peripheral loss, recorded by the Octopus, outside of 25^{o} eccentricity would tend to suggest some bilateral involvement. If this is eventually confirmed we can add support to the remarkable sensitivity of the VEP to compressive lesions in and around the chiasm.

FIGURE 6.5

SUBJECT: EM DOB: 4.8.'47

EYE: Right VA: $^{6}/_{36}$

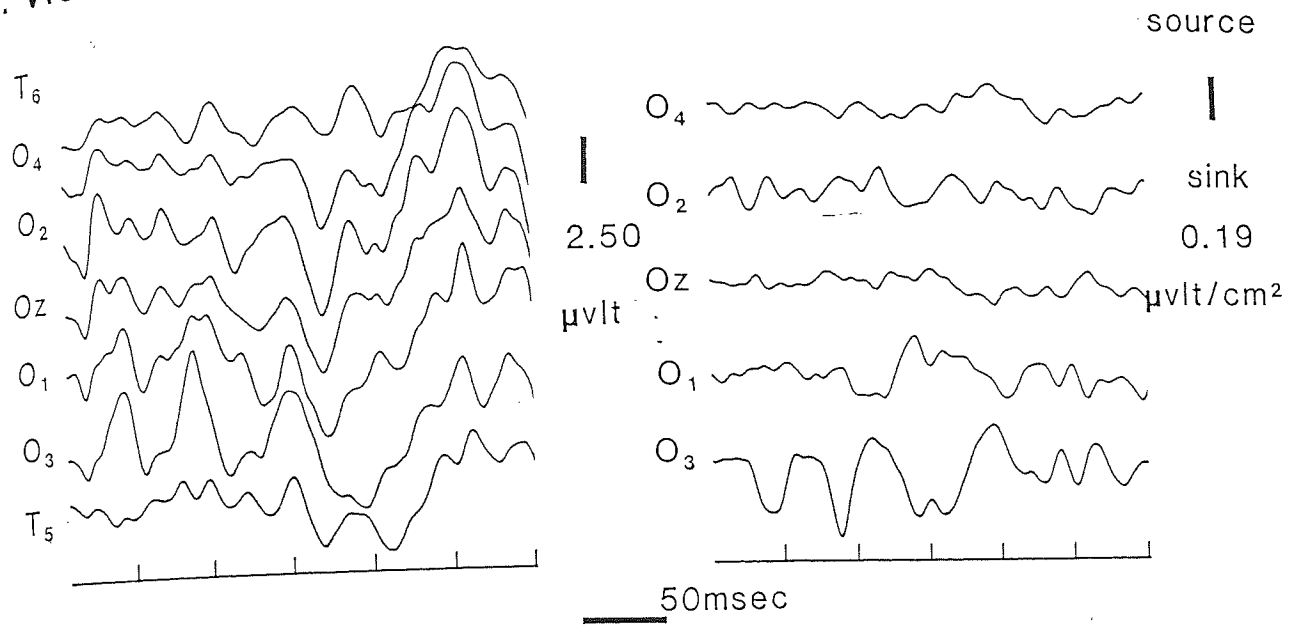
Diagnosis: Granulomatous Optic Neuritis
Secondary to Nematode Larvi

1. The visual evoked potential to full field stimulation
(Common Reference and Source Derivation)

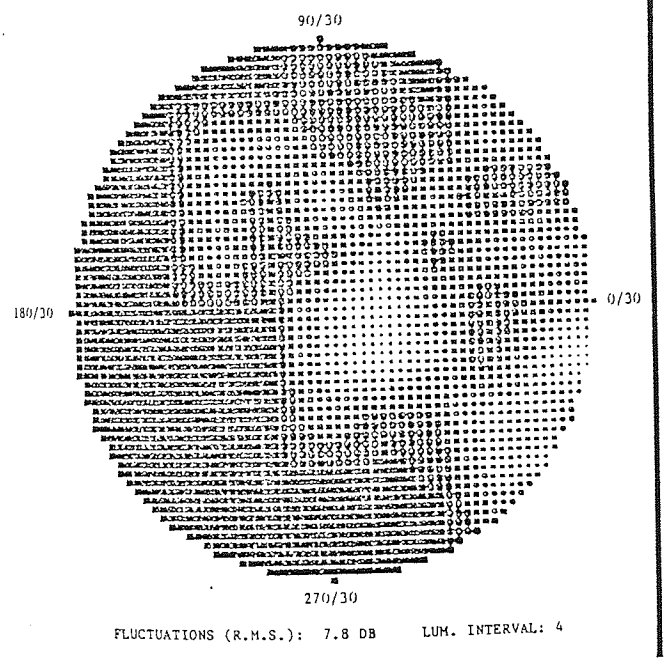
2. The visual field using the Octopus Programme 31

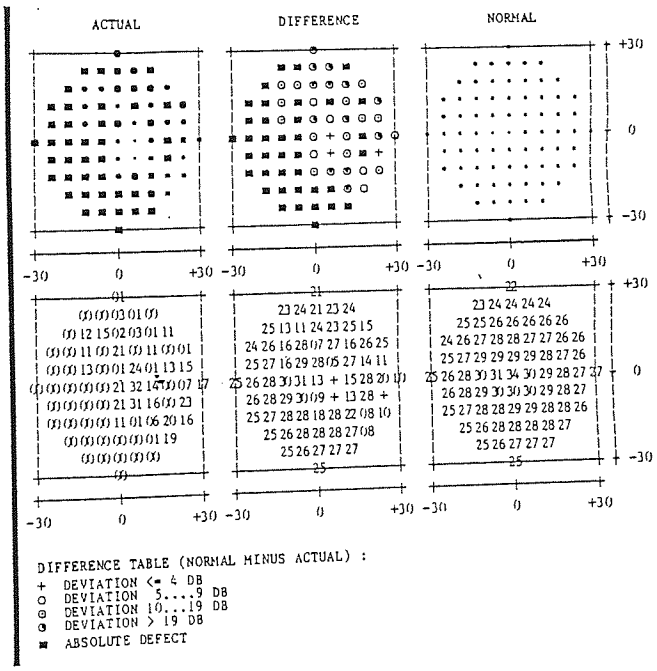
SUBJECT EM EYE RIGHT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD





Information Loss

86.35 %

Subject EM (Right Eye)

Visual Field

Examination using the Octopus Programme 31 showed an extensive deep visual field loss with a preserved island between the blind spot and the fovea.

The Depression Profile quantified an information loss of 86.35% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

The response was very poor although there may be a small P100 component at 116 msec or a PNP-complex at c.150 msec. Most channels are contaminated by alpha activity.

11. 10^{o} Full Field Stimulation

There appeared to be a small P100 component at 101 msec present over most channels and approximately symmetrical around the midline with a maximum amplitude of 1.91 microvolts.

FIGURE 6.6

SUBJECT: EM DOB: 4.8.'47

EYE: Left VA: $^{6}/_{6}$

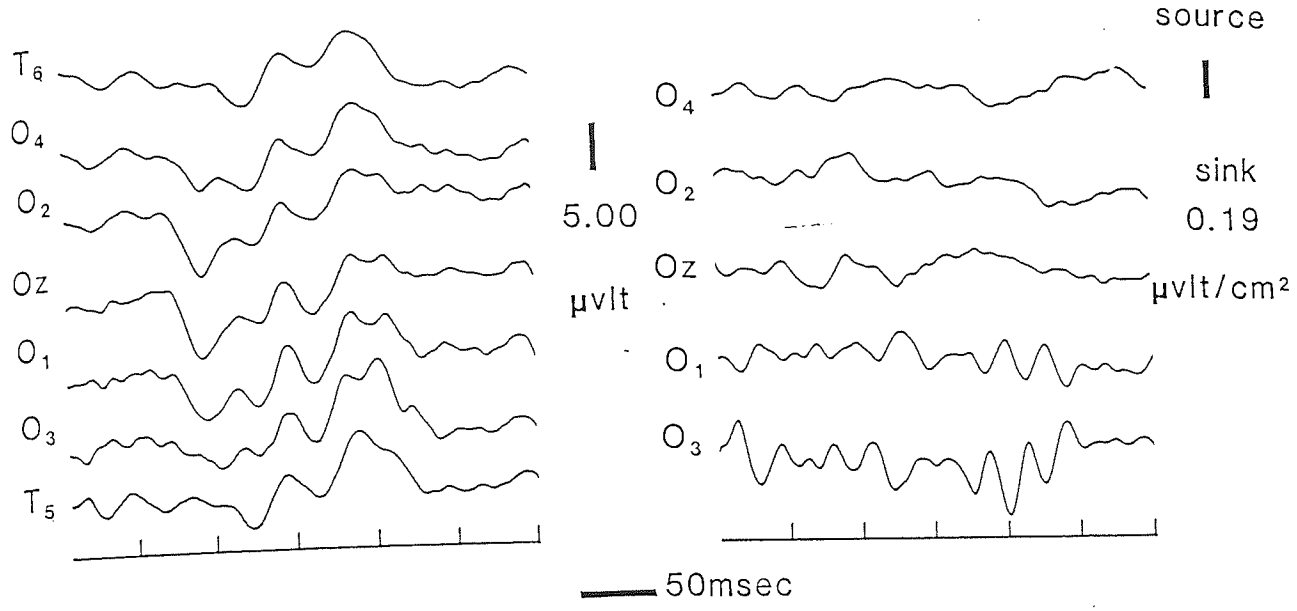
Diagnosis: Granulomatous Optic Neuritis
Secondary to Nematode Larvi

1. The visual evoked potential to full field stimulation
(Common Reference and Source Derivation)

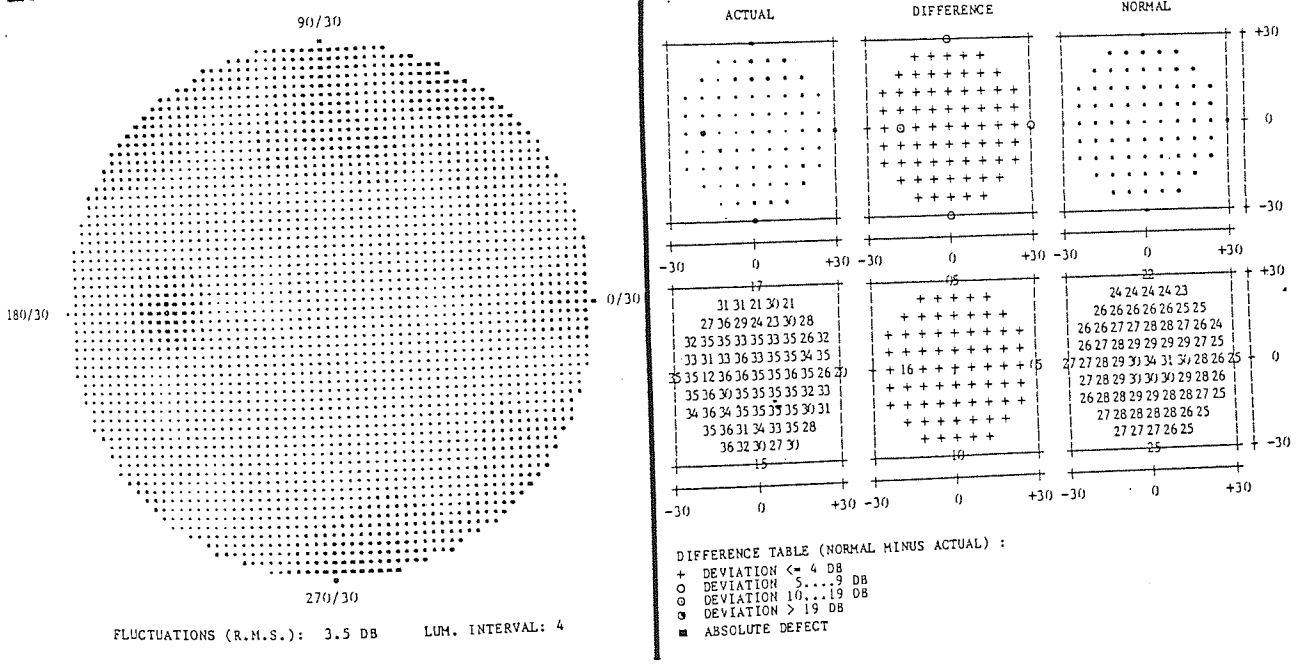
2. The visual field using the Octopus Programme 31

SUBJECT EM EYE LEFT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



Information Loss

0 %

Subject EM (Left Eye)

Visual Field

Examination using the Octopus Programme 31 showed a relatively normal visual field with only an isolated, relatively scotomatous point at the extreme of the inferior visual field.

The Depression Profile did not demonstrate any information loss.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Demonstrated a PNP-complex at 116 msec over each channel.

11. 30^{o} Right Half Field

Demonstrated a P100 component at 91 msec over the right occiput, ipsilateral to the stimulated hemifield.

111. 30^{o} Left Half Field

It is unclear whether we have an early ipsilateral P100 component over the left occiput at 83 msec or a contralateral response over the right occiput at 121 msec.

It is interesting to speculate how the two half field responses combine to give the poor PNP-complex following full field stimulation.

IV. 10^{o} Full Field Stimulation

Demonstrated a large, clear P100 component at 93 msec with a maximum on the midline of 6.51 microvolts.

V. 3^{o} Full Field Stimulation

Demonstrated a clear but small response with a P100 component at 105 msec with a maximum over the O2 electrode with 1.21 microvolts.

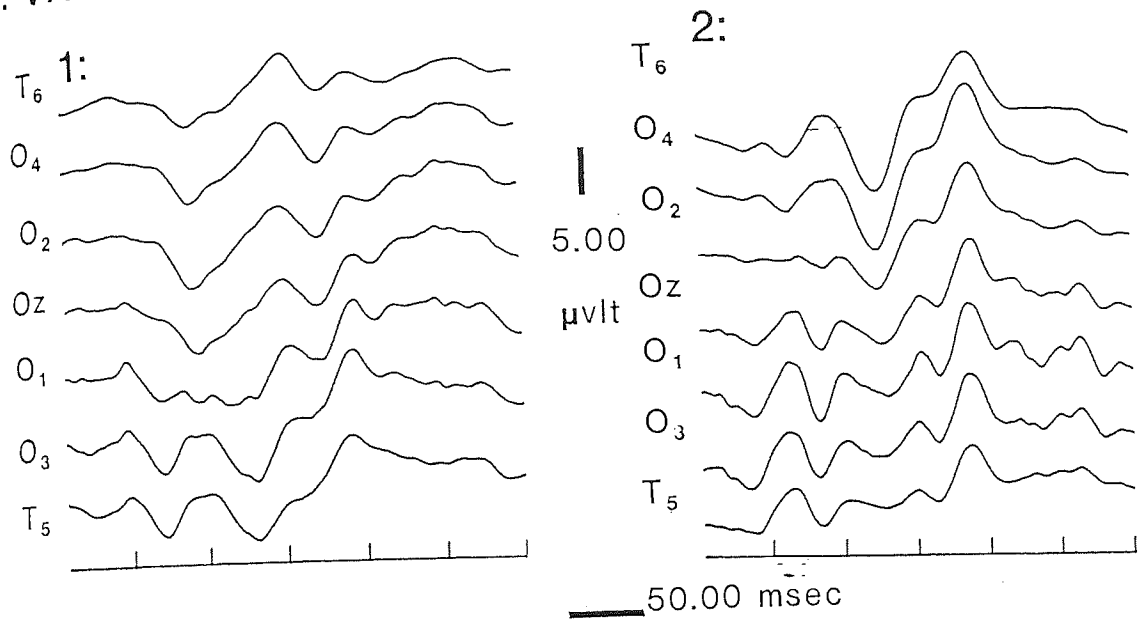
Comment

The right eye gave VEP results which had no identifiable or repeatable components. The visual field loss was severe with an extensive information loss.

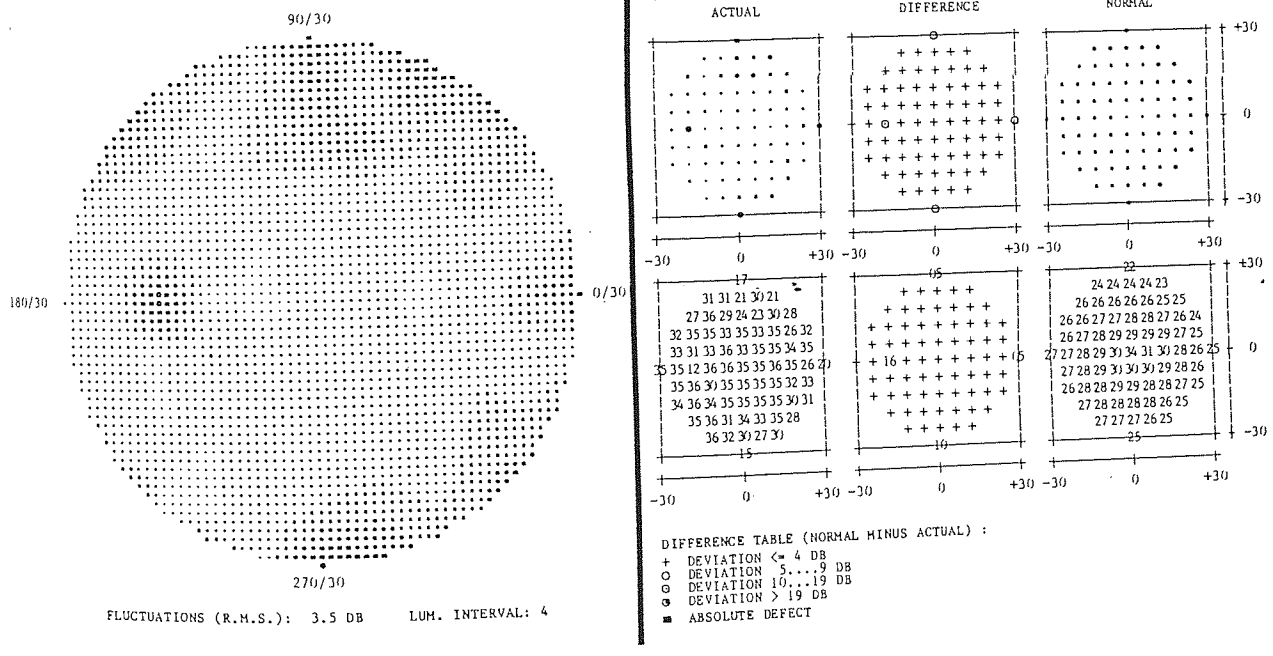
The left eye results were interesting as there was little or no recordable visual field loss but the morphology of the VEP following 30^{o} full field stimulation was a little poorer with a PNP-complex over most channels. Full field stimulation with the 10 and 3^{o} stimulus gave normal, clear responses. Thirty degree half field stimulation (Figure 6.7) gave positive components which correspond to

SUBJECT EM EYE LEFT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



3: DEPRESSION PROFILE

FIGURE 6.7 Half Field Stimulation (30^{o})

1/ Right Half Field
2/ Left Half Field

Information Loss

0 %

the positive peaks of the PNP-complex found in the full field result. The result may therefore be considered "normal" and provide an example similar to that discussed by Blumhardt (1982) in which the half field results appeared normal but may summate to give a poor full field result. The later positivity, at around 120 msec, appeared to result from an unusually large contralateral PNP-complex. Wildberger (1984b) discussed a similar example resulting from disparate upper and lower field results.

FIGURE 6.8

SUBJECT: EB DOB: 13.11.'23

EYE: Right VA: $^{6}/_{9}$

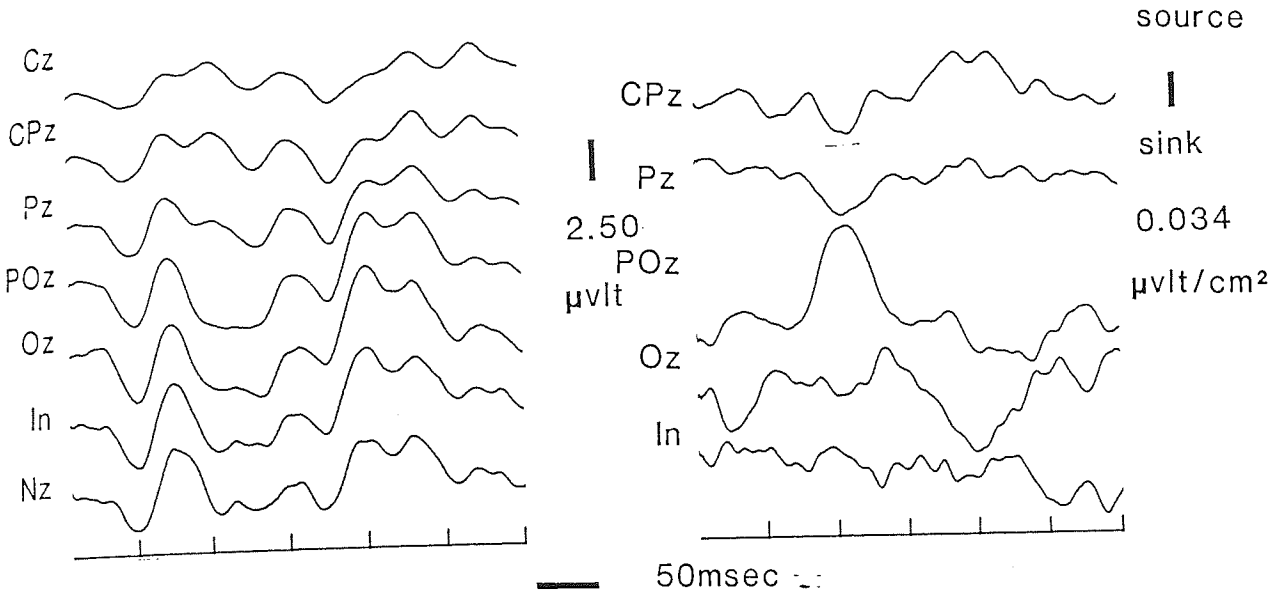
Diagnosis: Ischaemic Optic Neuropathy

1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

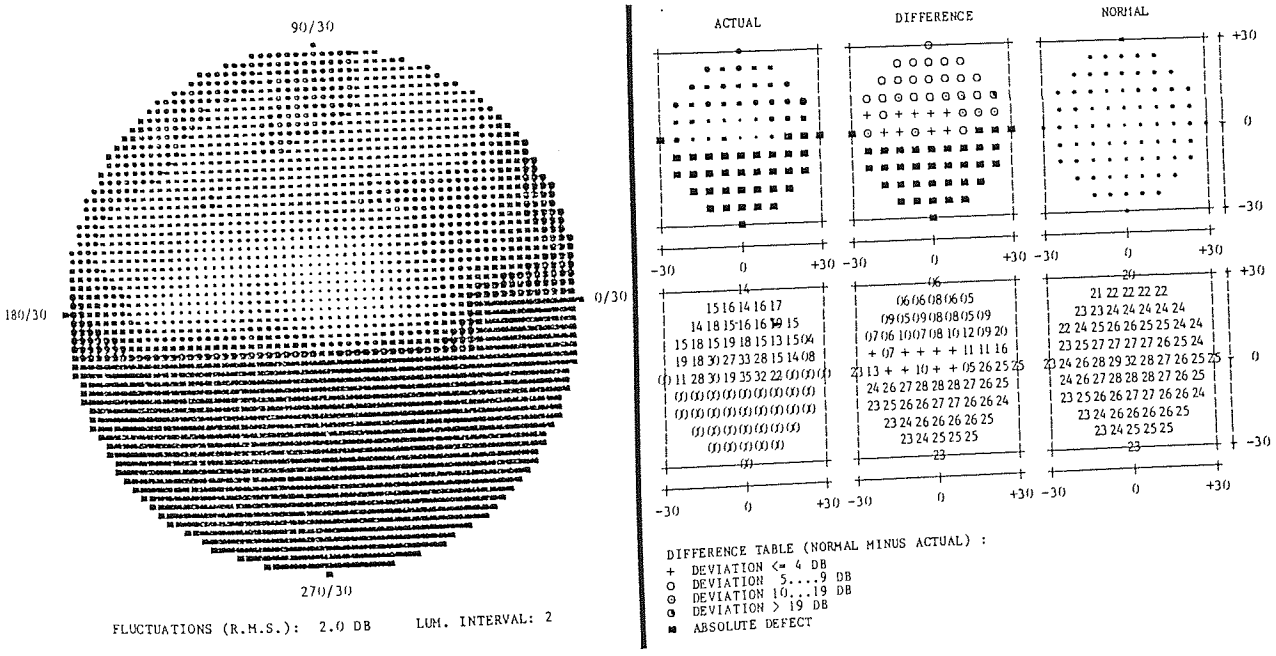
2. The visual field using the Octopus Programme 31

SUBJECT EB EYE RIGHT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



3: DEPRESSION PROFILE

Information Loss

68.32 %

Subject EB (Right Eye)

Visual Field

Examination using the Octopus Programme 31 showed an absolute lower altitudinal visual field loss with a horizontal border and steep edges. The preserved upper field showed a generalised reduction in sensitivity. Fixation was fully preserved. Only a severe restriction or injury to the vascular supply of the optic nerve could have produced such a unilateral defect and as such was entirely consistent with the diagnosis of an ischaemic neuropathy. The central 15^{o} were relatively unaffected in the upper field but severely affected in the lower field.

The Depression Profile quantified an information loss of 68.32% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Gave a P100 component at 114 msec which was of a poor morphology but present over all channels being approximately symmetrical around the midline. The maximum amplitude was over the midline at 3.70 microvolts.

11. 30^{o} Right Half Field

There was a poor ipsilateral response over the right occiput with a P100 component at 115 msec. The left occiput showed a larger, delayed positivity at approximately 140 msec which was consistent with a normal contralateral response.

111. 30^{o} Left Half Field

Gave an ipsilateral response with a P100 component present over the left occiput at 102 msec with the maximum amplitude over the midline at 4.46 microvolts. The morphology was again rather poor.

1V. 10^{o} Full Field Stimulation

Gave a poor response with a small P100 component at 107 msec.

V. 30^{o} Full Field Stimulation (Medial Montage)

Gave a broad, flat P100 component at 111 msec. This component phase reversed by electrode Pz giving a negativity over the more anterior electrodes. The response would be more consistent with a normal upper field result. The source derivation distribution showed a source over electrode POz with a sink at PCz.

V1. 30^{o} Upper Field

Gave a clear P100 component at 104 msec with a maximum amplitude between the inion and Oz at 4.61 microvolts. The response appeared as a relatively normal upper field result.

The source derivation distribution demonstrated a source over electrode POz with a sink at Pz.

V11. 30^{o} Lower Field

Gave a poor, flat response with a small P100 component at 107 msec. The maximum amplitude appeared over the Oz electrode at 3.39 microvolts.

FIGURE 6.9

SUBJECT: EB DOB: 13.11.'23

EYE: Left VA: $^{6}/_{5}$

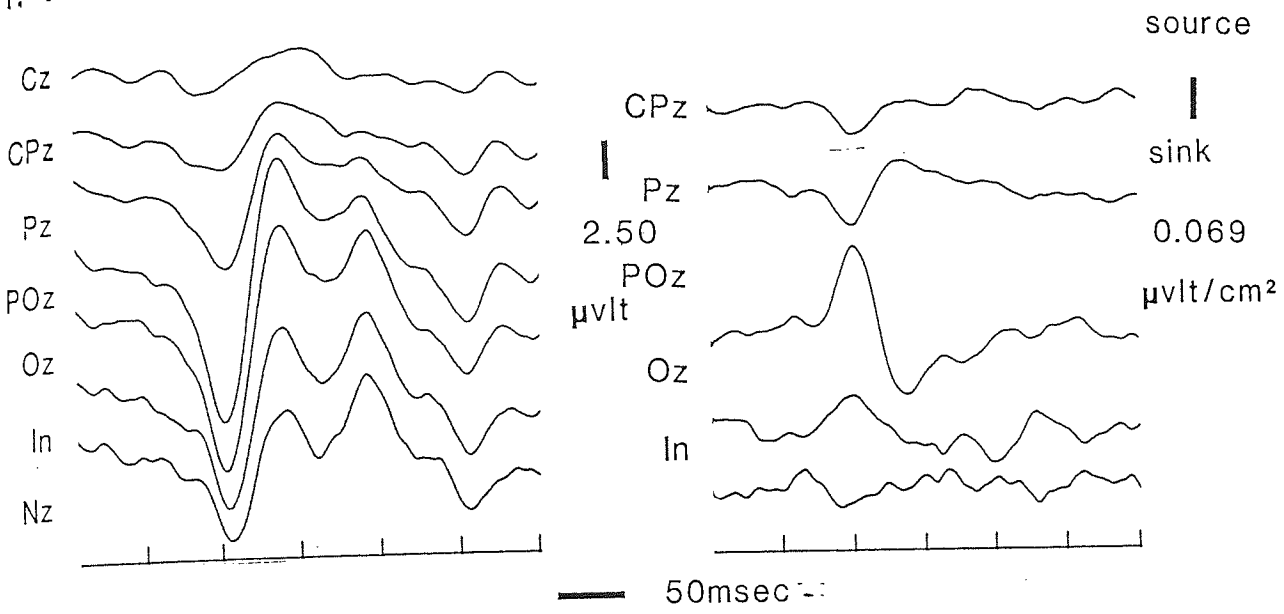
Diagnosis: Ischaemic Optic Neuropathy

1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

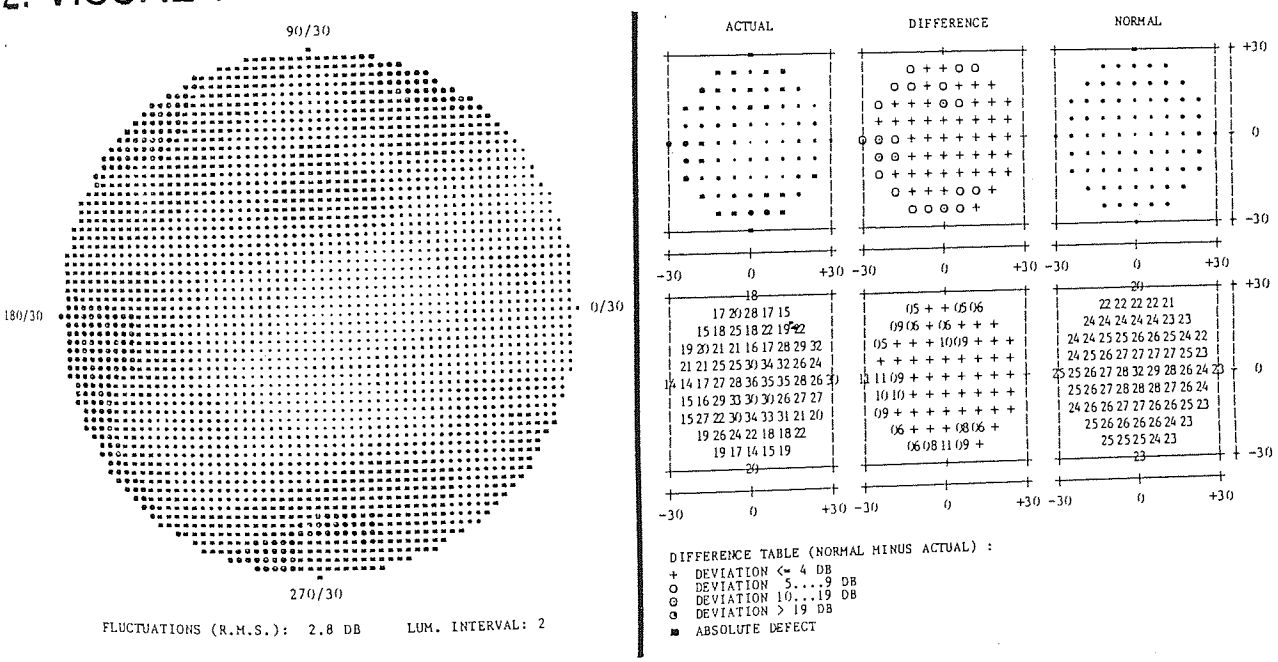
2. The visual field using the Octopus Programme 31

SUBJECT EB EYE LEFT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



3: DEPRESSION PROFILE

Information Loss

4.24 %

Subject EB (Left Eye)

Visual Field

Examination using the Octopus Programme 31 showed a peripheral reduction in sensitivity particularly in the temporal field. The central 15^{o} were unaffected.

The Depression Profile quantified an information loss of 4.24% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Gave an extremely good response with a P100 component at 100 msec which was slightly larger over the left occiput with a maximum amplitude over the midline at 10.08 microvolts.

11. 10^{o} Full Field Stimulation

Gave a good response with a P100 component at 100 msec and a maximum over the O1 electrode at 8.54 microvolts. Both of the above responses had a good morphology with all components clearly distinguishable.

111. 30^{o} Full Field Stimulation (Medial Montage)

Gave a clear and normal response with a P100 component

at 101 msec. The maximum amplitude was found over the POz electrode at 6.81 microvolts.

Comment

The results obtained are entirely consistent with those elicited from normal subjects following simulation of visual field defects. The value of using the medial montage and stimulation of the upper and lower fields was clearly demonstrated (Figure 6.10).

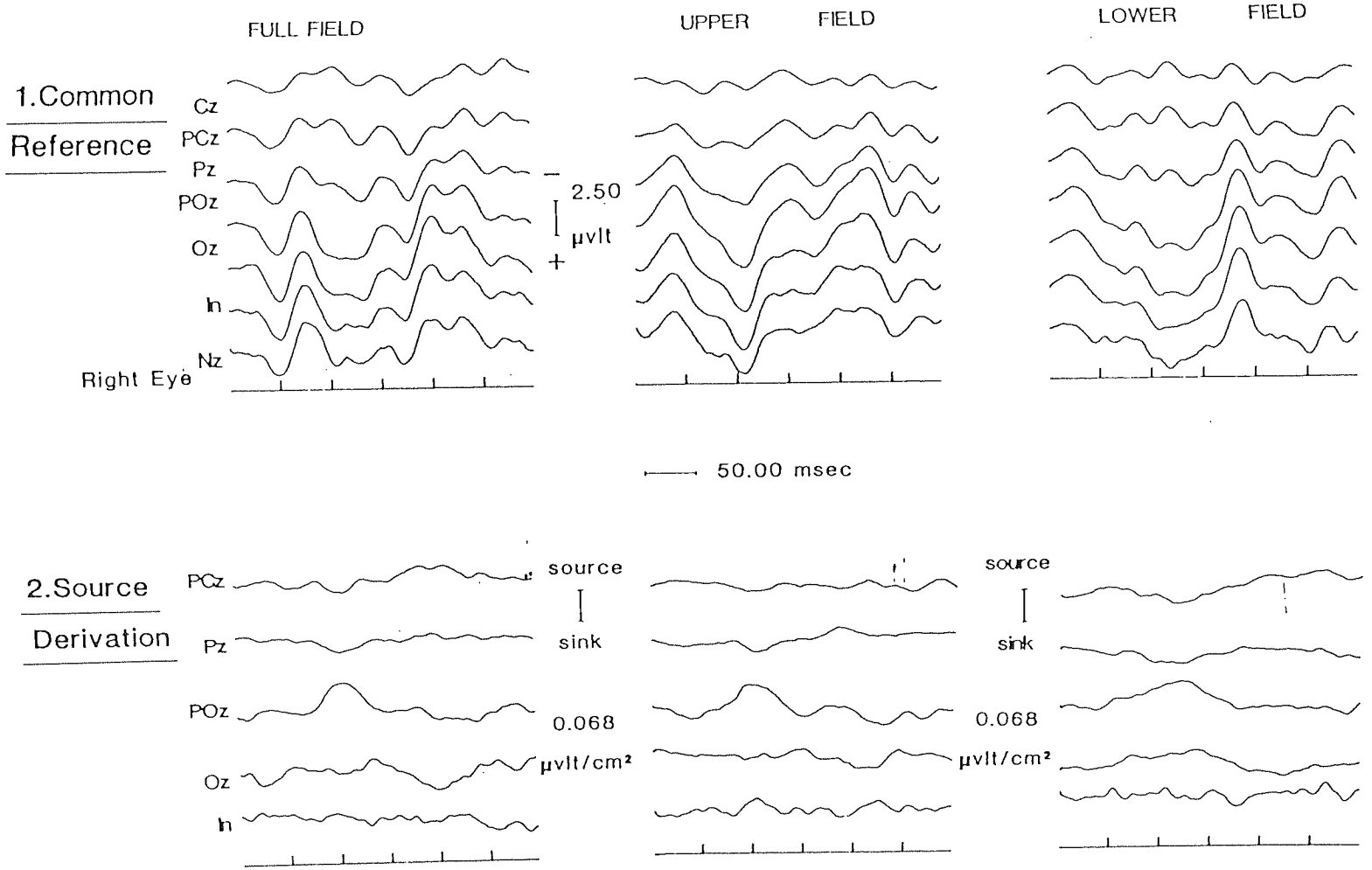


FIGURE 6.10 The VEP to Full Field, Upper Field and Lower Field Stimulation of subject EB's right eye

EYE LEFT

FIGURE 6.11

SUBJECT: JS DOB: 28.4.'54

EYE: Left VA: $^{6}/_{5-1}$

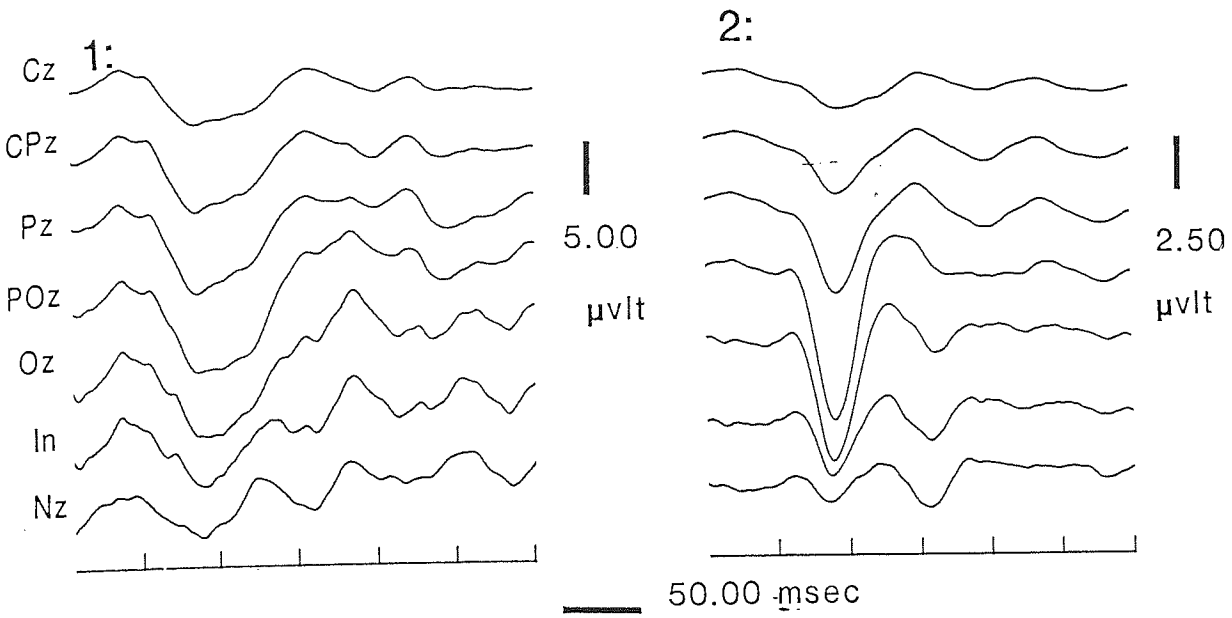
Diagnosis: Sectoral Retinitis Pigmentosa

1. The visual evoked potential to an upper field stimulus (1) and a lower field stimulus (2)

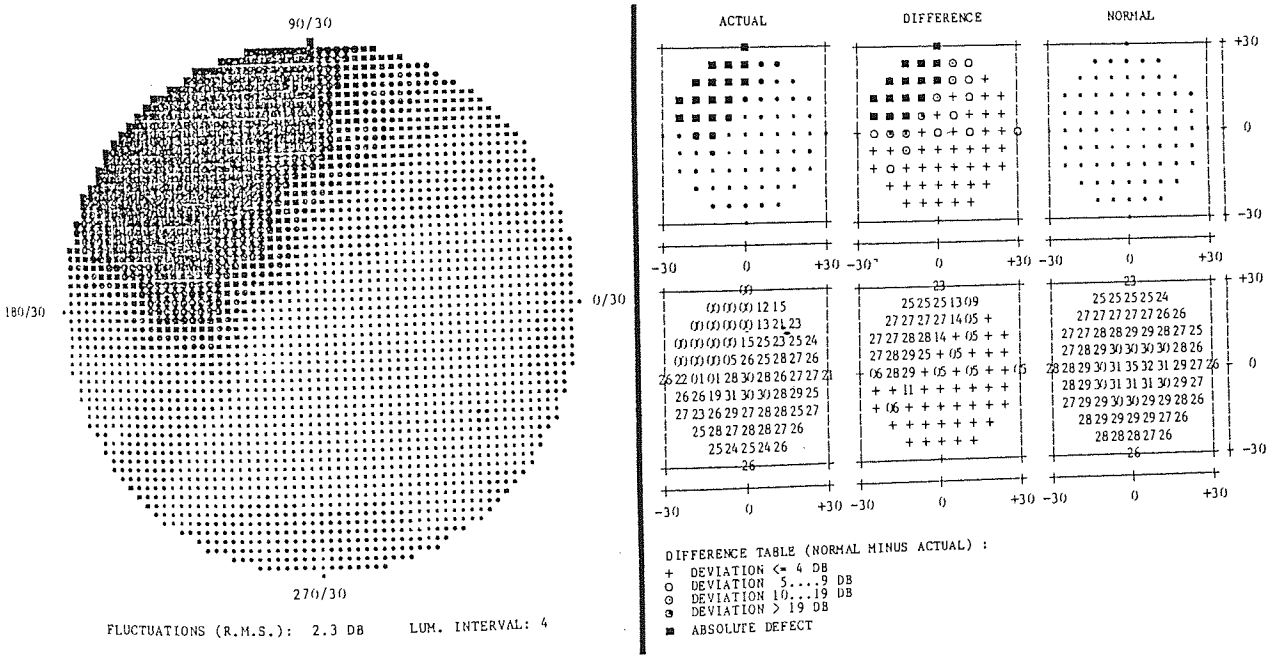
2. The visual field using the Octopus Programme 31

SUBJECT JS EYE LEFT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



3: DEPRESSION PROFILE

Information Loss

17.1 %

Subject JS (Left Eye)

Visual Field

Examination using the Octopus Programme 31 showed a deep, steep margined, localised reduction in sensitivity principally affecting the upper, temporal visual field. This type of defect was consistent with the diagnosis of a sectoral retinitis pigmentosa. The central 15^{o} was slightly affected in the superior, temporal quadrant.

The Depression Profile quantified an information loss of 17.1% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation (Medial Montage)

Gave a large, clear response with a P100 component at 92 msec. The maximum amplitude was over the POz electrode at 13.29 microvolts.

11. 30^{o} Upper Field

Gave a broad response of poor morphology with a P100 component at 91 msec. The maximum amplitude was over the POz electrode at 3.45 microvolts.

III. 30° Lower Field

Gave a large, clear response which appeared very similar to the full field result. The P100 component was at 88 msec with a maximum amplitude over the POz electrode at 12.41 microvolts.

IV. 10° Stimulation

The full field and lower field stimuli gave normal results with P100 components at 92 and 96 msec respectively. The upper field stimulus still gave a rather broad and flat P100 component at 96 msec but the amplitude elicited was larger than the 30° result with a maximum over the Oz electrode at 6.61 microvolts. The response would be considered normal.

V. 3° Stimulation

Gave normal results for all stimulus conditions with latencies for the P100 component at 105 msec for the full field stimulus; 111 msec for the upper field stimulus; and 99 msec for the lower field stimulus.

Comment

The results were consistent with a preserved upper hemiretina with the 30° full field and lower field results

appearing almost identical suggesting little involvement of the lower hemiretina which when stimulated gave a small response of poor morphology. The smaller 10^{o} and 3^{o} stimuli gave results which appeared normal. Full field stimulation alone would have given little cause for suspicion thus the results support the opinion of Wildberger (1984a,b) that upper and lower field stimulation should be considered an integral part of any clinical investigation.

Autosomal Recessive Retinitis Pigmentosa

The following four subjects all suffer from autosomal recessive retinitis pigmentosa and will be discussed together at the end of the Section.

FIGURE 6.12

SUBJECT: AD DOB: 16.5.'45

EYE: Right VA: $^{6}/_{12-1}$

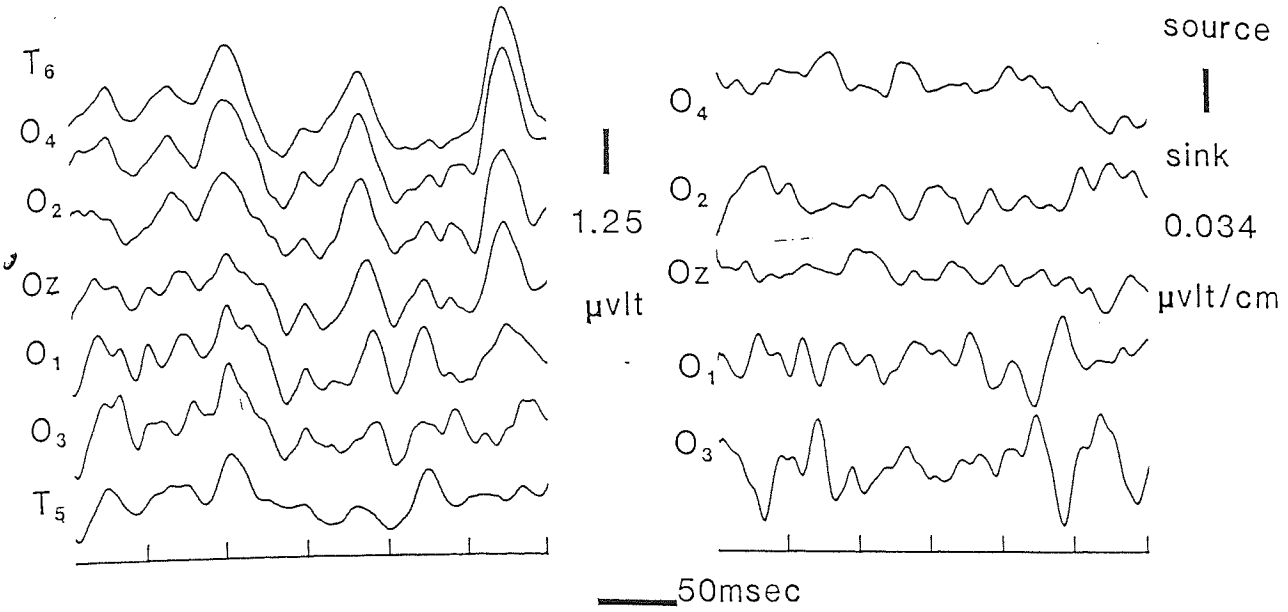
Diagnosis: Autosomal Recessive Retinitis Pigmentosa

1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

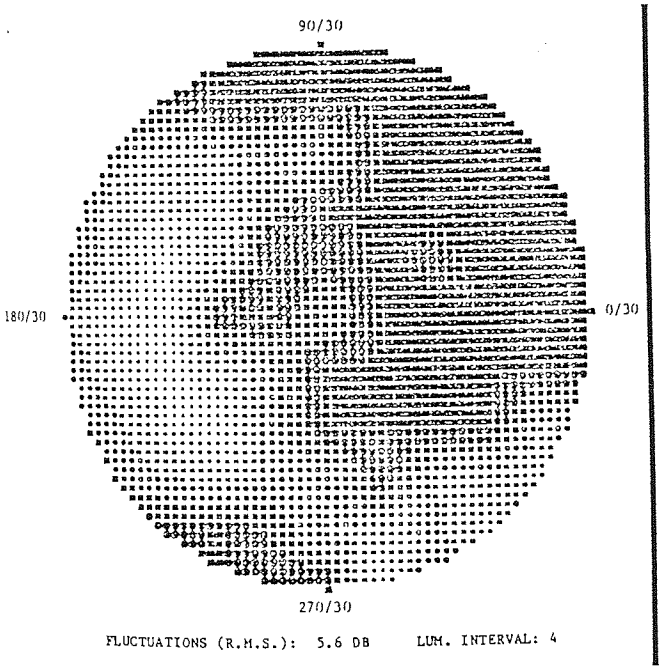
2. The visual field using the Octopus Programme 31

SUBJECT AD EYE RIGHT

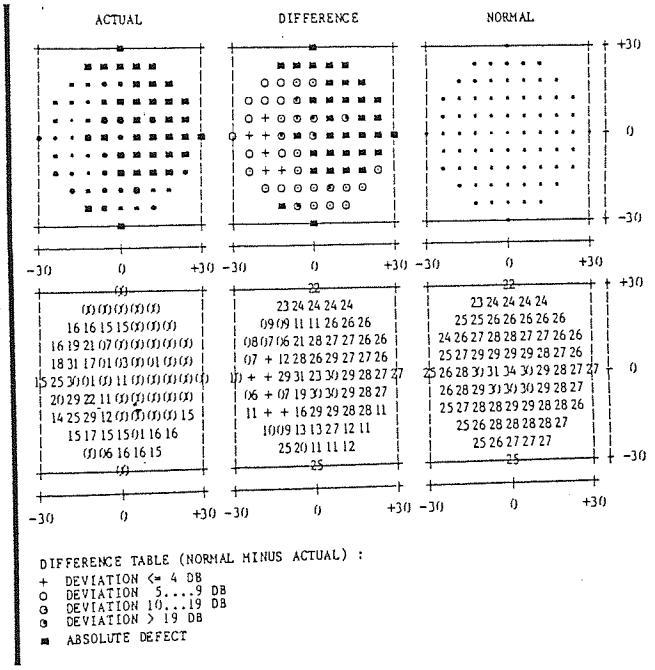
1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



FLUCTUATIONS (R.M.S.): 5.6 DB LUM. INTERVAL: 4



DIFFERENCE TABLE (NORMAL MINUS ACTUAL) :

+ DEVIATION <= 4 DB
o DEVIATION 5....9 DB
O DEVIATION 10...19 DB
■ DEVIATION > 19 DB
■ ABSOLUTE DEFECT

Information Loss

72.3 %

Subject AD (Right Eye)

Visual Field

Examination using the Octopus Programme 31 showed an extensive, deep field loss involving fixation with some preservation of the temporal and inferior visual field. The central 15^{o} was considerably affected with only slight preservation of the temporal field.

The Depression Profile quantified an information loss of 72.3% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

The response was poor with either a PNP-complex at 101 msec or a P100 component at 138 msec over all channels. The latter appeared to be the most consistent in morphology and latency particularly for the central channels.

11. 30^{o} Right Half Field

The response was again poor with a small P100 component at 100 msec which was slightly larger over the right occiput but of clearer morphology over the left occiput. The latency of this response may suggest that the component

which should be considered following full field stimulation was the earlier negativity at 101 msec.

III. 30^{o} Left Half Field

Demonstrated a small P100 component at 93 msec over all channels.

IV. 30^{o} Upper Field

Demonstrated the clearest response with a P100 component at 81 msec with a maximum amplitude over the midline at 1.20 microvolts.

V. 30^{o} Lower Field

Gave a small PNP-complex with the negative component at 90 msec.

Stimulation using smaller field sizes did not elicit an identifiable component.

FIGURE 6.13

SUBJECT: AD DOB: 16.5.'45

EYE: Left VA: $^{6}/_{18+2}$

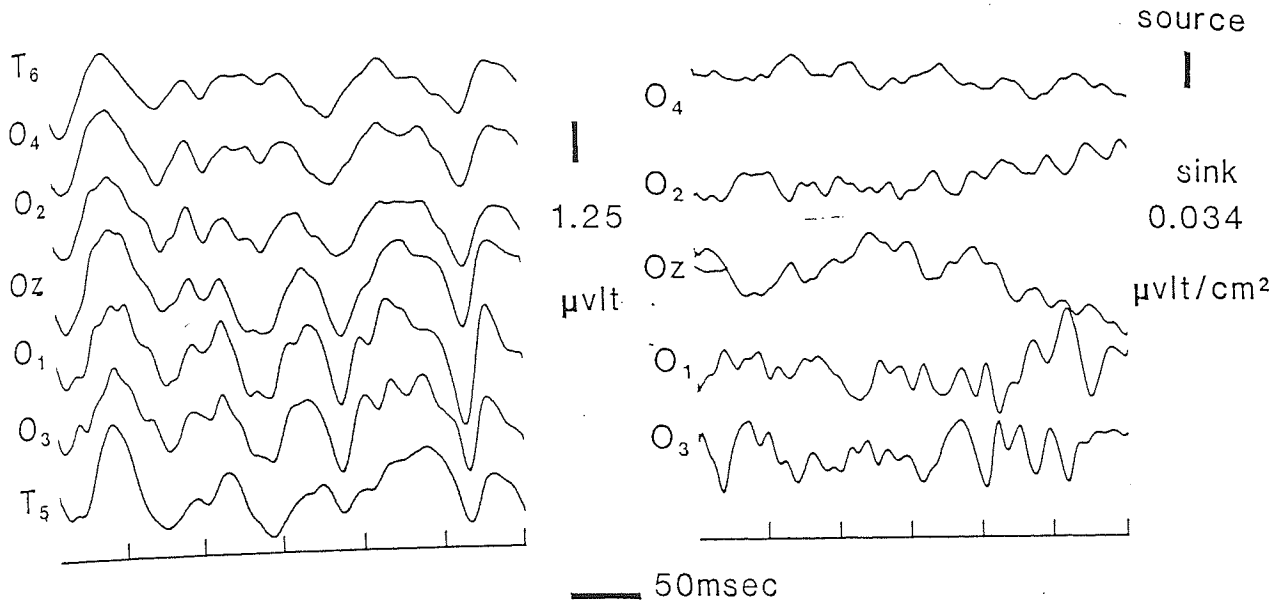
Diagnosis: Autosomal Recessive Retinitis Pigmentosa

1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

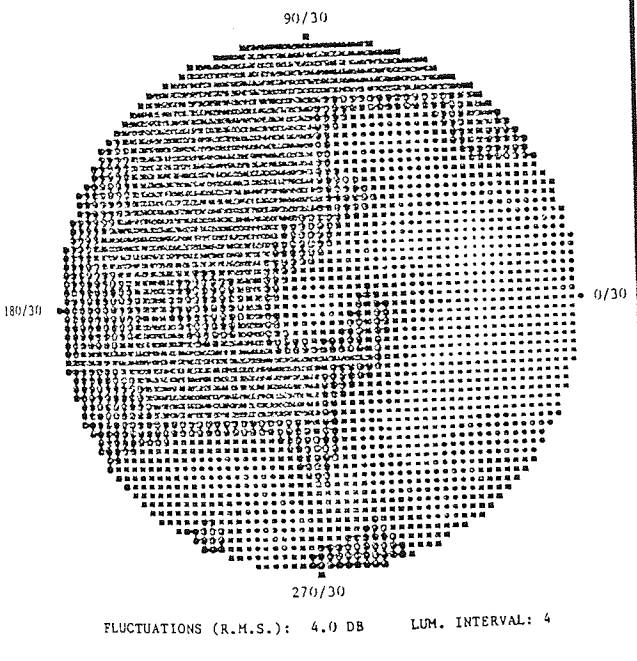
2. The visual field using the Octopus Programme 31

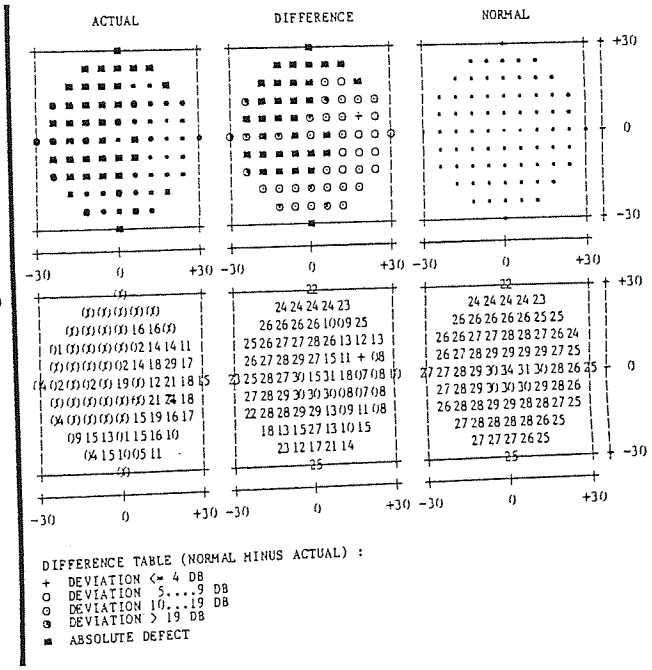
SUBJECT AD EYE LEFT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD





Information Loss

76.21%

Subject AD (Left Eye)

Visual Field

Examination using the Octopus Programme 31 also showed an extensive, deep field loss with some preservation of the temporal field but less preservation of the inferior field compared to the right eye. Fixation was affected but not as deeply as the right eye. The central 15^{o} was considerably affected with only slight preservation of the temporal field.

The Depression Profile quantified an information loss of 76.21% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

The response was poor with either a PNP-complex with a negative component at 92 msec or a P100 component at 135 msec. The latter appeared to be the most likely component.

There was no identifiable response to half field stimulation.

11. 10^{o} Full Field Stimulation

There was no identifiable response.

111. 3^{o} Full Field Stimulation

Demonstrated a clear PNP-complex with the negative component at 101 msec with the best response over the right occiput.

FIGURE 6.14

SUBJECT: RG DOB: 3.6.'31

EYE: Right and Left VA: R. $^{6}/_{36}$ L. $^{6}/_{24}$

Diagnosis: Autosomal Recessive Retinitis Pigmentosa

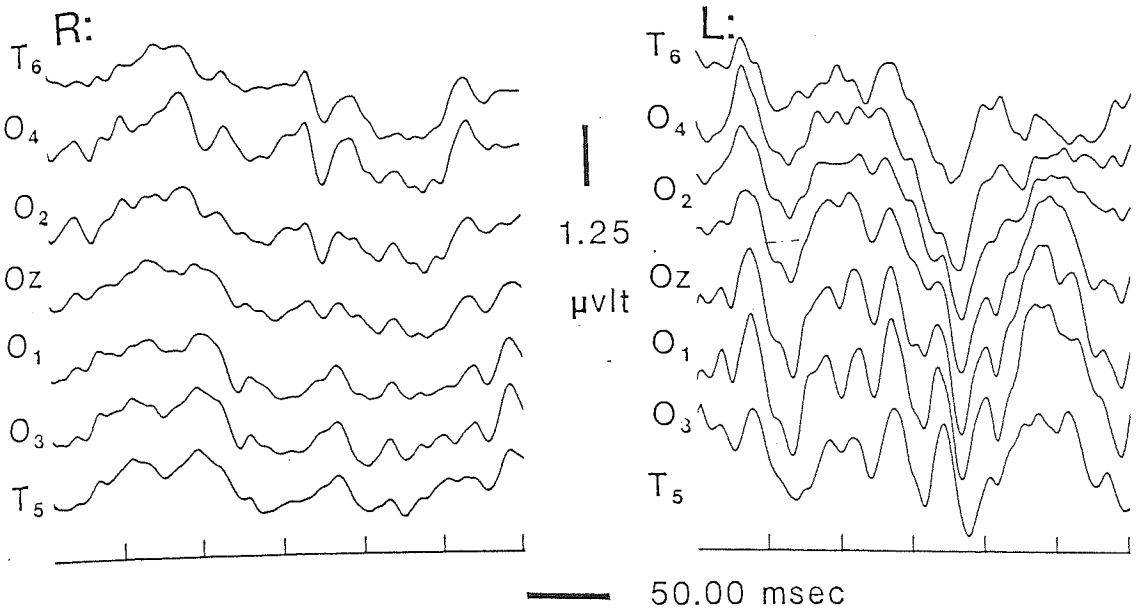
1. The visual evoked potential to full field stimulation
   (Common Reference)

2. The Depression Profile

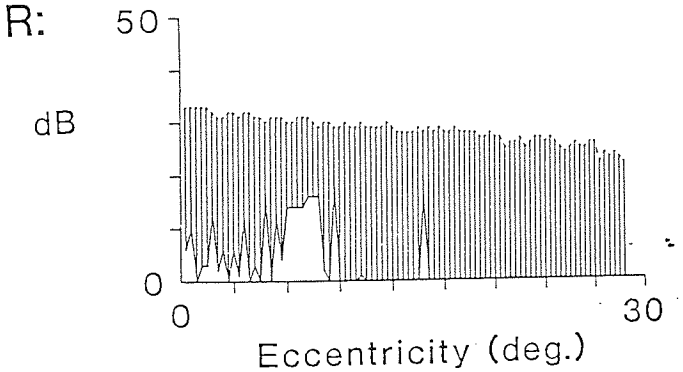
SUBJECT RG

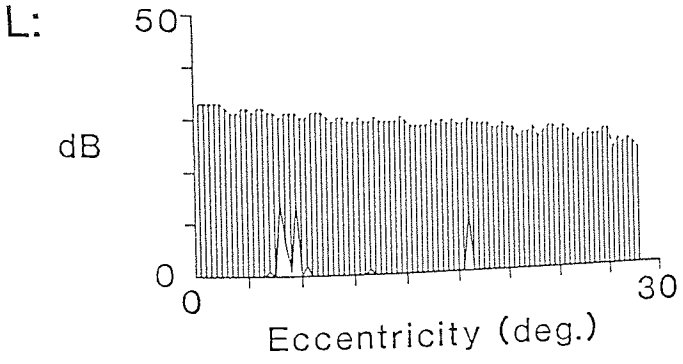
EYE RIGHT & LEFT

1: VISUAL EVOKED POTENTIAL



2: DEPRESSION PROFILE





Information Loss

R 90.25 %

L 97.95 %

Subject RG (Right Eye)

Visual Field

Examination using the Octopus Programme 31 showed no visual field survival. More detailed investigation of the central 30^{o} using the neural representation Sargon programmes showed some slight field survival within the central 5^{o} but of greatly reduced sensitivity. The depression profile quantified an information loss of 90.25% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Gave a very poor response with a possible P100 component at 121 msec over the left occiput.

11. 30^{o} Right Half Field

Gave a poor response with a possible PNP-complex at 113 msec.

111. 30^{o} Left Half Field

Gave a poor response with a possible PNP-complex at 117 msec.

1V. 10^{o} Full Field Stimulation

Gave a poor response but with an identifiable P100 component at 118 msec which was slightly larger over the right occiput.

Subject RG (Left Eye)

Visual Field

Examination using the Octopus Programme 31 showed no visual field survival in the central 30^{o}. The Depression Profile quantified an information loss of 97.95% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Gave a poor response with the most consistent component being a delayed P100 at 120 msec.

11. 30^{o} Right Half Field

Gave a small P100 component at 112 msec which was slightly clearer over the left occiput.

111. 30^{o} Left Half Field

Gave a clearer P100 component at 110 msec which was larger over the right occiput with a maximum on the midline at 1.26 microvolts.

1V. 10^{o} Full Field Stimulation

There was no identifiable response.

FIGURE 6.15

SUBJECT: RPG DOB: 4.2.'43

EYE: Right VA: $^{3}/_{60}$

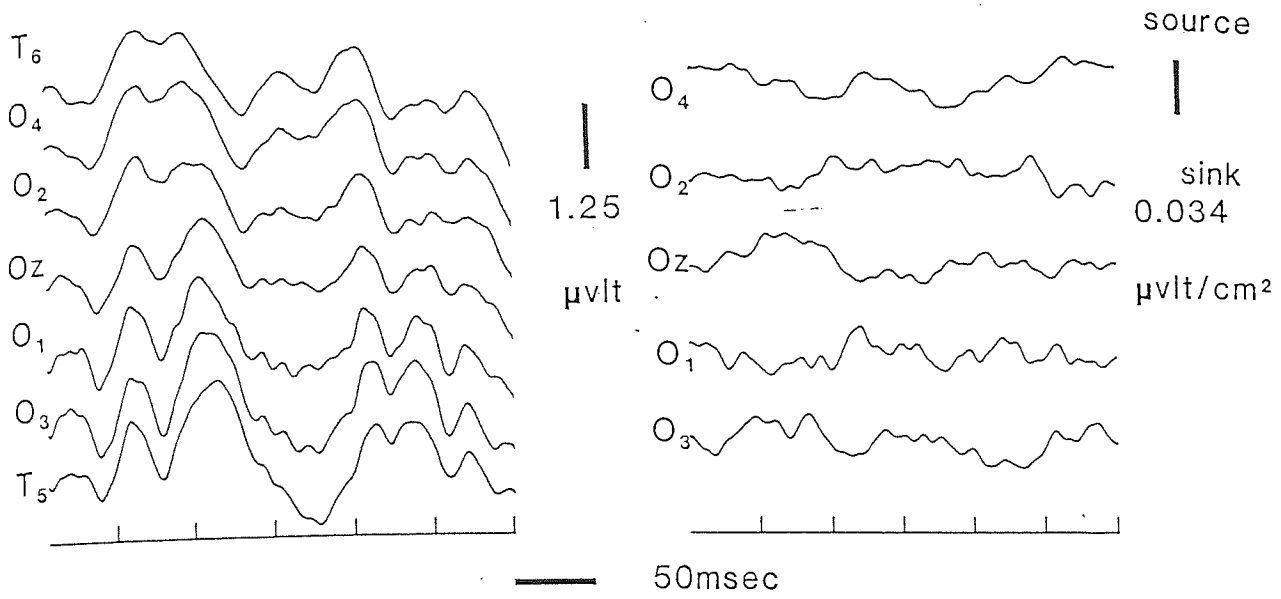
Diagnosis: Autosomal Recessive Retinitis Pigmentosa

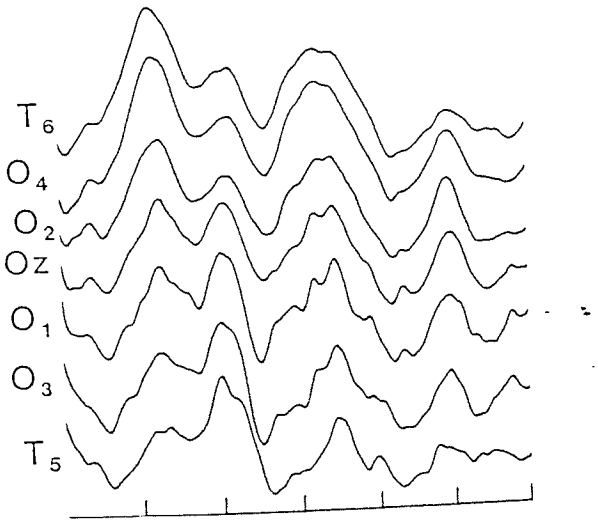
1. The visual evoked potential to full field stimulation
   1) Common Reference and Source Derivation following central fixation
   2) Common Reference following fixation to the left

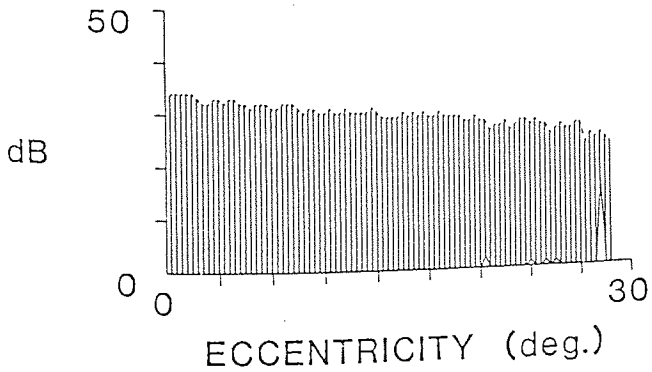
2. The Depression Profile

SUBJECT RPG EYE RIGHT

1: VISUAL EVOKED POTENTIAL







Information Loss
99.17 %

Subject RPG (Right Eye)

Visual Field

Examination using the Octopus Programme 21 showed an extensive, deep visual field loss with only a few remaining peripheral islands in the temporal field. The depression profile quantified an information loss of 99.17% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation (with central fixation)

There appeared to be a PNP-complex with a negative component at 103 msec. The response could also be interpreted as having a delayed P100 component over the right occiput at 133 msec. This would be more consistent with the temporal islands of the right half field.

11. 30^{o} Full Field Stimulation (with fixation at the left of the stimulus)

The subject found it easier to perceive the checkerboard stimulus by fixating to the left. This again elicited a PNP-complex but of a clearer morphology. The negativity was at 100 msec but the following positivity appeared much more like a delayed P100 component at 123 msec.

FIGURE 6.16

SUBJECT: RPG DOB: 4.2.'43

EYE: Left VA: $^{6}/_{60}$

Diagnosis: Autosomal Recessive Retinitis Pigmentosa

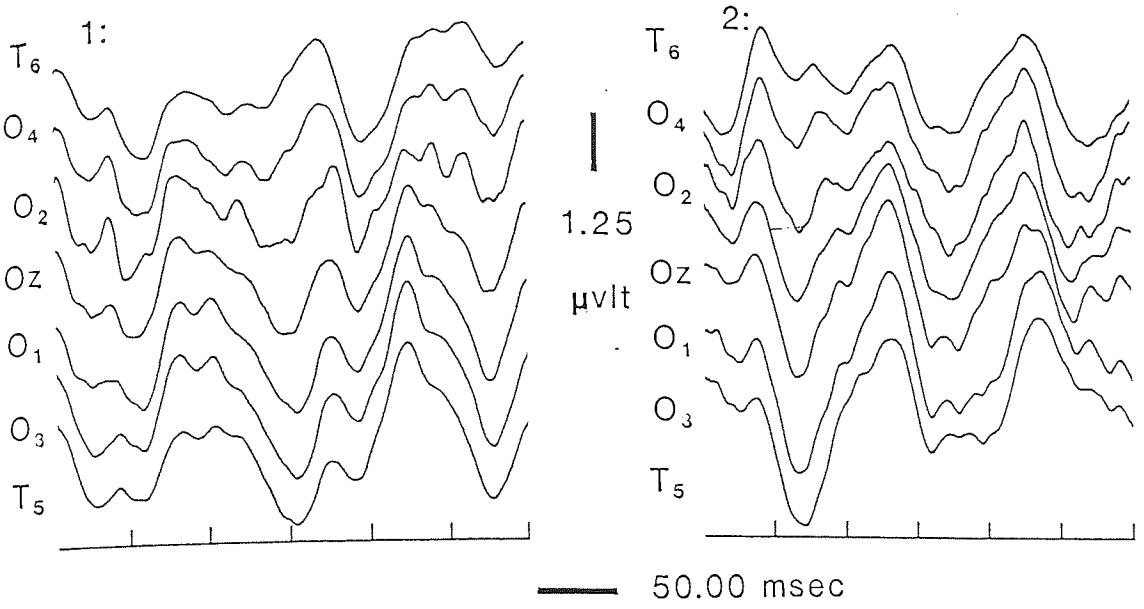
1. The visual evoked potential to full field stimulation
   1/ Following central fixation (Common reference)
   2/ Following fixation to the right (Common reference)

2. The visual field using the Octopus Programme 31

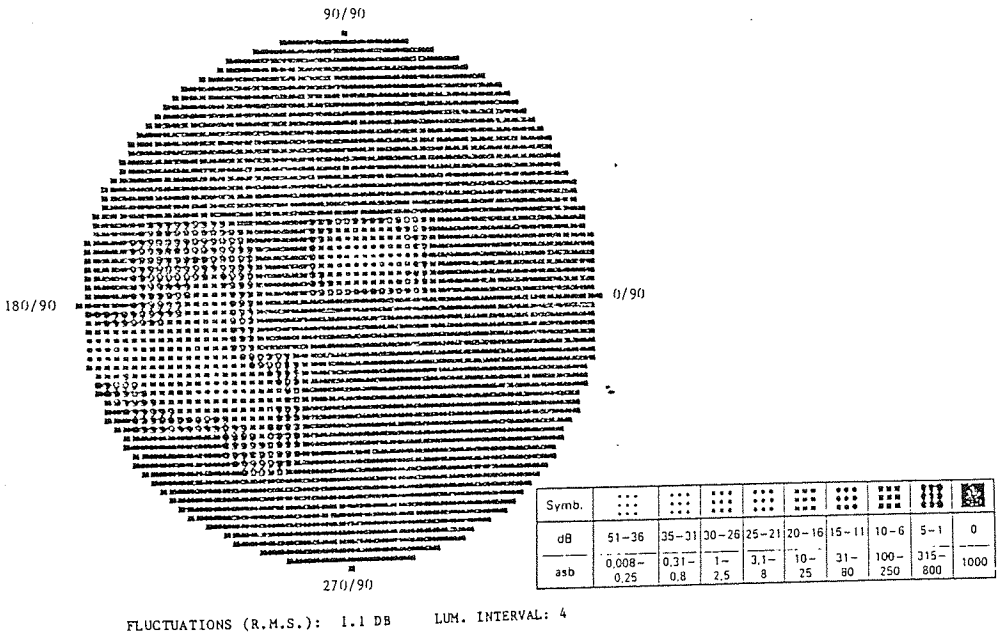
3. The Depression Profile

SUBJECT RPG EYE LEFT

1: VISUAL EVOKED POTENTIAL

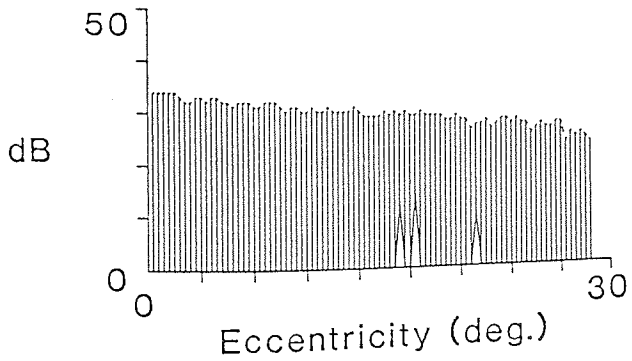


2: VISUAL FIELD



FLUCTUATIONS (R.M.S.): 1.1 DB LUM. INTERVAL: 4

3: DEPRESSION PROFILE



Information Loss

98.58 %

Subject RPG (Left Eye)

Visual Field

Examination using the Octopus Programme 21 showed an extensive, deep visual field loss with peripheral islands present in the temporal and superior visual field. The Depression Profile quantified an information loss of 98.58% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation (with central fixation)

The response appeared to show a very delayed P100 component at 154 msec which was present over the left occiput. This would be consistent with the surviving visual field in the temporal, left half field.

11. 30^{o} Full Field Stimulation (with fixation to the right of the stimulus)

The response was again grossly abnormal with a clear negativity at 126 msec with the following positivity, which could be a delayed P100 component, at 154 msec with a larger amplitude over the left occiput.

FIGURE 6.17

SUBJECT: RPW DOB: 14.12.'38

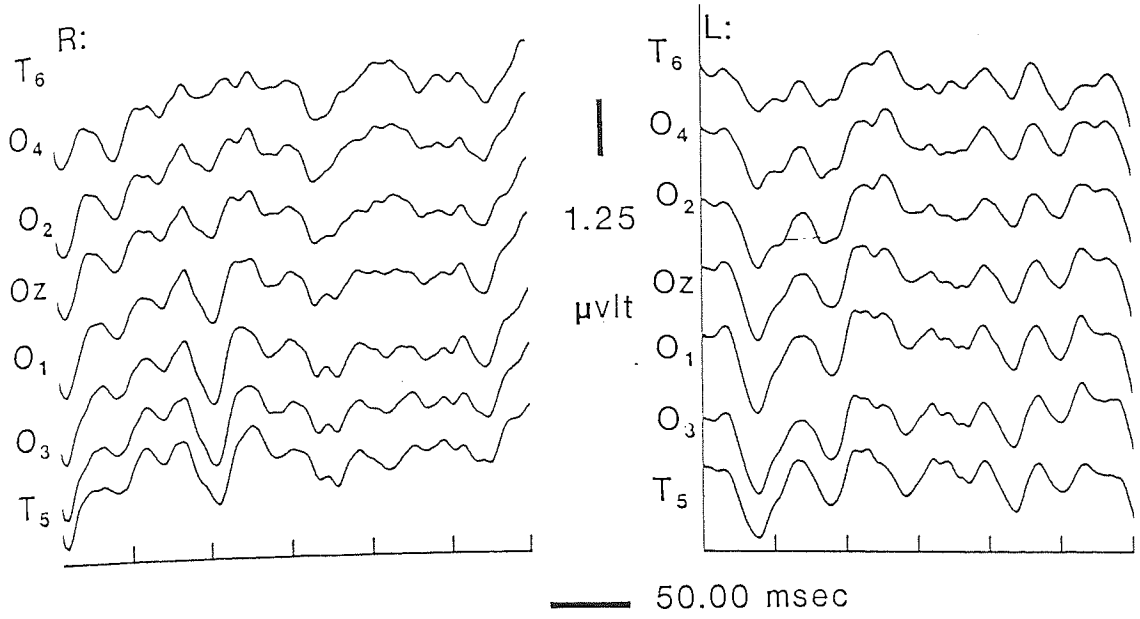
EYE: Right and Left VA: R. $^{2}/_{60}$ L. $^{2}/_{60}$

Diagnosis: Autosomal Recessive Retinitis Pigmentosa

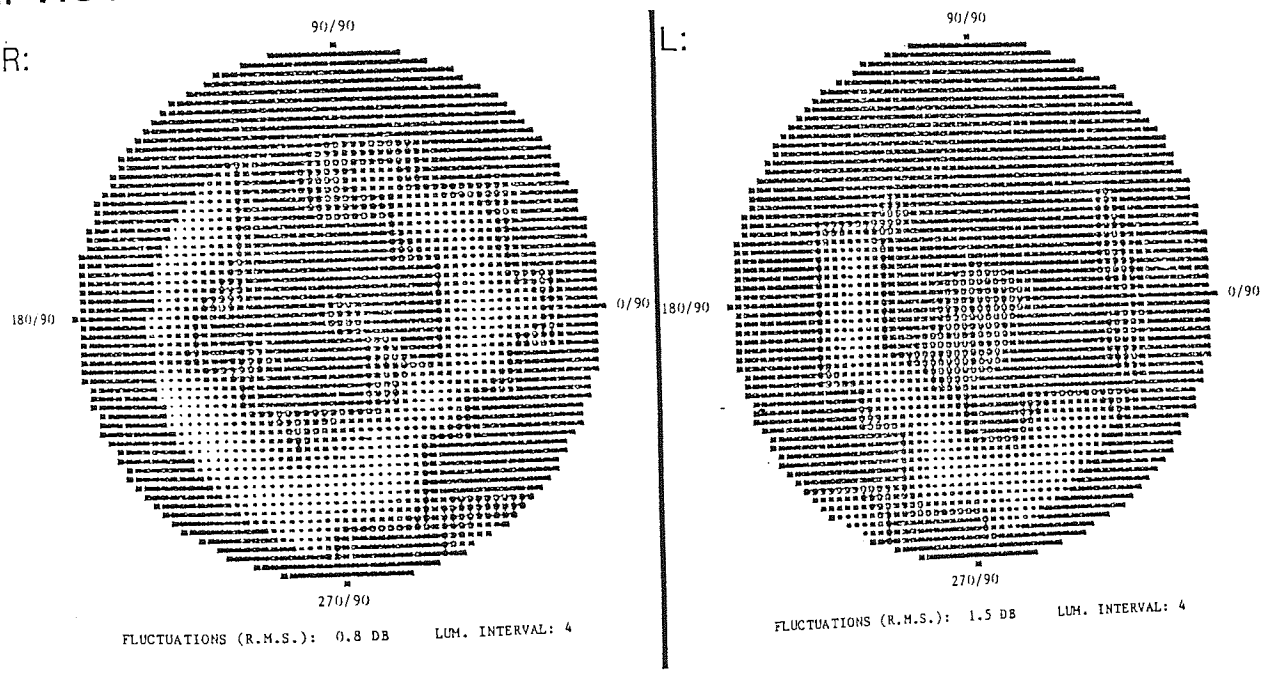
1. The visual evoked potential to full field stimulation
2. The visual field using the Octopus Programme 21
3. The Depression Profile

SUBJECT RPW EYE RIGHT & LEFT

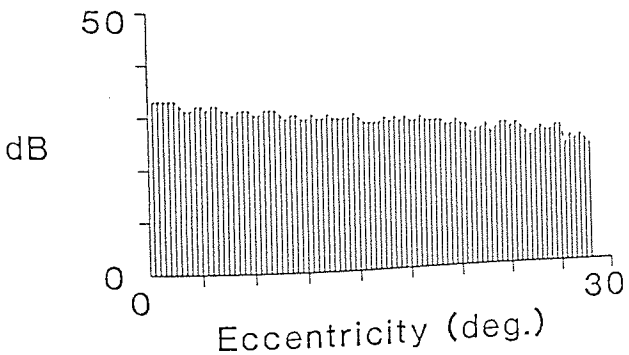
1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



3: DEPRESSION PROFILE



Information Loss

100 %

Right & Left

Subject RPW (Right Eye)

Visual Field

Examination using the Octopus Programme 21 showed a deep, central scotoma covering the majority of the central 30^{o} with a preserved peripheral ring which is only incomplete in the superior, nasal visual field.

The Depression Profile quantified an information loss of 100% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Gave a small but clear P100 component at 101 msec which was larger over the left occiput with a maximum at the Oz electrode of 1.04 microvolts.

11. 30^{o} Right Half Field

Gave a small P100 component at the slightly delayed latency of 116 msec which was slightly larger over the right, ipsilateral occiput with a maximum amplitude at the O4 electrode of 1.15 microvolts.

111. 30^{o} Left Half Field

Gave a poor response with a debatable P100 component at 96 msec.

Subject RPW (Left Eye)

Visual Field

Examination using the Octopus Programme 21 showed a deep, extensive field loss with a peripheral island in the inferior and temporal field. The Depression Profile quantified an information loss of 100% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Gave a small but clear P100 component at 90 msec.

11. 30^{o} Right Half Field

Gave a small P100 component at 107 msec which had a clearer morphology over the right ipsilateral occiput.

111. 30^{o} Left Half Field

Gave a P100 component at 98 msec which appeared slightly larger over the left, ipsilateral occiput.

Comment

The four subjects discussed were investigated as they

have a rare form of autosomal recessive retinitis pigmentosa resulting in central as well as peripheral visual field depravation. The condition is often referred to as inverse retinitis pigmentosa. In most cases identification of components was difficult but it would appear that the most consistent component was a grossly delayed and reduced P100 rather than a genuine "scotomatous negativity". In one instance, subject RPW, the response was remarkably clear and although reduced in amplitude was of normal latency. This subject also gave the maximum information loss within the central 30^{o}. There were, however, peripheral islands of vision recordable outside 30^{o} eccentricity.

This was perhaps a surprising group to investigate but in retrospect they have proven to be of great interest. The visual evoked potentials were severely abnormal but what is most surprising was that they were present at all. Flanagan et al. (1984b) have questioned the role of perimetry in patients with retinitis pigmentosa as it has been clinically observed that many subjects will demonstrate greater field survival if the stimulus parameters are altered to allow for longer presentation times and larger target sizes. This does not, however, imply an increase in stimulus intensity but may be associated with an abnormal spatial summation. Great care must therefore be taken when discussing perimetry. This would also imply care in the interpretation of the visual evoked potentials and the neural representation of visual space when the

subject is suspected of having an abnormal spatial summation. The relationship between the VEP and the visual field may only be fully appreciated when we know exactly the nature of a particular scotoma and which factors, eg. differential light threshold or flicker, relate most critically to the disease and therefore the VEP results. Alternatively, what psychophysical measurements best predict the type of damage to the visual system which will affect the VEP.

The source derivation distribution was of little additional value as the common reference distribution was poor.

Hereditary Optic Atrophy

The following five subjects all have a form of hereditary optic atrophy and will be discussed together at the end of the Section. All have undergone extensive investigations over many years including full family histories, colour vision tests (Farnsworth - Munsell 100-Hue test), visual acuity, electroretinograms, visual evoked potentials and perimetry. Subjects MG and JG and subjects PB and KS are from the same families.

FIGURE 6.18

SUBJECT: MG DOB: 21.8.'35

EYE: Right VA: $^{6}/_{60+1}$

Diagnosis: Autosomal Dominant Hereditary Optic Atrophy

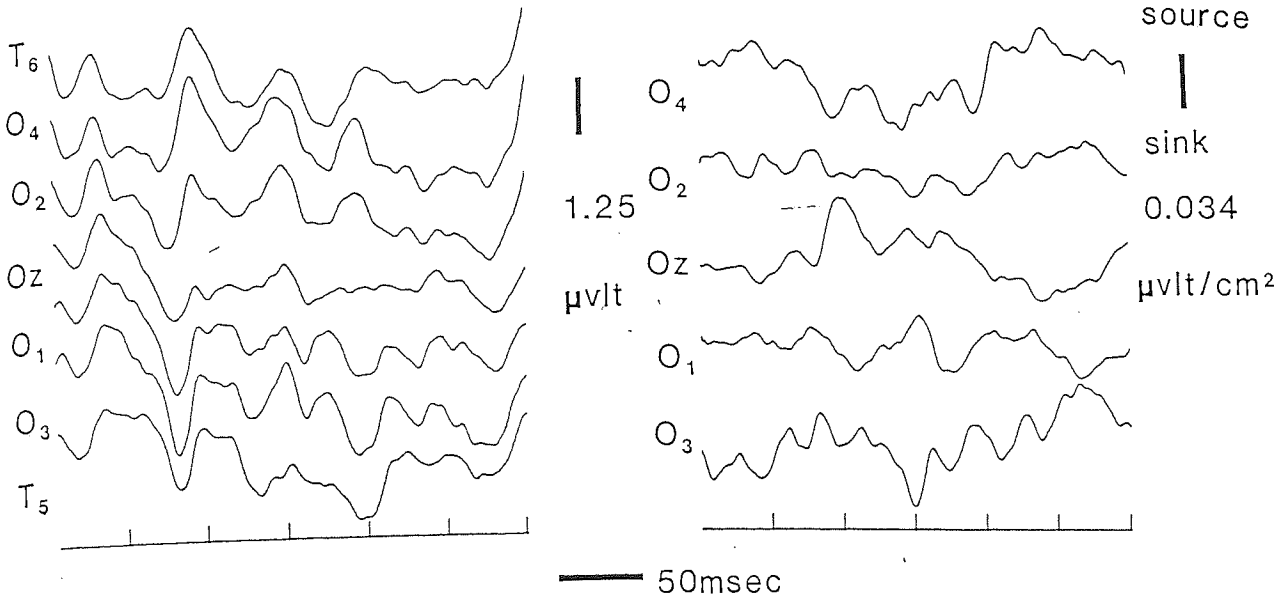
1. The visual evoked potential to full field stimulation (Common Reference and Source Derivation)

2. The visual field using the Octopus Programme 31

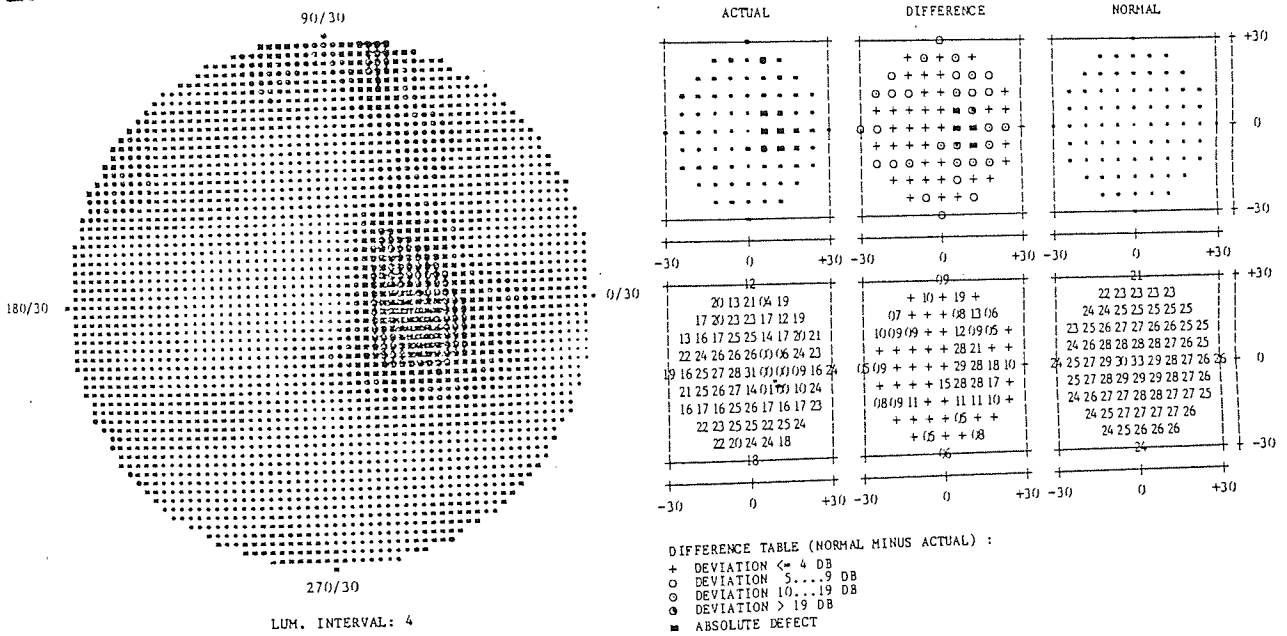
3. The Depression Profile

SUBJECT MG EYE RIGHT

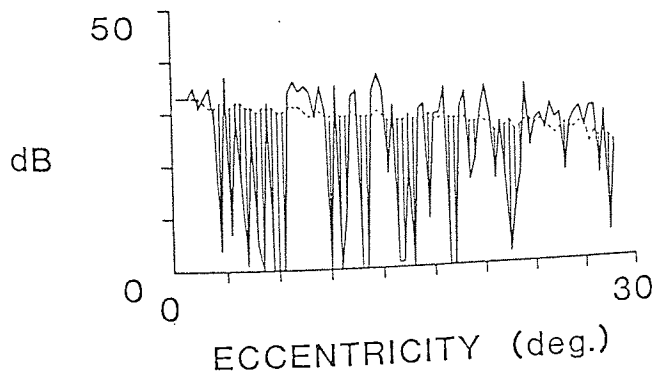
1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



3: DEPRESSION PROFILE



Information Loss
28.54 %

Subject MG (Right Eye)

Visual Field

Examination using the Octopus Programme 31 showed a deep, steep-margined paracentral, right sided-defect resembling an extensive enlargement of the blind spot with preservation of the central $2\frac{1}{2}^{o}$. There is also a mild generalised reduction in sensitivity. This is entirely consistent with autosomal dominant hereditary optic atrophy (Francois 1961).

Within the central 15^{o}, the area stimulated to elicit the VEP, the left half field was relatively unaffected but the right half field was severely abnormal.

The Depression Profile quantified an information loss of 28.54%.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Demonstrated a PNP-complex at 94 msec over all channels being largest over the right occiput with a maximum negativity at the O4 electrode (1.15 microvolts).

11. 30^{o} Right Half Field

There was a negligible response with the only possible component being a small P100 over the right occiput.

III. 30° Left Half Field

Demonstrated a clear PNP-complex at 112 msec which was present over both occiputs.

IV. 10° Full Field Stimulation

Elicited a small P100 component at 117 msec which was largest over the right occiput.

V. 3° Full Field Stimulation

There was no clearly identifiable response.

FIGURE 6.19

SUBJECT: MG DOB: 21.8.'35

EYE: Left VA: $^{6}/_{60+1}$

Diagnosis: Autosomal Dominant Hereditary Optic Atrophy

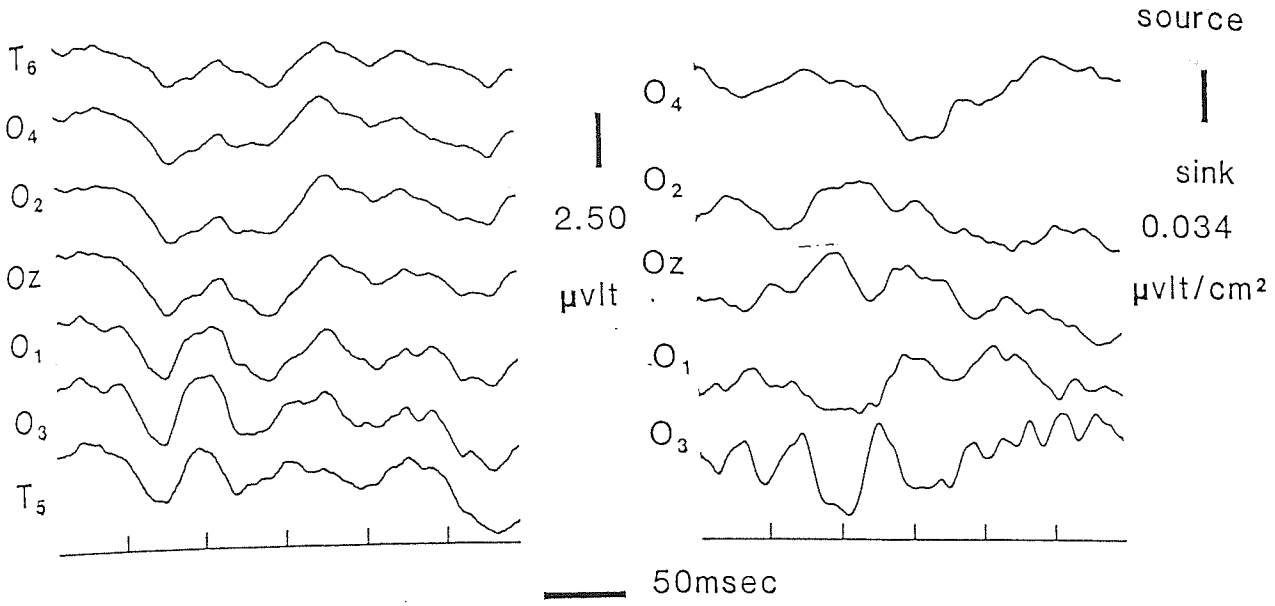
1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

2. The visual field using the Octopus Programme 31

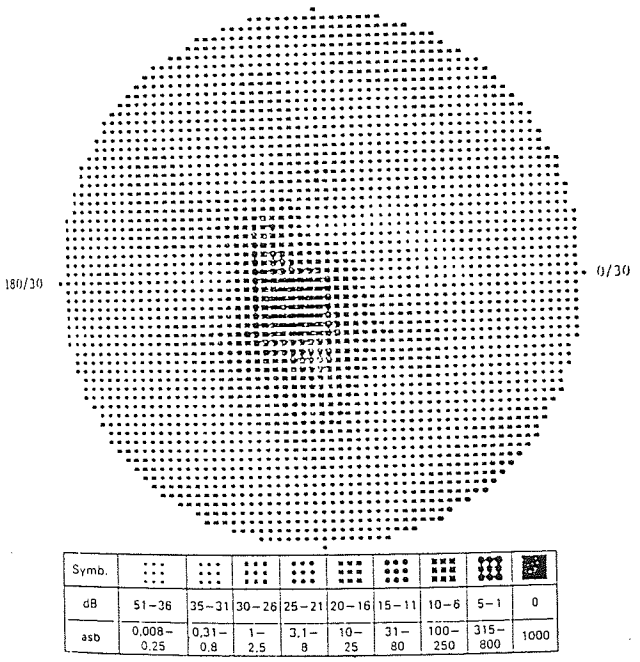
3. The Depression Profile

SUBJECT MG EYE LEFT

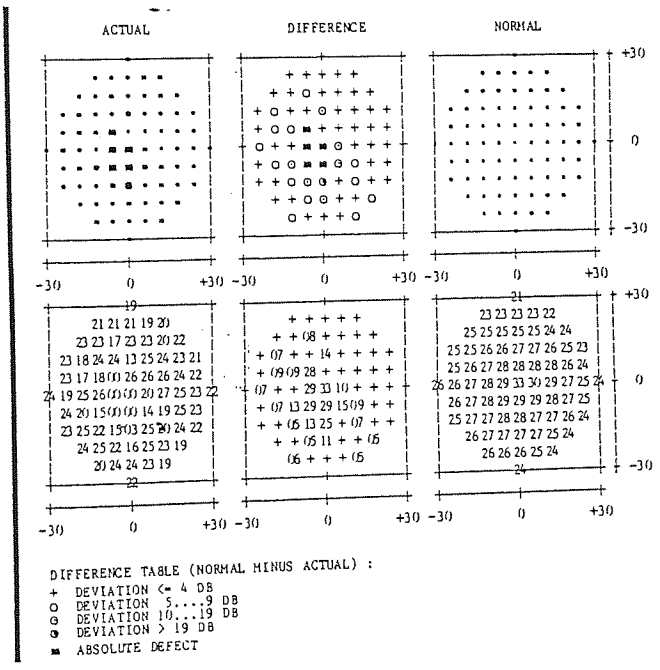
1: VISUAL EVOKED POTENTIAL



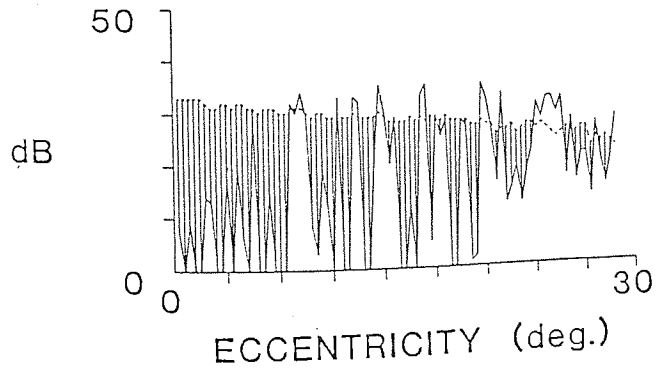
2: VISUAL FIELD



Symb.									
dB	51–36	35–31	30–26	25–21	20–16	15–11	10–6	5–1	0
asb	0.008–0.25	0.31–0.8	1–2.5	3.1–8	10–25	31–80	100–250	315–800	1000



3: DEPRESSION PROFILE



Information Loss

46.27 %

Subject MG (Left Eye)

Visual Field

Examination using the Octopus Programme 31 showed a deep, central defect which is consistent with the diagnosis of autosomal dominant hereditary optic atrophy (Francois 1961). The central 15^{o} was severely affected particularly over the left half field.

The Depression Profile demonstrated an information loss of 46.27%.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Demonstrated a PNP complex at 102 msec which was clearest over the left occiput with a maximum negativity at the O3 electrode (4.65 microvolts).

11. 30^{o} Right Half Field

Demonstrated a PNP complex at 94 msec over the left occiput with little response over the right occiput.

111. 30^{o} Left Half Field

There was a negligible response with only a slight

PNP-complex over the left occiput.

IV. 10^{o} Full Field Stimulation

Demonstrated a slight PNP-complex over the left occiput at 100 msec.

V. 3^{o} Full Field Stimulation

There was no clearly identifiable response.

FIGURE 6.20

SUBJECT: JG DOB: 27.7.'24

EYE: Right VA: $^{3}/_{60}$

Diagnosis: Autosomal Dominant Hereditary Optic Atrophy

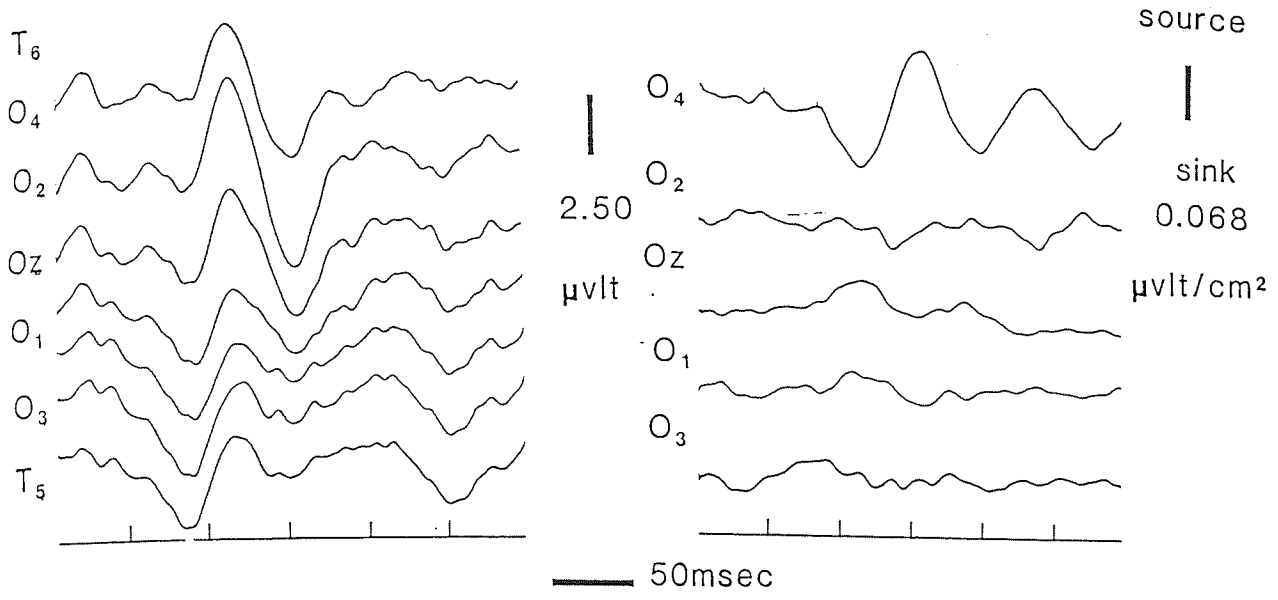
1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

2. The visual field using the Octopus Programme 31

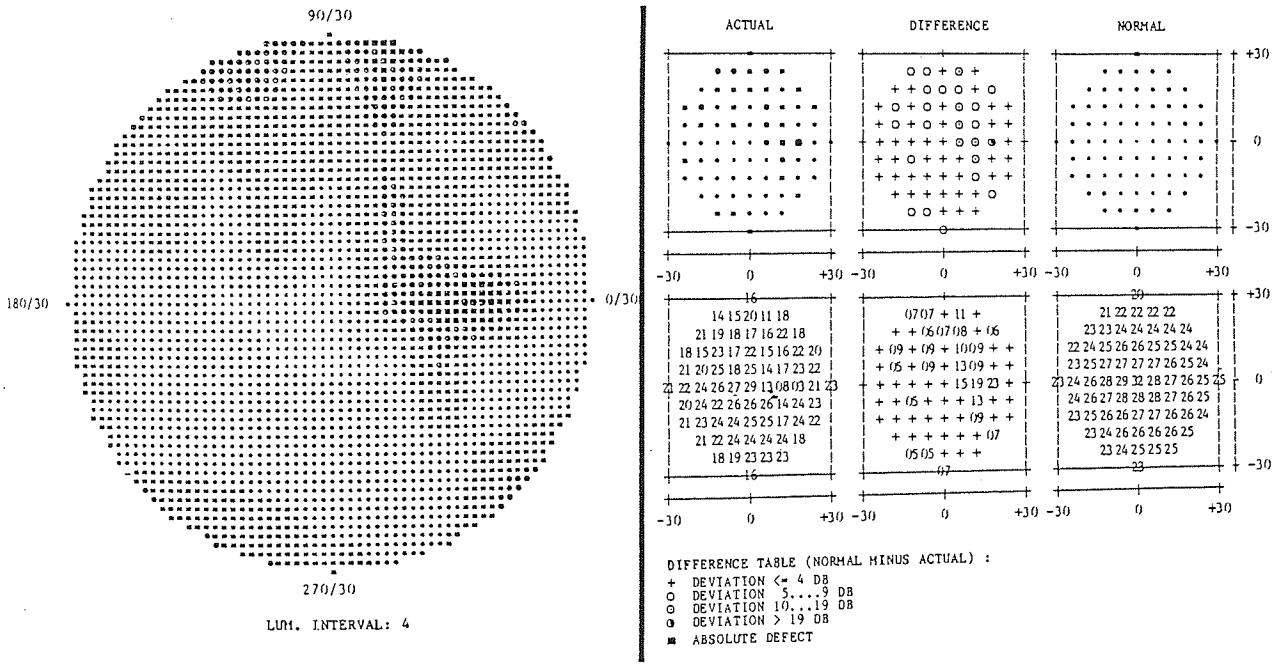
3. The Depression Profile

SUBJECT JG EYE RIGHT

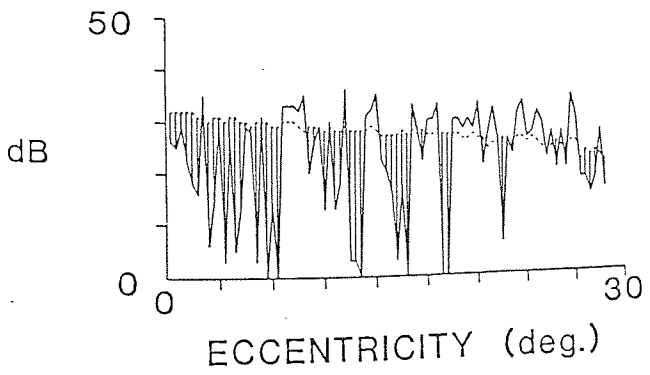
1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



3: DEPRESSION PROFILE



Information Loss

25.89 %

Subject JG (Right Eye)

Visual Field

Examination using the Octopus Programme 31 showed a relative scotoma which resembled an extensive enlargement of the blind spot with a slight peripheral depression in sensitivity being most marked in the superior field. This is consistent with the diagnosis of autosomal dominant hereditary optic atrophy (Francois 1961). Within the central 15^{o} the left half field was relatively unaffected compared to the right and fixation was within normal limits.

The Depression Profile quantified an information loss of 25.89% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Demonstrated a PNP-complex at 114 msec over all channels. The largest response was over the right occiput with a maximum negativity at the O4 electrode (4.34 microvolts).

11. 30^{o} Right Half Field

Gave a slight PNP-complex at 122 msec with the largest

response over the right occiput.

111. 30^{o} Left Half Field

Gave a large PNP-complex over the right occiput at 115 msec. The maximum negativity was again over the O4 electrode (4.35 microvolts).

FIGURE 6.21

SUBJECT: JG DOB: 27.7.'24

EYE: Left VA: $^{3}/_{60}$

Diagnosis: Autosomal Dominant Hereditary Optic Atrophy

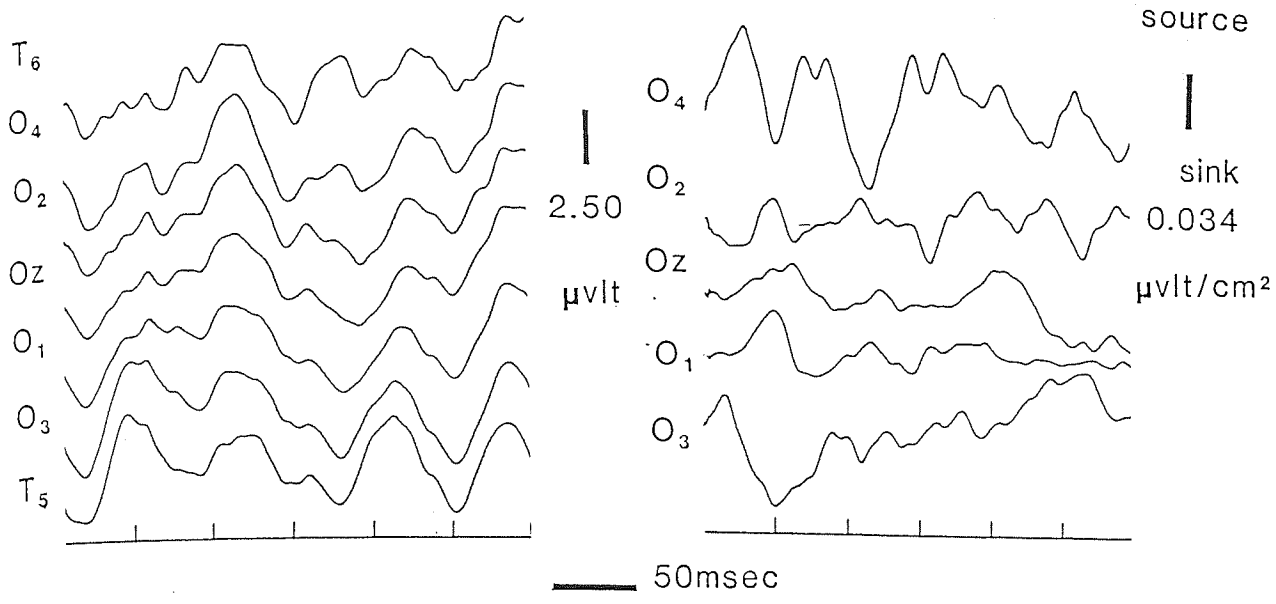
1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

2. The visual field using the Octopus Programme 31

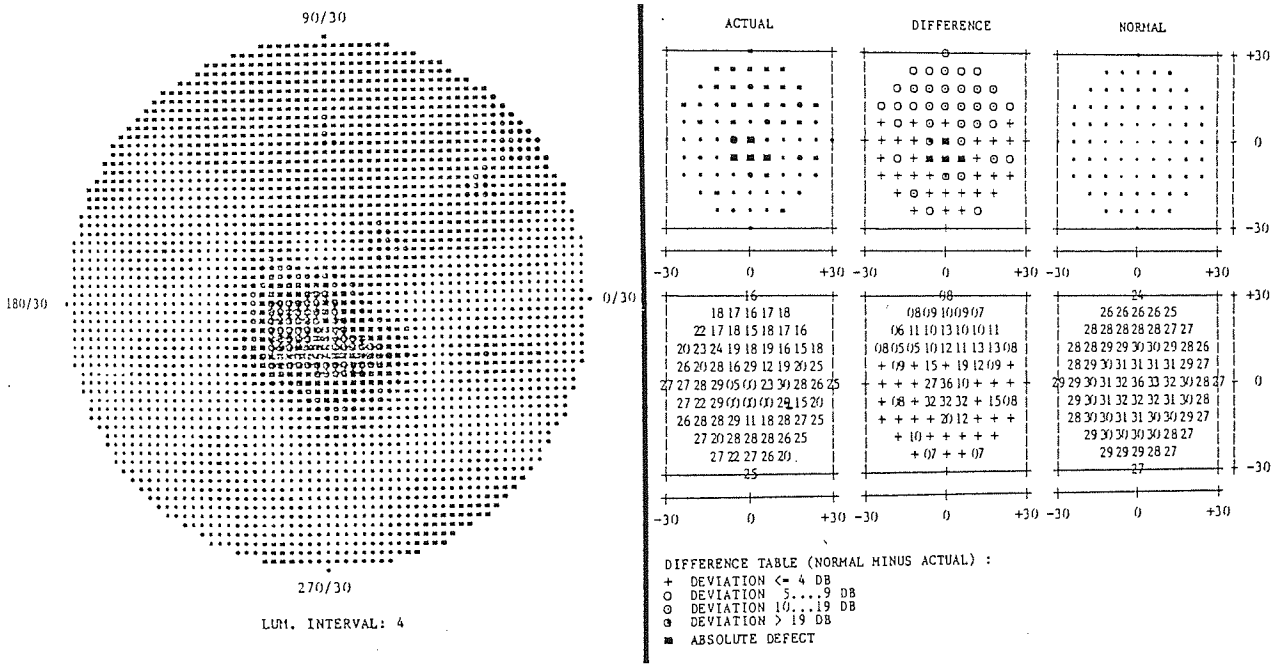
3. The Depression Profile

SUBJECT JG EYE LEFT

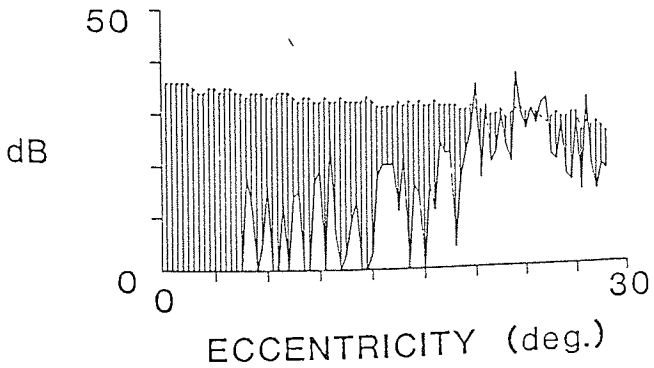
1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



3: DEPRESSION PROFILE



Information Loss

8.52 %

Subject JG (Left Eye)

Visual Field

Examination using the Octopus Programme 31 showed a deep, steep-margined central scotoma with a generalised, superior reduction in sensitivity. This was consistent with the diagnosis of autosomal dominant hereditary optic atrophy (Francois 1961). The field was severely affected in the central 15^{o}.

The Depression Profile quantified an information loss of 58.52% in the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

The response was poor but demonstrated a PNP-complex at 112 msec over all channels.

There was no identifiable response from half field stimulation or stimulation by smaller field and check sizes.

FIGURE 6.22

SUBJECT: PB DOB: 25.3.'42

EYE: Right VA: $^{6}/_{36}$

Diagnosis: Autosomal Dominant Hereditary Optic Atrophy

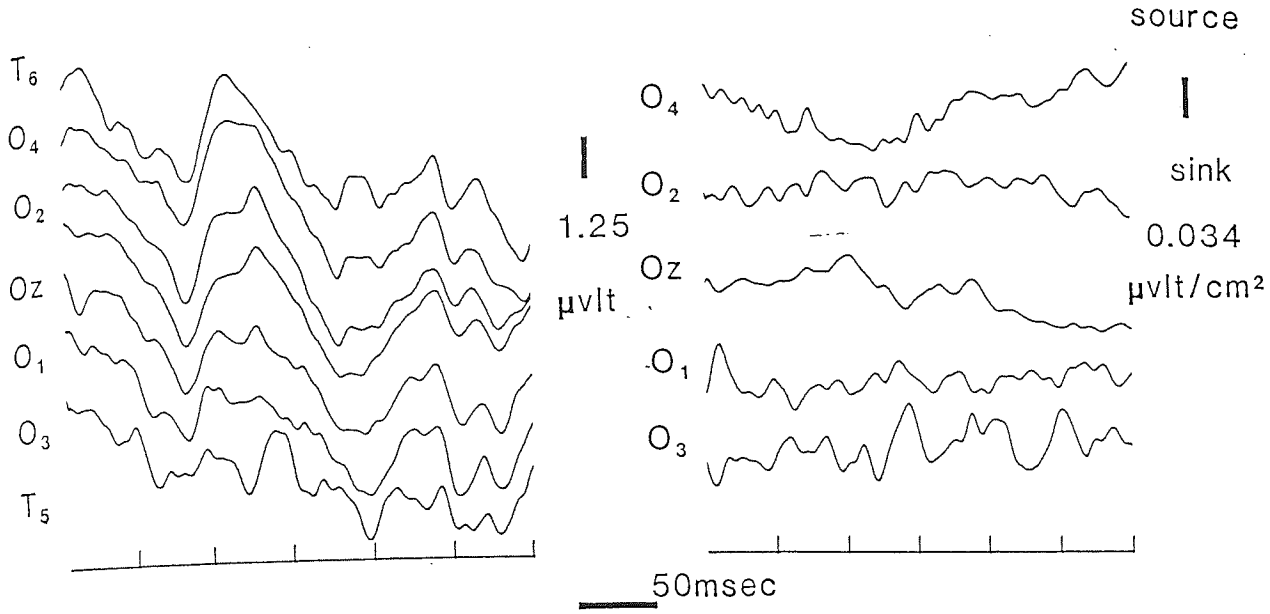
1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

2. The visual field using the Octopus Programme 31

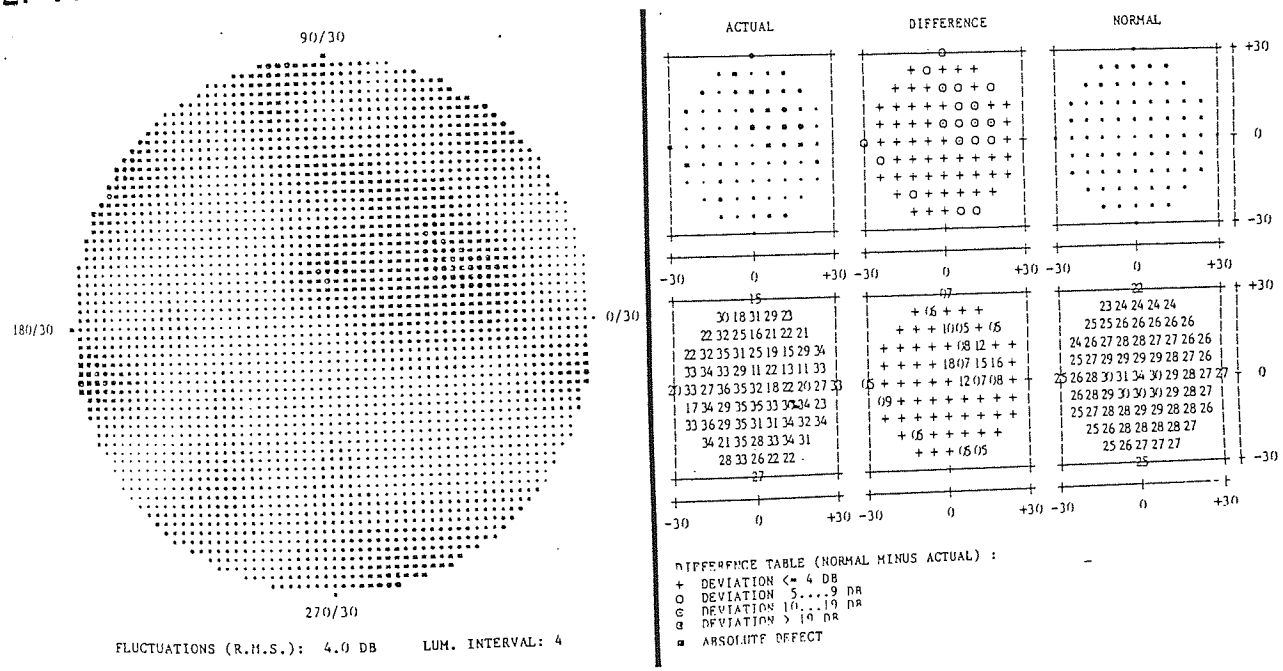
3. The Depression Profile

SUBJECT PB EYE RIGHT

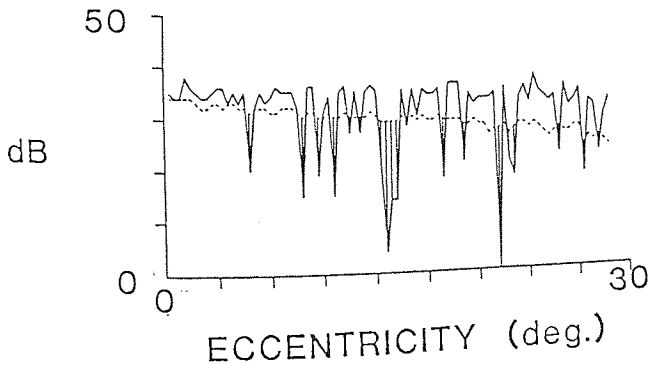
1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



3: DEPRESSION PROFILE



Information Loss

7.71 %

Subject PB (Right Eye)

Visual Field

Examination using the Octopus Programme 31 showed an enlargement of the blind spot with a slight, peripheral reduction in sensitivity. The central 15^{o} was affected in the superior, nasal quadrant only.

The Depression Profile quantified an information loss of 7.71% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Demonstrated a PNP-complex in all channels at 104 msec, with a maximum negativity at electrode 04 (2.50 microvolts).

11. 30^{o} Right Half Field

The response was complex with a negativity over the left occiput at 87 msec and a PNP-complex over the right occiput with the negative component at 118 msec. The midline electrode showed a small P100 component at 100 msec.

111. 30^{o} Left Half Field

Demonstrated a clear P100 component at 97 msec over the

left occiput which is ipsilateral to the stimulated hemifield.

IV. 10^{o} Full Field Stimulation

The response was poor with no identifiable components.

FIGURE 6.23

SUBJECT: PB DOB: 25.3.'42

EYE: Left VA: $^{6}/_{24+1}$

Diagnosis: Autosomal Dominant Hereditary Optic Atrophy

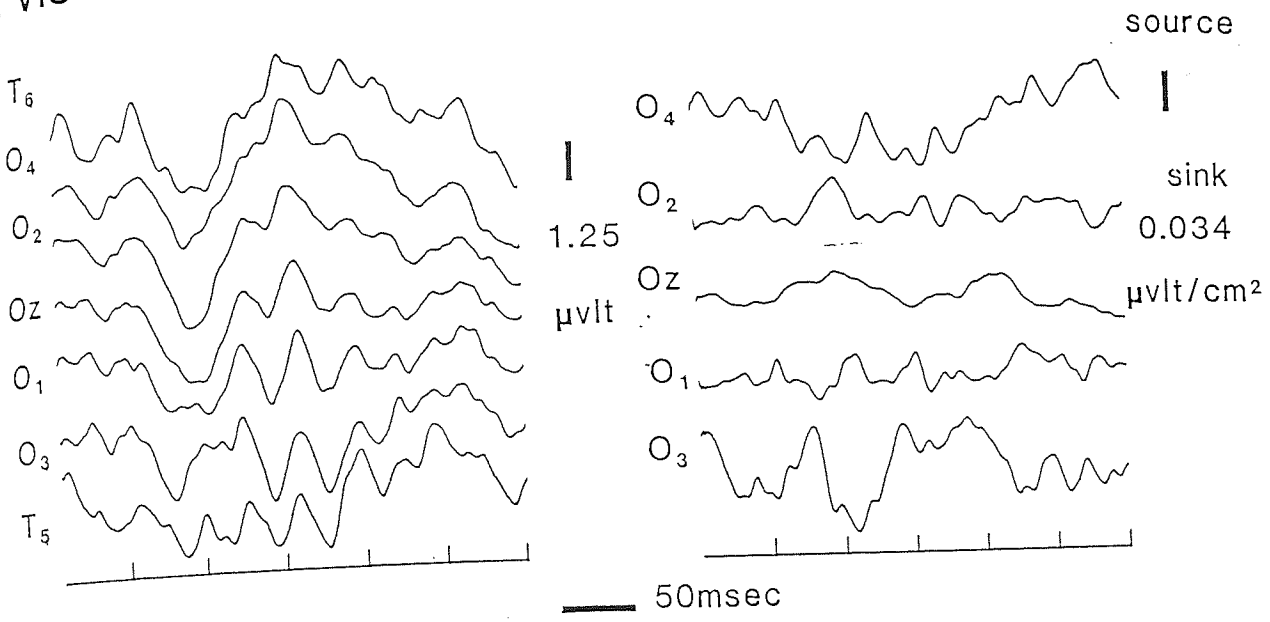
1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

2. The visual field using the Octopus Programme 31

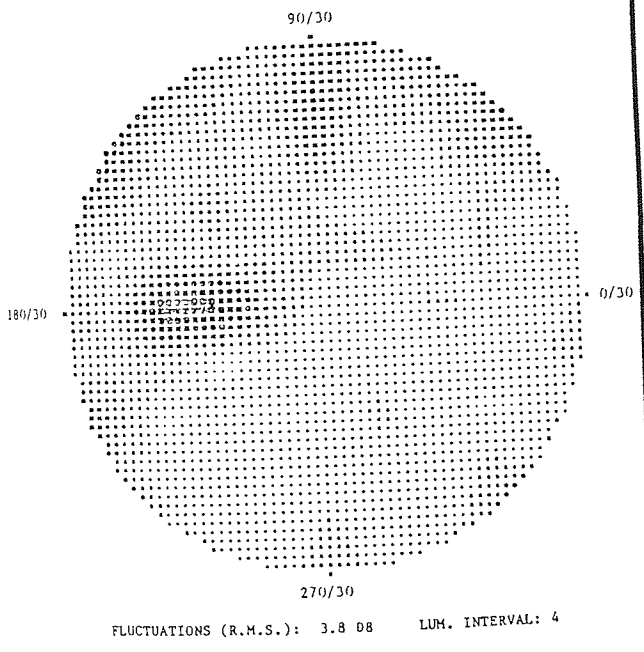
3. The Depression Profile

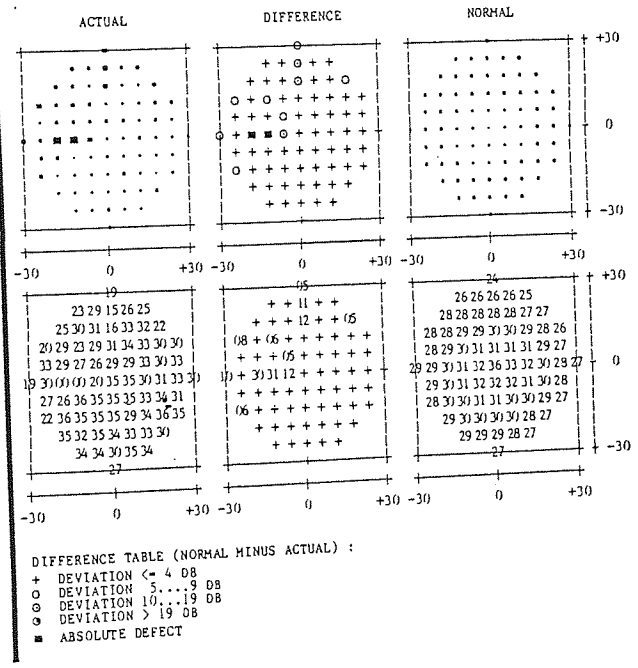
SUBJECT PB EYE LEFT

1: VISUAL EVOKED POTENTIAL

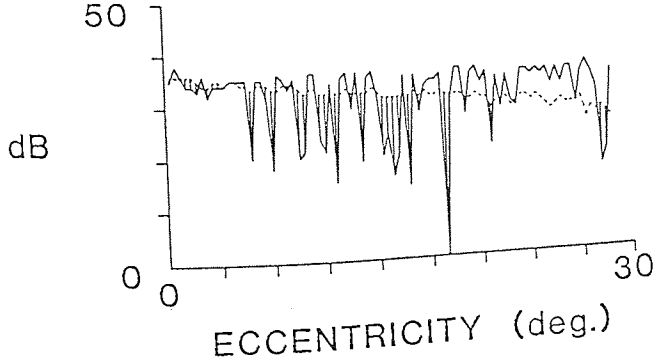


2: VISUAL FIELD





3: DEPRESSION PROFILE



Information Loss

9.19 %

Subject PB (Left Eye)

Visual Field

Examination using the Octopus Programme 31 showed a small but deep enlargement of the blind spot with a few isolated, relative reductions in sensitivity within the superior, nasal quadrant. The central 15^{o} was only affected in the superior, nasal quadrant.

The Depression Profile quantified an information loss of 9.19% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

The response was poor with a small P100 component at 96 msec over the right occiput.

11. 30^{o} Right Half Field

Demonstrated a P100 component at 99 msec over the right occiput with a maximum at electrode O4 (2.46 microvolts), which is ipsilateral to the stimulated hemifield.

111. 30^{o} Left Half Field

The response was poor with a small P100 component over the left occiput, ipsilateral to the stimulated hemifield.

IV. 10^{o} Full Field Stimulation

The response was poor with no identifiable components.

FIGURE 6.24

SUBJECT: KS DOB: 20.3.'47

EYE: Right VA: $^{6}/_{36}$

Diagnosis: Autosomal Dominant Hereditary Optic Atrophy

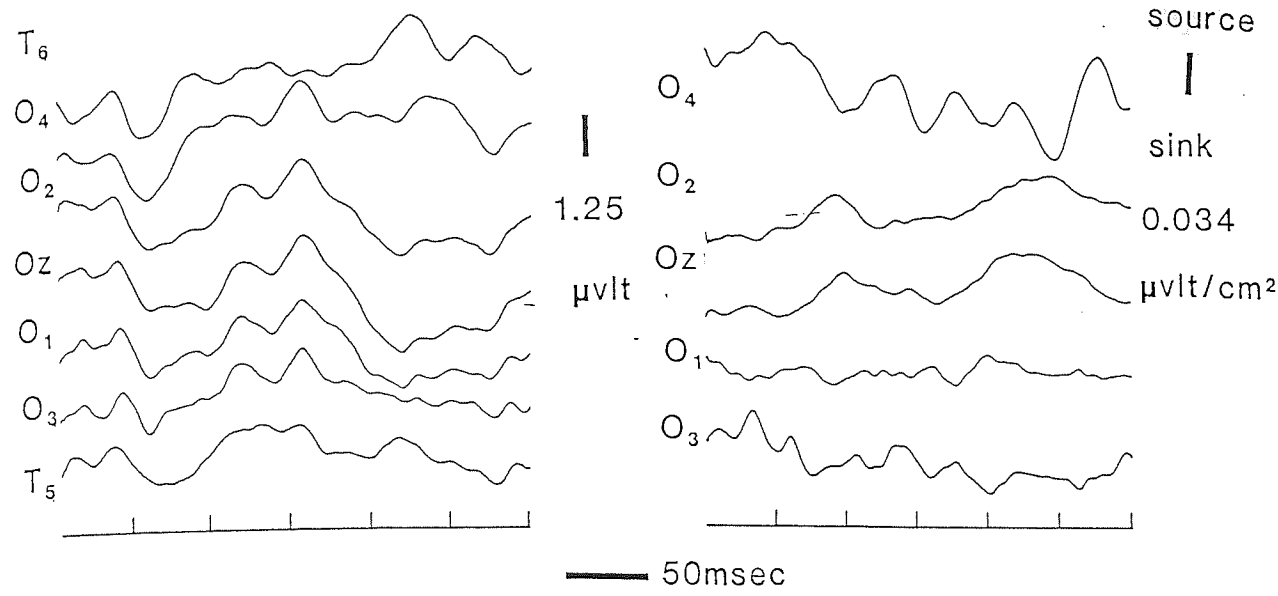
1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

2. The visual field using the Octopus Programme 31

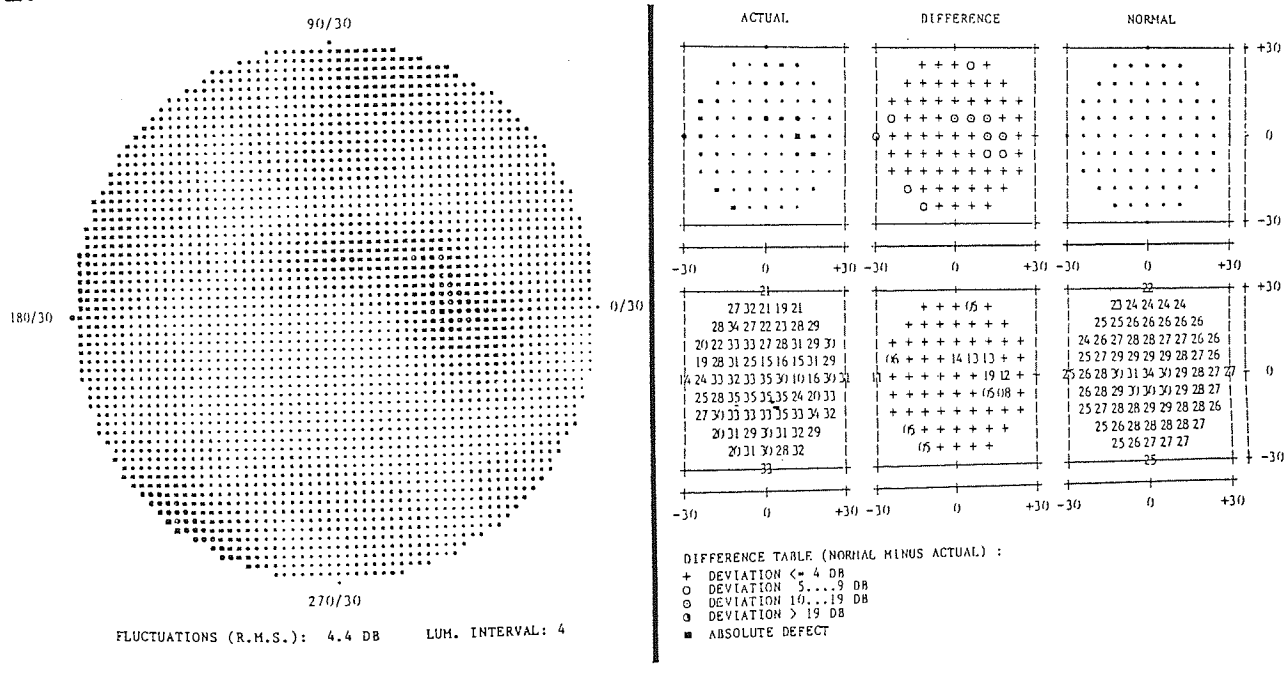
3. The Depression Profile

SUBJECT KS EYE RIGHT

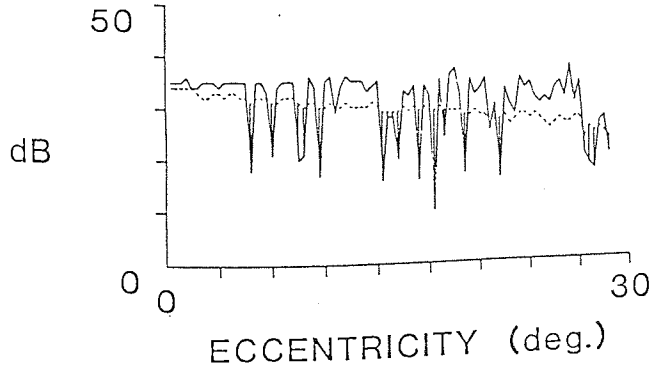
1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



3: DEPRESSION PROFILE



Information Loss

6.37 %

Subject KS (Right Eye)

Visual Field

Examination using the Octopus Programme 31 showed a relative scotoma which presented as an enlargement of the blind spot and a slight peripheral reduction in sensitivity. This is consistent with the diagnosis of autosomal dominant hereditary optic atrophy (Francois 1961). Only the superior right half field was slightly affected within the central 15^{o}.

The Depression Profile quantified an information loss of 6.37% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

The response was poor with the only consistent component being a PNP-complex at 119 msec.

11. 30^{o} Right Half Field

Demonstrated a P100 component over the left occiput at 120 msec.

111. 30^{o} Left Half Field

Demonstrated a P100 component with a "bifid" appearance

at 103 msec on all channels but the response was larger over the left occiput.

IV. 10^{o} Full Field Stimulation

The response was poor with the only consistent component being a delayed P100 at 135 msec which was largest over the right occiput.

V. 3^{o} Full Field Stimulation

The response was poor but there may be a PNP-complex at 138 msec.

FIGURE 6.25

SUBJECT: KS DOB: 20.3.'47

EYE: Left VA: $^{6}/_{60}$

Diagnosis: Autosomal Dominant Hereditary Optic Atrophy

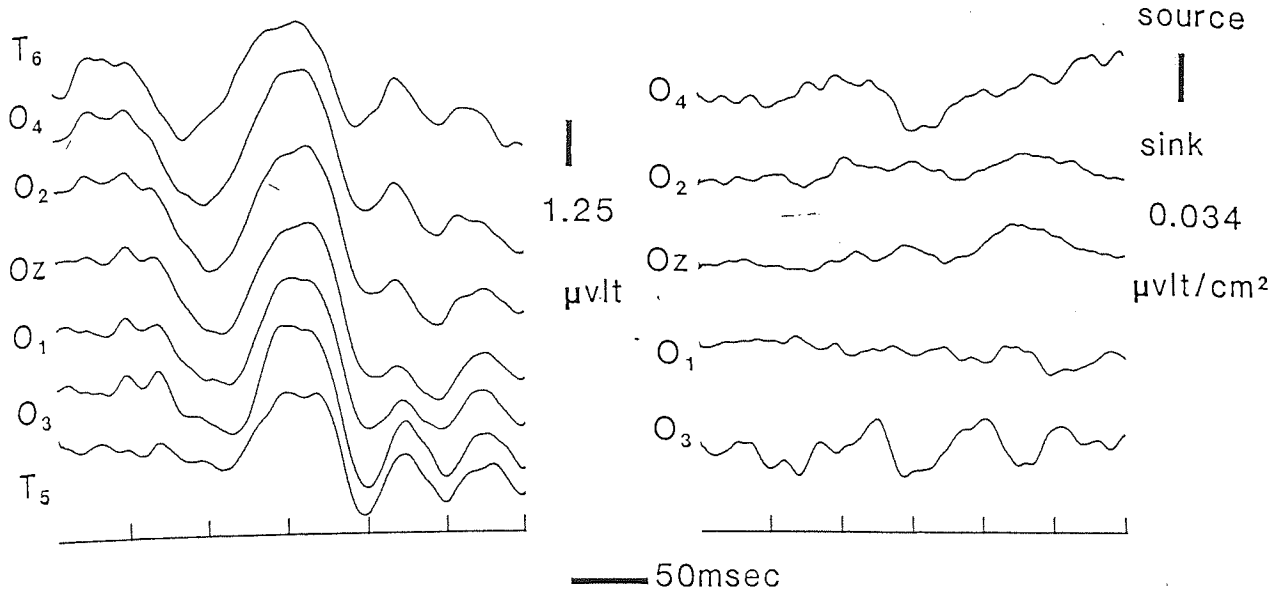
1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

2. The visual field using the Octopus Programme 31

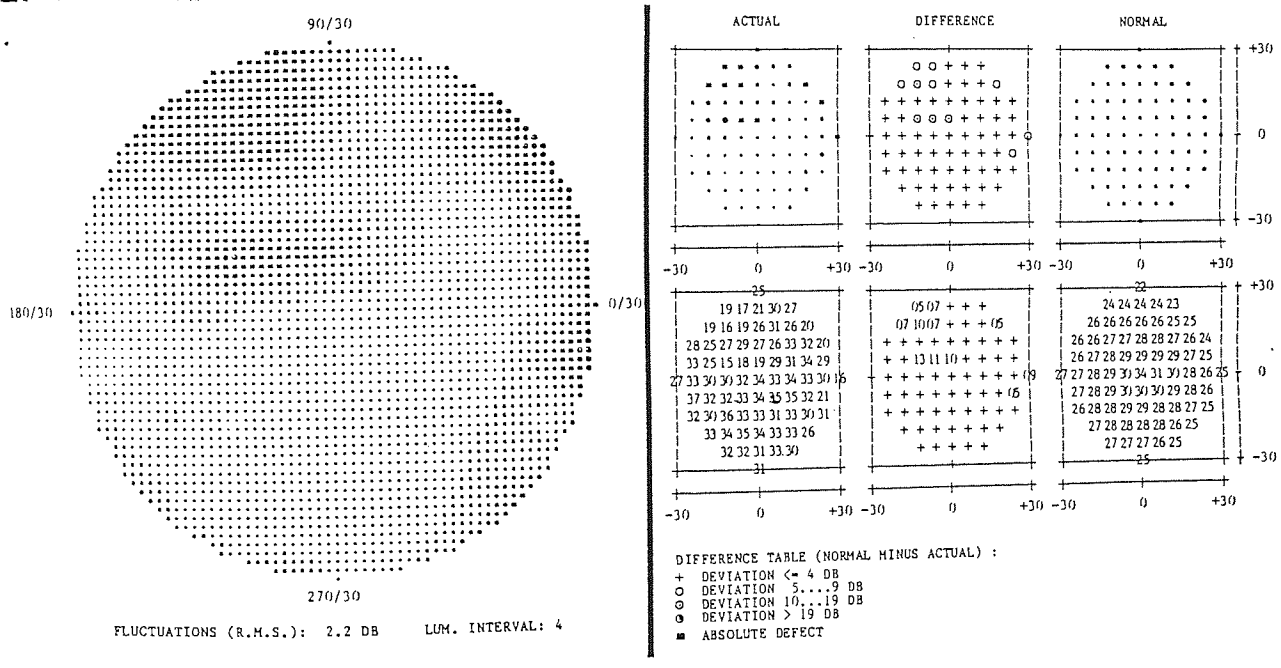
3. The Depression Profile

SUBJECT KS EYE LEFT

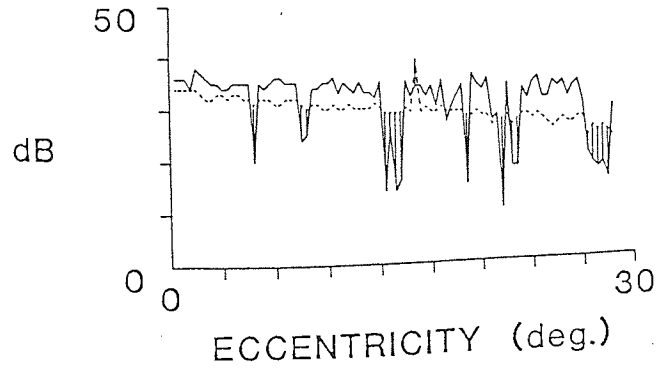
1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



3: DEPRESSION PROFILE



Information Loss

6.15 %

Subject KS (Left Eye)

Visual Field

Examination using the Octopus Programme 31 showed a small, relative scotoma extending the superior edge of the optic nerve with a localised reduction in sensitivity in the superior temporal quadrant. This is consistent with the diagnosis of autosomal dominant hereditary optic atrophy (Francois 1961). Within the central 15^{o} only the superior left half field was slightly affected.

The Depression Profile quantified an information loss of 6.15% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Demonstrated a small P100 component at 102 msec.

11. 30^{o} Right Half Field

Demonstrated a small P100 component over the right occiput at 98 msec.

111. 30^{o} Left Half Field

The response was poor but gave a small PNP-complex at

94 msec. Stimulation by the 10^{o} and 3^{o} fields could not elicit a response.

FIGURE 6.26

SUBJECT: DR DOB: 18.12.'32

EYE: Right VA: $^{6}/_{60}$

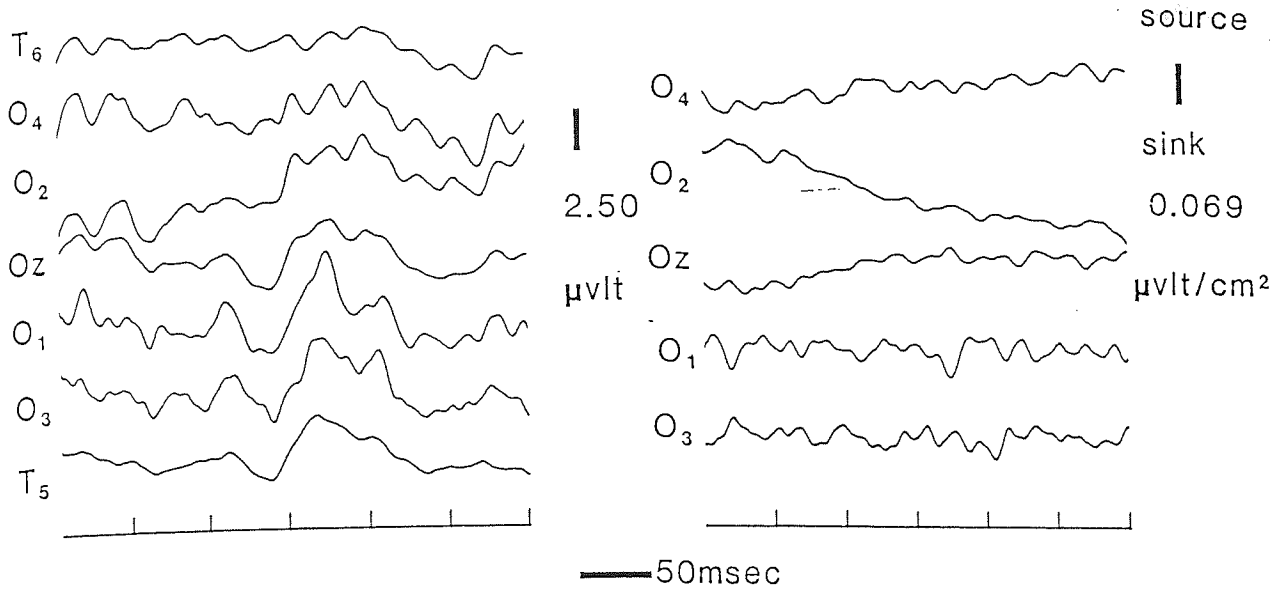
Diagnosis: Leber's Hereditary Optic Atrophy

1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

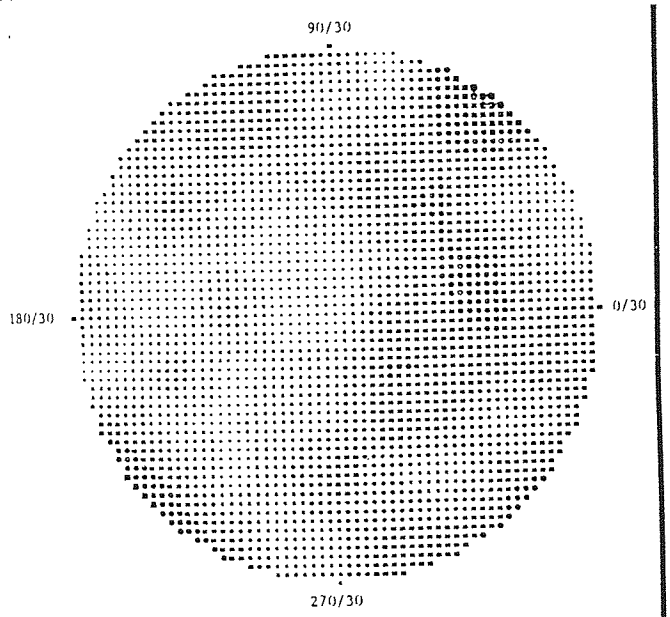
2. The visual field using the Octopus Programme 31

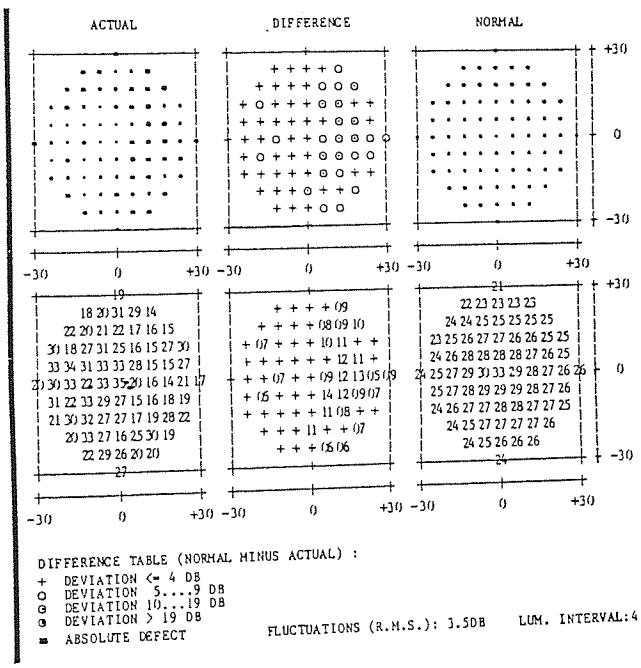
SUBJECT DR EYE RIGHT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD





Information Loss

13.56 %

Subject DR (Right Eye)

Visual Field

Examination using the Octopus Programme 31 showed an enlargement of the blind spot presenting as a relative scotoma principally affecting the right half field. Fixation was unaffected and the left half field was relatively normal. The central 15^{o} was only affected in the right half field.

The Depression Profile quantified an information loss of 13.56% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

The response was poor with a PNP-complex over the left occiput at 110 msec.

11. 30^{o} Right Half Field

Demonstrated a P100 component on all channels at 110 msec with a slightly larger response over the right occiput.

111. 30^{o} Left Half Field

The response was poor with a slight PNP-complex over the

right occiput at 91 msec.

IV. 10^{o} Full Field Stimulation

Demonstrated a small P100 component at electrodes Oz, O2 and O4 at 97 msec.

V. 3^{o} Full Field Stimulation

The response was poor but may demonstrate a small P100 component at electrodes O2 and O4 at 104 msec.

FIGURE 6.27

SUBJECT: DR DOB: 18.12.'32

EYE: Left VA: $^{6}/_{60}$

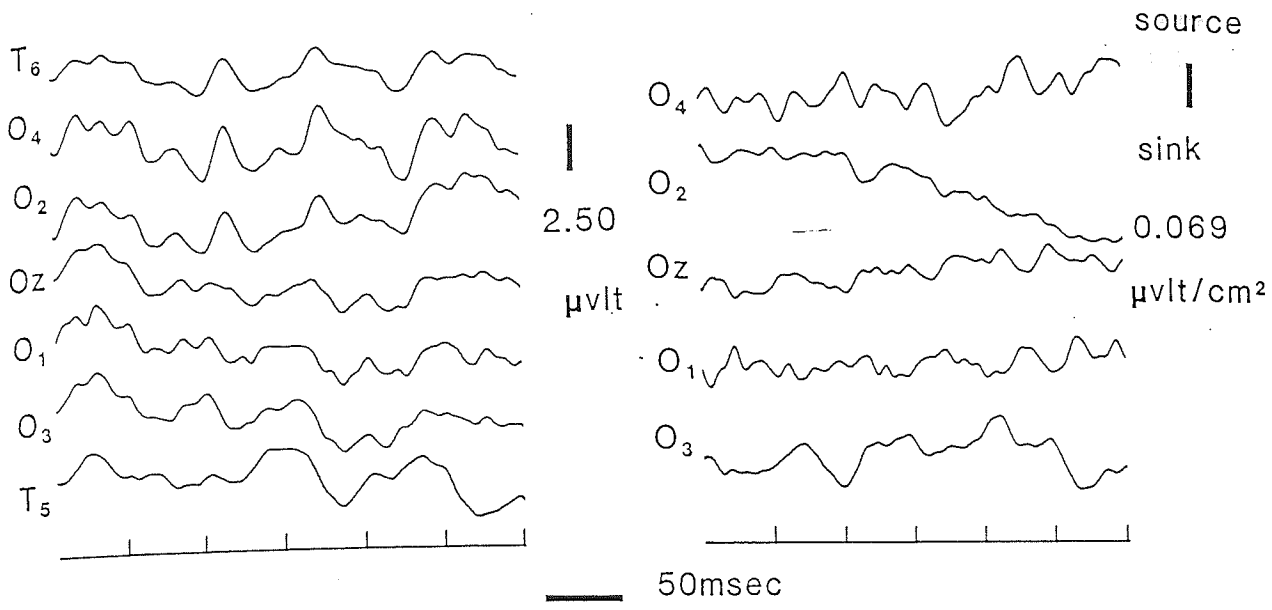
Diagnosis: Leber's Hereditary Optic Atrophy

1. The visual evoked potential to full field stimulation
(Common Reference and Source Derivation)

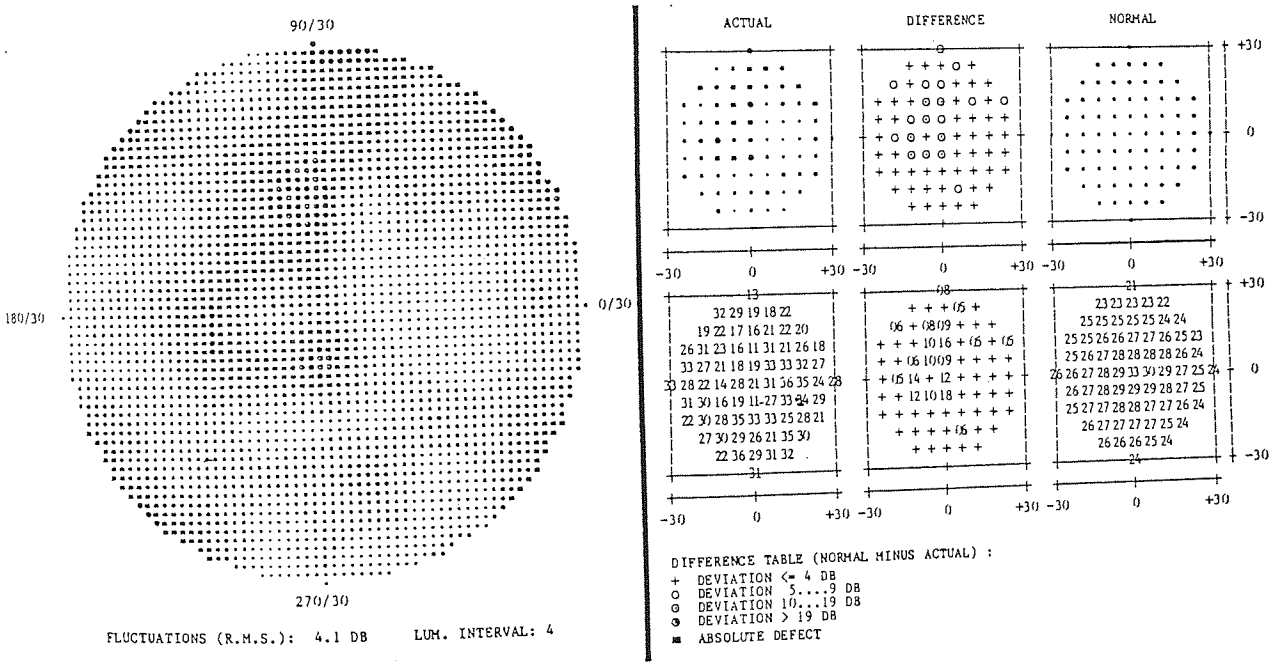
2. The visual field using the Octopus Programme 31

SUBJECT DR EYE LEFT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



Information Loss

12.35 %

Subject DR (Left Eye)

Visual Field

Examination using the Octopus Programme 31 showed a relative enlargement of the blind spot superiorly and inferiorly following an arcuate type extension to fixation resulting in a central depression of sensitivity. The central 15^{o} was considerably affected with the right half field more preserved than the left half field.

The Depression Profile quantified an information loss of 12.35% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Demonstrated a P100 component over the right occiput at 99 msec with a maximum at the O2 electrode (2.68 microvolts) and a PNP-complex over the left occiput at 100 msec with a maximum negativity at the O3 electrode (0.78 microvolts). The result was therefore consistent with a left half field type defect.

11. 30^{o} Right Half Field

The response was poor with a PNP-complex over the left

occiput at 100 msec and a slight P100 component over the peripheral O4 and T6 electrodes of the right occiput at the same latency.

III. 30° Left Half Field

Demonstrated a small P100 component over all channels at 101 msec. The right occiput gave a larger response and was contralateral to the stimulated hemifield.

IV. 10° Full Field Stimulation

There was no identifiable response.

V. 3° Full Field Stimulation

The response was poor but demonstrated a very small P100 component over the right occiput at 93 msec.

Comment

The five patients presented each have a form of hereditary optic atrophy (HOA). Four have autosomal dominant HOA and one suffers from Leber's HOA. Of the ten eyes examined only three had a recordable central reduction in sensitivity yet seven demonstrated a VEP with the characteristic PNP-complex described by Harding and Crews (1982) (Table 6.2). Of the three eyes exhibiting a central scotoma one demonstrated a P100 component. The degree of information loss within the central 30^{o} does not accurately correlate with the presence of a PNP-complex. These observations would appear to confirm the discussion of Harding and Crews (1982); Crews and Harding (1981); and Harding, Crews and Pitts (1979) that the presence of a dominant negativity is not related to central scotomata and must therefore predicate to the nature of the disease. Psychophysical investigations of patients suffering from hereditary optic atrophy have shown a reduction in the central flicker response without an accompanying reduction in central sensitivity measurable by perimetry (Alvarez, personal communication 1983). This clearly demands further investigation as a link between flicker sensitivity and VEP morphology may help clarify the physiological nature of the response.

Topographic investigation of the VEP would again appear justified as in several cases the midline electrode gave

TABLE 6.2

Summary of the characteristic visual fields and visual evoked potentials recorded from the five subjects with Hereditary Optic Atrophy

		VISUAL FIELD			VISUAL EVOKED POTENTIAL	
SUBJECT	EYE	CENTRAL SCOTOMA	ENLARGEMENT OF BLIND SPOT	INFORMATION LOSS	PNP-COMPLEX	P100 COMPONENT
MG	R	-	X	28.54	X	-
	L	X	-	46.27	X	-
JG	R	-	X	25.89	X	-
	L	X	-	58.52	X	-
PB	R	-	X	7.71	X	-
	L	-	X	9.19	-	X
KS	R	-	X	6.37	X	-
	L	-	X	6.15	-	X
DR	R	-	X	13.56	X	-
	L	X	X	12.35	-	X

TABLE 6.2

a poor response. The source derivation distribution was interesting as in most cases there would seem to be a midline source at the same latency as the dominant negativity.

One striking characteristic of these results was the scalp topography following half field stimulation. Subject MG, for example, gave a dominant PNP-complex over the left occiput following both right and left half field stimulation to the left eye. It would therefore seem inappropriate to attribute the negativity to a dominant contralateral N105 component as discussed by Blumhardt et al. (1978) and Halliday et al. (1979).

6.2.2 Discussion

Table 6.3 summarises the effect on the VEP for those subjects which have demonstrated a central scotoma. Only two of the fifteen eyes gave a dominant PNP-complex or Halliday's (1976) "scotomatous negativity". Both of these subjects had hereditary optic atrophy. Most of the remaining subjects had retinal lesions and confirmed the simulated central scotoma results of Chapter 5 by demonstrating a reduced P100 amplitude. All subjects revealing a reduced and delayed P100 component had an information loss of over 70% for the central 30^{o} of the visual field.

The scotomatous nature of the PNP-complex is therefore

TABLE 6.3

Summary of the VEP results from all subjects demonstrating a central scotoma

SUBJECT	EYE	INFORMATION LOSS	CENTRAL SCOTOMA	LESION	PNP	REDUCED P100	REDUCED AND DELAYED P100
ADa	R	48.35%	X	Retinal	-	X	-
CS	L	6.23%	X	Retinal	-	X	-
JP	R	43.64%	X	Optic Nerve (Compression)	-	X	-
EM	R	86.35%	X	Optic Nerve (Secondary Neuritis)	-	-	X
AD	R	72. 3%	X	Retinal	-	-	X
AD	L	76.21%	X	"	-	-	X
RG	R	90.25%	X	"	-	-	X
RG	L	97.95%	X	"	-	-	X
RPG	R	99.17%	X	"	-	-	X
RPG	L	98.58%	X	"	-	-	X
DW	R	100%	X	"	-	-	-
DW	L	100%	X	"	-	-	X
MG	L	46.27%	X	Optic Nerve (HOA)	X	-	-
JG	L	28.52%	X	"	X	-	-
DR	L	12.35%	X	"	-	X	-

TABLE 6.3

disputed. The results presented confirm the discussion of Harding and Crews (1982) that the PNP-complex "cannot be considered a scotomatous response". Further research is required to investigate the way in which the diseases that are characterised by a PNP-complex affect the visual pathway. It may be necessary to include studies of the spatial and temporal modulation transfer functions as well as the differential light threshold investigations performed by the modern computer assisted perimeters. Skalka (1980) has demonstrated a defective contrast sensitivity function in patients with optic nerve disease. Bruekink and Ten Doeschatte (1963) isolated abnormal de Lange Curves at either high or low temporal frequencies in five subjects with optic nerve atrophy.

To isolate the exact cause of the PNP-complex will take a concerted research effort. By establishing that it is not directly "scotomatous" in nature provides an initial contribution.

The advantages of multi-channel topographic recording of the visual evoked potential has been clearly demonstrated. Single channel, midline recording would have provided relatively little useful information in many of the subjects examined. The usefulness of the medial montage and half field stimulation was stressed by several subjects particularly when large field and check sizes were used.

6.3 CHIASMAL LESIONS

6.3.1 Results

Table 6.4 outlines the diagnoses of the 7 subjects investigated. The first 6 subjects to be presented possess bitemporal hemianopic field defects and will be discussed together. The following subject demonstrated a more unusual suspected chiasmal lesion resulting in a binasal hemianopia. This will be discussed separately.

TABLE 6.4

SUBJECT	DIAGNOSIS
AH	Acidophilic Pit. Adenoma (Acromegaly)
FH	" " " "
R Gr	" " " "
DG	Chromaphobic Pit. Adenoma
F Fe	" " "
BV	? Meningioma
LH	Suspected Space Occupying Lesion in supra-tentorial area

TABLE 6.4

PATIENT DIAGNOSIS

FIGURE 6.28

SUBJECT: AH DOB: 6.2.'16

EYE: Left VA: $^{6}/_{24}$

Diagnosis: Acidophilic Pituitary Adenoma (Acromegaly)

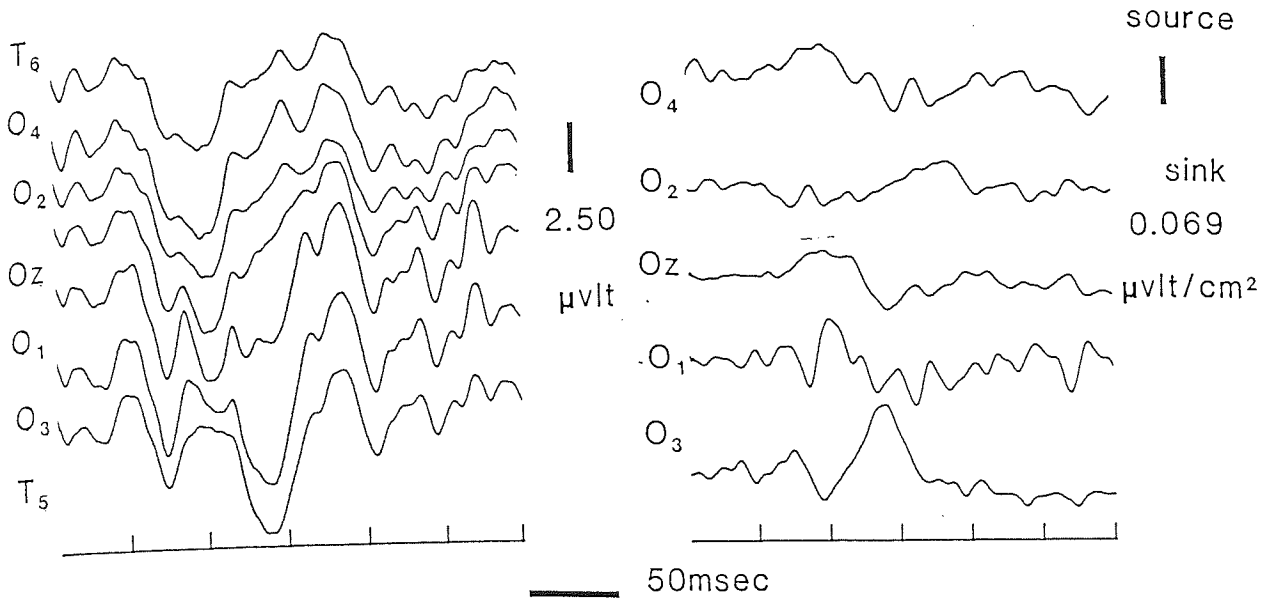
1. The visual evoked potential to full field stimulation (Common Reference and Source Derivation)

2. The visual field using the Octopus Programme 31

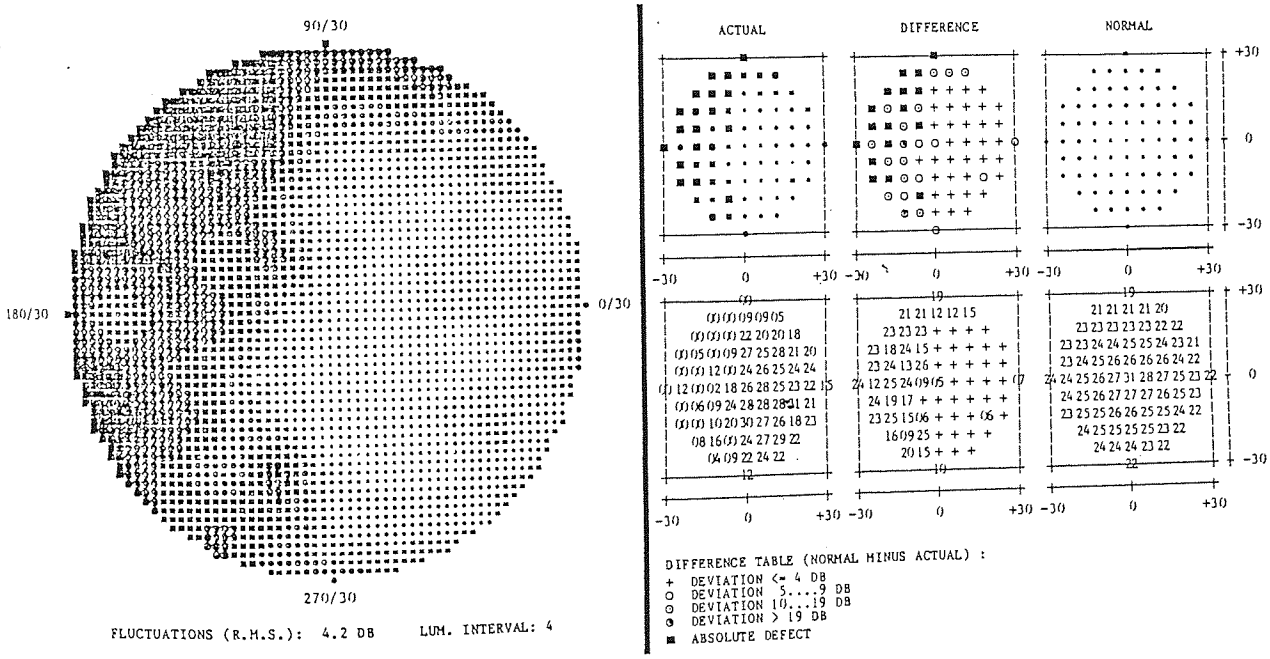
3. The Depression Profile

SUBJECT AH EYE LEFT

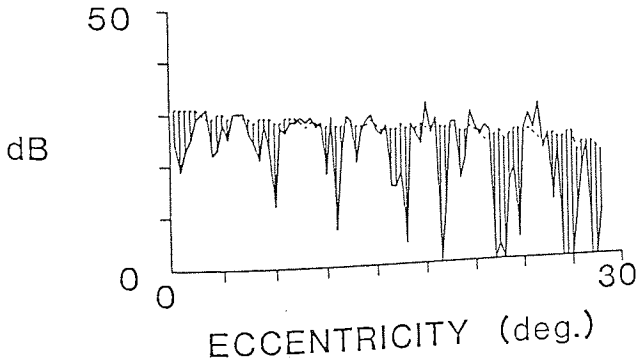
1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



3: DEPRESSION PROFILE



Information Loss

23.04 %

Subject AH (Left Eye)

Visual Field

Examination using the Octopus Programme 31 showed a deep, temporal hemianopic defect which straddles the midline superiorly and involves fixation although only slightly. The right half field within the central 15^{o} was relatively unaffected.

The Depression Profile quantified an information loss of 23.04% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Demonstrated a P100 component at 98 msec over the right occiput with a maximum amplitude on the midline at 5.38 microvolts. The source derivation distribution demonstrated a source-sink configuration over the left occiput.

11. 30^{o} Right Half Field

The response over the right occiput was of a poor morphology but showed a P100 component at 98 msec, ipsilateral to the stimulated hemifield. The clearest component was a contralateral negativity at the same latency.

III. 30° Left Half Field

The response over the right occiput was poor but there may have been a broad, flat P100 component at 102 msec. Again the clearest component was a negativity over the left occiput ipsilateral to the stimulated hemifield.

IV. 10° Full Field Stimulation

The response was poor with a small P100 component at 109 msec which appeared slightly larger over the left occiput.

Ten degree half field stimulation did not give reliable, reproducible responses.

V. 3° Full Field Stimulation

Gave a small P100 component at 126 msec which was slightly larger over the left occiput.

VI. 3° Right Half Field

Gave a small P100 component at 118 msec over the left occiput only, contralateral to the hemifield stimulated.

VII. 3° Left Half Field

The response was poor with no recognisable response.

FIGURE 6.29

SUBJECT: FH DOB: 8.1.'23

EYE: Right VA: $^{6}/_{9+2}$

Diagnosis: Acidophilic Pituitary Adenoma (Acromegaly)

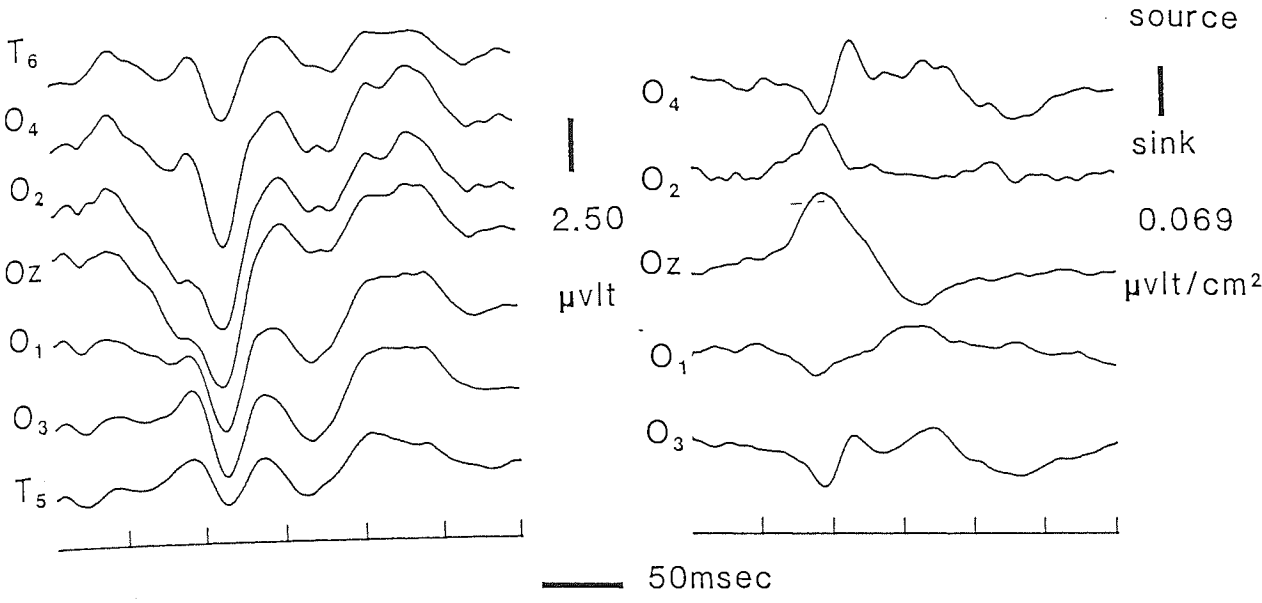
1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

2. The visual field using the Octopus Programme 31

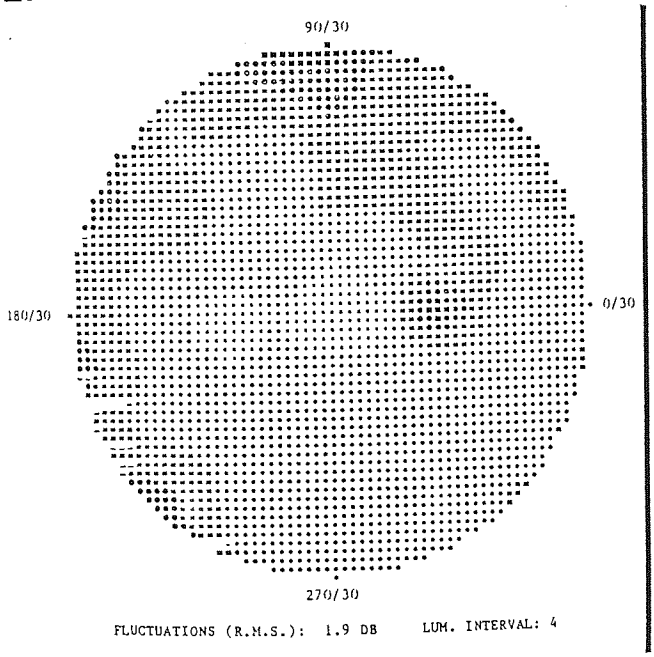
3. The Depression Profile

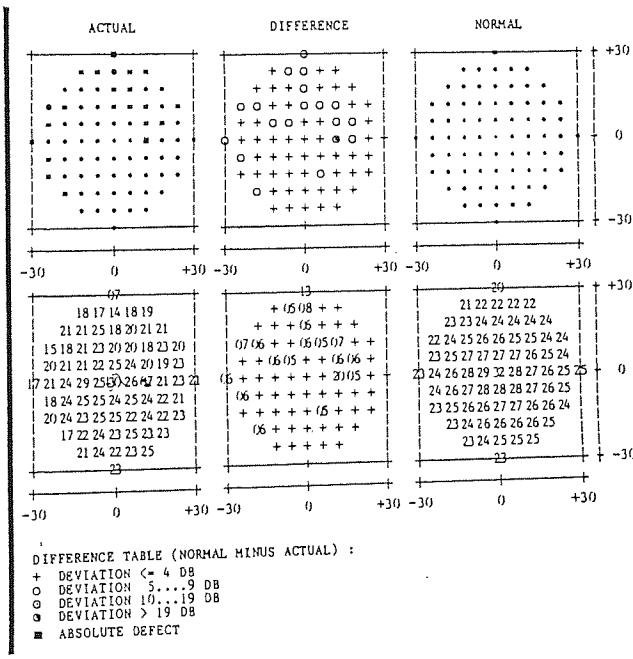
SUBJECT FH EYE RIGHT

1: VISUAL EVOKED POTENTIAL

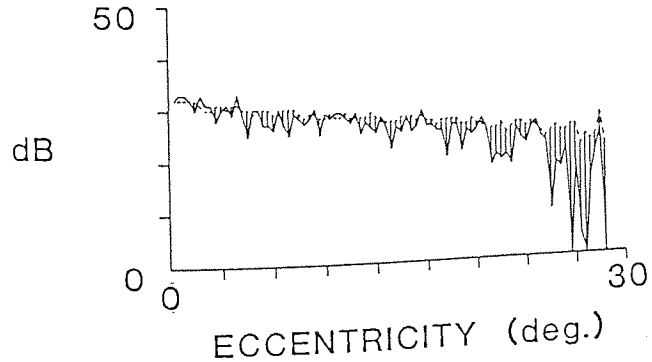


2: VISUAL FIELD





3: DEPRESSION PROFILE



Information Loss

11.32 %

Subject FH (Right Eye)

Visual Field

Examination using the Octopus Programme 31 showed an enlargement of the blind spot with a superior extension and a slight generalised reduction in sensitivity of the peripheral nasal field. The central 15^{o} was slightly affected in the superior and nasal field.

The Depression Profile quantified an information loss of 11.32% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Gave a slightly delayed but clear P100 component at 109 msec which was a little larger over the right occiput. The maximum amplitude was over the midline at 6.23 micro-volts. The source derivation distribution gave a source on the midline.

11. 30^{o} Right Half Field

Gave an ipsilateral response with a P100 component at 106 msec which was largest over the right occiput. The maximum amplitude was over the O2 electrode at 4.98 micro-volts.

III. 30° Left Half Field

Gave a P100 component at 109 msec which was of a better morphology over the left, ipsilateral occiput but was slightly larger over the right occiput. The maximum amplitude was over the midline at 3.30 microvolts.

IV. 10° Full Field Stimulation

Gave a clear P100 component, over all channels, at 122 msec. The distribution was approximately symmetrical with a maximum amplitude on the midline at 4.33 microvolts.

V. 3° Full Field Stimulation

Gave a P100 component which was sharp and clear over the right occiput at 102 msec but was broader and later over the left occiput at 110 msec. The maximum amplitude was over the O1 electrode at 1.38 microvolts.

FIGURE 6.30

SUBJECT: RGr DOB: 23.12.'34

EYE: Left VA: $^{6}/_{6}$

Diagnosis: Acidophilic Pituitary Adenoma (Acromegaly)

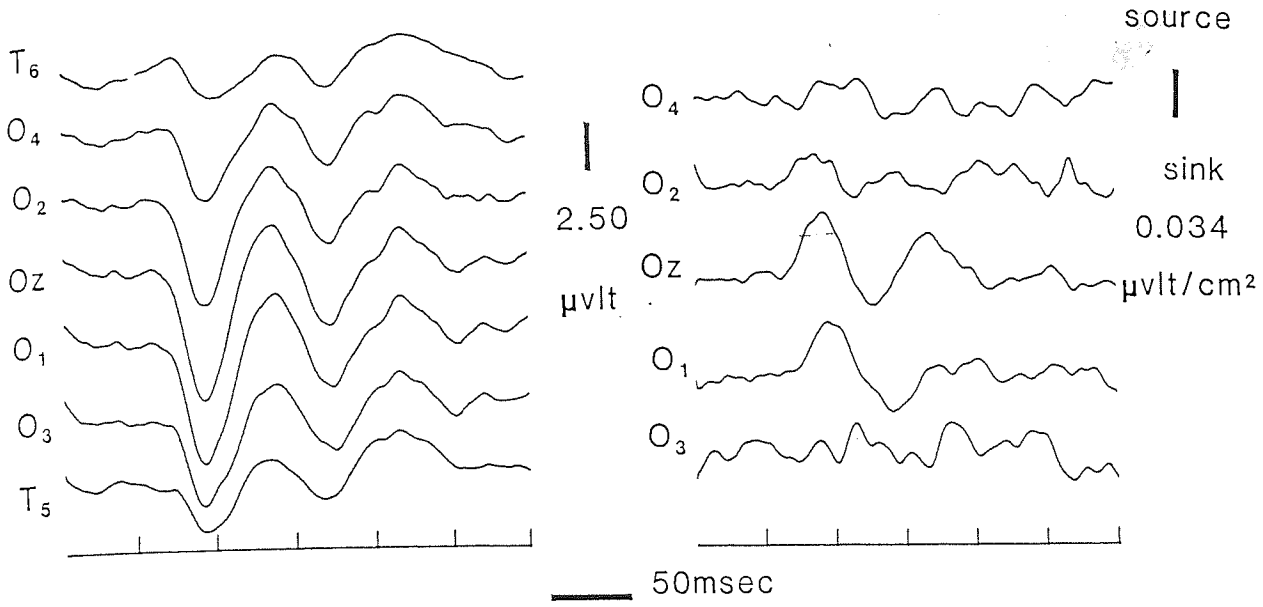
1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

2. The visual field using the Octopus Programme 31

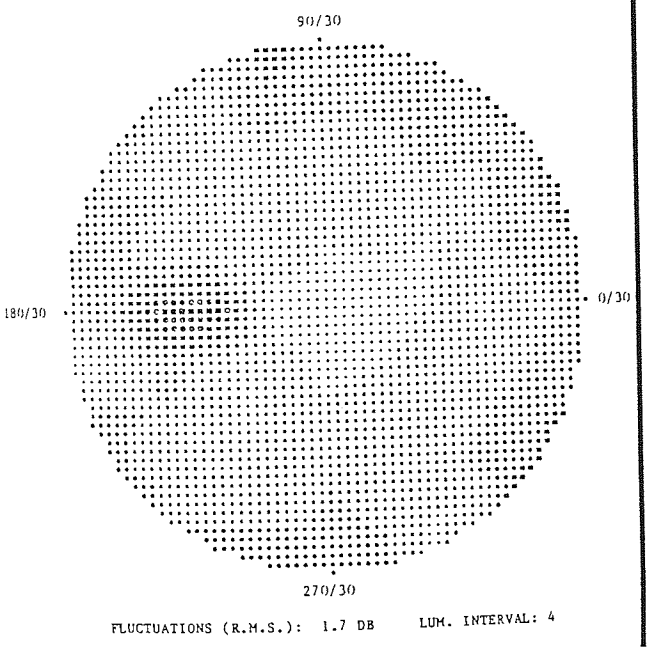
3. The Depression Profile

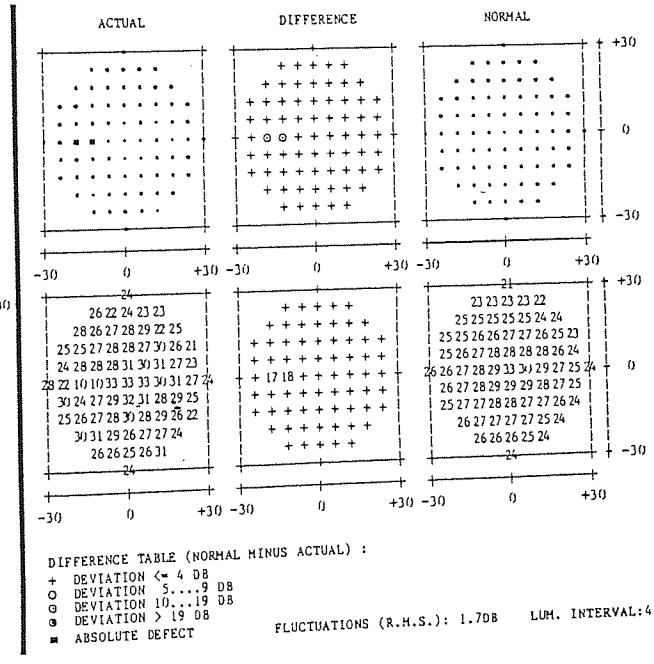
SUBJECT RGr EYE LEFT

1: VISUAL EVOKED POTENTIAL

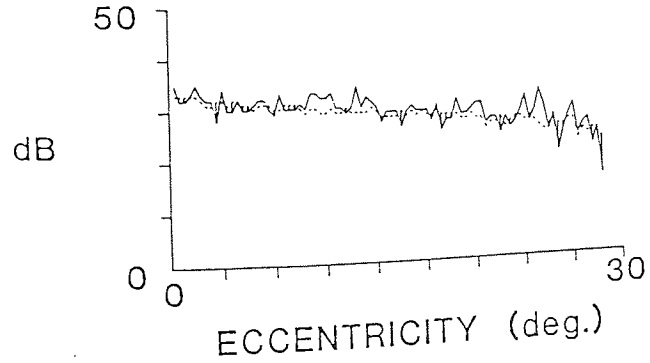


2: VISUAL FIELD





3: DEPRESSION PROFILE



Information Loss

2.05 %

Subject RGr (Left Eye)

Visual Field

Examination using the Octopus Programme 31 showed a small but deep enlargement of the blind spot. The central 15° were slightly affected in the temporal, left half field. The Depression Profile quantified an information loss of 2.05% for the central 30°.

Visual Evoked Potential

1. 30° Full Field Stimulation

Gave a clear P100 component at 92 msec which was larger over the left occiput with a reduction of 33% between the O4 and O3 electrodes. The maximum amplitude was over the midline at 5.70 microvolts. The source derivation distribution demonstrated a scalp current source on the midline.

11. 30° Right Half Field

Gave an ipsilateral P100 component at 94 msec being larger over the right occiput. The maximum amplitude was over the midline at 3.57 microvolts. The source derivation distribution gave a midline source with a contralateral sink over the O3 electrode.

III. 30^{o} Left Half Field

Gave an ipsilateral response of poor morphology, compared to the right half field results, at 94 msec. The maximum amplitude was over the midline at 4.00 microvolts.

The source derivation distribution gave a midline source with no identifiable sink.

IV. 10^{o} Full Field Stimulation

Gave a good response with a P100 component at 95 msec which was approximately symmetrical around the midline, although the maximum amplitude was over the O2 electrode.

V. 3^{o} Full Field Stimulation

Gave a poor response with a possible P100 component at 109 msec which was clearer over the right occiput.

FIGURE 6.31

SUBJECT: DG DOB: 9.3.'22

EYE: Right VA: $^{6}/_{9+1}$

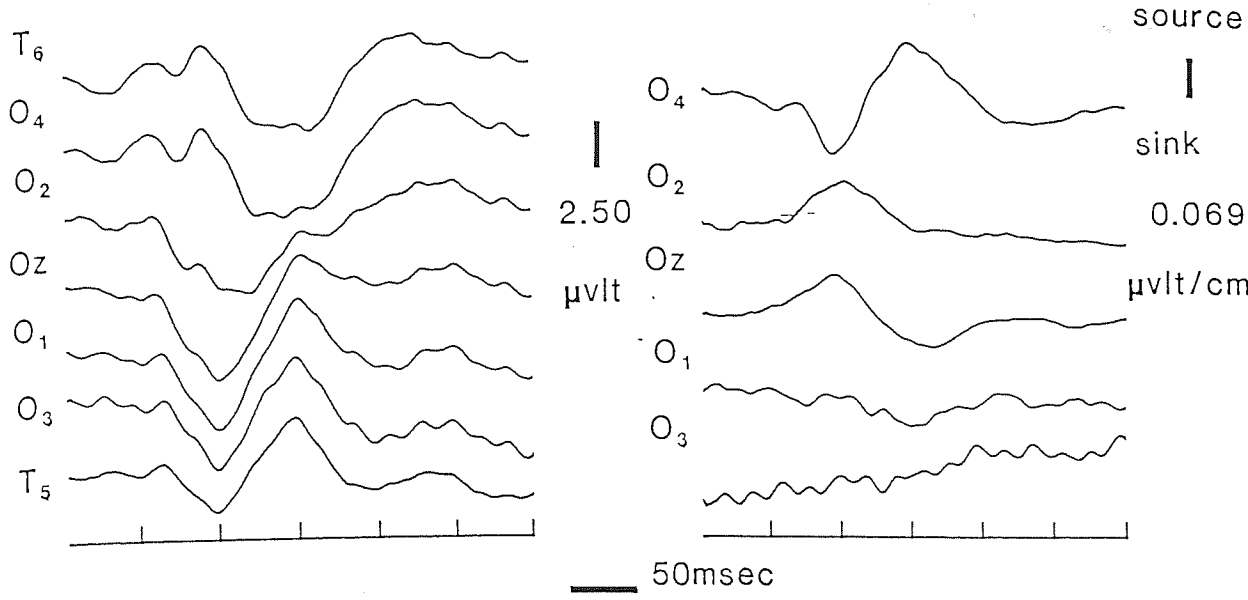
Diagnosis: Chromophobic Pituitary Adenoma

1. The visual evoked potential to full field stimulation
(Common Reference and Source Derivation)

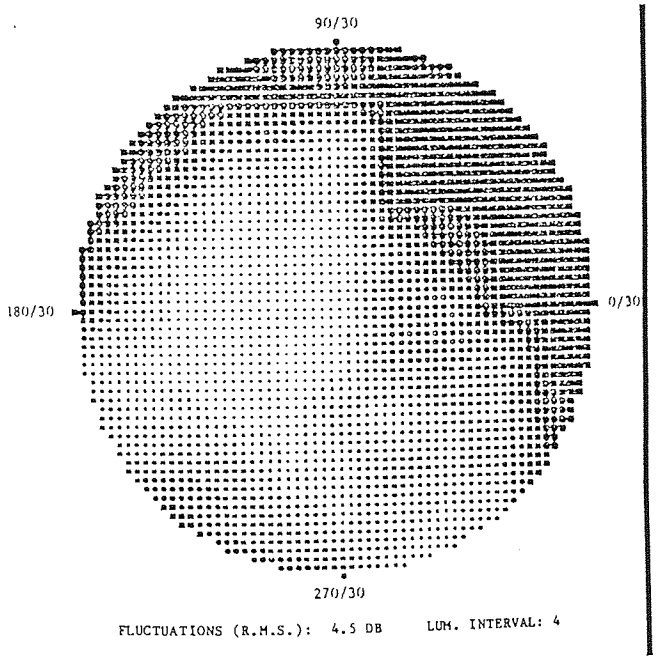
2. The visual field using the Octopus Programme 31

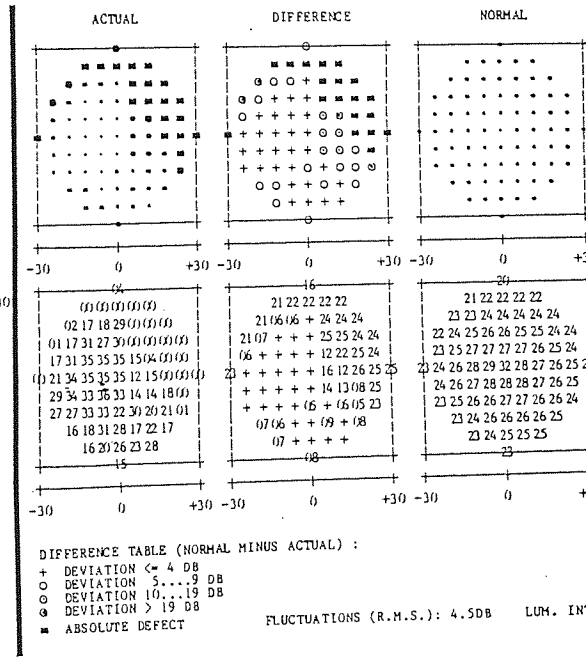
SUBJECT DG EYE RIGHT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD





Information Loss

29.34 %

Subject DG (Right Eye)

Visual Field

Examination using the Octopus Programme 31 showed an incongrous, temporal hemianopia which was particularly deep in the superior temporal quadrant. Fixation and the nasal field out to 20^{o} were normal with the central 15^{o} only being affected in the temporal, right half field.

The Depression Profile quantified an information loss of 29.34% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

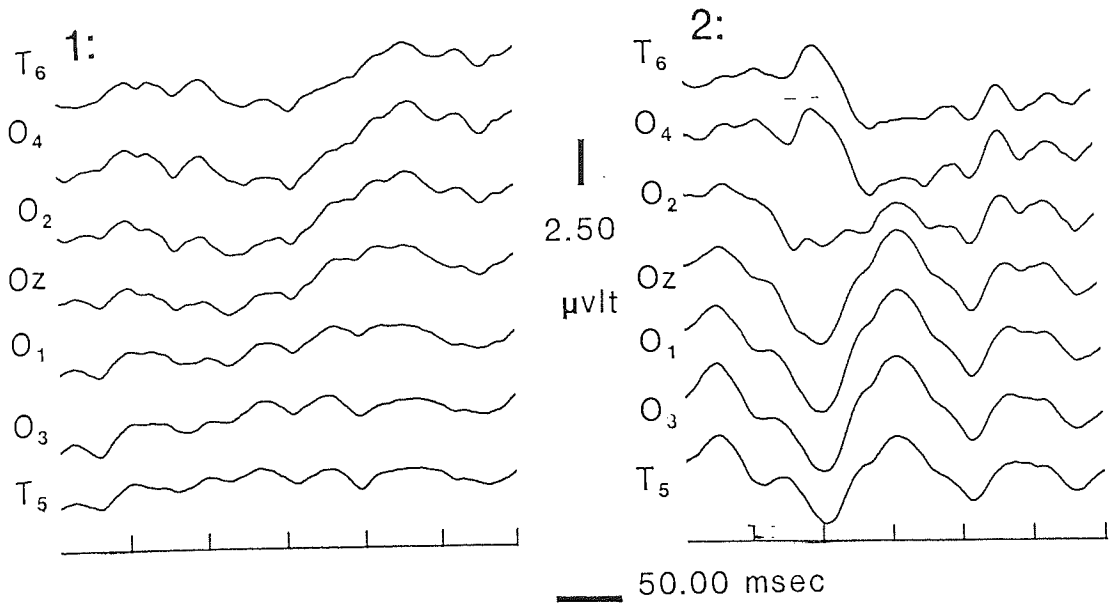
Gave a P100 component over the left occiput at 99 msec with a maximum amplitude on the midline at 4.37 microvolts. The right occiput demonstrated a negativity at approximately 80 msec. There was a 92% reduction in amplitude between electrodes O4 and O3. The source derivation distribution showed a source on the midline with a sink over the O4 electrode.

11. 30^{o} Right Half Field

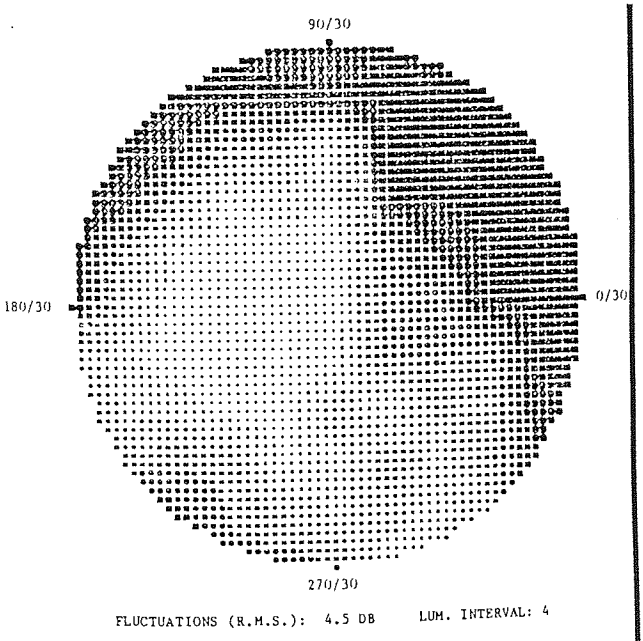
Gave a flat response with a very small possible P100 component at 112 msec.

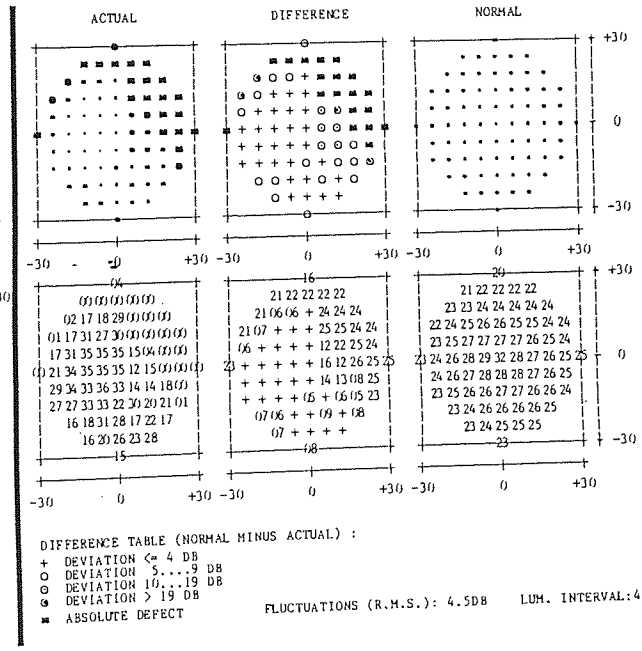
SUBJECT DG EYE RIGHT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD





3: DEPRESSION PROFILE

FIGURE 6.32 Half Field Stimulation (30^{o})

1/ Right Half Field
2/ Left Half Field

Information Loss

29.34 %

III. 30° Left Half Field

Gave a P100 component over the left occiput with a very similar distribution but better morphology than the full field response. The latency was 97 msec with a maximum amplitude over the O1 electrode at 3.28 microvolts. The source derivation distribution gave a maximum source at the contralateral O2 electrode with a sink over the O4 electrode.

IV. 10° Full Field Stimulation

Gave a small P100 component which was largest over the left occiput with a maximum amplitude on the midline of 2.00 microvolts. The source derivation distribution gave a source over the O2 electrode with a sink over the O4 electrode.

V. 3° Full Field Stimulation

No response was elicited.

FIGURE 6.33

SUBJECT: DG DOB: 9.3.'22

EYE: Left VA: $^{6}/_{6-2}$

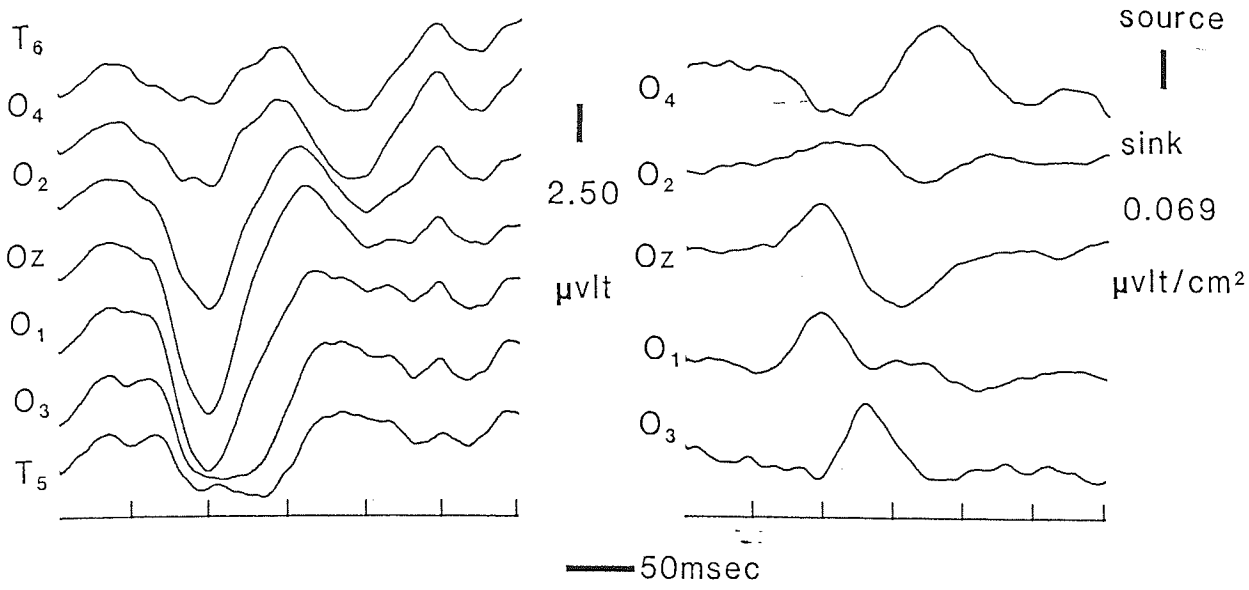
Diagnosis: Chromophobic Pituitary Adenoma

1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

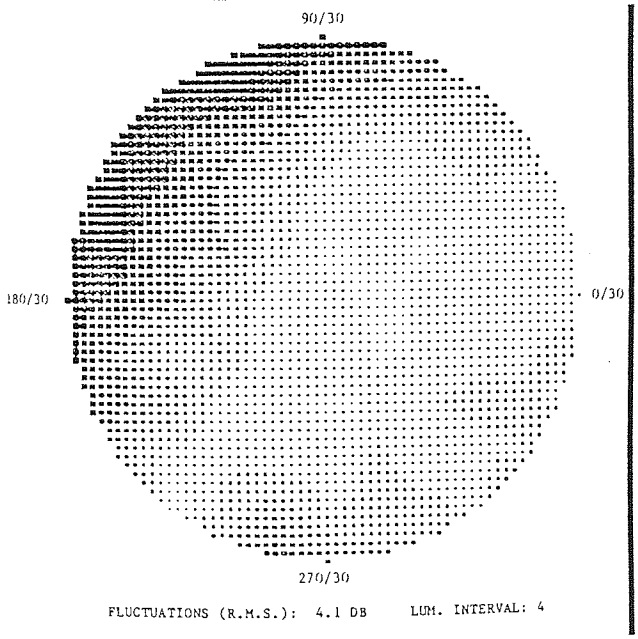
2. The visual field using the Octopus Programme 31

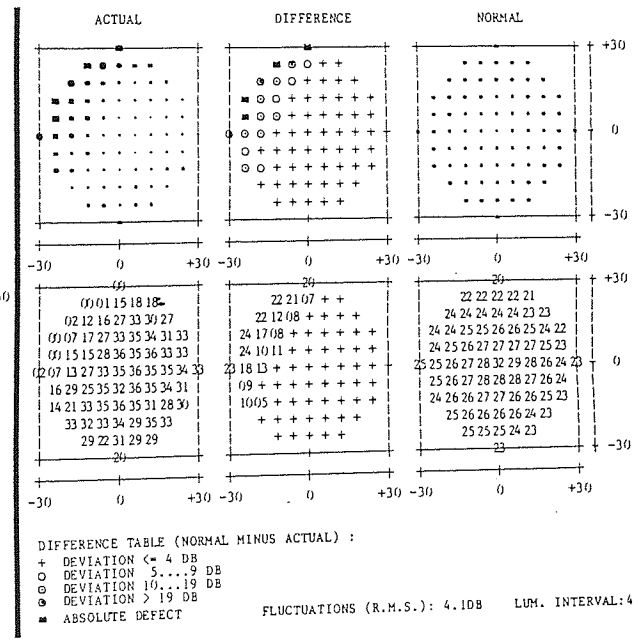
SUBJECT DG EYE LEFT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD





3: DEPRESSION PROFILE

Information Loss
12.83 %

SUBJECT DG (Left Eye)

Visual Field

Examination using the Octopus Programme 31 showed an incongrous, temporal hemianopia which was particularly deep in the superior temporal quadrant. The central 15^{o} was only affected in the temporal, left half field.

The Depression Profile quantified an information loss of 12.83% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Gave a P100 component at 98 msec which was of a better morphology and slightly larger over the left occiput. The maximum amplitude was on the midline at 7.74 microvolts. There was no peripheral negativity over the right occiput. The source derivation distribution gave a source over the midline with a sink over the O4 electrode.

11. 30^{o} Right Half Field

Gave an ipsilateral P100 component at 96 msec over the right occiput. The maximum amplitude was over the midline at 5.57 microvolts.

III. 30^{o} Left Half Field

Gave a poor response with a PNP-complex with the negativity at 107 msec which was better over the left ipsilateral occiput. The maximum amplitude was over the midline at 2.36 microvolts.

IV. 10^{o} Full Field Stimulation

Gave a P100 component at 92 msec which was of a better morphology and of larger amplitude over the left occiput. The maximum amplitude was over the O1 electrode at 3.92 microvolts. The source derivation distribution gave a source over the O1 electrode and a sink over the O4 electrode.

V. 3^{o} Full Field Stimulation

Gave a clear P100 component which was approximately symmetrical over each occiput at 104 msec although the maximum amplitude was over the O1 electrode at 2.16 microvolts.

FIGURE 6.34

SUBJECT: FFe DOB: 24.4.'15

EYE: Left VA: $^{6}/_{9-1}$

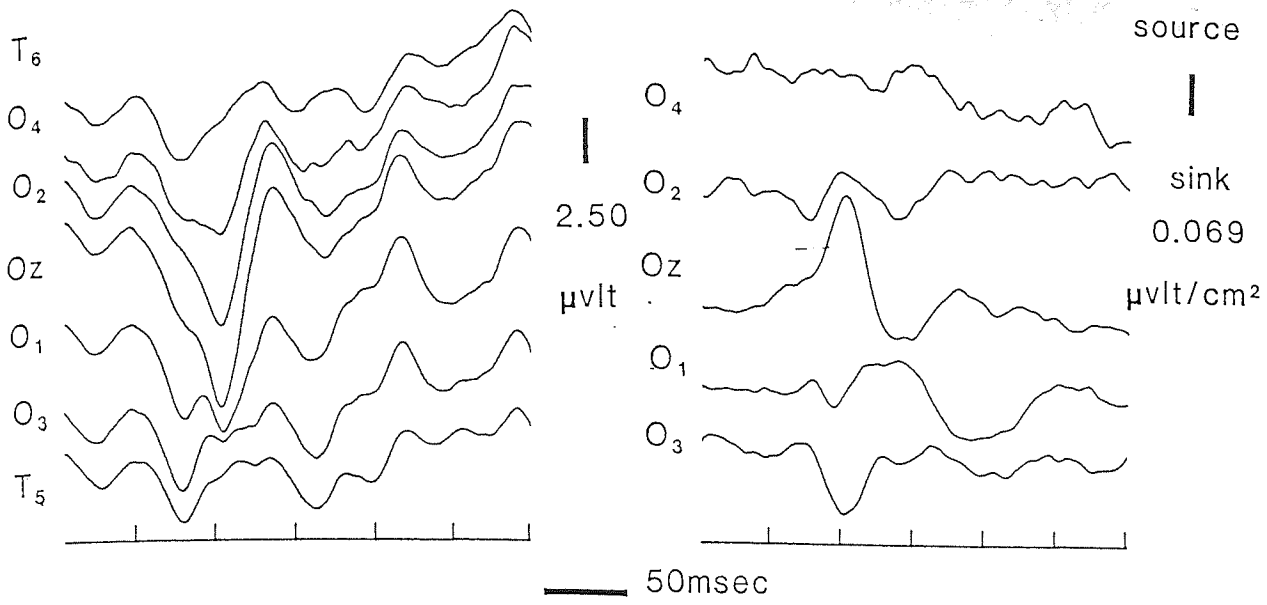
Diagnosis: Chromophobic Pituitary Adenoma

1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

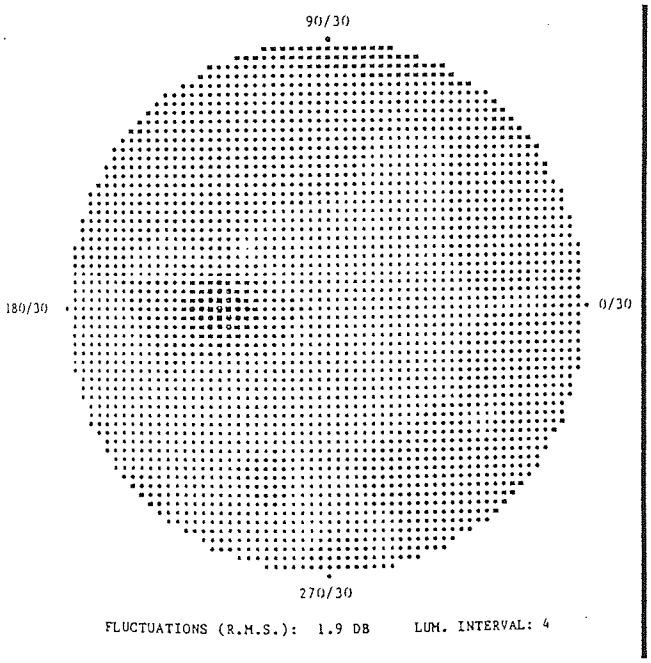
2. The visual field using the Octopus Programme 31

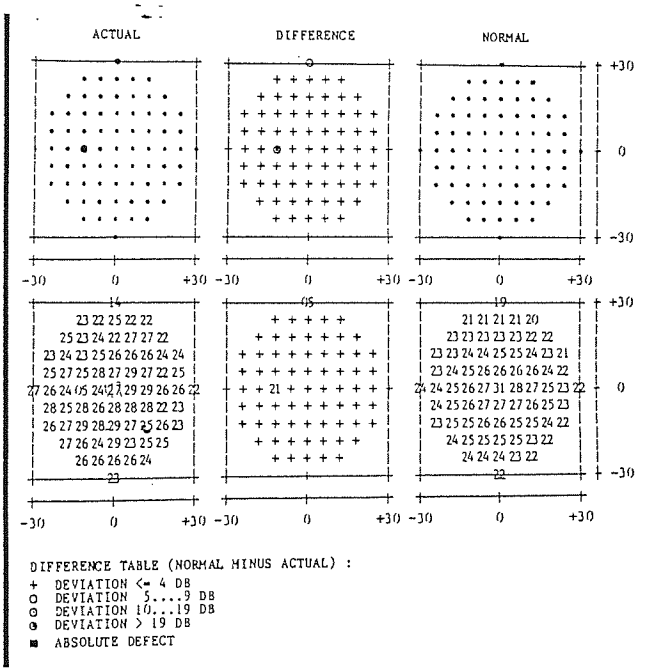
SUBJECT Tre EYE LEFT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD





Information Loss

0 %

SUBJECT FFe (Left Eye)

Visual Field

Examination using the Octopus Programme 31 showed no significant visual field loss. Programme 21 demonstrated a deep superior, peripheral reduction in sensitivity. The midline was not respected, as is usual for chiasmal lesions, but it was impossible to describe the field loss as either temporal or nasal.

The Depression Profile did not demonstrate any information loss in the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Demonstrated a large P100 component at 103 msec which was best over the right occiput. The maximum amplitude was on the midline at 8.71 microvolts. The source derivation distribution gave a source-sink configuration over the left occiput.

11. 30^{o} Right Half Field

Gave a clear response over the right occiput, ipsilateral to the stimulated hemifield, with a P100 component at 102 msec. The maximum response was on the midline at 7.23 microvolts.

III. 30^{o} Left Half Field

Gave a clear response over the left occiput, ipsilateral to the stimulated hemifield, with a P100 component at 87 msec. There is a contralateral negativity at 102 msec. The maximum amplitude was over the midline at 4.75 microvolts which was reduced compared to the right half field result.

IV. 10^{o} Full Field Stimulation

Gave a clear P100 component over all channels at 99 msec with a maximum on the midline at 7.82 microvolts.

V. 10^{o} Right Half Field

Gave a clear ipsilateral P100 component at 95 msec with a maximum on the midline at 6.39 microvolts.

VI. 10^{o} Left Half Field

The response had a poor morphology with a delayed P100 component at 108 msec with a maximum on the midline at 4.01 microvolts.

VII. 3^{o} Full Field Stimulation

Gave a good response with a P100 component at 124 msec with a better response over the right occiput and a maximum

on the midline at 2.70 microvolts.

VIII. 3^{o} Right Half Field

Gave a clear P100 component at 108 msec which was slightly larger over the right, ipsilateral, occiput. The maximum amplitude was on the midline at 3.16 microvolts.

IX. 3^{o} Left Half Field

The response was poor with a possible P100 component at 101 msec and a maximum on the midline at 2.13 microvolts. It could also be argued that there was a PNP-complex with the negative component at 128 msec. This response was largest over the left, ipsilateral, occiput.

FIGURE 6.35

SUBJECT: BV: DOB: 3.8.'26

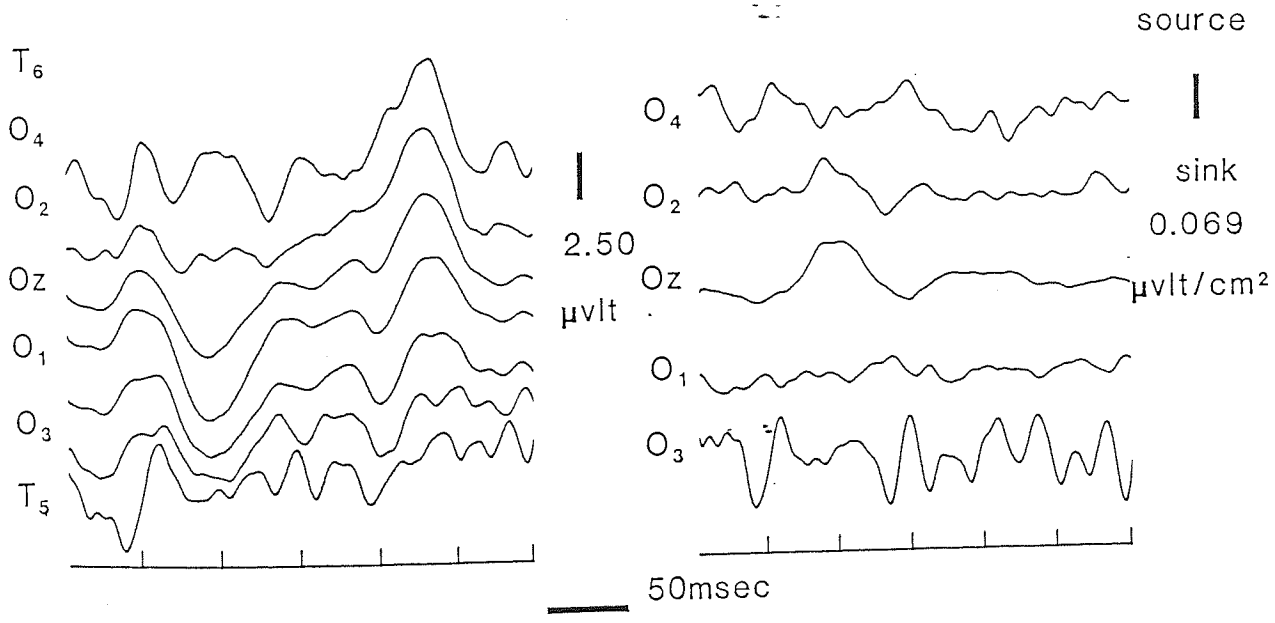
EYE: Right VA: $^{6}/_{24}$

Diagnosis: Large tumour (suspected meningioma) over the pituitary affecting the anterior fossa left of the midline

1. The visual evoked potential to full field stimulation
(Common Reference and Source Derivation)

SUBJECT BV EYE RIGHT

1: VISUAL EVOKED POTENTIAL



SUBJECT BV (Right Eye)

Visual Field

Examination using the Goldmann Bowl Perimeter with the I4e and I2e targets showed an extensive, deep, incongrous, temporal hemianopia without macula sparing. The central 15^{o} were severely affected with the most preserved area of the visual field being the nasal, right half field.

We were unable to quantify the information loss as the patient unfortunately died before an Octopus examination could be performed.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Gave a surprisingly clear P100 component with a latency of 92 msec. The response was larger over the left occiput with no P100 component over the O4 and T6 electrodes. The maximum response was on the midline at 4.58 microvolts. The source derivation distribution showed a source on the midline with a sink over the right occiput at the O4 electrode.

11. 30^{o} Right Half Field

Gave a small, poor response which was slightly clearer over the right, ipsilateral occiput. The P100 component

had a latency of 95 msec.

111. 30^{o} Left Half Field

Gave a clearer ipsilateral response with a P100 component at 89 msec which was larger over the left occiput with a maximum amplitude on the midline at 2.77 microvolts.

FIGURE 6.36

SUBJECT: BV DOB: 3.8.'26

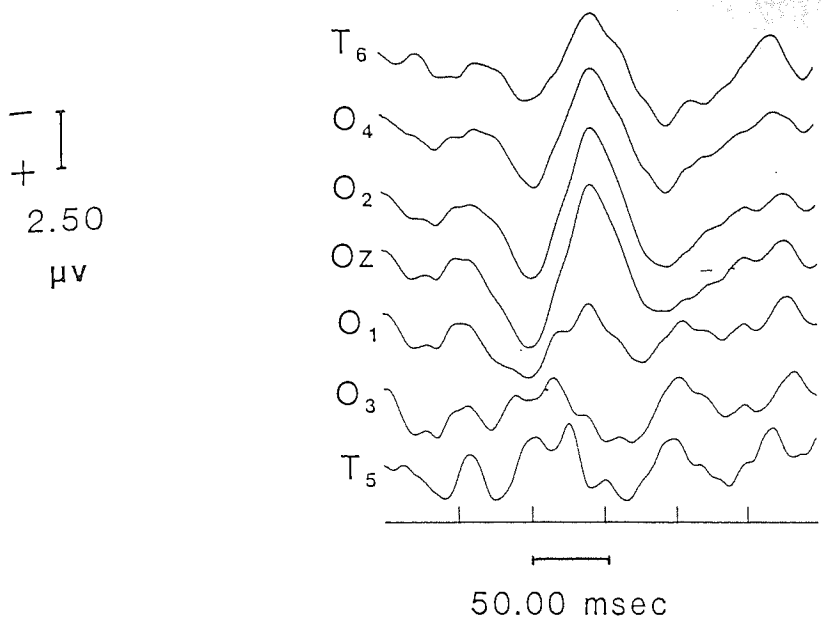
EYE: Left VA: $^{6}/_{9-2}$

Diagnosis: Large tumour (suspected meningioma) over the pituitary affecting the anterior fossa left of the midline

The visual evoked potential to full field stimulation

1. Common Reference
2. Bipolar
3. Source Derivation

1.Common Reference



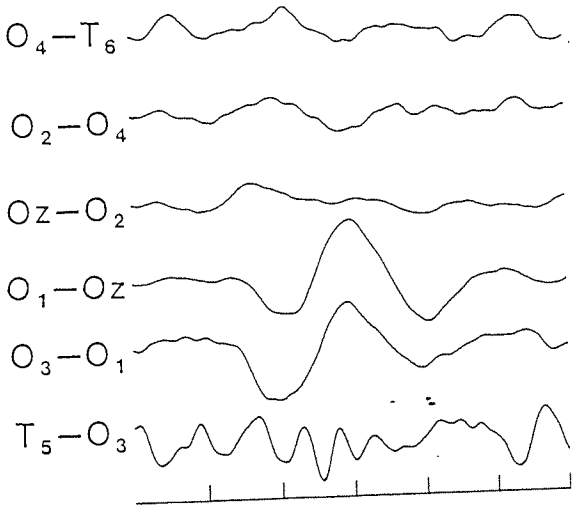
2.50
μv

Subject B.V.

Left Eye

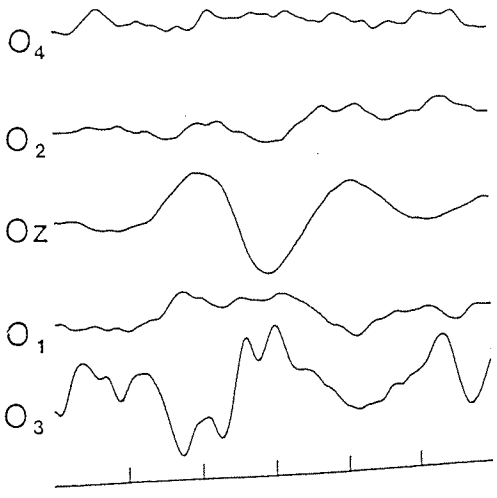
Full Field
Stimulation

2.Bipolar



0.43
μv/cm

3.Source Derivation



0.068
μv/cm²

source

sink

SUBJECT BV (Left Eye)

Visual Field

Examination using the Goldmann Bowl Perimeter with the I4e target showed a deep visual field loss with only a small amount of the nasal field remaining. We were unable to quantify the information loss.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Gave a surprisingly clear P100 component at 99 msec with a maximum amplitude on the midline of 4.35 microvolts. There was no response over the T5 and O3 electrodes. The source derivation distribution demonstrated a source on the midline with a sink over the O3 electrode.

11. 30^{o} Right Half Field

Gave an ipsilateral response with a clear P100 component at 96 msec over the right occiput. The maximum amplitude was over the midline at 3.71 microvolts. The source derivation distribution gave a source on the midline with a contralateral sink over O3.

111. 30^{o} Left Half Field

Gave a small, poor response with a delayed P100 component

of poor morphology at 111 msec. The maximum amplitude was over the ipsilateral O3 electrode at 0.99 microvolts.

6.3.2 Discussion

The six subjects and eight eyes examined in this group provided an interesting cross-section of typical chiasmal lesions. They ranged from the very severe with extensive field loss (Subject BV) to the barely significant demonstrating no visual field loss within the central 30^{o} (Subject FFe). It was immediately apparent (Table 6.5) that there was a strong correlation between the degree of information loss, the percentage of striate cortex affected, and the diagnostic value of the visual evoked potential. In the four eyes exhibiting an information loss of greater than 20% the 30^{o} full field stimulus was conclusive, ie. a reduction of more than 50% between the O3 and O4 electrodes, and was supported by half field stimulation. Full field stimulation using the smaller field and check sizes were not helpful in subject AH and were, if anything, misleading giving a maximum result over the opposite occiput. By relating these results to the normative half field distributions discussed in Chapter 5 it may never be established whether they were "incorrectly lateralised" or, in fact, still ipsilateral to the fully stimulated hemifield owing to the large asymmetry of the normal scalp distribution found in many subjects.

The four eyes discussed all displayed a degree of field loss within the central 15^{o}, the area stimulated during the recording of the VEP. In all cases the source derivation distribution gave a source-sink configuration

TABLE 6.5

Summary of the Percentage Information Loss and the Diagnostic Value of the Different Stimulus Parameters used to Elicit the VEP

SUBJECT	INFORMATION LOSS	VEP			
		30^{o} FULL FIELD	30^{o} HALF FIELD	10^{o}	3^{o}
BV(R)	High	◆	◆	-	-
BV(L)	High	◆	◆	-	-
DG(R)	29.34%	◆	◆	◆	X
AH(L)	23.04%	◆	◆	X	X
DG(L)	12.83%	X	◆	X	X
FH(R)	11.32%	X	◆	X	X
RG(L)	2.05%	X	X	X	X
FFe(L)	0%	X	◆	◆ ½ field	◆ ½ field

◆ Diagnostically Conclusive

X Not Conclusive

- Not Examined

TABLE 6.5

which was contralateral to the normally stimulated hemifield and helped clarify the result.

The remaining four eyes all possessed an information loss which was below 15% with the central 15^{o} being relatively unaffected. Full field stimulation could not be considered diagnostically conclusive for any of these subjects. Half field stimulation was more useful in three of the four with subject RG giving results within normal limits throughout. This would still suggest that, when using half field stimulation, the VEP was relatively sensitive to the detection of such lesions as it could give an abnormal or suspicious result by stimulation of an area of the retina which appeared unaffected when examining the differential light threshold by perimetry. The technique as used in this study, was somewhat limited, however, as it would appear to struggle in the detection of chiasmal lesions unless they are advanced and consequently affecting large portions of the central visual field. The results would advocate the use of half field stimulation in a normal clinical routine even if the full field result appeared to be within normal limits. Small field and check sizes do not appear to add any useful clinical information.

FIGURE 6.37

SUBJECT: LH DOB: 23.3.'47

EYE: Right VA: $^{6}/_{6}$

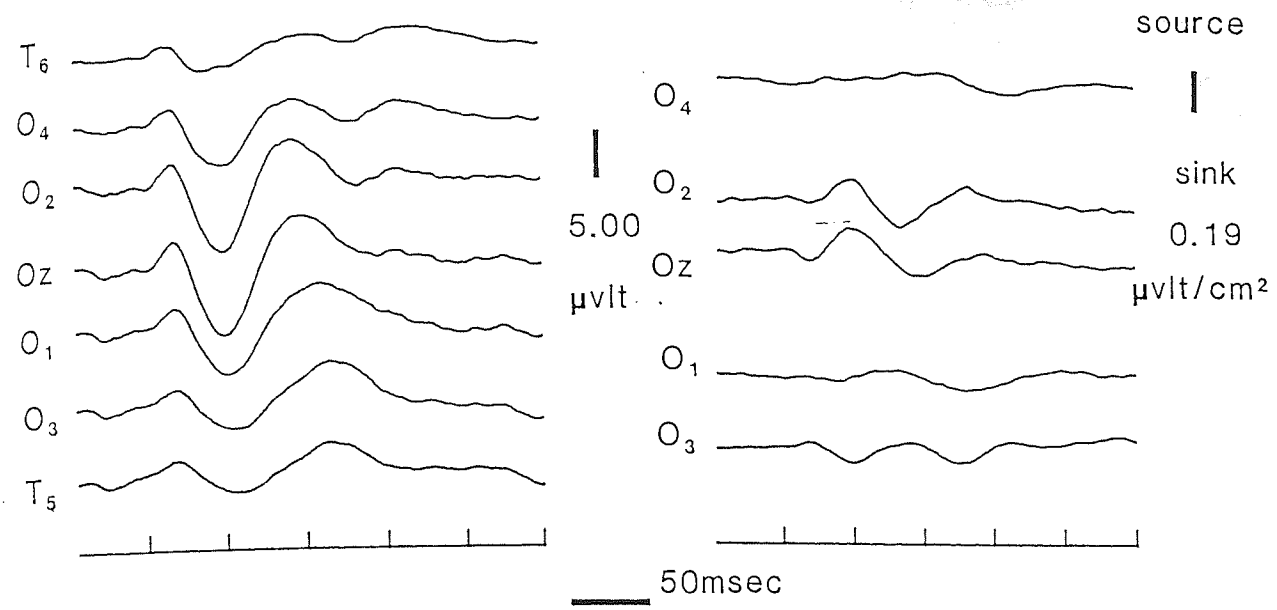
Diagnosis: Suspected space occupying lesion in supra-tentorial area

1. The visual evoked potential to full field stimulation
(Common Reference and Source Derivation)

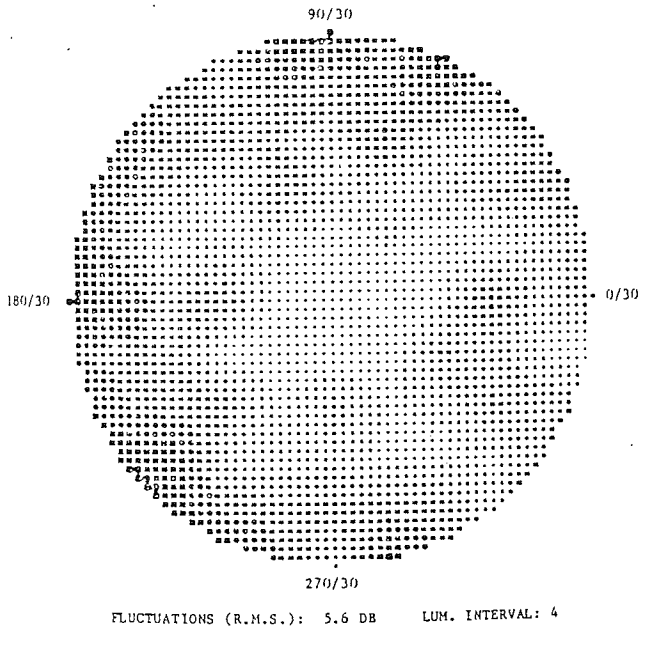
2. The visual field using the Octopus Programme 31

SUBJECT LH EYE RIGHT

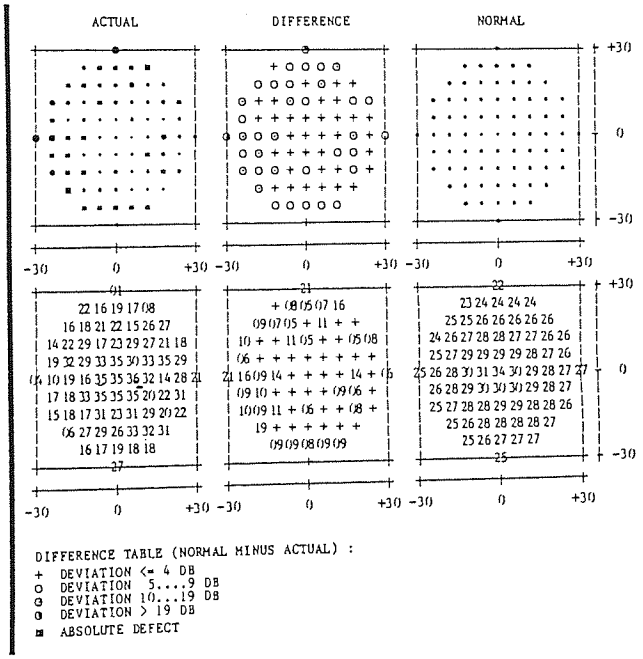
1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



FLUCTUATIONS (R.M.S.): 5.6 DB LUM. INTERVAL: 4



DIFFERENCE TABLE (NORMAL MINUS ACTUAL) :

+ DEVIATION <= 4 DB
O DEVIATION 5....9 DB
@ DEVIATION 10...19 DB
@ DEVIATION > 19 DB
■ ABSOLUTE DEFECT

Information Loss

11.2 %

SUBJECT LH (Right Eye)

Visual Field

Examination using the Octopus Programme 31 showed a generalised, peripheral reduction in sensitivity, particularly in the nasal and superior visual field, and the blind spot was slightly enlarged. The central 15^{o} was only marginally affected at its periphery.

The Depression Profile quantified an information loss of 11.2% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Demonstrated a P100 component at 97 msec which was largest over the right occiput with a reduction in amplitude of over 50% between the O4 and O3 electrodes. The maximum amplitude was found on the midline at 5.82 microvolts. There was no peripheral negativity over the left occiput but the source derivation showed a scalp current sink over the O3 electrode. This is not normally seen in the full field response.

11. 30^{o} Right Half Field

Gave a clear ipsilateral response with a P100 component at 89 msec. The maximum amplitude was over the Oz

electrode at 3.93 microvolts. The source derivation demonstrated a maximum scalp current source on the midline and a sink over electrode O3, contralateral to the stimulated hemifield.

III. 30^{o} Left Half Field

Gave a slight ipsilateral response but with a delayed latency at 102 msec. The maximum response was over the midline at 3.25 microvolts. The source derivation demonstrated a slightly contralateral source over electrode O2 but there was no clear scalp current sink.

IV. 10^{o} Full Field Stimulation

Gave a clear P100 component at 98 msec which was largest over the right occiput with a maximum amplitude over the O2 electrode at 5.78 microvolts. The amplitude was reduced by over 50% between O3 and O4. The source derivation distribution demonstrated a source over the O2 electrode with a sink over the left occiput at electrode O3.

V. 3^{o} Full Field Stimulation

Gave a P100 component at 112 msec which was relatively symmetrical around the midline with a maximum amplitude at electrode Oz of 3.58 microvolts. The source derivation distribution demonstrated a source on the midline but there was no clear scalp current sink.

FIGURE 6.38

SUBJECT: LH DOB: 23.3.'47

EYE: Left VA: $^{6}/_{5}$

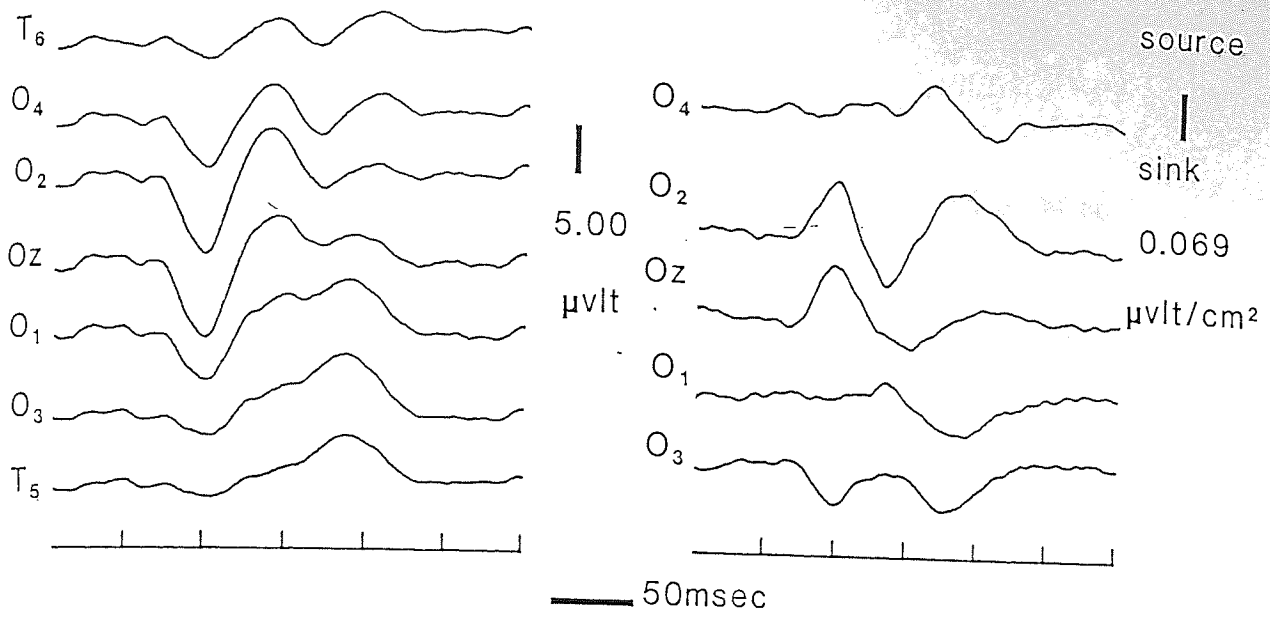
Diagnosis: Suspected space occupying lesion in supra-tentorial area

1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

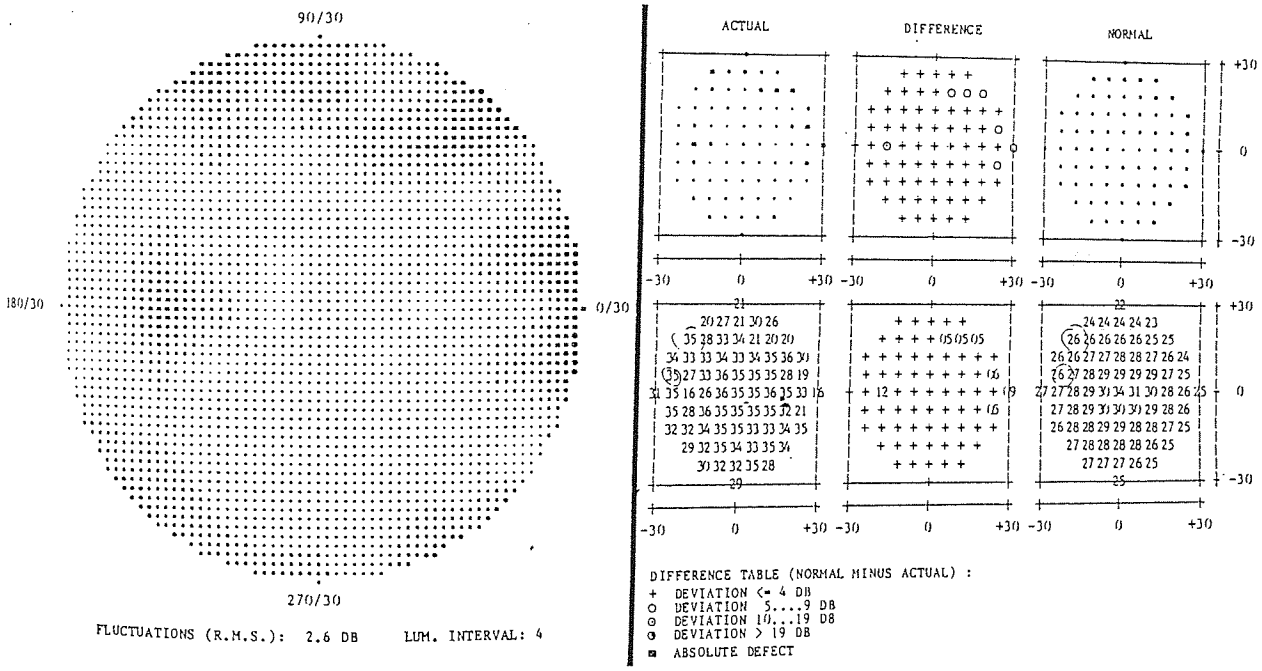
2. The visual field using the Octopus Programme 31

SUBJECT LH EYE LEFT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



Information Loss

1.12 %

SUBJECT LH (Left Eye)

Visual Field

Examination using the Octopus Programme 31 showed a very slight peripheral reduction in sensitivity in the nasal field. The central 15^{o} was not affected.

The Depression Profile quantified an information loss of 1.12% in the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Gave a P100 component at 99 msec which was much larger over the right occiput with an approximately 50% reduction in amplitude between electrodes O3 and O4. The maximum amplitude was over the O2 electrode at 6.84 microvolts. The source derivation distribution showed a source over the O2 electrode with a scalp current sink over the O3 electrode.

11. 30^{o} Right Half Field

Gave a clear ipsilateral response with a P100 component at 95 msec. The maximum amplitude was between the midline andthe O2 electrode at 4.00 microvolts. The source derivation distribution gave a midline source with a sink over the contralateral O3 electrode.

111. 30^{o} Left Half Field

Gave a clear ipsilateral response but again demonstrated a delayed latency at 102 msec. The maximum amplitude was over the midline at 3.52 microvolts. The source derivation gave a source over the contralateral O2 electrode but there was no recognisable sink.

1V. 10^{o} Full Field Stimulation

Gave a clear P100 component at 99 msec which was largest over the right occiput with a maximum over the O2 electrode at 3.53 microvolts. The source derivation distribution showed a scalp current source over the O2 electrode with no recognisable sink.

V. 3^{o} Full Field Stimulation

Gave a P100 component at 109 msec which was relatively symmetrical around the midline with a maximum amplitude at electrode Oz of 4.50 microvolts. The source derivation distribution demonstrated a source on the midline.

Comment

The VEP results from the right eye showed a reduction over the left occiput and a delayed response from the left half field which was consistent with a nasal visual field loss. The left eye gave a striking delay over the left

occiput. The VEP results suggested a left homonymous hemianopic defect whereas the visual field results showed if anything a binasal hemianopia although the left eye was only marginally affected.

A CT-scan was subsequently performed but no abnormality was found. The patient is to be reviewed periodically but her consultant has attributed the results as being migrainous in origin.

Discussion

Subject LH was of particular interest and demonstrated the great care required in interpreting the results obtained for both perimetric and electrophysiological investigations. She had been experiencing frequent transient episodes of peripheral field loss associated with extreme tiredness causing her to lie down and sleep. Owing to the CT-scan results the consultant considered this to be an atypical form of migraine.

Harrington (1976) reports on several patients who have exhibited a permanent homonymous hemianopia following many transient attacks, although this is considered to be rare. The most usual field loss associated with migraine is a transient homonymous hemianopia. Subject LH had not reported a recent attack on the day of the visual field examination but had certainly experienced many previous attacks and it is possible that there was a permanent field loss however slight. It is clear from the symptoms described however, that an attack causes a far greater degree of field loss. Further confusion was caused by the field result from the left eye. The loss was marginal but suggested a nasal defect. Binasal hemianopia associated with migraine has not been prominantly reported in the literature.

The visual evoked potentials suggested a left homonymous hemianopia with a reduction in amplitude of over 50% between the O3 and O4 electrodes following full field

stimulation of either eye and a slightly reduced and delayed response following left half field stimulation. There have been relatively few reports of the effects of migraine on the VEP. Regan and Heron (1970) found a similar amplitude reduction in 3 out of 5 patients with migraine following half field stimulation. MacLean, Appenzellar, Cordaro and Rhodes (1975) recorded a significant occipital asymmetry in all 4 subjects with a history of lateralised visual aura associated with migraine, whilst undergoing an attack. Two of the four subjects gave a similar asymmetry during a headache free interval. Richey, Kooi and Waggoner (1966) using flash stimulation on 50 migraine subjects found a significant reduction of the P2 component. Similarly lateralised EEGs have been reported in patients with hemiplegic migraine (Harding, Debney and Maheshwari 1977). Three children all showed "marked lateralised and localised slow wave abnormality" within 3 days of a severe attack. One of the 3 continued to show a similar abnormality well after an attack although the attacks were more frequent.

The evoked potentials recorded from subject LH would therefore appear consistent with a diagnosis of migraine but it is important that serial recordings should be taken as suggested by Harding et al. (1977) for the EEG.

This case record examplifies the way in which perimetry and clinical electrophysiology should be considered as useful tools of the clinician but that care must be taken when considering results in isolation.

6.4 Post Chiasmal Lesions

6.4.1 Results

This proved to be the most difficult group of subjects to find resulting in only one over the two and a half year period.

FIGURE 6.39

SUBJECT: PH DOB: 26.3.'42

EYE: Right VA: $^{6}/_{6}$

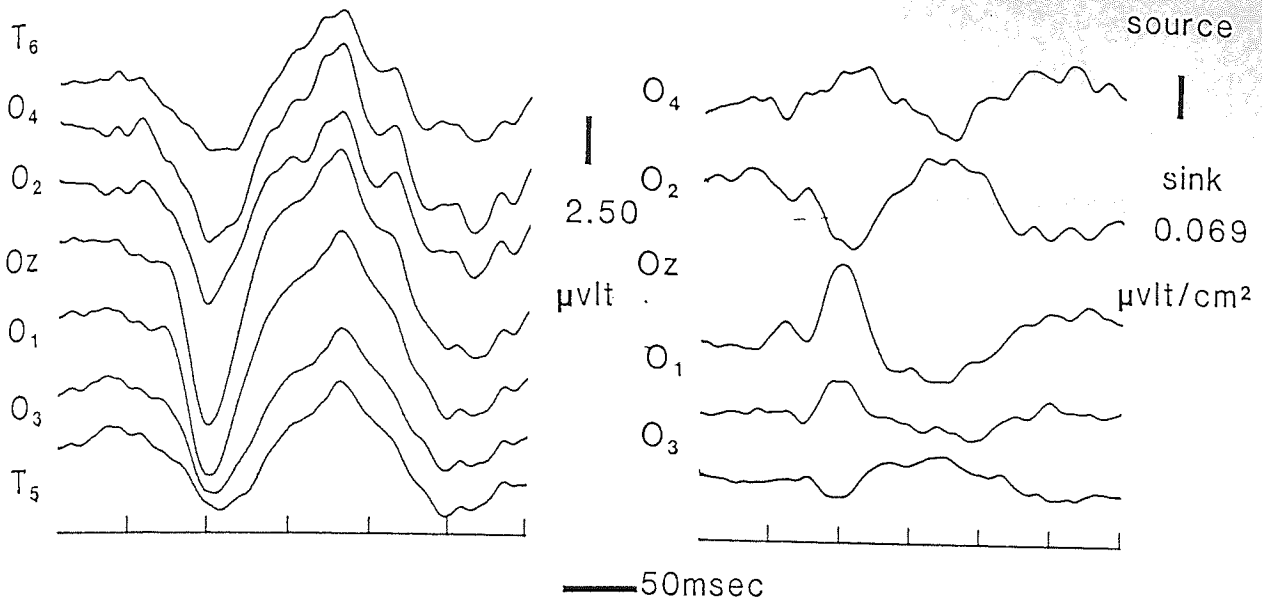
Diagnosis: Suspected Vascular Accident

1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

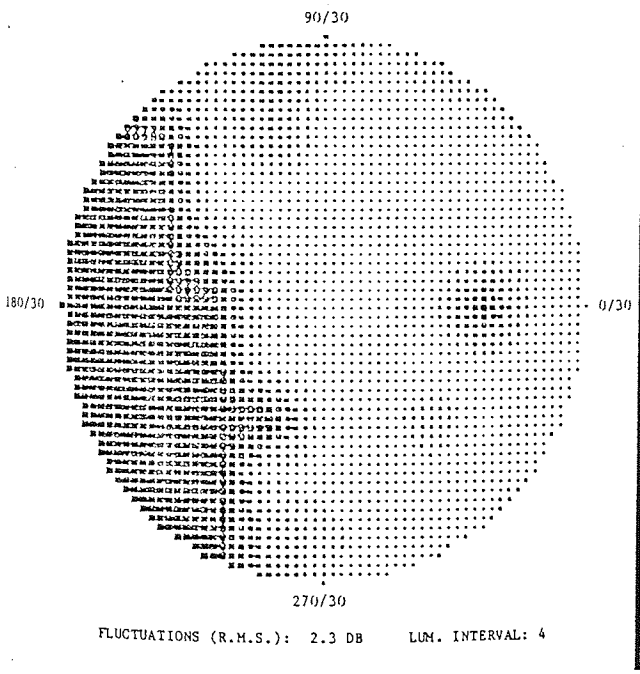
2. The visual field using the Octopus Programme 31

SUBJECT PH EYE RIGHT

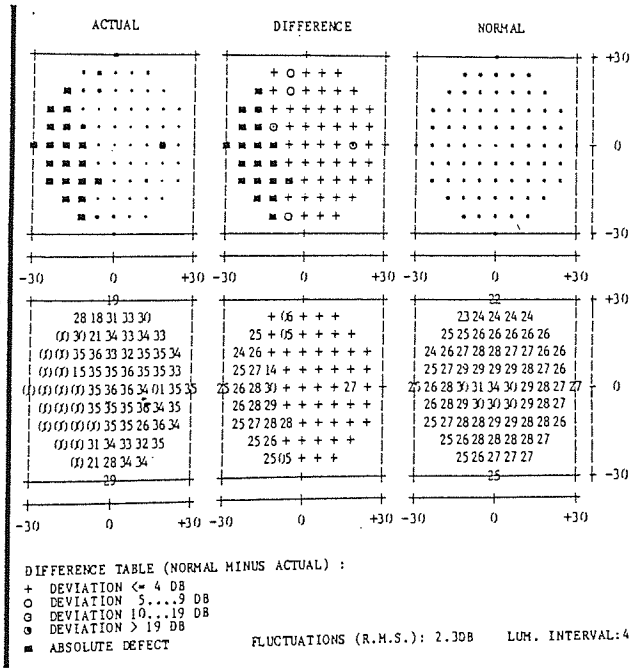
1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD



FLUCTUATIONS (R.M.S.): 2.3 DB LUM. INTERVAL: 4



FLUCTUATIONS (R.M.S.): 2.3DB LUM. INTERVAL:4

Information Loss

18.23 %

SUBJECT PH (Right Eye)

Visual Field

Examination using the Octopus Programme 31 showed a deep, steep margined hemianopic defect in the nasal visual field. The central 15^{o} were relatively unaffected.

The Depression Profile quantified an information loss of 18.23% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Gave a clear P100 component at 99 msec with a maximum amplitude on the midline at 6.50 microvolts. The source derivation distribution gave a source over the midline.

11. 30^{o} Right Half Field

Gave a small but clear ipsilateral P100 component at 101 msec with a maximum over the midline of 1.46 microvolts. The peripheral contralateral T5 and O3 electrodes demonstrated a negativity at 98 msec. The source derivation distribution gave a source on the midline with a contralateral sink over the O3 electrode.

111. - 30^{o} Left Half Field

Gave a clear ipsilateral P100 component at 98 msec with a maximum amplitude over the midline at 2.68 microvolts. The peripheral, contralateral T6 and O4 electrodes demonstrated a negativity at 97 msec. The source derivation distribution gave a source over the midline with a contralateral sink over the O4 electrode.

FIGURE 6.40

SUBJECT: PH DOB: 26.3.'42

EYE: Left VA: $^{6}/_{6-1}$

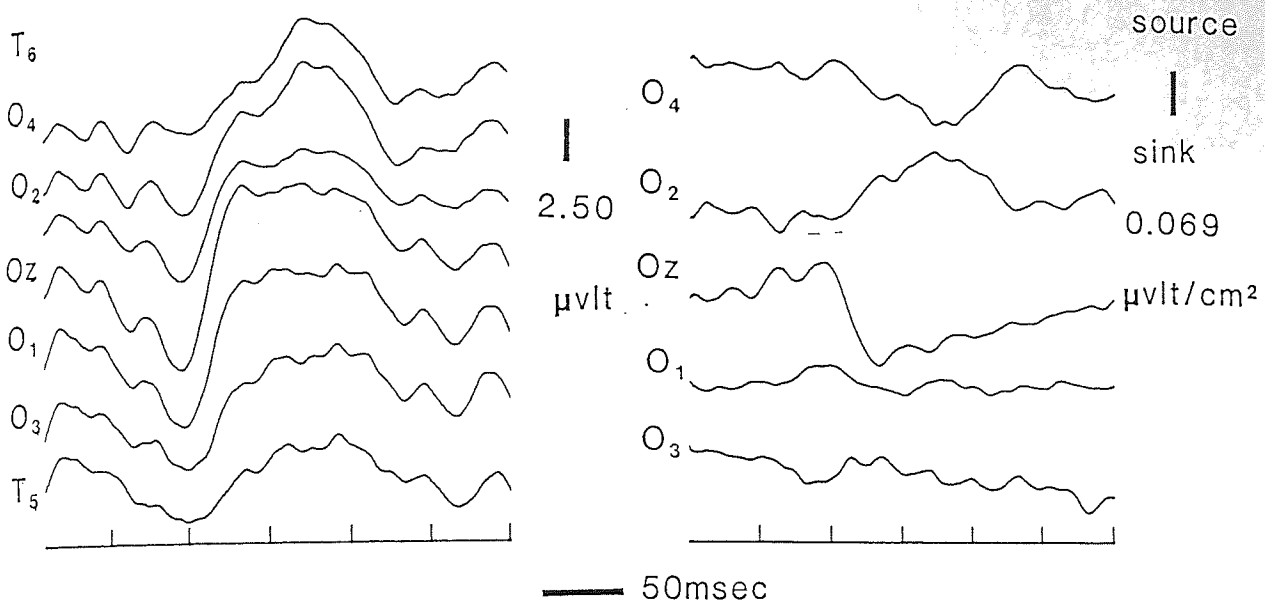
Diagnosis: Suspected Vascular Accident

1. The visual evoked potential to full field stimulation
   (Common Reference and Source Derivation)

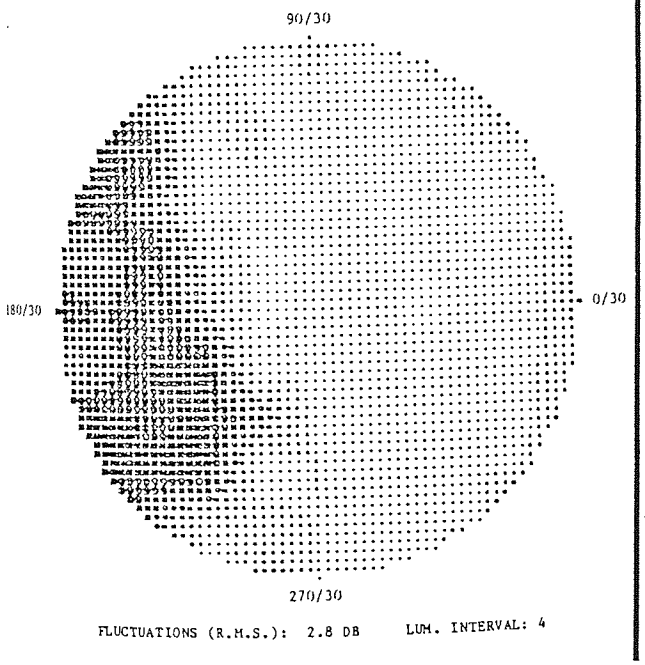
2. The visual field using the Octopus Programme 31

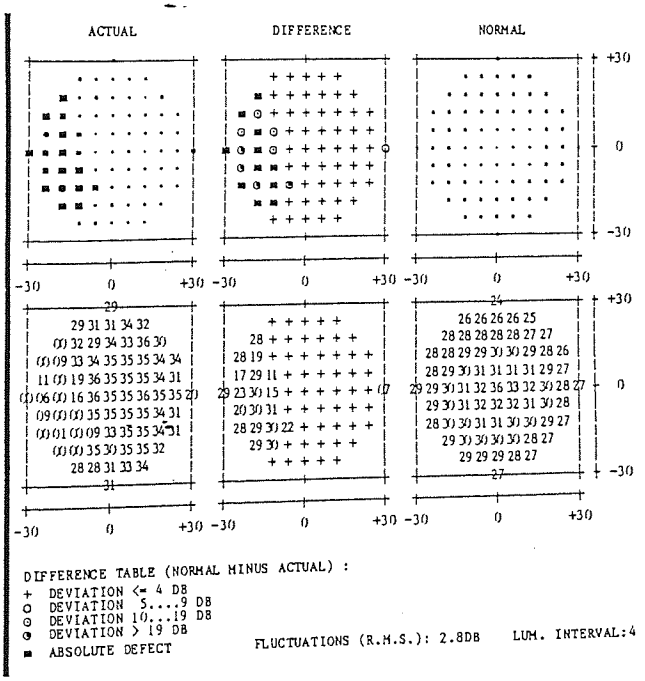
SUBJECT PH EYE LEFT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD





Information Loss

16.27 %

SUBJECT PH (Left Eye)

Visual Field

Examination using the Octopus Programme-31 showed a deep, steep margined hemianopic defect in the temporal visual field. The central 15^{o} was relatively unaffected.

The Depression Profile quantified an information loss of 16.27% for the central 30^{o}.

Visual Evoked Potential

1. 30^{o} Full Field Stimulation

Gave a clear P100 component at 94 msec with a maximum amplitude on the midline at 4.71 microvolts. The source derivation distribution gave a source on the midline.

11. 30^{o} Right Half Field

Gave a P100 component at 100 msec which had a clearer morphology over the right occiput suggesting an ipsilateral response although the amplitude was approximately equal over each occiput. The left occiput has a contaminated P100 component with a small abc complex. The maximum amplitude was over the midline at 2.68 microvolts. The source derivation distribution showed a midline source with no clear sink.

111. 30^{o} Left Half Field

Gave a clear ipsilateral P100 component at 92 msec with a maximum amplitude on the midline at 3.96 microvolts. The source derivation distribution showed a midline source with a contralateral sink over the O4 electrode.

Comment

The visual evoked potentials were entirely within normal limits. The visual fields showed a clear, left sided, homonymous hemianopia which was both deep and congrous with no central involvement indicating a lesion in the right visual cortex. The central 15^{o} of each field was relatively unaffected which may explain the lack of significant findings from the VEP investigation.

6.4.2 Discussion

Subject PH had undergone a heart transplant operation at Papworth Hospital 7 months prior to the above investigations. Two months before the operation he had experienced a severe visual disturbance losing all visual perception for several seconds. The sight gradually recovered in the right eye but he was still complaining of peripheral loss in the left eye. The condition was not investigated at the time as there were more serious worries over the patient's general health. The results obtained suggest a vascular accident involving the right visual cortex, but is presently being further investigated by the referring consultant.

Unfortunately, little can be added to the debate on the usefulness of the VEP in post-chiasmal lesions as only the one subject was examined. The result would tend to support the observation of Celesia et al. (1983) that only by preferentially stimulating the periphery with the detection rate of VEP's for post-chiasmal lesions be improved.

CHAPTER 7

CONCLUSION

The inter relationship between the visual evoked potential and the visual field has been investigated using both patients suffering from a variety of visual field abnormalities and normal subjects with simulated scotomata. From the literature there arose two areas of conjecture which presented frequently, and were responsible for much of the experimental design. The first involved the lateralisation of the VEP elicited by half field pattern reversal stimulation. The second concerned the nature of the PNP-complex commonly observed in particular lesions of the visual pathway which has previously been labelled the "scotomatous negativity" (Halliday 1976). In an attempt to resolve these anomalies new techniques have been adapted or developed and a number of new questions have been posed.

It was initially considered desirable to establish the most sensitive perimetric technique available for the assessment of the visual field. This led to a comparative and validative study of the Octopus Automated Perimeter performed in collaboration with a team of consultants, clinicians and technicians from Aston University and the Birmingham and Midland Eye Hospital. The measurement of the differential light threshold, particularly using programme 31 of the Octopus, offered many advantages over the more commonly available perimetric techniques. The

results were found to be more consistent, accurate and often quicker using the Octopus even when considering a wide range of patient abnormalities. The data was also more readily available for further analysis and manipulation.

One such manipulation resulted in the spirally scanned depression profile. The technique was initially used as a way of illustrating the method of visual field quantification developed from the Graticule of Drasdo (Drasdo and Peaston 1982). In attempting to score the level of visual field abnormality in terms of loss of information channel capacity, or reduction in cortical neural representation, it was hoped to relate the resultant percentage information loss with the resultant scalp distribution of the VEP. The depression profile, however, exceeded our expectations. The diagnostic potential of the shape factor has been tentatively proposed in Chapter 3 and the illustrations in Chapter 6 have demonstrated how helpful the profile can be, particularly in a marginal defect. It is proposed to continue development of the depression profile and scoring of mean information loss when using more standard perimetric grids. Some of the advantages of visual field quantification would thus be lost being based on arbitrary sampling. Such graphical and numerical displays might prove an important addition to the standard grey scale and numerical printouts commonly available on the present generation of computer assisted perimeters. Alternatively it might prove possible

to extrapolate grids based on specific projections of the visual field allowing a more scientifically based quantification (eg. the neural or retinal representation), without requiring additional examination of the visual field. If such quantifications can then be combined with information regarding the short and long term fluctuations of the individual patient, the assessment of the visual field will at least have kept pace with and taken advantage of the technology at present available.

This view has been supported in a recent publication (Flammer, Drance, Augustiny and Fankhauser, 1985) submitted subsequent to the development of these techniques. They have proposed similar methods of quantification which they have, at present, used in relation to glaucoma. The assessment of the visual field survival (Chapter 3) has so far remained unexplored but may prove to be the most useful application of the depression profile. Small localised progressions of a visual field defect are likely to be detected without necessarily showing a significant increase in the percentage information loss.

Scalp topography of the VEP presents many complications in its analysis. There have been numerous attempts to extrapolate the cortical origins from the scalp potential by dipole modelling (Chapter 4). Hjorth (1975) introduced a method for the manipulation of the electroencephalogram call The Source Derivation. His technique was adapted for further analysis of the scalp potential field recorded

as the VEP (Chapter 4). By minimising the influence of the reference electrode and providing a spatially finer mapping of the scalp potential the source derivation technique has proved extremely useful as an adjunct to routine clinical and experimental techniques. The information can be instantaneously computed, along with the bipolar distribution, from the common reference distribution. The name however, may unfortunately be misleading as the technique is simply a manipulation of raw data recorded as the scalp potential field. It does not purport to rival dipole techniques and identify cortical source and sinks but, within its own limitations, it has helped to unravel the controversy of the lateralisation of the half field response (Clement, Flanagan and Harding 1985).

The normative studies outlined in Chapter 5 gave rise to some rather surprising results. Previous literature had suggested (1.2.1) that the scalp topography of the VEP following full field stimulation was symmetrical around the midline. It would appear, however, that there is a bias towards the scalp potential recorded over the left occiput. This is not so apparent when using large field and check sizes, but is conclusive when the polar projections are preferentially stimulated. It is proposed that this topographic asymmetry is due to the foveal projections at the polar occipital cortex. The asymmetry in the scalp topography is also reflected in the distribution of the half field response. It would appear, if simulated scotomas can be related to real scotomas, that

it is easier to detect a left sided hemianopia than a right sided one.

When using a 50% asymmetry in amplitude as the criterion for abnormality only large field and check sizes gave reliable results, at electrodes at least 20% from the midline. The results using small field and check sizes were more variable and the lateralisation of the response more difficult to determine. The results obtained following simulation of a central 3^{o} scotoma provided further evidence that the scalp potential asymmetry is caused by the foveal projections. When the central 3^{o} was masked the scalp topography was remarkably symmetrical around the midline. There was no evidence to suggest that a central scotoma causes a PNP-complex.

The scalp potential distributions following stimulation by the upper and lower fields confirmed the delay in latency when the upper field stimulus was used. The clinical implications of this phenomenon suggested by Wildberger (1984a,b) were fully endorsed. When small field and check sizes were used there was a resultant skew in the scalp distribution with the maximum scalp potential appearing over the more anterior electrodes following a lower field stimulus. The largest field and check size used gave a scalp distribution which did not indicate a significant difference between the two. There was no evidence of consistent phase-reversal of the P100 component over the more anterior electrodes following an upper field stimulus.

Simulation of relative half field scotomas indicated that the detection of such field defects may prove extremely difficult. Reduction in the mean luminance when the right half field was stimulated indicated a slightly more lateralised and reduced response when large field and check sizes were used. The effect of a reduction in the mean luminance of a stimulus involving a small field and check size was, however, less predictable, the response at times being larger in amplitude. This phenomenon clearly requires further research using a range of stimulus luminance levels.

The relationship between the percentage information loss, or reduction in information channel capacity, and the extent of the VEP abnormality suggested that there was no form of simple, diffuse summation between scalp potential and cortical generators. It has however, proved possible to quantify the degree of scalp potential attenuation for M-scaled full field stimuli between 3^{o} and 30^{o}. Reasons for this attenuation have been proposed as depth, orientation and synchrony of the generating cortical sources, but we have been unable to define the effect of any one factor in isolation. The half field responses did not summate to give the full field response.

The major criticism of this study is the small number of subjects investigated. Within the constraints of time and laboratory availability, expansion of the study was not logistically feasible. It may have been preferable,

with hindsight, to have investigated a single eye of ten individuals but when designing the experiments, an investigation of interocular differences was considered to be important. In spite of the small numbers involved the results obtained have raised several important issues worthy of more extensive investigation. The ten eyes in five subjects investigated constitute however a larger topographical study than many previously reported, especially considering the number of stimulus conditions used. It should now be possible to investigate with larger population samples, many of the results discussed more fully in Chapter 5.

The results obtained from patients exhibiting pre-chiasmal lesions, outlined in Chapter 6, confirmed that the PNP-complex is not scotomatous in nature, as suggested by Halliday (1976), but is more likely to be related to specific diseases (Harding and Crews 1982). It is intended to investigate patients exhibiting a PNP-complex further to establish which psychophysical tests are affected and the way in which these may be related to the VEP scalp topography. The literature (see 6.2.2) suggests that both spatial and temporal modulation transfer functions should be studied.

A strong correlation between the percentage information loss and the diagnostic value of the visual evoked potential was shown in patients exhibiting chiasmal lesions. The advantage of topographic VEP recordings and half field stimulation became apparent and the source

derivation technique helped to clarify many of the results. Small field and check sizes did not appear to add any clinically useful information.

It is important that the clinical study undertaken be expanded, particularly for the post-chiasmal group. With the advent of extra channel capacity on the new generation of evoked potential equipment (16 + channels) such investigations will become quicker and easier with both the medial and transverse montages simultaneously recordable. This will also facilitate more elaborate investigations of the source derivation. It would be desirable to compare the distribution obtained by the three dimensional source derivation technique originally proposed by Hjorth (1975) and the two dimensional approach developed by Clement et al. (1985) and used in this thesis. Celesia et al. (1983) has suggested that the VEP will only show a better detection rate in post chiasmal lesions if the peripheral retina can be preferentially stimulated. The correlation between the degree of field loss and the VEP results for patients with chiasmal lesions and the results from the single patient examined in the post chiasmal group would tend to support this observation.

It is clear that the new technology available can greatly assist in the understanding of the VEP. It is both ironic and timely that as this thesis neared completion both Blumhardt (1985) and Holder (1985) published articles

re-iterating their opinion on the relationship between particular categories of visual field defects and scalp potential distribution recorded by different techniques. The studies within this thesis have used a common reference montage, similar to that of Blumhardt's, and yet have not been in agreement with all of his interpretations and conclusions. Figures 7.1 and 7.2 demonstrate the contralateral lateralisation found in routine clinical investigations at the Neurophysiology Unit at Aston University, when a widely spaced bipolar montage (occipital-sylvian, occipital-parietal) was used. The results were clinically useful and entirely predictable, particularly when the phase-reversal technique of Harding (1974) was used, yet the response appeared over the occiput opposite to that expected using common reference recording. It has been proposed (Chapter 1) that the relative activity of the C3 and C4 electrodes used in this montage may in fact increase the sensitivity in the scalp current flow. Further research preferably by simultaneous recording is required to compare the two methods. Such a comparative study was not undertaken within this thesis, but with the recent proliferation of 16 channel evoked potential equipment such comparisons could be more easily made. The examples illustrated simply underline the importance of understanding the potentials recorded, without necessarily lauding or denigrating any particular technique. It may well prove impossible to standardise VEP techniques on a global scale and this may also not be particularly desirable since investigations using different reference and bipolar montages can be advantageous. It has certainly

FIGURE 7.1

SUBJECT: PS DOB: 6.12.'27

EYE: Right and Left -- VA: R. 6/24-1
L. 6/18-1

Diagnosis: Binasal Hemianopia (?aetiology)

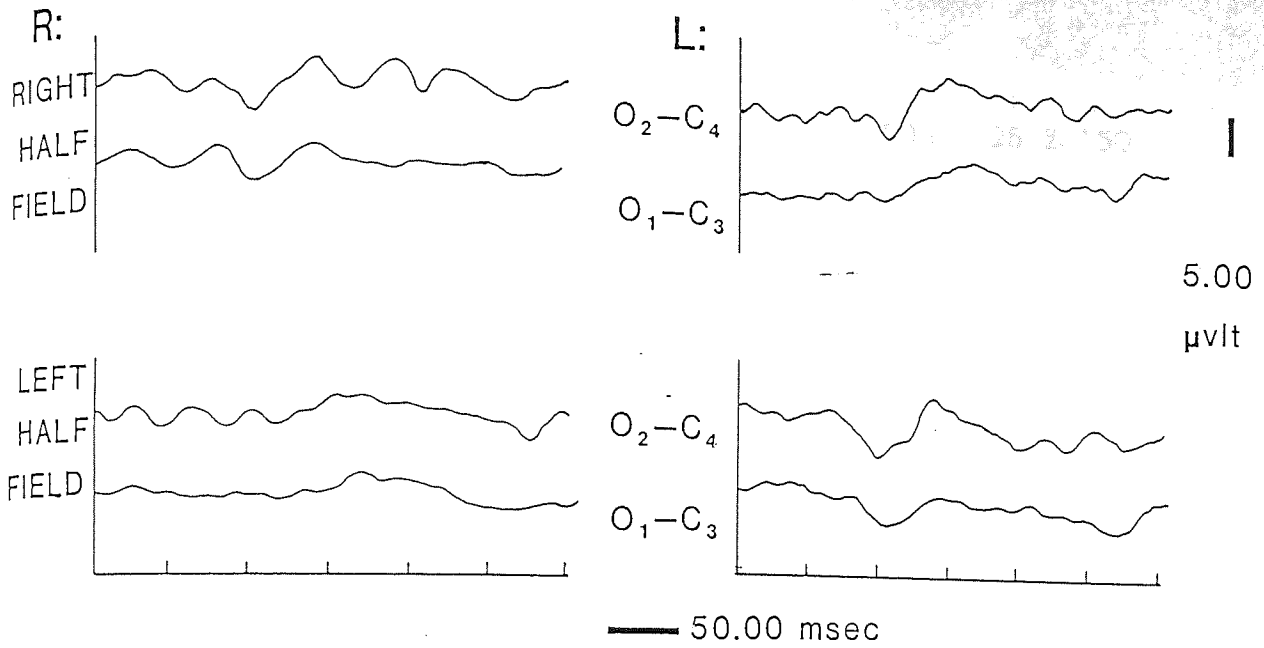
1. The visual evoked potential to half field stimulation
(Occipital-sylvian, occipital-parietal montage)

2. The visual field using the Octopus Programme 21

SUBJECT PS

EYE RIGHT & LEFT

1: VISUAL EVOKED POTENTIAL



2: VISUAL FIELD

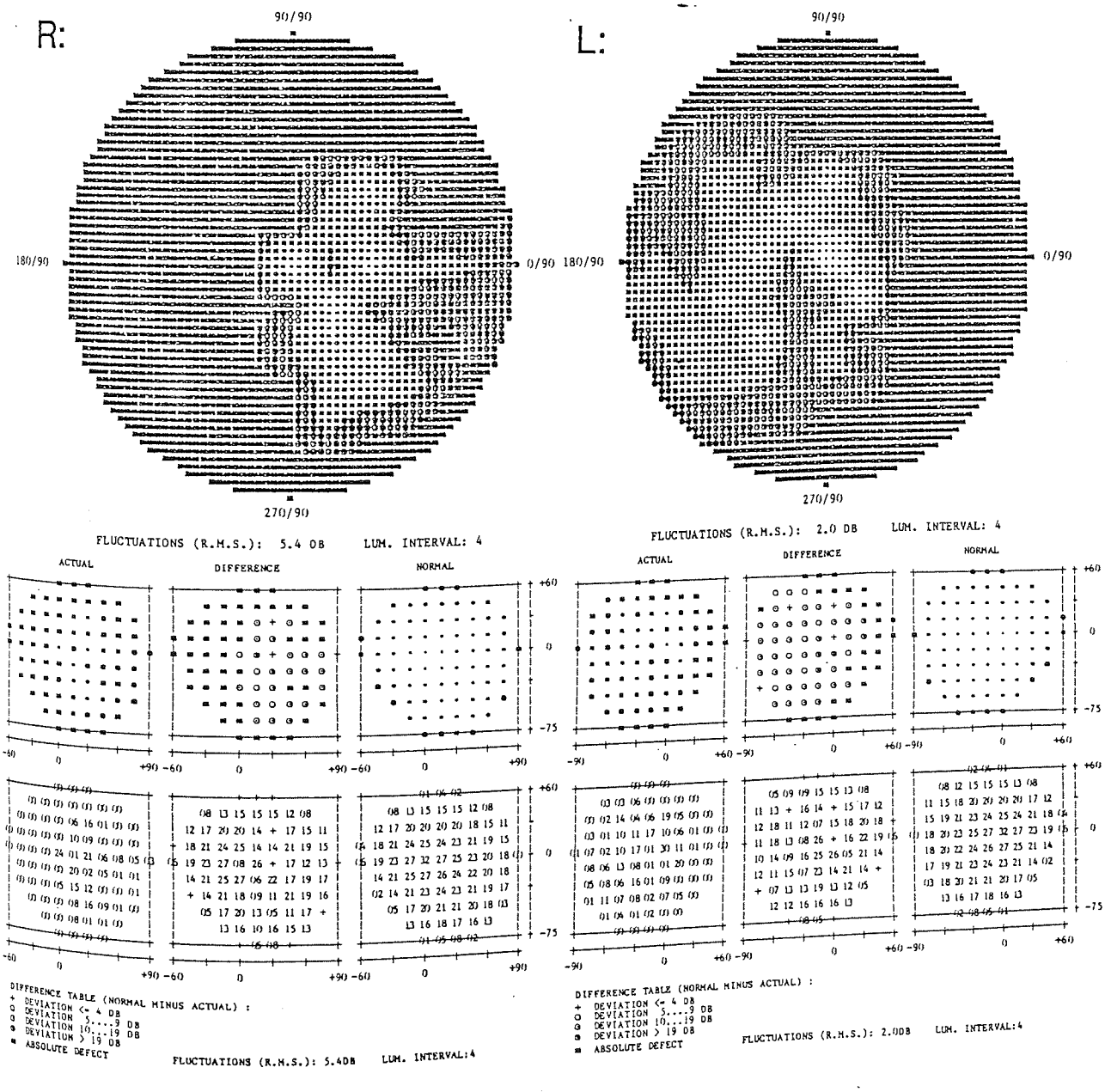


FIGURE 7.2

SUBJECT: VB DOB: 25.2.'50

EYE: Right and Left -- VA: R. $^{6}/_{6}$ L. $^{6}/_{6}$

Diagnosis: Tumour affecting right optic tract

1. The visual evoked potential to full field stimulation
   (Occipital-sylvian, occipital-parietal montage)

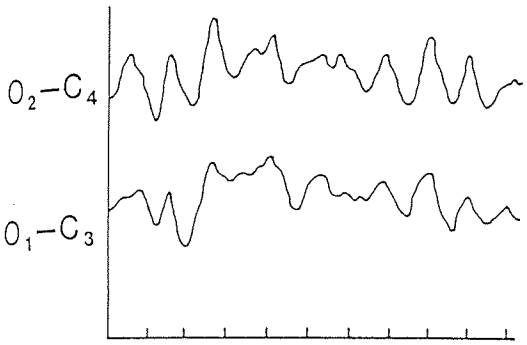
2. The visual field using the Octopus Programme 31

SUBJECT VB

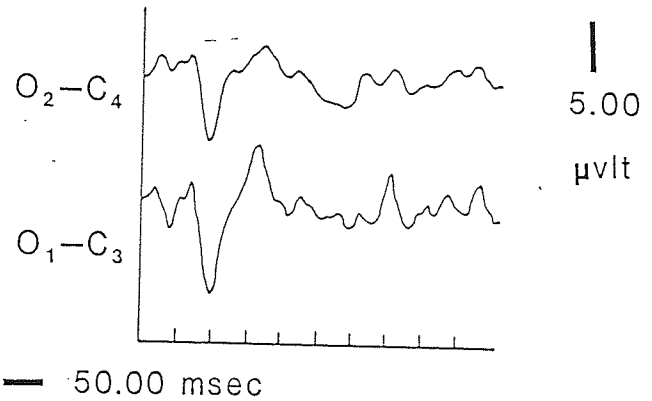
EYE RIGHT & LEFT

1: VISUAL EVOKED POTENTIAL

R:

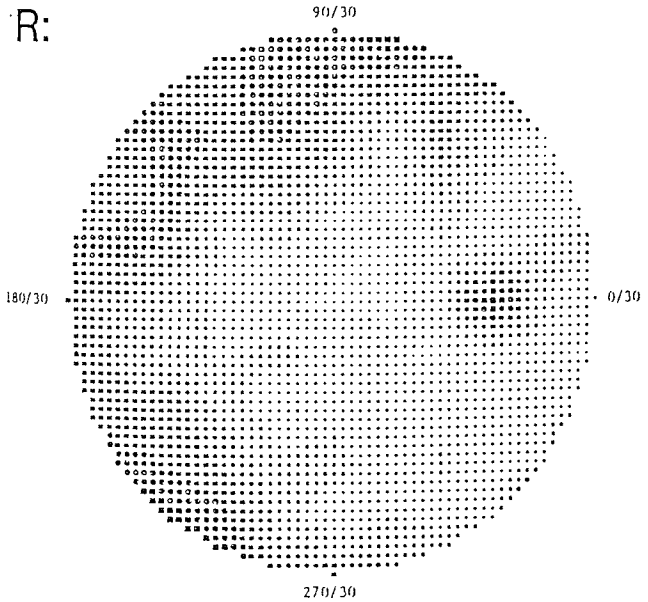


L:

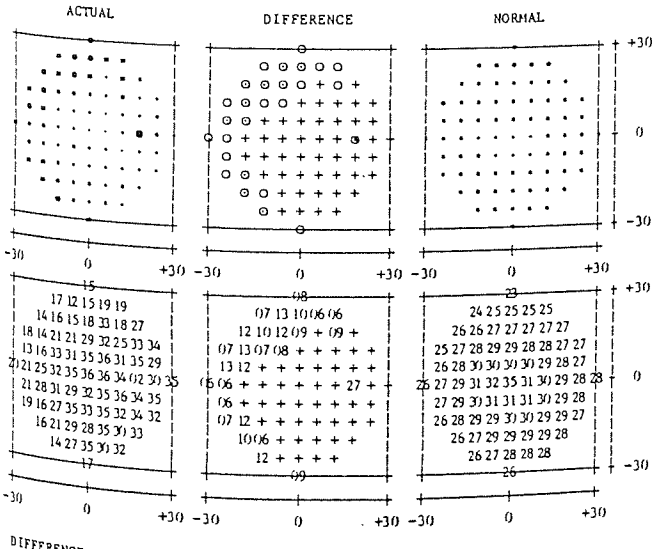


2: VISUAL FIELD

R:



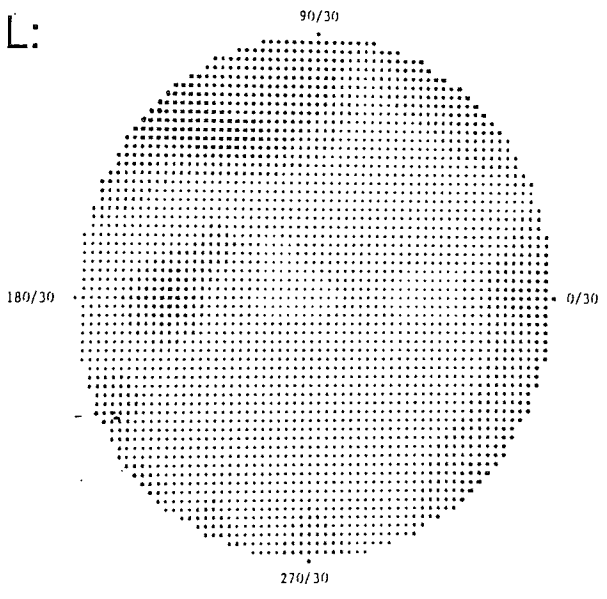
FLUCTUATIONS (R.M.S.): 3.3 DB LUM. INTERVAL: 4



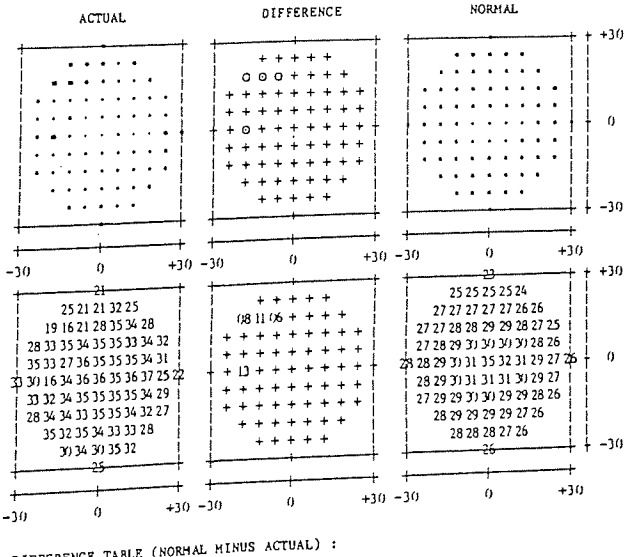
DIFFERENCE TABLE (NORMAL MINUS ACTUAL) :

+ DEVIATION <= 4 DB
○ DEVIATION 5...9 DB
◎ DEVIATION 10...19 DB
● DEVIATION > 19 DB
■ ABSOLUTE DEFECT

L:



FLUCTUATIONS (R.M.S.): 4.4 DB LUM. INTERVAL: 4



DIFFERENCE TABLE (NORMAL MINUS ACTUAL) :

+ DEVIATION <= 4 DB
○ DEVIATION 5...9 DB
◎ DEVIATION 10...19 DB
● DEVIATION > 19 DB
■ ABSOLUTE DEFECT

been helpful, at times, when recording the VEP in the clinical situation (Chapter 6) to compute instantaneously a bipolar or source derivation distribution. It is clear though, that great care must be taken to allow for the normal individual and inter-individual cortical asymmetries when using any recording technique.

APPENDICES

APPENDIX 1 PUBLICATIONS

APPENDIX 2 ABSTRACTS

APPENDIX 3 PUBLICATIONS IN PRESS

APPENDIX 1 - PUBLICATIONS

1 FLANAGAN JG, WILD JM, BARNES DA, GILMARTIN BA, GOOD PA and CREWS SJ. (1984)
The qualitative comparative analysis of the visual field using computer assisted, semi-automated and manual instrumentation : I Scoring system. Doc.Ophthalmol. 58: 319-324

2 WILD JM, FLANAGAN JG, BARNES DA, GILMARTIN BA, GOOD PA and CREWS SJ. (1984)
The qualitative comparative analysis of the visual field using computer assisted, semi-automated and manual instrumentation : II Statistical Analysis. Doc. Ophthalmol. 58: 325-340 (including statistical tables)

3 FLANAGAN JG, WILD JM, BARNES DA, GILMARTIN BA, GOOD PA and CREWS SJ. (1984)
The qualitative comparative analysis of the visual field using computer assisted, semi-automated and manual instrumentation : III Clinical Analysis. Doc. Ophthalmol. 58: 341-350

4 WILD JM, FLANAGAN JG, BARNES DA, GILMARTIN BA, GOOD PA and CREWS SJ. (1984)
The comparison of different test logics for the examination of the visual field. B.C.O.O. International Congress. Vol.2: pp166-172

5 CLEMENT RA, FLANAGAN JG and HARDING GFA. (1985)
Source derivation of the visual evoked response to pattern reversal stimulation. Electroenceph. clin. Neurophysiol. 62: 74-76

Documenta Ophthalmologica 58, 319–324 (1984).

The qualitative comparative analysis of the visual field using computer assisted, semi-automated and manual instrumentation: I Scoring system

J.G. FLANAGAN,[1] J.M. WILD,[2] D.A. BARNES,[2] B.A. GILMARTIN,[2] P.A. GOOD[3] and S.J. CREWS[3]

[1] Clinical Neurophysiology Unit, Department of Ophthalmic Optics, University of Aston in Birmingham, Birmingham, Great Britain
[2] Ophthalmic Optics Clinic, Department of Ophthalmic Optics, University of Aston in Birmingham, Birmingham, Great Britain
[3] Retina Department, Birmingham and Midland Eye Hospital, Birmingham, Great Britain

Abstract. Previous methods for the qualitative evaluation of visual field instruments are subject to certain limitations. A system is proposed to overcome these deficiencies. It has been developed from experiences of a clinical study involving 5 different visual field instruments. The method uses 4 levels of analysis and permits separate appraisals of diagnostic potential and detailed inter-instrument comparative evaluation.

Introduction

In recent years there has been a proliferation of Computer Assisted Perimeters and Semi-Automated Perimeters. The importance of assessing the performance of such instrumentation has been stressed by many authors; comprehensive references are given by Greve (1982). The literature shows, however, that the protocol adopted for comparative evaluation of instruments is non standardised. Although criteria for defining abnormality of the visual field are generally specified, some studies confuse the appraisal of diagnostic potential with a detailed inter-instrument comparison of the field plots. Often little attention is paid to the varying levels of field loss found between instruments and therefore useful comparative information is lost. Frequently, paired instrument comparisons have adopted one instrument as a reference against which to judge the other. This approach limits the definition of false positive and false negative results to the reference instrument whatever its inherent limitations. In addition, variation between studies in the chosen methodology precludes direct inter-study comparison. It is essential that all these limitations are examined and accounted for if comparative clinical evaluation of visual field instrumentation is to be effective.

We report on a qualitative method for the comparative clinical evaluation of visual field instrumentation. It has been developed from the experience of a clinical study involving 75 patients from the Birmingham and Midland Eye Hospital all of whom were assessed with the Octopus Automated Perimeter, the Goldmann Bowl Perimeter, the Bjerrum Screen and the Friedmann Visual Field Analysers Mk I and II. The method has been designed for a multi-instrument study but can be adapted to a two instrument comparison

and is suitable for any specified clinical protocol. It does not, however, attempt any form of quantitative analysis, but a system based upon percentage neural representation of the visual field (Drasdo & Peaston, 1980) is currently under development.

Method

The system uses four levels of analysis with each successive level possessing more exacting criteria.

Field loss is considered in terms of type, shape, area, depth and location.

The first two levels evaluate the diagnostic potential of each instrument in isolation whilst the third and fourth levels compare the results of each instrument relative to the others in the study. Following tabulation of the data, the system enables a between-instrument evaluation across any of the four levels of analysis and a within-instrument evaluation at any single level. Thus any given instrument can be evaluated in isolation or in comparison with any number of instruments in the group (Figure 1).

The first level determines whether the visual field is considered abnormal for each instrument, thus providing the most basic aspect of analysis.

The second level considers whether the visual field result obtained for each instrument is consistent with the diagnosis of a patient's condition.

The third level considers whether the visual fields for each individual patient are compatible with one another. This is important as it is possible to have a series of results which are all abnormal, all consistent with the diagnosis and yet display loss in different areas of the visual field from the other instruments used in the study.

The fourth level of analysis is considerably more complex. The results are compared to one instrument, acting as the reference. Each visual field result is judged to be either compatible or incompatible when compared to the reference field. This process is then repeated with each instrument in turn providing the reference field. If the reference and comparison fields are considered compatible then the comparison field is scored as to whether it possesses: (i) more visual field loss (Score I+); (ii) a similar degree of field

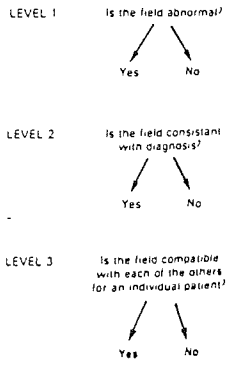


Figure 1. The first three levels of the scoring system.

loss (Score I); or (iii) less visual field loss (Score I–) relative to the reference field (Figure 2).

If, however, the two fields are considered to be incompatible and the reference field is abnormal, then the comparison field is scored as to whether it is: (i) abnormal but exhibits a different field loss (Score II); or (ii) normal (Score III).

If the reference field is normal then the comparison field is either abnormal scoring a I+ or normal scoring a I.

Finally, a combination may occur where both the reference and comparison fields are considered compatible yet have areas exhibiting different visual field loss, e.g. instrument one records a paracentral scotoma with a contraction in the superior nasal quadrant whilst instrument two records the same paracentral scotoma with a contraction in the superior temporal quadrant. Given such unusual circumstances, the two visual fields score I– when either is designated as the reference field.

An example of the Level 4 scoring is given in Figure 3.

The results are appropriate for analysis by a Chi-square (χ^2) test for k independent samples (Siegel, 1956). In this instance, k represents the number of different field plots or instruments employed. The procedure is a non-parametric statistical method which tests the significance of differences in visual field scores found between instruments. For example, at level 4, the data from our own study would be tabulated in the form of a 5 x 5 matrix

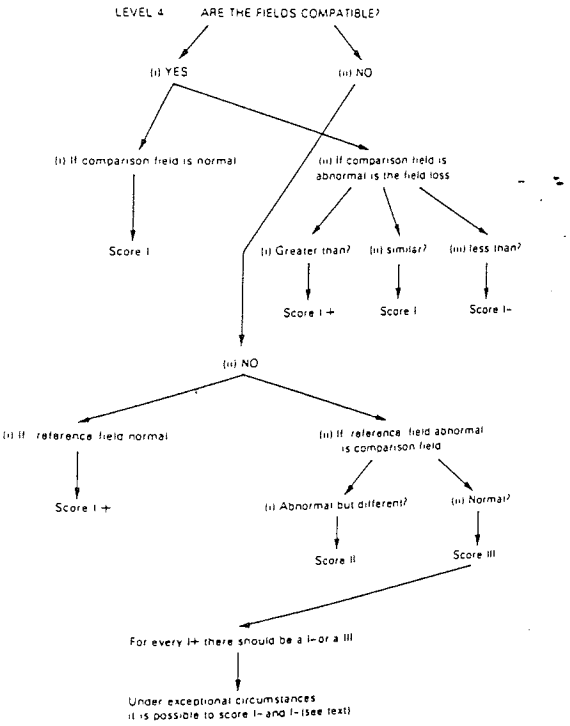


Figure 2. The fourth level of the scoring system.

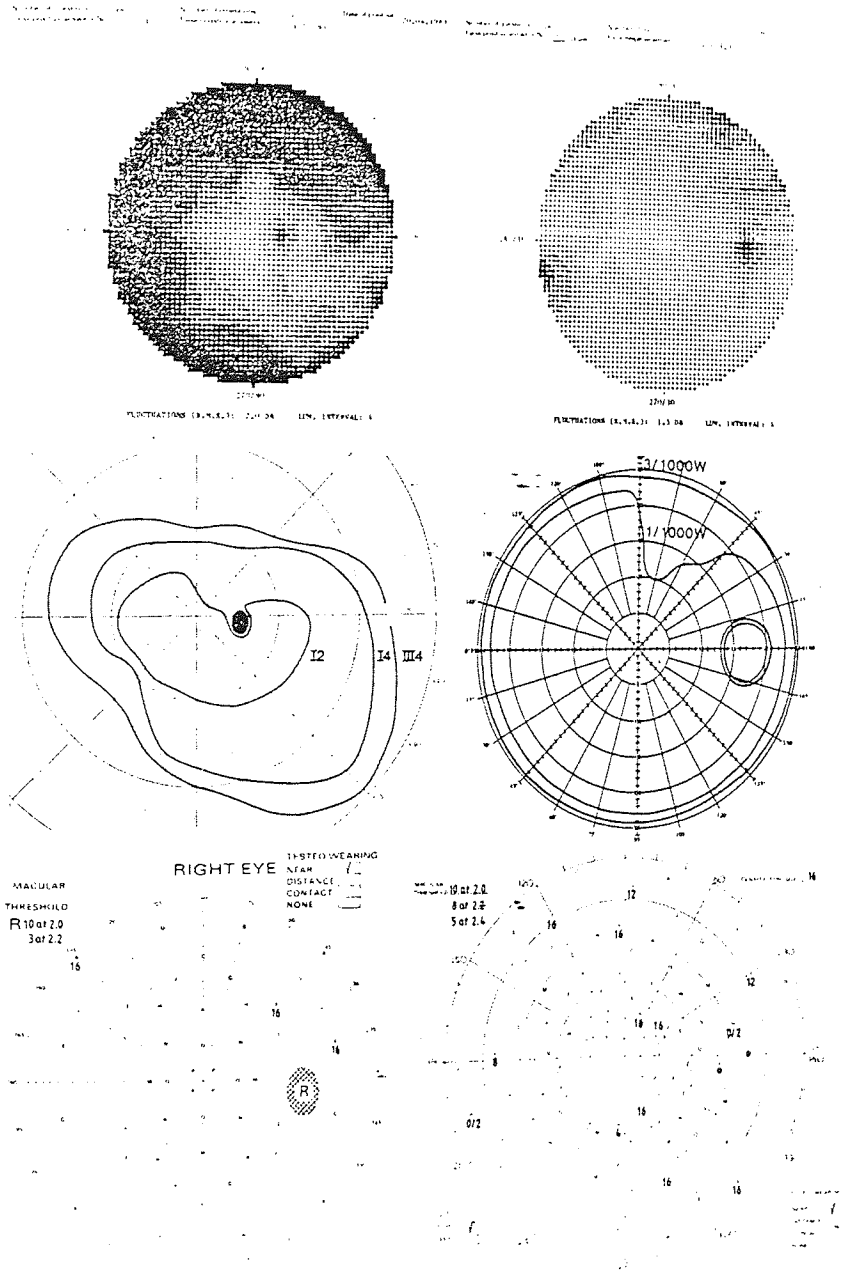


Figure 3. Example of level 4 scoring for a patient with suspected chiasmal lesion, Programme 21 as reference (top left). Programme 31 (top right) scored as category I; Goldmann (middle left) as I; Bjerrum (middle right) as I–; VFA Mk I (bottom left) as III; VFA Mk II (bottom right) as II.

with the individual instruments represented in rows and the scoring levels of the comparison fields relative to the reference field, represented in columns. If an overall difference is found to be statistically significant a χ^2 test for two independent samples, using a 2 x 5 matrix, can be applied to test for significant differences between any two of the 5 samples relative to the chosen reference field.

Discussion

The scoring system most similar to the one reported would appear to be that proposed by Schindler and McCrary (1981). They used a 'correlation grading system' to analyse their paired instrument comparisons. The fundamental difference between this method and the one reported is that Schindler and McCrary's system confounds the diagnostic and comparative information.

The method reported enables a more valid comparison between any of the increasingly diverse test regimes for the examination of the visual field, e.g. Suprathreshold Static, Kinetic or Threshold Static. The system can also be adapted for the analysis of long term visual field survival.

Previous qualitative inter-instrument comparisons have often used a single instrument as the standard by which to judge the other instruments (Feldman, 1975; Heijl and Krakau, 1975; Keltner, Johnson and Balestrery, 1979; McCrary and Feigon, 1979; Heijl and Drance, 1980; Neuhann and Greite, 1980; Heijl and Drance, 1981; Schindler and McCrary, 1981).

This limits the definition of false positive and false negative to the chosen reference instrument. The proposed system of analysis uses false positive and false negative as non-specific terms which depend upon the definition of normal and abnormal visual fields for each instrument when it is chosen as, or compared to, the reference.

In addition to testing for a significant difference in the results of the group as a whole, the Chi-square analysis may also allow the clinician to evaluate the relative performance of any chosen instrument when compared to any other within the given group for levels 1–3 and any pair relative to the reference field for level 4. These scores are essentially calculated from the comparison of the number of false positive and false negative results. Consequently, a clinician can make a valid inter-instrument comparison.

Conclusions

The method of analysis proposed allows a qualitative clinical comparison of any instrument with any other instrument and/or group of instruments for a given study under specified test conditions. The terms false positive and false negative should be considered non-specific. It is inappropriate to judge the performance of any given visual field technique by comparison with a single reference visual field.

Acknowledgements

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The qualitative comparative analysis of the visual field using computer assisted, semi-automated and manual instrumentation: II Statistical analysis

J.M. WILD[1], J.G. FLANAGAN[2], D.A. BARNES[1], B.A. GILMARTIN[1], P.A. GOOD[3] and S.J. CREWS[3]

[1] Ophthalmic Optics Clinic, Department of Ophthalmic Optics, University of Aston in Birmingham, Birmingham, Great Britain
[2] Clinical Neurophysiology Unit, Department of Ophthalmic Optics, University of Aston in Birmingham, Birmingham, Great Britain
[3] Retina Department, Birmingham and Midland Eye Hospital, Birmingham, Great Britain

Abstract. A comparative evaluation of the Octopus automated perimeter (Programmes 21 and 31), the Goldmann Bowl perimeter, the Bjerrum Screen and the Friedmann VFAs Mk I and Mk II was carried out on a heterogenous sample of 75 patients. The results for the sample as a whole were analysed statistically in terms of the scoring system developed by Flanagan, Wild, Barnes, Gilmartin, Good and Crews (1984a). Statistically significant differences between the instruments were found at each of the 4 levels of analysis.

Introduction

The emergence of the computer assisted perimeter over the last decade has resulted in a wider range of test logics available for the investigation of the visual field. Clearly, the importance of assessing the performance of these test logics relative to the more traditional logics is paramount.

One such recent instrument is the Octopus automated perimeter (Bebie, Fankhauser and Spahr, 1976a, 1976b; Spahr, Frankhauser and Bebie, 1976) a single stimulus static perimeter which utilizes a projection system to determine a threshold evaluation of the visual field. The Octopus has been compared to other computer assisted perimeters such as the Fieldmaster (Dannheim, 1979; Neuhann and Greite, 1980); the Competer and the Perimetron (Heijl and Drance, 1980) and the Peristat (Dannheim, 1979). Comparisons have also been made with manual instruments such as the Goldmann and/or Tubinger perimeters (Li et al., 1979; Kampik, Lund and Greite, 1979; McCrary and Faigon, 1979; Schmied, 1980; Krieglstein et al., 1981; Heijl and Drance, 1981). In general, these studies have evaluated the performance of a specific Octopus programme on a particular diagnostic group such as glaucoma or neurological disorders.

Comparisons with more fundamental and readily available instruments such as the Bjerrum Screen and the Friedmann VFAs have not, however, been undertaken. Similarly, the comparison of differing spatial target resolutions and the use of a broad range of patient abnormalities have both received little attention. In addition, as discussed elsewhere (Flanagan et al.,

1984b) some studies are subject to analytical limitations inherent in the experimental design and as a consequence provide limited descriptions of their findings. We report now the statistical analysis of a comparative study which was carried out on a heterogenous sample of patients using the Octopus Automated Perimeter (in full field and detailed modes), the Goldmann Bowl Perimenter, the Bjerrum Screen and the Friedmann VFAs Mk I and Mk II.

Clearly, the suitability of the latter two instruments, when operated according to the normative age setting might have an application in providing a cost effective prediction for the choice of the detailed Octopus Programme.

Methodology

The sample consisted of 75 patients (75 eyes) from the Retina Department of the Birmingham and Midland Eye Hospital. The patients were all volunteers and participated in the study following a request contained in a formal letter. The desired number of abnormal subjects was achieved by approaching 250 (approximately) patients all of whom were known to exhibit varying levels of field loss. The sample contained 10 subjects with no known history or symptoms of either visual or neurological disorders. Individuals younger than 5 or older than 80 years of age, those with a poor record of attendance, those likely to require transportation by ambulance and those residing more than 25 miles from the hospital were excluded from the study. The appropriate administrative procedures were undertaken by a single clinician. Confirmation of diagnosis and the eye designated for visual field investigation was determined by a second clinician. The resultant sample comprised 35 males and 40 females with a mean age of 39.5 years (range 10.0–69.5 years). The diagnostic categories are given in Table 1.

Each of the five instruments was operated by a single experienced clinician and a double blind protocol was followed throughout the study. The full field (Programme 21) Octopus and the Goldmann perimeter were performed at the Birmingham and Midland Eye Hospital on a single occasion. The Bjerrum and VFA Mk I and Mk II examinations were undertaken on a second occasion at the University of Aston. The detailed Octopus investigation (Programme 31) was performed on a third occasion. The sequence of the two initial sessions and the order of examination within each session were both randomized. All patients were refracted prior to the initial examination and wore the appropriate near vision correction for each instrument. The examination of each individual patient was completed within a maximum period of three weeks.

The Octopus programmes were used with target size 3 (0.431°). The bowl luminance was 3.15 asb.

The Goldmann investigation comprised kinetic isopters III4, I4 and I2 plotted consecutively in a clockwise manner every 15° up to fixation. The

Table 1. The diagnostic categories of the 75 patients in the sample

Retinitis pigmentosa	8	Glaucoma	9
Hereditary optic atrophy	5	West Indian amblyopia	1
Optic atrophy (with various related conditions)	4	Anisometropic amblyopia	1
Ischaemic optic neuropathy	3	Macular degeneration	3
Papilloedema	2	Stargardt's macular dystrophy	1
Papillitis	2	Vitelliform macular dystrophy	1
Intracranial hypertension	1	Ethambutol toxicity	1
Angioma of optic nerve	1	Homonymous hemianopia	1
Optic nerve lesion	1	Homonymous quadrantanopia	1
Periorbital abscess	1	Pituitary tumour (including erosion of pituitary and acromegaly)	9
Orbital pseudo tumour	1	Posterior vitreous detachment	1
Retro-bulbar neuritis	1	Trauma	2
Demyelination	2	Unknown aetology	1
Vascular insufficiency	1	Normal	10

examiner had free range to investigate the blind spot and any field loss encountered. In cases where the III4 target could not be detected the IV5 isopter was plotted. The bowl luminance was 31.5 asb.

The Bjerrum screen examination employed a similar routine to that of the Goldmann investigation. The 3/1000 white isopter was plotted initially followed by that for the 1/1000 w. The 5/1000 w and 10/1000 w isopters were plotted in cases where the 3 mm target could not be seen. The screen illuminance was standardised at the recommended level of 75 lux.

The Friedmann VFA Mk I and Mk II were used according to the normative age setting. The screen illuminance was 11 and 14 lux respectively. A sample of 16 patients, the majority of whom exhibited either a normal field or minimal levels of field loss, were subsequently re-examined on a further occasion using the threshold technique of Greve (1971) in which two out of three correctly identified presentations were designated as 'seen'.

The Octopus results were considered abnormal if two or more adjacent points were greater than 2.5 x, or any single point 10 x, the R.M.S. fluctuation below the normative values. The test location closest to the blind spot nasally and on line with fixation was ignored for the purposes of analysis as this point was frequently found to be within the normal blind spot.

The Goldmann results were considered abnormal if there was a contraction or depression of the peripheral isopter of $\geqslant 10^{\circ}$, a central scotoma of $\geqslant 5^{\circ}$ or a mapped scotoma.

The Bjerrum screen results were considered abnormal if there was a contraction or constriction of $\geqslant 5^{\circ}$ or a mapped scotoma.

The Friedmann VFA results were considered abnormal if a point was 0.4 log units below the specified manufacturers' normative age values (Friedmann, 1966). The test location M for the VFA Mk II, immediately inferior to the blind spot of the right eye, was ignored for the purposes of analysis as this point was frequently found to be within the normal blind spot.

Table 2. The frequency of abnormal and normal fields detected by the six test strategies. (Level 1 analysis)

Test regime	Category of field and number of patients	
	Abnormal	Normal
Programme 21	67	3
Programme 31	61	9
Goldmann	58	12
Bjerrum	64	6
Friedmann VFA Mk I	52	18
Friedmann VFA Mk II	55	15

$\chi^2 = 17.64$; degrees of freedom = 5; two tailed probability $p < 0.0034$

The field plots for each instrument were designated as either abnormal or normal by the appropriate clinician in isolation.

Results

Five patients failed to complete all of the six investigations. The results for the remaining 70 patients were considered in terms of four levels of analysis which permitted a between instrument evaluation across any of the four levels and a within instrument evaluation at any single level (Flanagan et al., 1984a).

LEVEL 1

The results of the first level are given in Table 2. This illustrates the incidence of abnormal and normal fields detected by each of the six investigations and is based upon the criteria for abnormality detailed previously. The results represent the incidence of abnormal and normal field plots and are not considered in relation to the clinical diagnosis.

The Octopus Programme 21 detected the greatest proportion of abnormal fields (67) whilst the Friedmann VFA Mk I recorded the least number (52).

The distribution of the visual field status between each of the instruments was analysed using a χ^2 test based upon a 6 x 2 contingency table. The overall difference in the distributions was found to be statistically significant ($p < 0.0034$) and further analysis was carried for each of the 2 x 2 contingency tables. The complete statistical analysis for each of the 4 levels is given in the Appendix.

It was recognized that the 2 x 2 samples were not independent of the overall 6 x 2 sample. Indication of the relative differences between the various distributions is therefore provided by the ranked order of the significance levels rather than by the actual values themselves. This form of analysis and interpretation of the associated significance levels was adopted for all the subsequent scoring levels.

Table 3. The frequency of abnormal and normal fields detected by the six test strategies considered in relation to the category of patient. (Level 1 analysis)

Test regime	Visual field designated as abnormal		Visual field designated as normal	
	Abnormal patients	Normal patients	Abnormal patients	Normal patients
Programme 21	60	7	1	2
Programme 31	58	3	3	6
Goldmann	58	0	3	9
Bjerrum	58	6	3	3
Friedmann VFA Mk I	50	2	11	7
Friedmann VFA Mk II	51	4	10	5

Statistically significant differences were found between the results for Programme 21 and those for both the VFA Mk I, VFA Mk II and the Goldmann ($p < 0.0004$ $P < 0.0024$ and $P < 0.014$ respectively). In addition, the distribution of the scores from the Bjerrum screen were also significantly different to those from the two VFAs ($p < 0.007$ and $p < 0.033$).

Further inspection of the data, however, revealed that Programme 21 recorded 7 of the 9 normal subjects to be abnormal and 6 were also designated as abnormal with the Bjerrum (Table 3). The results closest to the expected distribution were those obtained from the Goldmann (58 from a posible total of 61 abnormal fields and 9 out of 9 normal fields) and the detailed Octopus programme (58 and 6 respectively).

In 3 of the 9 subjects with an expected normal field, the results from the majority of the instruments clearly showed an abnormality which was not detected by the Goldmann. When these findings are taken into account, the Goldmann would appear to have performed less well than Programme 31.

LEVEL 2

The results for the second level of analysis are given in Table 4. This illustrates the number of field plots for each instrument considered to be consistent

Table 4. The frequency of field plots from the six test strategies scored in terms of consistency with diagnosis and considered in relation to the category of patient. (Level 2 analysis)

Test regime	Visual field designated as consistent with diagnosis			Visual field designated as inconsistent with diagnosis		
	Abnormal patients	Normal patients	Total	Abnormal patients	Normal patients	Total
Programme 21	55	2	57	6	7	13
Programme 31	56	6	62	5	3	8
Goldmann	56	9	65	5	0	5
Bjerrum	54	3	57	7	6	13
Friedmann VFA Mk I	44	7	51	17	2	19
Friedmann VFA Mk II	48	5	53	13	4	17

$\chi^2 = 13.59$; (based upon 6 × 2 contingency table of total scores) Degrees of freedom = 5; two tailed probability $p < 0.018$.

Table 5. The frequency of field plots from each of the six test strategies scored in terms of compatibility with the remaining plots derived from any given patient. (Level 3 analysis)

Test regime	Number of fields considered to be consistent/inconsistent with the majority of the fields from any given patient	
	Consistent	Inconsistent
Programme 21	62	8
Programme 31	67	3
Goldmann	63	7
Bjerrum	57	13
Friedmann VFA Mk I	53	17
Friedmann VFA Mk II	53	17

$\chi^2 = 18.00$; degrees of freedom = 5; two tailed probability $p < 0.0029$

with diagnosis. The score closest to the ideal distribution of 70 is demonstrated by the Goldmann whilst the poorest is given by the Friedmann VFA Mk I. The scores for the Goldmann are significantly better than those for Programme 21, the Bjerrum and both VFAs ($p < 0.021$, $p < 0.021$, $p < 0.0008$, and $p < 0.0026$ respectively).

Programme 31 also performs better than the two VFAs ($p < 0.009$ and $P < 0.016$). Further analysis reveals that both the Octopus strategies, the Goldmann and the Bjerrum yield almost identical scores for the abnormal plots consistent with diagnosis. Programme 21 and the Bjerrum, however, would seem to incorrectly classify a greater proportion of normal patients than either the Goldmann or the detailed programme. When the three anomalous normal cases, discussed earlier, are removed from the analysis the Goldmann and Programme 31 yield identical scores. Interestingly, of the 5 abnormal fields designated as inconsistent with diagnosis only 2 were common to both instruments.

LEVEL 3

The results for the third level of analysis are given in Table 5. This illustrates the number of field plots for each instrument considered to be compatible with those derived from the other instruments, for a given patient. The closest to the ideal score of 70 is exhibited by Programme 31 whilst the poorest scores are shown by both the VFAs. The appropriate χ^2 analysis reveals that the score for Programme 31 is significantly better than the scores from the VFA Mk I ($p < 0.00035$), Mk II ($p < 0.00035$) and Bjerrum ($p < 0.004$). The Goldmann and Programme 21 also exhibit significantly better scores than the two VFAs but the magnitude of the significance level is considerably less than that for Programme 31. Neither the Goldmann nor Programme 21 show a significant difference when compared with the Bjerrum.

In 33 of the 70 patients, the fields from each of the six techniques were considered to be in complete agreement and 17 patients exhibited only one

Table 6. The frequency of field plots from the 5 comparison strategies in each of the 5 scoring levels relative to the reference strategies. (Octopus Programme 21)

Test regime	Number of patients and scoring level for comparison field relative to reference field (Programme 21)				
	Compatible information			Incompatible information	
	I⁻ More	I Similar	I⁻ Less	II Different field loss	III Normal
Programme 31	9	42	10	3	6
Goldmann	8	31	16	4	11
Bjerrum	6	27	22	9	6
Friedmann VFA Mk I	4	17	20	14	15
Friedmann VFA Mk II	4	18	20	15	13

$\chi^2 = 44.27$; degrees of freedom = 16; two tailed probability $p < 0.0002$.

discordant result. The only detectable trend in the remaining 20 fields was the agreement exhibited in 9 patients by the two Friedmann VFAs. In one case no concordance was found among any of the six fields and was undoubtedly due to the poor responses from this particular patient.

LEVEL 4

The fourth level describes the compatibility of each individual visual field from the various instruments, to that derived by the reference field.

Programme 21 as reference. The results for the five techniques, when compared to Programme 21 are given in Table 6. The major differences relative to Programme 21 are found between Programme 31 and the two VFAs (Table 6, rows 1 and 4 and rows 1 and 5). In particular, column 2 shows that in 42 cases Programme 31 gave a highly compatible field to that of Programme 21 whilst a similar agreement was only found in 17 and 18 cases respectively with the VFA Mk I and Mk II.

The differences in compatibility between Programme 31 and each of the two VFAs, when compared to Programme 21, are highly significant ($p < 0.00002$ and $P < 0.00004$ respectively).

The Goldmann differs from the two VFAs when compared to Programme 21 ($p < 0.017$ and $P < 0.019$) and this is particularly due to the poor VFA scores in category I and category II. Programme 31 also provides a closer agreement to Programme 21 when compared with the Bjerrum ($p < 0.023$). The differences between the Goldmann and the Bjerrum, however, are not significant.

Programme 31 as reference. When compared to Programme 31 as reference (Table 7), the results for Programme 21 are very much better than either of the two VFAs and the differences between the distributions are highly

Table 7. The frequency of field plots from the 5 comparison strategies in each of the 5 scoring levels relative to the reference strategy. (Octopus Programme 31)

Test regime	Number of patients and scoring level for comparison field relative to reference field (Programme 31)				
	Compatible information			Incompatible information	
	I+ more	I similar	I- less	II Different field loss	III Normal field
Programme 21	15	42	10	3	0
Goldmann	9	39	12	4	6
Bjerrum	9	35	13	10	3
Friedmann VFA Mk I	5	23	19	12	11
Friedmann VFA Mk II	6	24	19	11	10

$\chi^2 = 43.97$; degrees of freedom = 16; two tailed probability $p < 0.0002$

significant ($P < 0.000005$ and $p < 0.00003$ respectively). The Goldmann also provides a closer agreement to Programme 31 than the VFA scores, although the differences between the distributions are much less significant than those corresponding to Programme 21 ($(p < 0.015$ and $p < 0.041$ respectively). The Bjerrum also exhibits a slightly better score than the VFAs. The difference between the Bjerrum and the VFA Mk I is significant ($p < 0.05$) whilst that between the Bjerrum and the VFA Mk II is not significant.

Goldmann Bowl Perimeter as reference. When compared to the Goldmann as reference (Table 8), both Octopus programmes provide a markedly better measure of consistency than either of the two VFAs and the differences between the respective distributions are highly significant ($p < 0.00001$ and $P < 0.00002$ for Programme 21; $p \leq 0.0002$ and $p < 0.0003$ for Programme 31).

Table 8. The frequency of field plots from the 5 comparison strategies in each of the 5 scoring levels relative to the reference strategy. (Goldmann Bowl Perimeter)

Test regime	Number of patients and scoring level for comparison field relative to reference field (Goldmann)				
	Compatible information			Incompatible information	
	I+ more	I similar	I- less	II Different field loss	III Normal field
Programme 21	27	31	7	4	1
Programme 31	18	39	7	4	2
Bjerrum	16	29	15	7	3
Friedmann VFA Mk I	7	24	18	12	9
Friedmann VFA Mk II	8	23	21	10	8

$\chi^2 = 53.68$; degrees of freedom = 16; two tailed probability $p < 0.000006$

Table 9. The frequency of field plots from the 5 comparison strategies in each of the 5 scoring levels relative to the reference strategy. (Bjerrum Screen)

Test regime	Number of patients and scoring level for comparison field relative to reference field (Bjerrum)				
	Compatible information			Incompatible information	
	I+	I	I-	II	III
Programme 21	27	27	4	9	3
Programme 31	16	35	3	10	6
Goldmann	17	29	7	7	10
Friedmann VFA Mk I	11	14	14	15	16
Friedmann VFA Mk II	9	21	13	14	13

$\chi^2 = 50.53$; degrees of freedom = 16; two tailed probability $p < 0.00002$

Bjerrum Screen as reference. When compared to the Bjerrum as reference (Table 9), both Octopus programmes again provide a closer agreement than either of the VFAs. The magnitude of the statistical significance, however, is less in the case of the VFA Mk II than for the VFA Mk I ($p < 0.0002$ and $p < 0.005$; $p < 0.00002$ and $p < 0.0001$). The Goldmann also gives a closer agreement to the Bjerrum than the VFA Mk I ($p < 0.001$) but there is no significant difference in the results between the Goldmann and the VFA Mk II.

Friedmann VFA Mk I as reference. When the VFA Mk I acts as reference (Table 10), the overall 5 x 5 Chi-square analysis is not statistically significant. This indicates that the VFA Mk I is the major source of variability between the six test logics. The VFA Mk II provides the closest agreement to the VFA Mk I, but the remaining instruments all yield a large proportion of cases in which extra information is obtained.

Friedmann VFA Mk II as reference. When the VFA Mk II acts as reference (Table 11), the VFA Mk I provides a better agreement than either the two

Table 10. The frequency of field plots from the 5 comparison strategies in each of the 5 scoring levels relative to the reference strategy. (Friedmann VFA Mk I)

Test regime	Number of patients and scoring level for comparison field relative to reference field (Friedmann VFA Mk I)				
	Compatible information			Incompatible information	
	I+ more	I similar	I- less	II Different field loss	III Normal field
Programme 21	32	17	6	14	1
Programme 31	29	23	3	12	3
Goldmann	25	24	4	12	5
Bjerrum	27	14	9	15	5
Friedmann VFA Mk II	17	33	7	10	3

$\chi^2 = 23.03$; degrees of freedom = 16; two tailed probability $p < 0.113$.

Table 11. The frequency of field plots from the 5 comparison strategies in each of the 5 scoring levels relative to the reference strategy. (Friedmann VFA Mk II)

Test regime	Number of patients and scoring level for comparison field relative to reference field (Friedmann VFA Mk II)				
	Compatible information			Incompatible information	
	I+ more	I similar	I- less	II Different field loss	III Normal field
Programme 21	31	18	3	15	3
Programme 31	27	24	3	11	5
Goldmann	25	23	6	10	6
Bjerrum	23	21	7	14	5
Friedmann VFA Mk I	8	33	12	10	7

$\chi^2 = 31.236$; degrees of freedom = 16; two tailed probability $p < 0.012$

Octopus programmes, the Goldmann or the Bjerrum. These differences between the various distributions are all statistically significant.

Discussion

Inspection of the first three levels of analysis reveals that the detailed Octopus programme was superior to all test logics at Levels 1 and 3 and identical to that of the Goldmann at Level 2. The validity of the Goldmann fields to the diagnosis may, however, break down as in some instances the prior diagnosis would undoubtedly have been made in conjunction with previous Goldmann plots. The Goldmann proved to be slightly superior to Programme 21 at Level 2 and similar at Level 3. A difference in the scores occurred at the first level due to the false classifications of the normal patients by Programme 21, and the abnormal patients by the Goldmann. The false classification of the patients by Programme 21 was also the explanation for the difference in the scores at Level 2. The results from the Bjerrum at all three levels were inferior to both the two Octopus strategies and to the Goldmann, but superior to the two VFAs which, in turn, gave similar results to each other.

A similar trend can be seen in the Level 4 analysis. Compared to Programme 21, Programme 31 ranks slightly better than the Goldmann which, in turn, is better than the Bjerrum which is better than either of the two VFAs. It might be argued, however, that evaluations of the scores from the Goldmann would be biased towards those from the full field Programme 21. When comparing the central field plots with those of the peripheral field, however, great care was taken to ensure that only the central information was utilized. The superiority of Programme 31 arose because a surprisingly high proportion of the plots contained more peripheral loss than was evident in either the Bjerrum or the two VFA fields.

When compared to Programme 31, a similar trend is present in that the full field Octopus programme and the Goldmann are comparable but the former produced more information (1^+ scores) than the latter. The Bjerrum again proved superior to either of the VFAs. It is interesting to note the similarity of the results from the two VFAs when compared to either Programme 21 or to Programme 31; the greater number of stimuli on the Mk II would appear to provide no further advantage here.

When compared to the Goldmann, Programme 31 is superior to Programme 21 in that it provides fewer 1^+ scores and more I scores. It would appear, therefore, that Programme 21 gives a greater field loss when compared to either Programme 31 or to the Goldmann.

This observation could be explained by differences in the depth and/or area of field loss. A comparison of the depth of field loss recorded by Programmes 21 and 31 was therefore undertaken by evaluating the difference between the points on the 4 cardinal meridians at 30° eccentricity which were common to both programmes and which exhibited field loss. In the majority of cases, there was no difference in the depth of the field loss between the two programmes indicating that the extra information recorded by Programme 21 resulted from a difference in area.

Both programmes exhibit a high proportion of 1^+ scores when the Goldmann acts as reference but Programme 21 yields a greater score than Programme 31 in this respect. The extra information recorded by the two programmes is attributable to both a greater depth and area of field loss. These findings are in accord with the work of Koerner, Fankhauser, Bebie and Spahr (1976) who reported a steeper sensitivity gradient and a more severe visual loss with Programme 21 when compared to the Goldmann and Tubinger. This conclusion can now be extended to Programme 31.

Further comparison of the Octopus data also reveals that the extrapolated central value for Programme 21 was repeatedly lower (less sensitive) than that for the measured central target of Programme 31 and also lower than the corresponding expected value from the normative data.

The relative lack of agreement between the Bjerrum and Goldmann when compared to Programme 31 is surprising in that both employ kinetic methods.

When compared to the Bjerrum, Programme 31 again provides fewer 1^+ scores and more I scores than Programme 21 whilst the Goldmann provides a similar level of I scores and fewer 1^+ scores than Programme 21. It is also interesting to note the superiority of the VFA Mk II scores over the Mk I. Indeed, when compared to the VFA Mk II, the VFA Mk I exhibits the greatest proportion of 1^- scores (i.e. compatible fields, but less information compared with the reference field) than any other instrument. In some cases this was undoubtedly due to the reduction of stimuli present in this instrument. In addition, the difference between the statistical significance levels for the two VFA 5 x 5 matrices also reveals the superiority of the Mk II over the Mk I.

Clearly, the latter two instruments, when operated according to normative age setting, relate poorly to both Octopus modes and to the Goldmann and, in particular, would fall short as a predictor of Programme 31.

It is recognised that when operated at threshold the VFA may provide a closer relationship to these instruments, but that the time factor is greatly increased. Of the 16 patients who were re-examined with Greve's modified threshold technique, 13 were designated as having threshold fields, ($\leqslant 0.4$ log units below the normative values). In 8 of these 13 cases the VFA Mk I produced field loss which scored better than that derived by the normative setting mode. The three fields designated as having a deep loss ($\geqslant 0.6$ log units below normative values) did not improve at the retesting. The corresponding results for the VFA Mk II show that 6 of the 12 threshold fields improved whilst 2 of the 4 with deep loss also improved. This latter apparent improvement, however, resulted from a relatively insensitive initial assessment compared to the original VFA I field.

From these results it would appear that the threshold technique gives an improved result for approximately half of the cases with superficial field loss ($\leqslant 0.4$ log units below the normative age value). The extra time involved, however would not justify the use of the VFA as a predictor of Programme 31.

A surprising result was the time necessary for the completion of each test. Automated perimetry is frequently criticized on account of the excessive examination time. In many cases, however, Programme 31 took no longer than the Goldmann and was faster than Programme 21, the Bjerrum and Greve's modified threshold VFA technique, but slower than the normative VFA technique.

Conclusion

Programme 21 exhibits slightly greater loss than Programme 31. Both exhibit a deeper and greater area of loss when compared to the Goldmann. The peripheral information derived from Programme 21 and the Goldmann is more consistent with Programme 31 than with either the Bjerrum or the VFAs. This would support the observation that the Octopus results produce a deeper field loss. The results for the Goldmann are more similar to Programme 31 than Programme 21.

The Bjerrum, although better than the VFAs operated at normative values, was not considered to be sufficiently consistent with either the Octopus or the Goldmann. There was no strong relationship between the two kinetic techniques. Programme 31 exhibited more concordance with the Bjerrum than did the Goldmann and also agreed more closely with the Goldmann than did the Bjerrum.

The VFA Mk II gave more comparable results than the Mk I but both related poorly at normative settings to the Goldmann and to both Octopus

programmes and in this mode would therefore be a poor predictor of Programme 31 for a heterogenous patient sample. When operated in a threshold mode a definite improvement was noted but this was not considered sufficient to suggest the use of this latter technique as a predictor of Programme 31.

The results refer to a heterogenous sample of patients and the relationship to location of field loss is considered elsewhere (Flanagan et al., 1984b).

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Appendix

Table A1. χ^2 and associated two-tailed probability values based upon 2 × 2 contingency tables (df = 1) for the data level 1 analysis listed in Table 2

Strategy	Programme 21	Programme 31	Goldmann	Bjerrum	VFA Mk I	VFA Mk II
Programme 21	–	$\chi^2 = 2.28$ $p < 0.131$	$\chi^2 = 6.05$ $p < 0.014$	$\chi^2 = 1.07$ $p < 0.301$	$\chi^2 = 12.60$ $p < 0.0004$	$\chi^2 = 9.18$ $p < 0.0024$
Programme 31		–	$\chi^2 = 0.50$ $p < 0.478$	$\chi^2 = 0.67$ $p < 0.412$	$\chi^2 = 37.2$ $p < 0.054$	$\chi^2 = 1.81$ $p < 0.178$
Goldmann			–	$\chi^2 = 2.29$ $p < 0.130$	$\chi^2 = 1.53$ $p < 0.216$	$\chi^2 = 0.41$ $p < 0.520$
Bjerrum				–	$\chi^2 = 7.24$ $p < 0.007$	$\chi^2 = 4.54$ $p < 0.033$
VFA Mk I					–	$\chi^2 = 1.81$ $p < 0.178$
VFA Mk II						–

Table A2. χ^2 and associated two-tailed probability values based upon 2 × 2 contingency tables (df = 1) for the data (level 2 analysis) listed in (Total) columns of Table 4

Strategy	Programme 21	Programme 31	Goldmann	Bjerrum	VFA Mk I	VFA Mk II
Programme 21	–	$\chi^2 = 1.40$ $p < 0.118$	$\chi^2 = 4.08$ $p < 0.021$	$\chi^2 = 0$ $p < 0.5$	$\chi^2 = 1.46$ $p < 0.113$	$\chi^2 = 0.68$ $p < 0.205$
Programme 31		–	$\chi^2 = 0.760$ $p < 0.191$	$\chi^2 = 1.40$ $p < 0.118$	$\chi^2 = 5.55$ $p < 0.009$	$\chi^2 = 3.94$ $p < 0.016$
Goldmann			–	$\chi^2 = 4.08$ $p < 0.021$	$\chi^2 = 0.86$ $p < 0.0008$	$\chi^2 = 7.76$ $p < 0.0026$
Bjerrum				–	$\chi^2 = 1.46$ $p < 0.113$	$\chi^2 = 0.68$ $p < 0.205$
VFA Mk I					–	$\chi^2 = 0.15$ $p < 0.349$
VFA Mk II						–

Table A3. χ^2 and associated two-tailed probability values based upon 2 × 2 contingency tables (df = 1) for the data (level 3 analysis) listed in Table 5

Strategy	Programme 21	Programme 31	Goldmann	Bjerrum	VFA Mk I	VFA Mk II
Programme 21	–	$\chi^2 = 2.47$ $p < 0.058$	$\chi^2 = 0.07$ $p < 0.392$	$\chi^2 = 1.40$ $p < 0.118$	$\chi^2 = 3.94$ $p < 0.023$	$\chi^2 = 3.94$ $p < 0.023$
Programme 31		–	$\chi^2 = 1.72$ $p < 0.094$	$\chi^2 = 7.06$ $p < 0.004$	$\chi^2 = 11.43$ $p < 0.0003$	$\chi^2 = 11.43$ $p < 0.0003$
Goldmann			–	$\chi^2 = 2.10$ $p < 0.073$	$\chi^2 = 5.03$ $p < 0.012$	$\chi^2 = 5.03$ $p < 0.012$
Bjerrum				–	$\chi^2 = 0.68$ $p < 0.205$	$\chi^2 = 0.68$ $p < 0.205$
VFA Mk I					–	$\chi^2 = 0$ $p < 0.5$
VFA Mk II						–

Table A4. χ^2 and associated two tailed probability values based upon 2 × 5 contingency tables (df = 4) for the data (level 4 analysis: Programme 21 as reference) listed in Table 6

Strategy	Programme 31	Goldmann	Bjerrum	VFA Mk I	VFA Mk II
Programme 31	–	$\chi^2 = 4.72$ $p < 0.318$	$\chi^2 = 11.36$ $p < 0.023$	$\chi^2 = 26.82$ $p < 0.00002$	$\chi^2 = 25.43$ $p < 0.00004$
Goldmann		–	$\chi^2 = 4.90$ $p < 0.297$	$\chi^2 = 12.03$ $p < 0.017$	$\chi^2 = 11.76$ $p < 0.019$
Bjerrum			–	$\chi^2 = 7.71$ $p < 0.103$	$\chi^2 = 6.37$ $p < 0.173$
VFA Mk I				–	$\chi^2 = 0.206$ $p < 0.995$
VFA Mk II					–

Table A5. χ^2 and associated two tailed probability values based upon 2 × 5 contingency tables (df = 4) for the data (level 4 analysis: Programme 31 as reference) listed in Table 7

Strategy	Programme 31	Goldmann	Bjerrum	VFA Mk I	VFA Mk II
Programme 21	–	$\chi^2 = 7.93$ $p < 0.094^*$	$\chi^2 = 9.30$ $p < 0.054$	$\chi^2 = 29.75$ $p < 0.000005$	$\chi^2 = 26.13$ $p < 0.00003$
Goldmann		–	$\chi^2 = 3.83$ $p < 0.430$	$\chi^2 = 12.32$ $p < 0.015$	$\chi^2 = 10.01$ $p < 0.041$
Bjerrum			–	$\chi^2 = 9.50$ $p < 0.050$	$\chi^2 = 7.59$ $p < 0.108$
VFA Mk I				–	$\chi^2 = 0.203$ $p < 0.0995$
VFA Mk II					–

Table A6. χ^2 and associated two tailed probability values based upon 2 × 5 contingency tables (df = 4) for the data (level 4 analysis Goldmann as reference) listed in Table 8

Strategy	Programme 21	Programme 31	Bjerrum	VFA Mk I	VFA Mk II
Programme 21	–	$\chi^2 = 3.05$ $p < 0.550$	$\chi^2 = 7.61$ $p < 0.107$	$\chi^2 = 27.90$ $p < 0.00001$	$\chi^2 = 26.51$ $p < 0.00002$
Programme 31		–	$\chi^2 = 5.52$ $p < 0.238$	$\chi^2 = 21.71$ $p < 0.0002$	$\chi^2 = 21.15$ $p < 0.0003$
Bjerrum			–	$\chi^2 = 8.58$ $p < 0.072$	$\chi^2 = 7.16$ $p < 0.128$
VFA Mk I				–	$\chi^2 = 0.56$ $p < 0.967$
VFA Mk II					–

Table A7. χ^2 and associated two tailed probability values based upon 2 × 5 contingency tables (df = 4) for the data (level 4 analysis: Bjerrum as reference) listed in Table 9

Strategy	Programme 21	Programme 31	Goldmann	VFA Mk I	VFA Mk II
Programme 21	–	$\chi^2 = 504$ $p < 0.283$	$\chi^2 = 7.18$ $p < 0.127$	$\chi^2 = 26.81$ $p < 0.00002$	$\chi^2 = 21.85$ $p < 0.0002$
Programme 31		–	$\chi^2 = 3.72$ $p < 0.445$	$\chi^2 = 22.59$ $p < 0.0001$	$\chi^2 = 14.95$ $p < 0.005$
Goldmann			–	$\chi^2 = 13.14$ $p < 0.011$	$\chi^2 = 8.27$ $p < 0.082$
VFA Mk I				–	$\chi^2 = 1.98$ $p < 0.739$
VFA Mk II					–

Table A8. χ^2 and associated two tailed probability values based upon 2 × 5 contingency tables (df = 4) for the data (level 4 analysis: VFA Mk II as reference) listed in Table 11

Strategy	Programme 21	Programme 31	Goldmann	Bjerrum	VFA Mk II
Programme 21	–	$\chi^2 = 2.25$ $p < 0.690$	$\chi^2 = 4.25$ $p < 0.373$	$\chi^2 = 3.55$ $p < 0.47$	$\chi^2 = 25.98$ $p < 0.00003$
Programme 31		–	$\chi^2 = 1.24$ $p < 0.872$	$\chi^2 = 2.48$ $p < 0.848$	$\chi^2 = 17.53$ $p < 0.0015$
Goldmann			–	$\chi^2 = 1.01$ $p < 0.908$	$\chi^2 = 12.62$ $p < 0.013$
Bjerrum				–	$\chi^2 = 12.24$ $p < 0.016$
VFA Mk I					–

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The qualitative comparative analysis of the visual field using computer assisted, semi-automated and manual instrumentation: III Clinical analysis

J.G. FLANAGAN[1], J.M. WILD[2], D.A. BARNES[2], B.A. GILMARTIN[2], P.A. GOOD[3] and S.J. CREWS[3]

[1] Clinical Neurophysiology Unit, Department of Ophthalmic Optics, University of Aston in Birmingham, Birmingham, Great Britain
[2] Ophthalmic Optics Clinic, Department of Ophthalmic Optics, University of Aston in Birmingham, Birmingham, Great Britain
[3] Retinal Department, Birmingham and Midland Eye Hospital, Birmingham, Great Britain

Abstract. A comparative evaluation of the Octopus automated perimeter (Programmes 21 and 31), the Goldmann Bowl perimeter, the Bjerrum Screen and the Friedmann VFAs Mk I and Mk II was carried out on a heterogenous sample of 75 patients. Field loss was categorized using a modification of the classifications proposed by Greve (1982). The results were analysed using the Level 4 analysis developed by Flanagan, Wild, Barnes, Gilmartin, Good and Crews (1984a). The performance of the various test logics was found to differ between the categories of field defect.

The various computer assisted perimeters introduced in recent years have been the subject of comparative evaluations with the more long standing forms of perimetry (Greve, 1982).

Wild, Flanagan, Barnes, Gilmartin, Good and Crews (1984) have compared Programmes 21 and 31 of the Octopus Automated Perimeter, the Goldmann Bowl Perimeter, the Bjerrum screen and the Friedmann VFAs Mark I and II. This study presented results for a heterogenous sample of 75 patients with each of the instruments above acting in turn as the reference field. The present paper extends the initial proposals by considering the possible variations which may arise in the investigation of specific conditions or types of field loss.

Methodology

The sample comprised 75 patients from the Birmingham and Midland Eye Hospital with various conditions. The full field Octopus programme and the Goldmann were undertaken at one session, the Bjerrum and the two VFAs were performed on a second occasion and the detailed Octopus programme on a third. The three sessions were completed within a 3 week period. Each instrument was operated by a separate single experienced clinician and a double blind protocol was followed throughout. A detailed description of both the sample and the methodology is given elsewhere (Wild et al., 1984). The compatibility of the individual fields for each of the instruments to the corresponding field derived from the reference instrument was scored in terms of the level 4 analysis described by Flanagan et al. (1984), and adopted by Wild et al. (1984).

Table 1. Classification and number of field defects for the 70 patients

	Number of patients
Normal	9
General reduction of sensitivity (GRS)	16
Local reduction of sensitivity (LRS)	12
Glaucomatous visual field defects	8
Central island	4
Central defects	9
Miscellaneous paracentral defects inside 25° eccentricity	4
Peripheral defects outside 25° eccentricity	3
Blind spot defects	26
Hemianopic defects	9

Field loss for the particular instrument in question was considered in terms of the type, shape, depth, area and location of loss and scored as to whether it was compatible or incompatible with that of the reference instrument. A compatible field was additionally scored as to whether it possessed information that was more (Category 1^+), less (Category 1^-) or similar (Category 1) to the reference field. A field considered to be incompatible was scored as to whether it was a different field loss (Category II) or normal (Category III). The location of the field loss for a given patient was classified using a system modified from that of Greve (1982). This classification is given in Table 1. The essential difference between Greve's classification and the one adopted in this study is that, due to the limited number of glaucomatous, central and hemianopic patient groups, the sub-classifications defining depth of loss have been omitted. In some cases more than one area of field loss was present and, therefore, the number of defects used in the analysis exceeds the number of patients in the study.

Difficulty sometimes arose in the differentiation between general and local reduction in sensitivity. If the loss constituted the majority of the peripheral part of the field, it was designated as a general reduction. If an overriding, deep, local reduction in sensitivity was present in conjunction with a general reduction in sensitivity, the field was designated as being a local reduction. In addition, some fields contained more than one area with a local reduction in sensitivity.

Results and discussion

The results are illustrated in Figure 1 and are presented in terms of location and scoring for each instrument against the reference instrument. Of the 75 patients who participated in the study, five failed to complete all the sessions. Accordingly, the results are presented for a sample of 70.

1. *Local reduction in sensitivity*

When Programme 31 was used as the reference field, Programme 21 scored the greatest proportion in Category I (i.e. 9 out of 12). No instrument scored

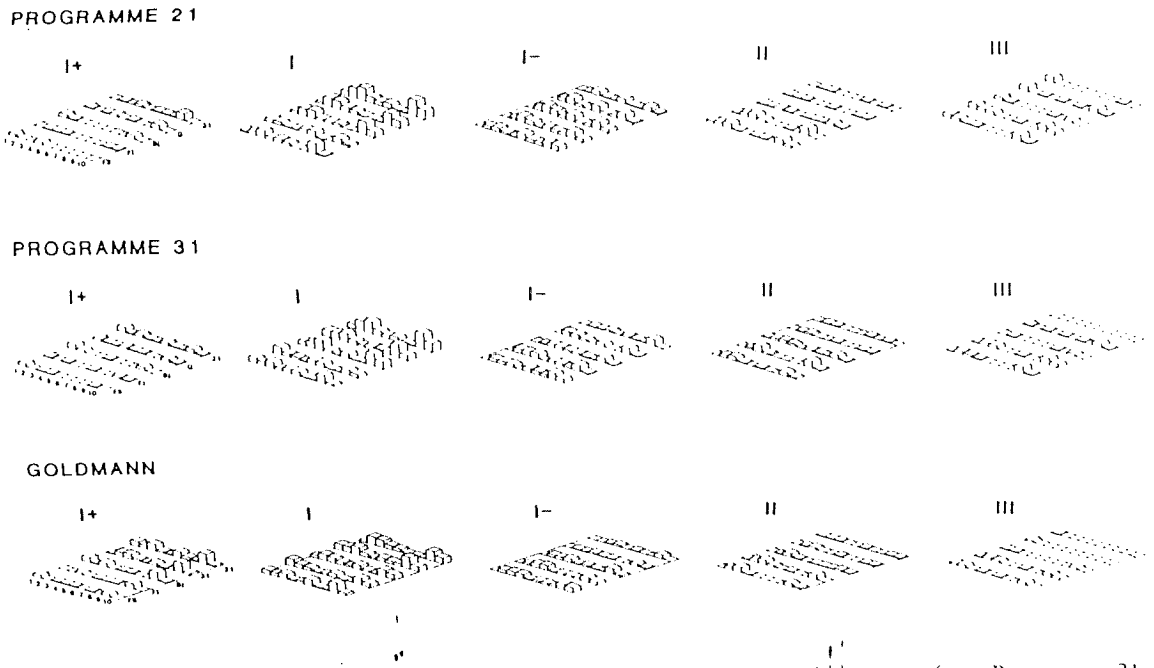

Figure 1. Category of field loss, test logic and frequency of level 4 score relative to the reference instrument (top: Programme 21 as reference; middle: Programme 31 as reference, bottom: Goldmann as reference). 1 = normal, 2 = local reduction of sensitivity, 3 = general reduction of sensitivity, 4 = glaucomatous visual field defects, 5 = central island, 6 = central defects, 7 = miscellaneous paracentral defects inside 25° eccentricity, 8 = peripheral defects outside 25° eccentricity, 9 = blind spot defects, 10 = hemianopic defects.

highly in the 1^+ category, but the Goldmann and VFAs all scored 4 out of 12 in the 1^- category. Both the VFA Mk I and Mk II gave 3 out of 12 normal results when compared to the abnormal Programme 31.

When Programme 21 was used as the reference, Programme 31 and the Goldmann both scored highly in the I category (9 and 8 out of 12 respectively). The VFAs both scored poorly (3 out of 12). All instruments scored in the 1^- category, particularly the Goldmann, Bjerrum and VFA II (3 out of 12). Both VFAs scored 3 out of 12 in the II and III categories. These results indicate that for the limited number of subjects both Programme 31 and the Goldmann showed a high consistency with Programme 21 for local reduction in sensitivity, whereas the VFAs provided a relatively poor prediction of the Octopus result with only half of the fields giving any form of compatibility.

When the Goldmann was used as a reference, Programme 21 scored the highest proportion in the I category (8 out of 12). Programme 31 gave the highest score in the 1^+ category but both Octopus programmes showed a relatively high proportion of results which exhibited more information. The VFAs scored in a similar manner to that for Programme 21 as reference.

It would appear, therefore, that for local reduction in sensitivity Programme 31 gives the most reliable results, followed by Programme 21 and the Goldmann. Neither the Bjerrum nor the VFAs were good predictors of the detailed Octopus mode. In addition, contrary to the results found for the heterogenous group by Wild et al. (1984), Programme 21 does not give more information when compared to Programme 31 for this type of field loss. Both programmes, however, do exhibit a relatively high proportion of 1^+ scores when compared to the Goldmann. All three instruments record a high proportion of scores in the 1^+ category when compared to the Bjerrum and to the VFAs.

2. *General reduction in sensitivity*

When Programme 31 was used as the reference, Programme 21 and the Bjerrum gave the highest score in the I category (11 and 10 out of 16 respectively). Interestingly, the Bjerrum seemed to perform slightly better than the Goldmann (8 out of 16). Programme 21 scored 3 out of 16 in the 1^+ category; the remaining instruments exhibited similar scores in the 1^- category.

The VFA I scored worse than the VFA Mk II giving only 2 out of 16 for the I category compared to 6 out of 16. Programme 31 demonstrated a greater field loss than all the strategies with the exception of Programme 21 which indicated an even greater loss thus confirming, for the general reduction group, the observations for the heterogenous sample (Wild et al., 1984).

When Programme 21 was used as the reference, Programme 31 gave the highest score in the I category (11 out of 16). The Goldmann and Bjerrum scored similarly throughout the various categories. The VFA Mk I scored only I out of 16 for the I category and was worse than the VFA II (6 out of 16)

which was similar to the Bjerrum and Goldmann. A high score was recorded for all instruments in the 1^- category, again giving support to the hypothesis that Programme 21 shows a greater degree of field loss.

When the Goldmann was used as the reference, the two Octopus programmes gave the highest scores in the I category, with the Bjerrum and VFA II scoring significantly less, but similarly (5 out of 16). Programme 21 exhibited the highest score in the 1^+ category, followed by Programme 31 and the Bjerrum, thus giving a deeper or greater field loss than any other instrument.

Surprisingly, it would appear that the Bjerrum performs better than the Goldmann in general reductions i.e. it is a better predictor of the Octopus results. The VFA II scored better than the VFA I but neither could be considered a particularly good predictor of the Octopus.

3. *Glaucomatous visual field defects*

Although the glaucoma group only consitutes eight patients, agreement is found between the Octopus programmes and the Goldmann. The VFAs, however, both show a low score in the 1 category when compared to these instruments and the results for the VFA Mk II record that 2 out of 8 patients showed no level of compatibility.

4. *Central island*

There were too few subjects in this group to observe any obvious trends. It must be noted, however, that the VFAs were the only instruments to score 4 out of 4 in the 1 category when compared to the Octopus 31 programme.

This result would appear to support empirical clinical observations, which have not yet been substantiated experimentally, that retinitis pigmentosa patients find difficulty observing target size 3, but not target size 5 on the Octopus 21 programme, although the threshold value should theoretically be identical. It is generally accepted that a static test logic is more reliable than a kinetic test logic and certainly subjectively easier for these patients. Although it must be stressed that such opinion has not been substantiated experimentally, compared to a threshold static regime, a suprathreshold static regime may possibly be more reproducible and certainly of equal benefit to the clinician.

5. *Central defects*

When Programme 31 was used as the reference, no particular trend was evident in the results. Programme 21, however, gave the highest score in the 1^+ category (3 out of 9). When Programme 21 was used as the reference, it is interesting to note that the VFA I gave an identical score to Programme 31. The most significant finding, however, is that every instrument gave the highest score in the 1^- category with the VFAs scoring similarly to any other instrument. These results again indicate that Programme 21 exhibits a greater degree of field loss.

6. *Miscellaneous paracentral defects < 25°. Peripheral defects > 25°*

There are insufficient subjects in these two groups to observe any trends. The Goldmann and Octopus 31 do, however, give the highest level of agreement.

7. *Blind spot*

Although this group constituted the largest sample, no trend is evident. Programme 21, in this case, does not give the greatest score in the 1^+ category, but both the Octopus programmes do score highly in this category when compared to the Goldmann (11 and 10 out of 26 respectively). The Bjerrum also gave a high proportion in the 1^+ category when compared to the Goldmann (9 out of 26). This is not surprising when considering the resolution of the Goldmann around the blind spot area. The two VFAs, however, scored a high proportion of normal fields when compared to the remaining instruments with the Mk I scoring slightly worse than the Mk II throughout. This finding is compatible with the differences in the distribution of the targets around the blind spot for these two instruments.

8. *Hemianopia*

When compared to Programme 31 as reference, Programme 21 and the Bjerrum gave the highest proportion in the I category (8 and 7 out of 9) followed by that for the Goldmann (5 out of 9). This indicates that, in patients with hemianopia, the Bjerrum may provide a good prediction of the Programme 31 result. The VFAs again scored badly with little difference between the two instruments.

When Programme 21 was used as reference, Programme 31 gave the highest proportion in the I category and the VFAs gave the poorest results.

The two Octopus programmes both scored 2 out of 9 in the 1^+ category when compared to the Goldmann, but there is no suggestion that in hemianopic patients Programme 21 gives a greater field loss than Programme 31.

9. *Normals*

When Programme 31 was used as the reference, the VFA I gave the highest proportion in the I category. In this case, however, the result is due to the apparent low sensitivity gradient which causes a disproportionate amount of threshold field plots to be scored as normal and which inevitably correctly identifies the normals in the I category (7 out of 9). Programmes 21 and the Bjerrum both scored 5 out of 9 for the 1^+ category indicating a greater degree of field loss. This is further supported when Programme 21 is used as the reference as each instrument manifests its highest score in the III category.

When the Goldmann was used as reference, the results were very similar to those obtained when the Octopus 31 acted as reference. The salient points, raised by the results for the normals are discussed elsewhere (Wild et al., 1984).

Threshold VFA. It was noted by Wild et al. (1984) that when the VFAs were used according to Greve's threshold technique (Greve, 1971), the scores were improved. Eight of the nine hemianopics were retested by this method. In one of the eight subjects, an improvement, i.e. a more compatible result, was demonstrated with both VFA Mk I and Mk II; three of the eight subjects demonstrated an improved result with the VFA Mk I only; and the remaining four subjects showed an improvement with the VFA Mk II only.

It must be concluded that in the hemianopic group, the VFAs improve their performance sufficiently to be a reasonable predictor of the Octopus results. The use of the VFA for this group could not, however, be recommended as the threshold technique took longer to perform than any other instrument.

It is apparent that Programme 31 provides the most consistent and most desirable results for each condition when compared to the other instruments and techniques used throughout the study. It would therefore, be appropriate to rank the other five techniques relative to this programme. This should not, however, be interpreted as support for the use of a single reference instrument. The sample sizes are, in most cases, insufficient to draw any major conclusions, but from the observations directions may be indicated for future research and instrument soft-ware design.

When considering each instrument in turn relative to Programme 31, and with particular reference to the sub-groups defined earlier, it is found that:

I Programme 21

The general observations made by Wild et al. (1984) that Programme 21 exhibits a greater field loss than Programme 31 appears to be restricted to certain specific groupings i.e. general reduction, central defects and normals. There is a particularly high agreement exhibited between the two Octopus programmes in local reduction, general reduction, glaucoma, central island and hemianopia.

Both Programmes exhibit an equal but greater field loss compared to the remaining instruments for local reduction and blind spot abnormalities.

Programme 21 proved incompatible with Programme 31 for the normal group and for miscellaneous paracentral defects within 25° and peripheral defects without 25° of eccentricity.

II The Goldmann Bowl Perimeter

The Goldmann exhibits good agreement with Programme 31 in the normal group. It would also appear to be a good predictor for miscellaneous defects within 25° and for peripheral defects without 25° eccentricity. It scores better than any instrument with the exception of Programme 21 for glaucoma and gives similar results to the Bjerrum for local reduction and for blind spot

abnormalities, but again neither instrument is as compatible as Programme 21.

The Goldmann performs less well relative to the other strategies for general reduction, island defects or hemianopics.

III The Bjerrum Screen

The Bjerrum appears to be a good predictor of Programme 31 for central defects and is similar to Programme 21 for general reduction and hemianopics. The Bjerrum performed less well, however, for the normals, glaucoma and particularly for the central island defects. It proved to be most time consuming and therefore this may be an unacceptable feature despite the compatibility in certain conditions and the relatively low initial cost.

It is interesting to note that the original and much quoted observation of McLean (1937), subsequently supported by Blum, Gates and James (1959) that probably 95% of all significant ophthalmo-neurological lesions are quantitatively discoverable readily within this (central) area, and that the use of a fussy and exhausting 180° perimeter is a rare necessity, cannot be substantiated by this study despite identical stimulus conditions in all three studies. A 2 m Bjerrum Screen would probably have scored better than the 1 m, but the time factor would still have been a problem.

McLean's (1937) observations are supported for the central 30° when considering the threshold static technique utilized by Programme 31. This is understood when considering Traquair's (1927) original analogy to the island of vision. If threshold is accurately measured the island is relatively high, but on a similar contour to that predicted by suprathreshold techniques and will, therefore, indicate peripheral abnormalities within a lesser eccentricity (Figure 2).

IV The VFA Mk I and Mk II

In spite of both VFAs being criticised heavily throughout this report when used in the normative age-setting mode, both give a very high level of compatibility with Programme 31 for conditions which result in the preservation of a central island of vision. The VFAs also give a high level of compatibility for central abnormalities, although it must be noted that both scored particularly badly for blind spot abnormalities and glaucoma.

In general reduction and blind spot abnormalities the VFA Mk II gives a more compatible result than the VFA Mk I. For all other groups the two instruments scored surprisingly similar results. The original premise that the VFA Mk I and Mk II could be used in the normative age-setting mode to provide a quick and cost-effective predictor for the efficient use of Programme 31 must now be discounted. This is unfortunate as the initial outlay and cost of maintenance rather than the examination time seem to prohibit the use of the Octopus as a screening instrument.

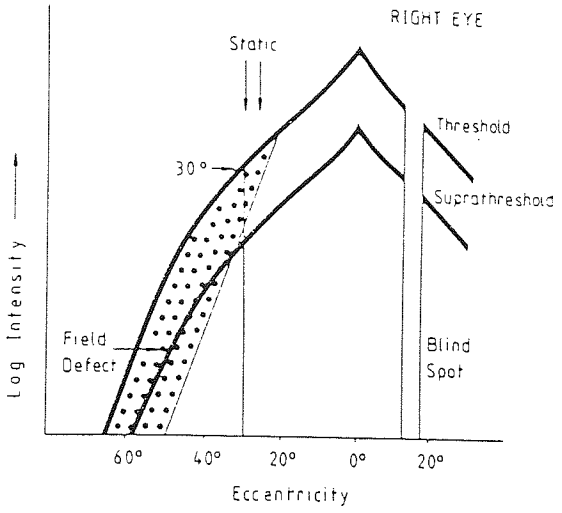

Figure 2. Comparison of threshold and suprathreshold modes in the detection of peripheral abnormalities within the central 30°.

In conclusion, the trends indicate that future soft-ware design should pay more attention to the development of testing logics for specific conditions rather than to the development of an extensive instrument menu. A large variety of programmes with differing spatial resolutions, may permit the testing of particular areas of the visual field, but the investigative technique, e.g. threshold static, cannot generally be altered. Certain conditions, however, may be reliably monitored and produce less patient fatigue by using a suprathreshold and/or a mixed testing logic. Such observations are supported to some extent by the work reported here.

We suggest that along with the many advances being made in electrodiagnostic techniques, 'layer by layer perimetry' and the quantification of visual space in terms of neural representation, there is still much development necessary to improve our basic perimetric techniques. The arrival of computer assisted perimeters and their soft-ware capabilities should, with appropriate application, ensure that perimetry will keep pace with these related areas and remain a clinically desirable test.

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THE COMPARISON OF DIFFERENT TEST LOGICS FOR THE EXAMINATION OF THE VISUAL FIELD

J. M. Wild, J. G. Flanagan, D. A. Barnes and B. A. Gilmartin
Department of Ophthalmic Optics, University of Aston in Birmingham,
Gosta Green, Birmingham B4 7ET, UK

P. A. Good and S. J. Crews
Retina Department, Birmingham and Midland Eye Hospital, Birmingham UK

Abstract

Over the last decade there has been a shift towards the automation and computer assistance of visual field instrumentation. The aim of the study was to compare established instruments with recent developments in visual field investigation. Five clinicians employing a double-blind protocol compared the Octopus Automated Perimeter, Goldmann Bowl Perimeter, Friedmann Visual Field Analysers Mk I and II and Bjerrum Screen, using a pseudo-random sample of patients (N=75) from the Birmingham and Midland Eye Hospital.

A five-point ranking system was developed for the inter-instrument comparison of the visual field plots. This system avoids the use of a standard reference, thus permitting a full clinical comparison of any two instruments within the group.

Differences between instruments for the group as a whole, and also for various types of visual field loss are presented.

Introduction

The apparent superiority of conventional perimetric instruments, such as the Bjerrum Screen and the Goldmann and Tubinger Bowl Perimeters, has in recent years been challenged by more modern instrumentation. These later instruments utilise microprocessor technology to control the decision-making process (Greve, 1982). Some are semi-automated and usually provide a suprathreshold test comprising a given target intensity at fixed points in the visual field. As such, these instruments are designed primarily for the detection phase of the visual field investigation. Others are more fully computer-assisted and, as a result, can provide threshold evaluations at variable sets of predetermined points in the visual field. They can also present graphical and statistical displays of the data. These latter instruments possess flexible strategies suitable for the limited assessment phase and some can also undertake the extended phase of the visual field examination (Greve, 1973, 1982). It is clear therefore that some instruments, such as the Friedmann Visual Field Analyser (VFA) and the automated tangent screen, are suitable for optometric use, whereas others are designed for hospital investigations. Nevertheless, all possess certain advantages, namely a precisely defined and reproducible examination strategy and ease of operation. Indeed, the current emphasis by manufacturers is on the development and design of software capability to permit variable and flexible test routines and presentation of the data in question. Not all instruments, however, include the necessary control over the various stimulus parameters and the question must be posed as to whether some are manufactured without a thorough consideration of such features. With advancing technology,

the possibility of "semi-intelligent" software and the probability of a reduction in cost, automated perimeters will become a permanent feature in both optometric and ophthalmological practice.

One is therefore faced with the problem of how to evaluate the new generation of perimeters. This is compounded by the fact that many instruments employ test strategies which differ from those used in the current standard, the Goldmann Bowl Perimeter, which is largely used in the kinetic mode.

Attention must be paid to the choice and type of instrumentation and therefore to the effect on the sensitivity gradient of such photometric parameters as mode of stimulus generation; stimulus duration, size, luminance and spectral emission; inter-stimulus duration; number and location of multiple or single stimuli; threshold static, supratheshold static or kinetic presentations and background luminance.

The composition of the patient sample is also important as the sensitivity gradient various with physiological factors, such as age, sex, pupil size and refractive error. Indeed, many of these variables have been investigated in detail by Fankhauser (1979). Comparative evaluations of computer-assisted perimeters (CAPs) have mostly utilised glaucoma or neurological groups. The value of investigating heterogeneous patient groups, however, should not be underestimated since it is reasonable to hypothesise that differences may exist between patient groups in the response to the differing forms of test logic. The level of field loss exhibited by the particular sample is important and is closely related to whether the detection and/or assessment phases of the visual field examination are being studied. Patient samples should also include a proportion of normal subjects in order that both the sensitivity and the specificity (Greve, 1973; Kleinstein, 1982) can be determined. The limitations inherent in the use of a single instrument as a standard by which to make such judgements have recently been discussed by Flanagan et al. (1984a). In addition, the scoring system for the comparative evaluation of inter-instrument performance should also separately consider the results in terms of the detection and assessment phases and reflect both the diagnostic capability and the descriptive difference between the field plots obtained from the various instruments.

We report now on our own experiences resulting from a validation study of the Octopus Automated Perimeter. The Octopus was developed by Bebie et al (1976a, b). It is a computer-assisted perimeter which utilises a projection system to generate a single, static stimulus which is comparable to that of the Goldmann. A threshold evaluation of the visual field is obtained and the number, spatial resolution and location of the test points vary depending upon the particular program selected.

Methodology

Two Octopus programs were utilised, Program 21, a full-field program with a low (15°) resolution and Program 31, a central-field program with a higher (6°) resolution. The Octopus was compared to the Goldmann III4, 14 and 12 isopters) the Friedmann VFAs Mk I and Mk II (normative age settings) and the Bjerrum Screen (3/1000W, 1/1000W). The Friedmann VFAs were included in order to investigate the hypothesis that the results from the supratheshold mode could be used as a cost-effective and reliable predictor of the appropriate threshold

Octopus program. The suitability of the Friedmann VFA MkII was under particular scrutiny as a possible instrument for use in the study of neural representation currently being undertaken in the Clinical Neurophysiology Unit at the University of Aston (Drasdo and Peaston, 1980; Flanagan et al., 1984). In addition, a sample of patients (N=16) from those who had demonstrated either a field within normal limits or slight levels of field loss with the VFAs were re-examined using the threshold technique of Greve (1971). The Bjerrum Screen was incorporated in the study as it is still frequently the instrument of choice, particularly among ophthalmic opticians. The Octopus in both the general and detailed modes of visual field investigation was thus compared with a range of kinetic and static perimeters, including both "diagnostic" and "screening" instruments.

A sample of 75 patients (75 eyes) from the Birmingham and Midland Eye Hospital was examined. The sample comprised patients exhibiting varying levels of field loss and 10 normal individuals with no known field abnormality. All patients were volunteers and had responded to a request for participation contained in a formal letter. The diagnostic categories are given in Wild et al (1984).

The full-field Octopus mode and the Goldmann were undertaken at the Birmingham and Midland Eye Hospital on one occasion, the Bjerrum and Friedmann VFA examinations at the University of Aston on a second occasion and the detailed Octopus program on a third occasion. Each of the five instruments was operated by a single experienced clinician and a double-blind protocol was followed throughout. The sequence of examinations within an individual session and the order in which the first two sessions were carried out were randomised. All three sessions for a given patient were completed within a maximum period of three weeks. The detailed methodology is described elsewhere (Wild et al., 1984).

Results

A total of 5 individuals failed to complete all the examinations within the specified period. The results for the remaining 70 patients were analysed using the system developed by Flanagan et al. (1984a) for scoring data from multi-instrument visual field studies.

Table 1: Level 1 analysis of the 70 fields considered in terms of sensitivity and specificity

Test strategy	Sensitivity (maximum 61)	Specificity (maximum 9)
Program 21	60	2
Program 31	58	6
Goldmann	58	9
Bjerrum	58	3
VFA Mk I	50	7
VFA Mk II	51	5

This system consists of 4 scoring levels, each of increasing complexity, which permits a between-instrument evaluation across any level and a within-

instrument evaluation between any level. The results for the sample as a whole have been described in full by Wild et al. (1984). The simplest level (Level 1) corresponds to the detection phase of the visual field examination and records the incidence of abnormal visual field plots. From this level, the sensitivity and specificity can be calculated (Table 1). Program 21 exhibited the highest sensitivity (detecting 60 of the 61 pathological fields) but the lowest specificity (correctly identifying only 2 of the 9 normal fields). Program 31, the Goldmann and the Bjerrum each detected 58 pathological fields. The Goldmann confirmed all 9 normal fields, however, whilst Program 31 and the Bjerrum only recorded 6 and 3 normal fields respectively. The Goldmann therefore appeared to have yielded the best results overall. An interesting anomaly arose, however, in that 3 of the supposedly normal patients were each found to have an abnormal field when examined with the majority of the instruments. Having taken this factor into account, Program 31 was found to demonstrate results closest to the ideal distribution.

The second level of analysis records the number of fields from each instrument which are considered to be in agreement with the diagnosis of the patient's condition. This level represents the transition from a consideration of the detection phase to a consideration of the assessment phase of the visual field examination. From the second level analysis, a refinement of the sensitivity can be calculated (Table 2). Indeed, all the instruments, with the exception of the two VFAa, showed similar results.

Table 2: Level 2 analysis considered in terms of sensitivity

Test strategy	Sensitivity (maximum 61)
Program 21	55
Program 31	56
Goldmann	56
Bjerrum	54
VFA Mk I	44
VFA Mk II	48

The third level of analysis considers whether the field plots from each of the instruments for a given patient are compatible with one another. This level is necessary as it is possible to have a series of field plots which are all abnormal, all consistent with diagnosis and yet contain different areas of loss relative to each other. The most consistent strategy was found to be Program 31 (67 out of 70) whilst the poorest was exhibited by the two VFAs (each with 53 out of 70).

The fourth level of analysis undertakes a detailed comparative evaluation of the fields for a given patient based upon a knowledge of the diagnosis and a consideration of the type, location, size, shape and depth of defect. Each instrument is used in turn as the standard by which to judge, on five-point scale (Table 3), the plots from the remaining instruments. This level of analysis in particular can be considered both in terms of the results for the various conditions as a whole (Wild et al., 1984) and in terms of those for individual diagnostic categories (Flanagan et al., 1984b).

Table 3: The five-point scale used in the Level 4 analysis

Scoring Category	Definition
1^+	Comparison field and reference field compatible. Comparison field exhibits greater field loss.
1	Comparison field and reference field compatible.
1^-	Comparison field and reference field copmpatible. Comparison field exhibits less field loss
II	Comparison field and reference field incompatible.
III	Comparison field normal, reference field abnormal

For the group as a whole, Program 21 recorded a high proportion of 1^+ scores when compared to Program 31, the Goldmann or the Bjerrum. This indicates that Program 21 produced a deeper and/or greater area of field loss than these three instruments. In addition, Program 31 also recorded more loss than either the Goldmann or the Bjerrum.

The difficulty in relating the results from automated visual field instruments to an accepted standard is highlighted by these findings. The greater number of 1^+ scores recorded by Programs 21 and 31 suggests that the Octopus examinations either yielded results which were better than the Goldmann or which provided too much information. By relating the Level 4 results to those from Levels 1 and 2, it was concluded that Program 21 provides too much information whereas Program 31 appears to perform better than the remaining instruments. Interestingly, it has been shown elsewhere (Wild et al., 1984) that Program 21 provides a greater area of loss than Program 31, but that both Program 21 and Program 31 record a deeper and greater area of loss than the Goldmann.

The scores from the Bjerrum proved to be superior to those from the two VFAs operated in the normative age setting mode but inferior to those from the Goldmann.

When compared to Program 21, Program 31 and the Goldmann, there was little difference between the performance of the two VFAs and both related poorly to these reference instruments. The VFA MkII, however, performed better than the MkI in relation to the results obtained with the Bjerrum. It is very clear that even when operated as a screener in the normative age setting mode, both VFAs fail to detect a major proportion of individuals with minimal field loss (Level 1) and that when compared to the other instruments (Level 4) each shows poor correlations, regardless of the depth of field loss. Indeed, these findings are compatible with those of Greve (1971) and more recently Gutteridge (1983). When operated in the threshold mode, the results from the two VFAs showed a marked improvement, but the extent of the improvement was not as great as had been

expected from the literature. Furthermore, this conclusion is compounded when it is considered that the results were obtained from the full threshold mode. The performance of the two most commonly advocated alternative methods (increasing the filter setting by 0.2 units from the normative age setting; operating at 0.4 log units less than the individual threshold) would thus lie between those from the two methods used here. As the complexity of the Friedmann mode increases, the examination time also increases; the time necessary for the Greve method was found to be greater than for the other three strategies, including Program 21.

For the group as a whole, Program 31 was found to give the most consistent overall performance.

The field plots from each patient were classified in terms of location using a system modified from Greve (1982). Compared to Program 31, Program 21 yielded more 1^+ scores than any other instrument for the group exhibiting general reduction in sensitivity, and the Bjerrum gave a similar proportion of 1 scores to Program 21. Both Octopus Programs recorded a compatible field loss in cases of local reduction in sensitivity which was frequently greater than the Goldmann and the Bjerrum which, in turn, produced similar results to each other. The two VFAs at normative age setting performed particularly poorly in the glaucoma group. In contrast, they produced the closest agreement of any instrument to Program 31 in conditions which resulted in the preservation of a central island of vision. The two kinetic strategies, however, performed the least well for this group. No instrument was particularly outstanding for the central defects group: the Bjerrum recorded the highest proportion of 1 scores and Program 21 yielded the most 1^+ scores compared to Program 31. Both Octopus programs produced a deeper loss for the blind spot abnormality group. Interestingly, however, the Bjerrum performance for this group was very similar to that of the Goldmann despite the differences in resolution between the two instruments. Compared to Program 31, the Goldmann and the normative age setting VFAs performed the least well of all the instruments for the hemianopic category.

There were insufficient patients within groups having miscellaneous paracentral defects inside 25° or peripheral defects outside 25° for any noticeable trends to be detected.

Conclusions

The number of subjects within most of the categories is insufficient to draw any definite conclusions. Nevertheless, the results do form the basis for further work which, in turn, may indicate the approach to the design of future computer-assisted perimeters. Indeed, it would seem from these initial results that future software should incorporate the facility to offer a variety of testing logics. These logics would be controlled by "semi-intelligent" means and would overcome the need to use all of the test location options offered in the current range of menus. The software would enable both the detection and the assessment phases of the visual field examination to be featured in the same instrument which, we predict, would be comparable in price to the present-day screeners. The former mode would be used for screening purposes by, for example, ophthalmic opticians whilst the latter mode would be of paramount importance in the diagnostic process.

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Short communication

SOURCE DERIVATION OF THE VISUAL EVOKED RESPONSE TO PATTERN REVERSAL STIMULATION

R.A. CLEMENT, J.G. FLANAGAN and G.F.A. HARDING

Clinical Neurophysiology Unit, Department of Ophthalmic Optics, University of Aston in Birmingham, Woodcock Street, Birmingham B4 7ET (England)

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The lateralisation of the visual evoked response to half-field pattern reversal stimulation has been described as paradoxical (Barrett et al. 1976) in that it is maximal over the cortex ipsilateral to the half field stimulated. In this study we demonstrate that the source derivation procedure devised by Hjorth (1975), which has proved pertinent to the interpretation of EEG (Wallin and Stålberg 1980), simplifies the interpretation of the pattern reversal response.

Methods

Twenty male subjects were used, age range 19–24, all of whom had a visual acuity of 6/6 or better following optical correction where necessary. Only the right eye of each subject was used. Seven electrodes were placed in a transverse row 10% of the inion-nasion distance apart across the occiput. Five of the electrode locations correspond to standard positions (T_5, O_1, O_z, O_2, T_6) in the 10-20 system. The electrode midway between T_5 and O_1 will be referred to as O_3 and the electrode midway between O_2 and T_6 will be referred to as O_4. Each electrode was referred to a common reference at F_z.

The pattern reversal stimulation was produced by a mirror which moved rapidly to and fro once per second. The checks subtended 56 min of arc, and the circular field of the stimulus subtended 28° of arc. The luminance of the dark checks was 180 cd/m and the luminance of the light checks was 1100 cd/m, giving a contrast of 0.736. Half-field stimulation was produced by blanking off half of the whole-field stimulus.

For each stimulus, 100 sweeps were recorded. The potentials were averaged on a Nicolet Pathfinder II, using bandpass filters with a low frequency cut off at 0.5 Hz and a high frequency cut off at 70 Hz, and stored on discs.

The bipolar and source derivation distributions were computed from the stored data. The bipolar derivation was computed by application of the difference operator:

$$B_n = C_{n+1} - C_n$$

where B_n is the nth bipolar channel from the subjects's left and C_{n+1} and C_n are the n + 1th and nth common reference channels from the subject's left. This bipolar derivation corresponds to a bipolar chain from left to right (Barrett et al. 1976). The source derivation was computed by a repeated application of the difference operator, i.e.:

$$S_n = B_{n+1} - B_n = (C_{n+2} - C_{n+1}) - (C_{n+1} - C_n)$$
$$= C_{n+2} + C_n - 2C_{n+1}$$

where S_n is the nth source derivation channel from the subject's left.

The amplitudes of the responses were measured with respect to the F_z reference. In order to investigate the distribution of the P100 component, the latency of the component on the channel on which it was maximal was determined, and the amplitude was measured on the other channels at this latency.

Hjorth (1975) specified the size of the source derivation as a voltage, whereas Katznelson (Ch. 7 Nunez 1981) has related it directly to the physical concept of the Laplacian of the potential field by expressing it in units of $\mu V/cm^2$. In order to facilitate interpretation of the source derivation recordings in terms of sources and sinks in the scalp current flow, the latter units were adopted. The appropriate scaling was achieved by dividing the source derivation by the square of the distance between the electrodes, measured in centimetres. With the sign conventions used in this study, a positive value in the source derivation indicates the presence of a current sink, whilst a negative value indicates the presence of a current source at the electrode.

Results

The response to whole-field pattern reversal stimulation on the midline consisted of an NPN wave form (Blumhardt et al. 1977). The 3 peaks had mean latencies of 63.7, 96.9 and 140.4 msec with standard deviations of 7.0, 8.4 and 15.4 msec respectively. The amplitude of the NP component had a mean of 8.2 μV with a standard deviation of 4.2 μV, while that of the PN component had a mean of 8.7 μV with a standard deviation of 4.4 μV.

An example of the evoked responses to half-field pattern reversal stimulation is shown in Fig. 1. The common reference recordings show a clear lateralisation ipsilateral to the hemifield stimulated. The source derivation reveals a source located at O_z, and a sink located at O_3 with stimulation of the right half field and at O_4 with stimulation of the left half field.

The distributions of the amplitude of the major positive

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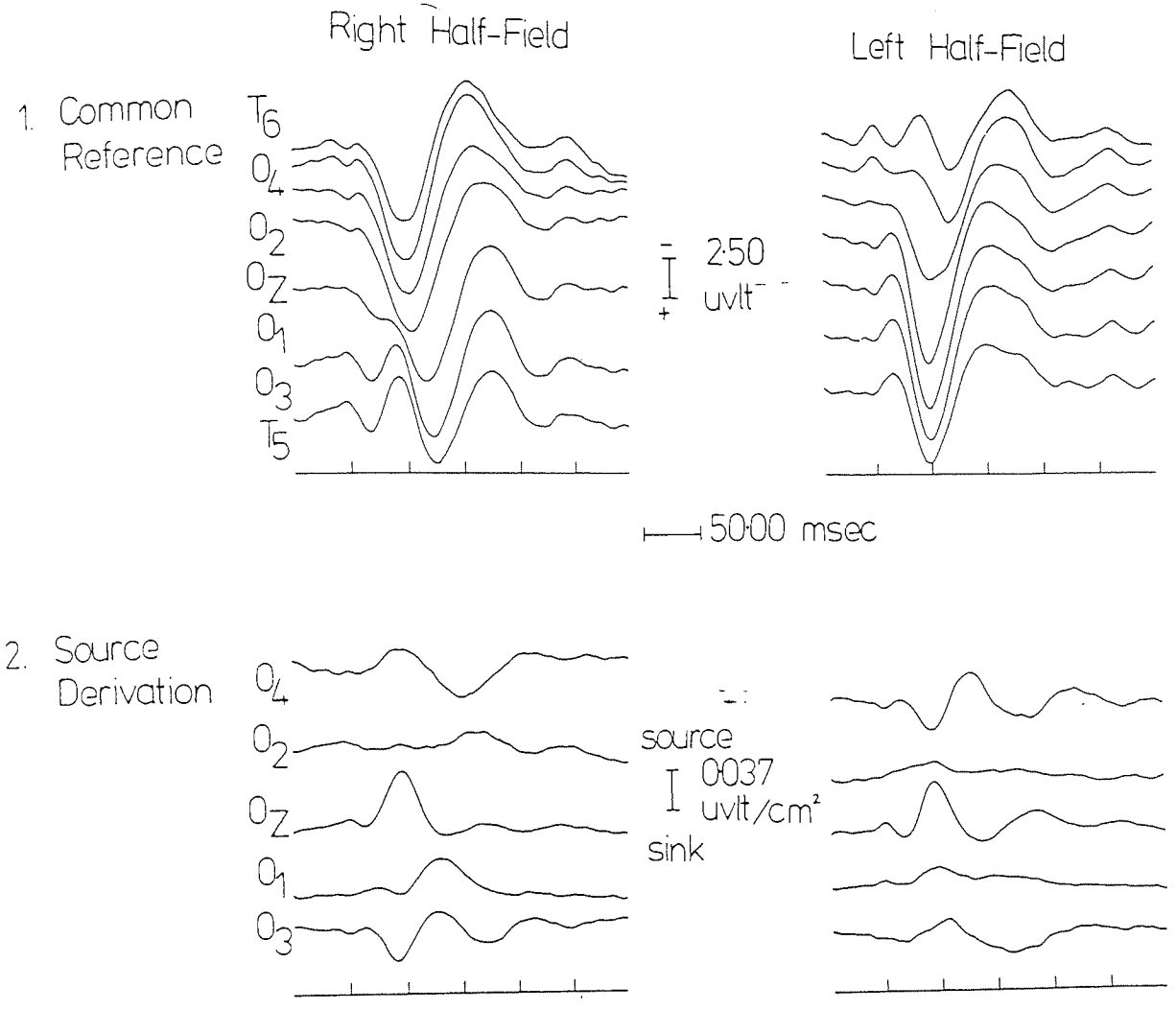

Fig. 1. Half-field responses to pattern reversal stimulation and their associated source derivations.

component in the group averages of the common reference responses to half-field stimulation, together with the bipolar and source derivation distributions computed at the latency at which the major positive was maximal, are shown in Fig. 2. In order to emphasise the lateralisation of the distributions, each distribution has been normalised so that its maximum value, be it positive or negative, is unity.

Although the main current generator, as revealed by the source derivation, is a source located at O_z, which does not shift with a change in the half field stimulated, there is also a sink which appears contralateral to the hemifield stimulated. The bipolar recording shows that current is flowing away from the midline, towards the cortex contralateral to the hemifield stimulated.

In order to test the statistical significance of the trends in the group averages, two-way analysis of variance was carried out, using the hemifield stimulated as one treatment and the recording electrode location as the other treatment. To simplify the interpretation of the test, the electrode location was specified in terms of a row from the cortex ipsilateral to the cortex contralateral to the hemifield stimulated. Only 19 subjects were used for the statistical analysis, since in one subject the P100 component with half-field stimulation could not be reliably identified. The way in which the source derivation changed with recording electrode location was found to be highly significant ($F_{4,72} = 15.1$, $P < 0.001$), demonstrating that the source-sink configuration found in the group average has not arisen by chance. There was no significant difference in the source derivation between the two half fields stimulated, and the interaction effect was also not significant, showing that the way in which the source derivation changes with recording electrode location does not depend on the half field stimulated.

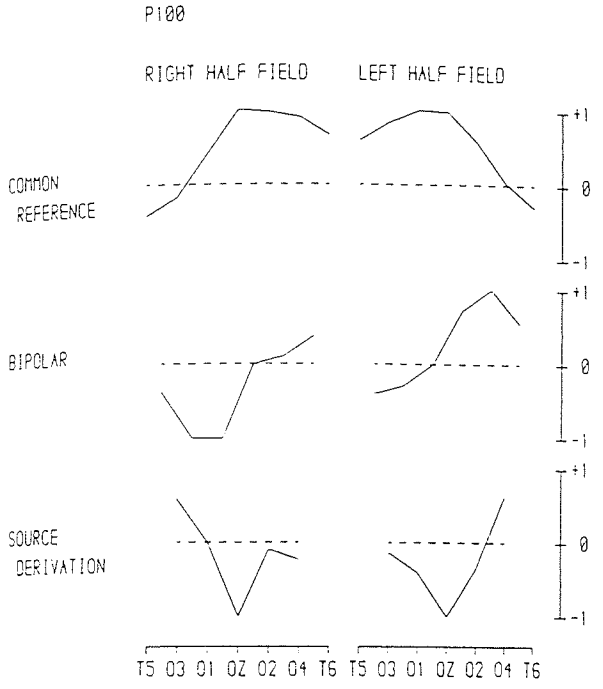

Fig. 2. Amplitude distributions of the P100 component in the group average of the pattern reversal responses to half-field stimulation, together with the associated bipolar and source derivation distributions. All the distributions have been normalised so that their maximum value is unity.

Discussion

The approach to analysis of the visual evoked responses to pattern stimulation that we have adopted here is that the common reference potential distribution reflects current flow in the scalp and that the sources and sinks in the scalp current flow, associated with cortical activity, can be identified by the source derivation procedure (Nunez 1981). The interpretation of our results is reasonably straightforward in that with half-field pattern reversal stimulation we found current flowing away f.om a source on the midline towards the cortex contralateral to the hemifield stimulated.

Our results with respect to source derivation are implicit in the findings of previous studies (Cobb and Morton 1970; Barrett et al. 1976; Shagass et al. 1976; Blumhardt and Halliday 1979). We believe that our reappraisal of their findings will be of use clinically since source derivation reveals lateralisation in direct accordance with the anatomical data.

Summary

This study demonstrates that the source derivation procedure described by Hjorth (1975) reveals lateralisation of the visual evoked response to pattern reversal stimulation in accord with the anatomical data.

Résumé

Dérivation de la source de la réponse visuelle évoquée à un renversement de pattern

Cette étude montre que la procédure de dérivation de la source décrite par Hjorth (1975) révèle une latéralisation de la réponse visuelle évoquée à une stimulation par renversement d'un pattern qui s'accorde avec les données anatomiques.

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APPENDIX 2 - ABSTRACTS

1 FLANAGAN JG, DRASDO N and HARDING GFA. (1984) The neural representation of the visual field - automated assessment and interpretation. Ophthal. Physiol. Opt. Vol. 4: No.2, pp.188 (Abstract from 1983 'Society of Experimental Optometry')

2 HARDING GFA and FLANAGAN JG. (1984) Source derivation of the visual evoked potential. ISCEV. 22nd Symposium, May 1984. pp73

3 FLANAGAN JG and HARDING GFA. (1984) The computation of source derivation of the VEP. AVA Newsletter. No. 48, pp17

4 BARNES DA, WILD JM, FLANAGAN JG, GOOD PA and CREWS SJ. (1985) The role of dynamic range in the investigation of the visual field. Ophthal. Physiol. Opt. Vol. 5: No. 2, pp233 (Abstract from 1984 'Society of Experimental Optometry')

5 WILD JM, BARNES DA, FLANAGAN JG, GOOD PA and CREWS SJ. (1985) The relationship between sensitivity gradient and definition of abnormality in the Friedmann VFA Mk. II. Ophthal. Physiol. Opt. Vol. 5: No. 2, pp233 (Abstract from 1984 'Society of Experimental Optometry')

6 FLANAGAN JG and HARDING GFA. (1985)
The visually evoked potential for upper and lower field stimulation. Ophthal. Physiol. Opt. Vol. 5: No. 2, pp234
(Abstract from 1984 'Society of Experimental Optometry')

The neuronal representation of the visual field--automated assessment and interpretation. By J. G. FLANAGAN, N. DRASDO* and G. F. A. HARDING, Department of Ophthalmic Optics, University of Aston, Gosta Green, Birmingham B4 7ET, U.K.

The Octopus automated perimeter has been programmed to investigate the visual field in terms of neuronal representation in an attempt to interrelate the visually evoked potential and the visual field. One new method discussed of displaying the data is the use of a depression profile technique which it is hoped will have a potential value in both diagnosis, by analysis of the form of the profile and disability assessment, by measuring the integrated area using a logarithmic ordinate. This technique could be incorporated into future automated diagnostic decision-making procedures.

SOURCE DERIVATION OF THE VISUAL EVOKED POTENTIAL

Harding, G.F.A. and Flanagan, J.G.
Clinical Neurophysiology Unit, University of Aston
Woodcock Street, Birmingham B4 7ET, England

There has been much recent conjecture over the apparent source location of the Visually Evoked Potential particularly when considering the lateralisation found in half-field pattern reversal stimulation. These results have commonly been explained in terms of dipole models (Barrett et al. 1976; Jeffries and Axford 1972; Van Lith et al. 1980; Lehmann et al. 1982), in spite of the problems inherent within such computations of dipole location (Kavanagh et al. 1978; Henderson et al. 1978; Sencaj and Auron 1982).

This paper presents an alternative by directly identifying the sinks or sources present in the scalp current flow as these correspond to the maximal current flow into or out of the cortex (Nunez 1981). Hjorth (1975) introduced a practical procedure for source derivation which has proved useful in the interpretation of the EEG (Wallin and Stahlberg 1980).

We have applied source derivation to cortical evoked potentials and present results obtained from right and left half-field stimulation, upper and lower half-field stimulation and in both normal subjects and patients with visual deficits.

THE COMPUTATION OF THE SOURCE DERIVATION OF THE VEP

Flanagan JG and Harding GFA

The apparent source location of the Visually Evoked Potential has caused much controversy particularly when considering the lateralisation found in half field pattern-reversal stimulation. These results have commonly been explained in terms of dipole models in spite of the problems inherent within such computations of dipole location.

By differentiating a common reference VEP recording with respect to spatial position we can differentiate once to compute the Source Derivation. This enables an alternative method to the dipole modelling by directly identifying the sinks and sources present in the scalp current flow as these correspond to the maximal current flow into or out of the cortex (Nunez 1981).

Results are presented using these techniques for right and left half-field stimulation, upper and lower half-field stimulation and subjects with visual field defects.

The Role of Dynamic Range in the Investigation of the Visual Field D. A. BARNES,* J. M. WILD* and J. G. FLANAGAN,† Department of Ophthalmic Optics, University of Aston, Gosta Green, Birmingham B4 7ET, UK, P. A. GOOD and S. J. CREWS, Birmingham and Midland Eye Hospital, Birmingham, UK

The variation in sensitivity gradient was assesed under different stimulus and luminance conditions, using a sample of 10 clinically-normal subjects on 3 current visual field instruments. The Threshold Static Profile programme of the Dicon Autoperimeter 2000 was operated at different bowl luminances. The technique of Greve (1971) was used to determine the Friedmann VFA MK II field. Programme 21 and a Programme Sargon of the Octopus Automated Perimeter were employed to match the Dicon and VFA stimulus locations respectively. Variations within a particular stimulus/luminance combination and also between combinations are presented. From these results and experience of abnormal fields, it would appear that the ability to assess sensitivity gradients for a given patient across the dynamic range of an instrument is a neglected area in the design of current C.A.P.s.

The Relationship Between Sensitivity Gradient and Definition of Abnormality in the Friedmann Visual Field Analyser MK II J. M. WILD,* D. A. BARNES* and J. G. FLANAGAN, Department of Ophthalmic Optics, University of Aston, Gosta Green, Birmingham B4 7ET, UK, P. A. GOOD and S. J. CREWS, Birmingham and Midland Eye Hospital, Birmingham, UK

A sample of 10 clinically-normal, age-matched subjects were examined with the Friedmann VFA MK II using the threshold technique of Greve (1971). From the threshold plots the results were analysed according to various methodologies and definitions of abnormality. The same procedures were carried out on a group of 19 patients exhibiting minimal levels of field loss. Variations in individual sensitivity gradients in the normal eye were shown to limit the application of any one scoring technique for determining abnormality of the visual field.

The Visually Evoked Potential for Upper and Lower Field Stimulation J. G. FLANAGAN† and G. F. A. HARDING, Department of Ophthalmic Optics, University of Aston, Gosta Green, Birmingham B4 7ET, UK

There has been much contradiction in recent literature over the morphology, amplitude and latency of the major components of the Visually Evoked Potential to Upper and Lower Field stimulation. A topographic study was undertaken using 18 normal male subjects with an age range of 19 – 24 and a visual acuity of 6/6 or better. Results were obtained using pattern-reversal checkboard stimulation of the whole, upper and lower fields. A 30° circular field with 56′ check size was used.

Techniques to establish the source derivation of the evoked potentials were used and showed, surprisingly, that the majority of subjects had a stable source on the midline over the occiput for both upper and lower field stimulation. There was a significant increase in the latency for upper field and stimulation when compared to lower field stimulation. These results are discussed and compared to previous studies.

APPENDIX 3 - PUBLICATIONS IN PRESS

1 FLANAGAN JG and HARDING GFA. Source derivation of the visual evoked potential. Doc. Ophthalmol. (In Press)

2 BARNES DA, WILD JM, FLANAGAN JG, GOOD PA and CREWS SJ.
The manipulation of sensitivity in visual field investigation. Doc. Ophthalmol. (In Press)

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