STUDIES ON THE OCCIPITAL ALPHA ACTIVITY OF THE HUMAN ELECTROENCEPHALOGRAPHY AND ITS RELATIONS TO THE EXTRA-OCULAR MUSCLE TREMOR AND OTHER PHYSIOLOGICAL TREMORS

by

CHOK-LEUNG CHAN, B.SC(ENG), M.I.E.E.E.

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ABSTRACT

The main objective of the present work is to investigate the origin of the alpha rhythm of the human electroencephalography. The rhythm has long been regarded as the reflection of the electrical activity of the human brain. Experiments were carried out to demonstrate that they are in reality the electrical concomitants of the extra-ocular tremor. In order to obtain reliable results, new techniques were employed in the FT and EOMT recordings. The physiological tremor, including FT and EOMT, is shown to be emanating from the stretch-reflex-arc. No relationship between the alpha waves and FT was found but a good correlation was obtained for the waves and EOMT. Various experimental tests were found to impose similar changes on the two correlated phenomena. In addition, the source of the alpha potential was found to be the corneo-retinal potential. It is thus suggested that the alpha activity is generated from the modulations of the CRP by the EOMT. A significant diurnal variation was found for EEG, EOMT and FT with some interesting discoveries. EEG, EOMT and EOG studies in a case of cortical blindness show that the alpha rhythm (if any) of the blind is actually generated by the same mechanism as the normals. Similar studies in a dizygotic twin pair demonstrate that genetic factors may have significant influence on the phenomena. Alpha feedback training was found to be effective for EOMT also. Overall, the eye-tremor and the stretch-servo hypotheses are supported.

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LIST OF ABBREVIATIONS

EEG	Electroencephalography, Electroencephalogram
EOG	Electro-oculography, Electro-oculogram
EMG	Electromyography
EOM	Extra-ocular muscle
EOMT	Tremor of the extra-ocular muscle, EOM tremor
FT	Finger tremor
ET	Eye-tremor
OMN	Oculomotor nucleus
CRP	Corneo-retinal potential
EC	Eye-close
EO	Eye-open
AT	Activity time
r	Product moment correlation coefficient
D	Wave interval or duration
n	Frequency of occurrence
REM	Rapid eye movement
DZ	Dizygotic

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CHAPTER ONE

INTRODUCTION

1.1 WHAT IS ELECTROENCEPHALOGRAPHY ?

The discovery that the brain manifests continual electrical activity during waking states as well as sleep, as revealed by electroencephalography (EEG), has served as a tremenduous impetus to further studies on the electrophysiological characteristics of the brain. When recording electrodes were placed on the scalp, the electroencephalogram cculd be obtained via bioelectric amplifiers and specific electronic filters. Good preparations of electrode locations were important to obtain a good record. In normal subjects, four wave frequencies may be recorded, the alpha, beta, delta and theta rhythms. The alpha rhythm dominates records from the occipital region or from the posterior parts of the parietal and temporal lobes. It consists of rhythmical oscillations in electrical potential ocurring at 8 to 13 Hz and are often referred as the 10 Hz oscillations in the brain waves. The waves have a voltage of about 10 to 50 μV on the averages. The brain rhythms are designated as follows:

	Frequency range	Voltage range	Region of prominence
Delta :	0.5 - 4 Hz	20 - 200 μV	during asleep
Theta :	4 - 8 Hz	5 - 100 μV	frontal and temporal
Alpha :	8 - 13 Hz	5 - 100 μV	occipital and parietal
Beta :	13 - 25 Hz	2 - 20 μV	precentral and frontal

Electroencephalographic records during excitement, relaxation, and varying degrees of sleep are completely different (Fig. 1.1). Many conditions favour the appearance of the alpha rhythms such as eye closure, patterned visual fields if eyes are open and, of primary importance, a lack of ocular fixation. On the other hand, such things as pattern vision, ocular fixation, intense concentration on mental tasks or on non-visual stimuli and the perception of surprising, alerting, or affective stimuli favour the " abolition " or blocking of alpha activity (Adrian and Matthews 1934) (Fig. 1.2). The ubiguity of the alpha waves, their greater prominence and their reactivity to sensory stimulation tended to focus interests of investigators on them from the beginning (Lindsley and Wicke 1974).

Recent advances on the subject are tremendous. No one knows precisely how many laboratories there are now, a conservative estimate might to 10,000 (Silverman 1972). The value of EEG as a diagnostic tool for the neurologist and neurosurgeon, and in more recent years, for the internist, pediatrician and psychiatrist is certainly an important factor for this astonishing growth. The outcropping over the past years of advertisements for " alpha training ", " brain programming ", " brofeedback machines ", " mind-control ", " brain waves as a new system for human development " leads to the growth and popularity of EEG. The investigations for the origin and characteristics of the alpha waves and introduction of EEG as a legitimate medical investigative procedure by Medicare and Medicaid recently are also factors involved. The above are also recent trends of study into the subject.

1.2 WHAT ARE PHYSIOLOGICAL TREMORS ?

When one tries to keep a finger in a given position or posture by muscle action, it is never at a complete standstill but makes minute oscillations. These oscillations have a strikingly stable frequency at about 10 Hz. Together with their regularity and persistence, they are termed physiological tremors. They are small and involuntary muscular oscillations superimposed on voluntary muscle movements. They are so small that can hardly be detected by naked eyes. Position, velocity or acceleration transducers can be used to record these tremors. Dynamic mikes, variable impedance transducer, pressure transducer and laser techniques were employed in our work. We appreciate the excellent performances of the dynamic mikes but to our surprise, they are neglected by other investigaters. The outputs from the transducers were fed into the bioelectric amplifiers (Hp 8811A) and recorded in the EEG recording machine (Hp 7702B). The signals were then recorded in tapes and analysed as in the case of EEG signals. We recorded the tremors at the finger (finger tremor), the wrist (wrist tremor), the elbow (elbow tremor) and the forehead. The extra-ocular muscle tremor (eye tremor) was recorded at the surface of the cornea or over the lid. Strangely enough, research works hitherto have not yet come to definite conclusion on the origin of these small tremors. This puzzle will be dealt with in later chapters.

1.3 OBJECTIVES OF THE PROJECT

The long-standing interest in and the far-reaching applications of the human electroencephalography have been emasculated by the uncertainty in the mechanism underlying its generation. It is the main objective of this work to show that the alpha waves are actually electrical concomitants of the extra - ocular muscle tremor and that the corneo-retinal potential serves as the potential source. Two separate fields are therefore involved in this work, namely, the electroencephalography and the physiological tremor. In order to have a firm support for the hypothesis which contradicts the long held view that alpha waves are generated in the cortical electrical activity, numerous experiments under various conditions were carried out. These make the thesis quite lengthy and scattered on the first look. Chapter one is the introduction. The origin of the alpha rhythm is investigated in Chapter two. Theorectical and experimental considerations leading to the eye-tremor hypothesis are given. The origin of this eye-tremor is then studied in Chapter three. Theorectical and experimental considerations are given in support of the stretch-reflex servo hypothesis. The extra-ocular muscle servo as a stretch-reflex is then studied to a greater depth. Having settled with the eye-tremor and the stretch-reflex servo hypothesis which are the basis of the alpha origin, the occipital alpha waves and the extra-ocular muscle tremor (EOMT) are correlated under different experimental conditions in Chapter four. It is shown that the two signals are strongly correlated in all the cases. This is important as it is the strongest evidence for the eye-tremor hypothesis. Should there be any discrepancies, the hypothesis would be doubted. The potential source for the alpha waves is then investigated in Chapter five. With some interesting findings, the corneo-retinal potential as the source is confirmed. The whole mechanism for the generation of the occipital alpha is then known. Further supports are given in Chapter six and seven. Some discoveries on the circadian rhythm of alpha waves and tremors are given in Chapter six. The alpha waves and eye-tremor are shown to vary in a similar manner diurnally but not finger tremor. The effect of feeding time and metabolic rate is also discussed. A case of cortical blindness and a case of fraternal twins are studied in Chapter Seven. The results conform to the earlier findings. EEG recordings in a blind subject seem to reject the hypothesis but the reverse is found to be true. A final conclusion is given in the last Chapter.

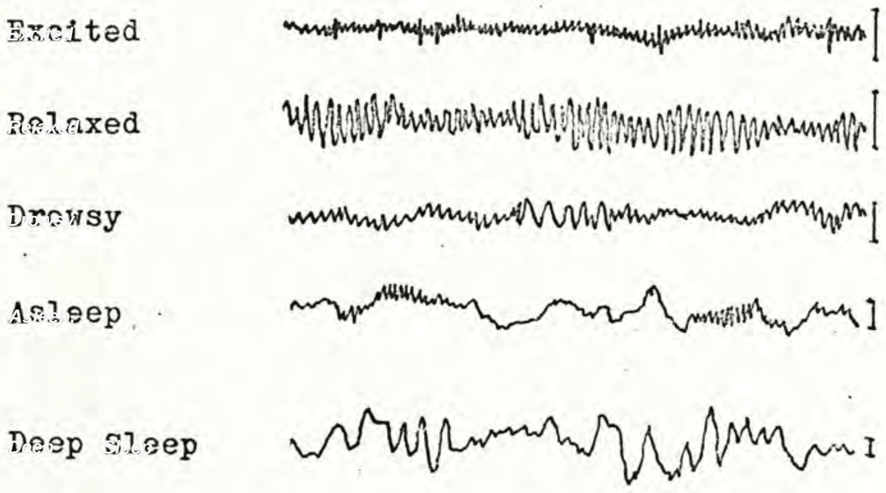


Fig. 1.1 Electroencephalographic records during excitement, relaxation, and varying degrees of sleep.
(From Jasper, 1941.)

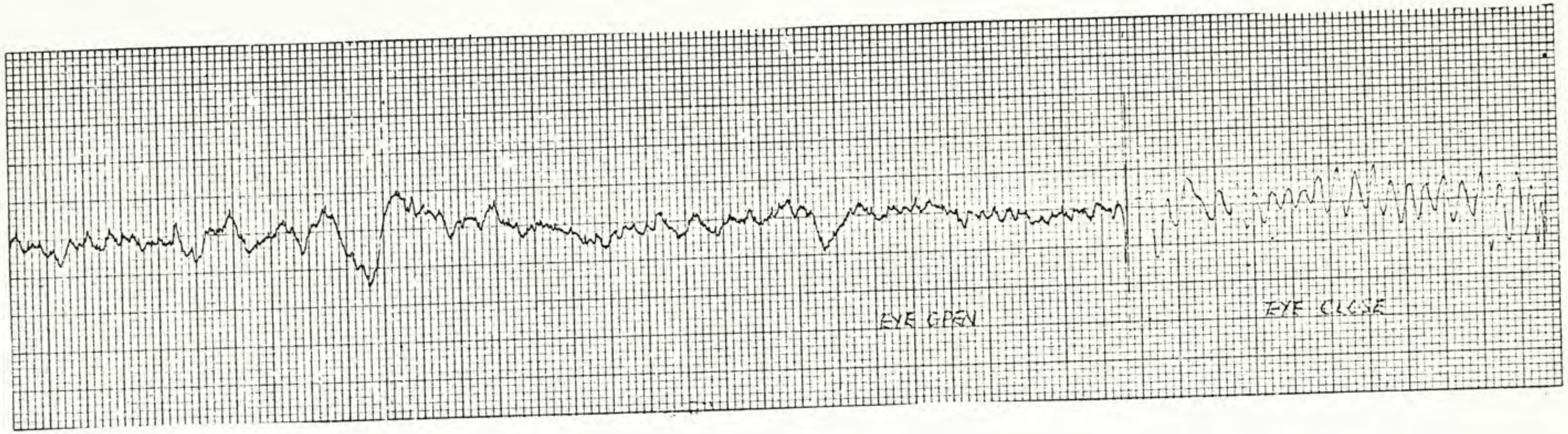


Fig. 1.2 EEG records with eyes opened and eyes closed. Note the distinct delta rhythm during eye-open and the dominant alpha rhythm during eye-close conditions. The variations of other rhythms and their magnitudes should also be observed.

CHAPTER TWO

ORIGIN OF THE OCCIPITAL ALPHA RHYTHM

2.1 A BRIEF REVIEW OF HISTORY

Caton in 1875 made the first discoveries of the electrical activity of the brain in rabbits and monkeys (Caton 1875). Notwithstanding extensive investigations by electrophysiologists in the intervening years including the discoveries of the effect of flicker on brain potentials (1887) and alpha blocking after sensory stimulations (1890), it was not until half a century later that Hans Berger (1929) made the first EEG record in man. Berger pointed out in his electrical brain recordings that there were regular rhythmic sequences of waves at about 10Hz in the relaxed adult subject and that they were best seen with the eyes closed in the absence of stimulation or other mental activities such as imaging or problem solving. He called these "alpha" waves and called the entire electrical record of the brain activity the Elektrenkephalogram (Electroencephalogram), abbreviated as EEG. Adrian and Mathews (1934) confirmed the validity of his findings. Walter (1937) first demonstrated an association between the presence of focal slow waves in the EEG and a cerebral tumour and confirmed Berger's observations on the effect of epileptic seizures on brain waves. This began the clinical application of the EEG recordings to the investigation of cerebral disorders.

Today, applications of EEG are numerous. These include applications in epilepsy, intracranial space-occupying lesions, head injuries, cerebral infections, delirium, pseudodementia, level of monitor of anaesthesia, indication for cerebral death, etc.

The history of the study of occipital alpha rhythm in humans can be summed up - as an index of mental processes and behaviour, it was overrated; as an orderly, predictable phenomenon, it was underrated (Mulholland 1972). The future hopes of EEG making greater and more valuable contributions may well lie in a great~~h~~er knowledge of the physiological basis of the EEG. Nevertheless, research works hitherto have not yet found a universally accepted theory on the origin of brain waves.

2.2 THE SIGNIFICANCE OF THE INVESTIGATION

Electroencephalography is becoming as important in the clinic of cerebral lesions as electrocardiography is in the clinic of heart diseases (Konradi, 1960). But what is happening actually? The physiological basis underlying the generation of alpha rhythm must be known before they are of any true diagnostic value. A good deal of literature has been based upon the assumption that the rhythm is a reflection of the underlying electrical activity of the brain itself, but where precisely? Do they arise from particular types of cells or networks? Are they due to processes in dendrites, axons, synaptic junctions, along cell membranes, in neuropil, in granular or agranular regions, in glia or in combinations of these? The problem was pointed out by Berger nearly half a century ago. Today we are heirs to vast technological developments and yet numerous experiments conducted in the way to find out the cortical or subcortical pacemakers did not give very determinative results. In fact, the waves are suspected to be generated by extracerebral potentials. It is thought that the tremor of the extraocular muscles modulates the corneoretinal potential and this modulation is recorded at the occiput because of the anatomical organisation of the orbital contents within the skull (Lippold 1970). This hypothesis contradicts the generally accepted view that alpha waves are generated by the electrical activities of cells inside the cerebral cortex. Thence a vast number of experimental evidences and theoretical considerations should be provided in support of it. Before proceding on with the experiments, it would be an advantage to review some of the published theories and hypotheses to have a greater understanding of the previous works on the subject.

2.3 SOME PUBLISHED THEORIES AND HYPOTHESES

Berger in his twelfth report (1937) came to the conclusion that the alpha waves arise in the internal principal zone of the human cerebral cortex, and that they are the electrical concomitants of its continuous physiological activity. But in his thirteenth report (Berger 1937), two years before his death, he abandoned his earlier working hypothesis because of the distortion of his records by artefacts. In fact Berger himself had grave doubts about the validity of his contention that the alpha waves actually did arise in the brain substances. At the same time, Berger interpreted that alpha blocking was the result from intention in general (Berger 1929). When Adrian and Matthews (1934) subsequently found that alpha activity was generated in the occipital lobe that was connected with vision rather than from the whole cortex, and that it was blocked far more effectively by visual than by non-visual activity, they advanced the idea that non-visual blocking was caused by a spread of desynchronising activity from other areas to the occipital lobe. They also explained the effects of eye opening and closure on the alpha waves by the presence and absence of visual attention. Largely as a result of the Nobel-prize winning work of Lord Adrian, it has long been accepted that the alpha rhythms originate from within the brain, particularly in the occipital lobes which are concerned with visual function. At those days, it was thought that closing the eyes would remove the stream of impulses entering the occipital lobes, the part of the brain concerned with visual processes, from the million or so fibres of the optic nerves. However, it is now known that with no visual input to the eye the optic pathway is occupied with the so-called 'dark discharge', an excitation almost as profuse as that occasioned by a patterned retinal input. In addition, the hypothesis suffered from the defect that many properties of the brain waves cannot be explained.

Jasper and Cruikshank (1937) found that the duration of alpha blocking was directly related to the length of the after-image of visual stimulation. Motoka~~rv~~wa (1941) and Nagasawa and Obonai (1957) reported similar observations. Eberlin and Yager (1968) restudied the problem and found that a positive interaction between after-images and attention and not attention itself blocked alpha waves. Cobb (1963) proposed that pattern vision may cause the blocking response by the series of momentary stimuli resulting from repeated fixation and accomodation and that this happened when something had to be in focus. Actually Adrian and Matthews (1934) noted the subjective sensation of accomodation and convergence when they attempted to block activity in the absence of visual stimulation. Adrian (1943) clearly pointed to changes of lens accomodation and eye fixation as salient variables involved in the desynchronisation or blocking of the occipital EEG.

The'attention or visual attention hypothesis' is finally challenged by the hypothesis that alpha blocking is due to processes of fixation, lens accomodation and pursuit tracking (Mulholland 1965, 1966, 1968, 1969, 1971, 1972; Storm van Leeirweir, Bickford, Brazier, Cobb, Dondey, Gastaut, Gloor, Henry, Mess, Knott, Kugler, Lairy, Loeb, Magnus, Oller, Daurella, Petsche, Schwab, Walter and Widen 1966; Dewan 1967). The extreme upward position of the eye enhanced alpha activities and a tight relationship between oculomotor efferent 'commands' and the occurrence of the occipital alpha rhythm was confirmed. Mulholland (1971) suggested that 'visual attention' as indicated by alpha blocking is, operationally, oculomotor change.

Apart from the oculomotor correlates of alpha activities, there are the neuronal streams of theories and hypotheses. Alpha waves were proposed to represent the excitability associated with the motor cortex (Bartley and Bishop 1933; Bishop 1933, 1936; Bartley 1940 ,; Bishop and O'Leary 1940 ; Marshall 1949 ; Chang 1951 ; Bishop and Clare 1952 ; Bates 1951 ; Kibbler and Richter 1950; Lindsley 1952, Lansing 1959). Vorontsov (1960) suggested that the surface EEG reflected only excitability of cortical neurons which are oriented in a vertical manner. Sherwood (1967) proposed that the EEG was the result of neuronal network activity, and the added or derived potential fluctuations caused by the chemical processes subserving their function. This conforms to the hypothesis that EEG rhythm reflected electrochemical events occurring at cell membrane level. (Margerison 1962). The theory of membrane excitability suggested that the excitable membrane was responsible for transmission for nervous impulses and presumably for the EEG (Offner 1972). However, no sustained oscillations suggestive of the alpha rhythm have as yet been found, though highly damped oscillations were obtained. The dendritic discharge hypothesis, on the other hand, proposed that EEG is the summation of the dendirtic activities especially in those vertically oriented and close to the surface. Zhadin (1969) excluded the possibility of EEG being the mere summation of potentials of independent cells. He suggested a mutual connection in the cell activity. Andersen and Eccles (1962) proposed a different mechanism dependent upon a prolonged apparently recurrent, postsynaptic inhibition in primary thalomocortical projection fibers. This inbition stops cell discharge of 0.1 second and no driving mechanism to discharge these neurons upon recovery to normal excitability has been proposed. Andersen and Andersson (1968) further pointed out that the thalamus is the pacemaker for the alpha rhythm. However, a survey of their records shows nothing like alpha rhythm. (Lippold, personal communication, 1977). Thereupon their assumption that the barbiturate spindle activity in animals is analogous to the human alpha rhythm is doubted.

Other hypotheses have been proposed. The scalp has been hypothesised to act as an averager of electrical activity from underlying cortical areas, averaging out the local random rhythms and transmitting the rhythms which are common to and synchronous over relatively large areas (DeLucchi, Garoutte and Aird 1962 , Cooper et al. 1965). Kennedy (1959) has argued that alpha rhythm recordings are artifacts caused by the mechanical pulsation (Choroid plexus 'pump') of a gel (the living brain) with different electrical potentials (Miller 1968). Keidal et al. (1971) emphasized the existence of an 'internal clock' triggering eye movements as part of a complex closed-loop system as suggested by Norbert wiener. Others correlate the alpha waves with cerebral blood flow (Sulg and Ingvar 1968; Sulg, Horman and Ingvar 1965), nystamic abnormalities and ENG responses (Barac 1965), metabolic rate (Lindsley and Rubenstein 1937), finger tremor (Lindquist 1941, Jasper 1936), reaction time (Lansing 1957; Callaway and Yeager 1960; Stevens, Lonsburg and Goel 1972; Survillo 1972, 1975) and Decision time (Surwillo 1963).

Here presented are some of the published theories and hypotheses on the alpha origin and yet sufficient to perplex an investigator. Some of them are plausible but some obscure or even implausible. No matter how well supported they are, they must be able to explain a very simple fact discovered half a century ago. That is the striking effect of eye opening and eye closure on the alpha waves. In addition, alpha rhythm cannot be due to neurone action potentials because it is not possible to find a reversal point as a recording microelectrode is gradually lowered through the thickness of the grey matter (this will be discussed in detail in the next section). Thereupon Lippold proposed the most recent hypothesis in 1970 that is able to explain some of the odd effects of the occipital alpha rhythm that cannot be explained by other hypotheses (Lippold 1970, 1971, 1973).

2.4 THEORETICAL CONSIDERATION FOR THE PROPOSED HYPOTHESIS

Lippold (1970) postulated that the occipital alpha rhythm in man is not generated in the occipital cortex, but by tremor of the extraocular muscles. It is thought that the tremor modulates the corneoretinal potentials and this modulation is recorded at the occiput because of the anatomical organisation of the orbital contents within the skull. To account for the effect of eye-open and eye-close, the mechanism for the generation of alpha waves is studied. The control of eye movement is achieved by two systems. One is a feedback involving the visual cortex and the retina , the other is a muscle servo-loop acting via muscle spindles and their reflex connexions with the group of oculomotor nuclei. Tremor occurs in a muscle when the loop-gain in the stretch servo exceeds unity and leads to the occurrence of oscillation. In the ocular muscles, this happens when the eyes are closed. When they are open and a sharp image is present on the retina, fixation via the visual cortex prevents it. The hypothesis will be studied in this thesis in detail.

1. Anatomical approach

There are six extra-ocular muscles responsible for the delicate movements of the eye (Fig. 2.1). Actually they are among the most sensitive muscles in the human body. The four recti muscles function principally to direct the line of vision. The superior and inferior rectus control the vertical eye movements whereas the

the medial and lateral rectus control the horizontal ones. The oculomotor inervates the superior, inferior and medial recti but the lateral one is controlled by the abducens or the sixth cranial nerve. The oblique muscles aid the oblique or rotatory movements of the eye in rotating the eyeball in the anterio-posterior axis. The oculomotor nerve innervates the inferior oblique and the trochlear or the fourth cranial nerve inervates the superior one. The recti arise from the margin of the fibrous cuff, which is fixed behind to the optic foremen and to the dural sheath of the optic nerve. Each muscle is enclosed in an aveolar sheath. Prolongations of these sheaths extend to the capsule of tenon, a connective tissue, bursal sheath surrounding the whole eye and its muscles. A resultant of tremors from the six extrinsic and striated muscles leads to an axial, translatory displacement of the eye. A simplified picture of those portions of the nervous system involved in eye movements is shown in Fig. 2.2.

The apex of the orbital cavity is within a centimetre of the middle of the cranium. The orbital muscles arising at such a point favours Lippold's hypothesis. A question raised is how are the electrical potentials transmitted to the occipital lobes of the brain. The subarachnoid system containing the conducting cerebrospinal fluid and including the cerebral ventricles is studied. Four spaces called ventricles are found inside the brain. Each of the two lateral ventricles occupies one of the halves of the cerebrum, the larger upper portion of the brain (Fig. 2.3a).

They are filled with conducting cerebrospinal fluid (CSF), which circulates through them and, after escaping through the three openings in the fourth ventricle, continues into the subarachnoid space around the brain and cord. The CSF consisting of watery portions of the blood filtered through the walls of the capillaries located in the ventricle walls into the spaces, plus some salts, sugar and a little protein, is certainly an extremely good conductor as compared with the surrounding brain tissue. Each lateral ventricle is thus a good conductor and probably forms a continuous conducting path from the posterior part of the retina to the occipital lobes on the same side of the head (Fig. 2.3b).

2. Hemispherectomy and Occipital Lobectomy

The work of Cobb and Sears in 1960 showed a support of the above suggestions. They found that on the removal of half the brain (Hemispherectomy) in human patients, EEG was still present on both side of the head. The frequency and amplitude of the waves did not alter appreciably on the lesion as well as the normal side. If the resultant cavity within the skull was air-filled, the amplitude of the electrical waves recorded from the scalp on the lesion side was enhanced. If it was fluid filled, the waves were attenuated. Experiments showed that the fluid acted as a shunt to decrease the surface potentials. Partial loss of one hemisphere with cavity formation was also studied in four human patients. Alpha waves were found to be present on the side having no cerebral cortex. Obrador and Larramendi (1950) and Marshall and Walker (1950) reported similar observations. It is not rational for the electrical activity of the no-cortex side to be due to the spread of the electrical activity of the normal side because the waveforms recorded on both sides do not correspond with each other. These findings contradicts the hypothesis that the alpha rhythm originates in cerebral cortical tissue. On the other hand, they support extra-cerebral potentials to be the sources for the rhythm.

Apart from the hemispherectomy, EEG was also found to be present in cases of occipital lobectomy (Masland, Austin and Grant 1949). Presumably, these results indicate that alpha waves do not originate in the occipital lobes.

3. Eye movements

Joynt (1959) reported two cases of palatal myoclonus in extra-ocular muscles and the EEG records showed spiky waves due to the abnormal clonic muscular contractions. This suggested a connection between the eye muscle tremor and EEG waves. Eye movements were proposed to be the source of the kappa waves (Harlan, White and Bickford 1958). These waves are sinuisoidal potentials occuring in the temporal regions and are similar to the alpha waves. The results suggested eye movements may also be the source of the alpha waves. Bates (1951) showed conclusively that eye movements (blinking) were connected with the phase of occipital alpha waves. There must be a link of some kind between alpha waves and eye-blinking, which does not depend on visual stimulation, perception or attention (Diamond 1964). Occipital waves evoked by jerky eye movements were also found by Evans in 1952.

4. Recordings within the cortical grey matter

The ultimate proof that alpha waves do not originate in cortical grey matter must be either that neuronal spikes are found which are in synchrony with the alpha waves or that slow waves, having a well-defined phase reversal point as a recording electrode penetrates the thickness of the grey matter, can be demonstrated to correlate with the surface-recorded alpha waves (Lippold 1973). Nevertheless, no evidence of the above has been found in the literature for human subjects. Visual and other cortical neuronal spikes recorded in humans show no evidence of modulation at the alpha frequency as one might expect if alpha waves were generated by cortical neurones (Lippold 1973).

Gastaut (1949) showed that alpha waves in human subjects did not reverse with depth. Besides, the wave form becomes larger in amplitude as the electrode penetrades deeper. The absence of a phase reversal implies no sources or sinks in the region. The results thus ignore the possibility of an origin of the electrical activities in any neuronal region.

5. Synchrony of neuronal firing

Synchrony of neuronal firing with a period of approximately 50 msec is found in some individuals and indicates a power spectrum peak near 20 cps (Gaarder and Speck 1967). This suggested that alpha is not due to synchronous neuronal firing but beta may be, viz. when alpha is blocked. Even then, synchronous firing was reported in some cases only. The appearance of beta including irregularity, instability and small amplitudes may favour this supposition.

6. Sleep

Increased slow rolling eye movements, as with early sleep onset, were clearly associated with diminished alpha density (Paskewitz and Orne 1973). Besides, the bursts of rapid eye movements (REM) during spontaneous sleep are associated with the 14Hz 'sleep spindles' superimposed on 'slow waves' of the EEG records.

2.5 EXPERIMENTAL STUDIES

1. Recording of the EEG

EEGs were recorded in the laboratory by the HP7702B oscillographic recording system and HP8811A Bioelectric amplifiers. HP14322A disc-cup electrodes, HP14050A disc electrodes, IVM skin cleaner (for electrode applications) and the Spectra 360 Electrode gel were used. A tape recording system consisted of the cassette deck and the modulation and demodulation system was built to transfer the signals to tapes (section 4.3.1) (Fig. 2.4). The records were then studied by analog, computer and time-series methods. Headbands were made of thick rubber bands (3/8 " width) lined with cotton pads to reduce discomfort of the suyjects and tailored to suit them one for each. With the sophisticated electronic filters as well as careful groundings and shieldings of the EEG recorder and other equipments, shielding was found to be unnecessary.

Before actual recording, careful preparations were performed in order to obtain a good record. The electrode sites on the scalp of the subject were de-oiled by skin cleaners and then rubbed gently with the electrode gel in order to have a good conductive media. Electrodes with paste applied were then placed on these sites on the scalp under the headband. The electrodes were inserted according to the International 10-20 System (Jasper 1951). In certain experiments, electrodes were placed on the focus points 5 cm lateral to the mid-line and 5 cm up from the inion (Lippold 1970). The most commonly used were the T5-O1 and T6-O2 locations. Recordings were of bipolar mode since localization would be much better. Electrodes were thoroughly cleaned after each experiment by immersing in alcohol in an ultrasonic cleaner to allow no paste residual to damage them. Artefacts were avoided by instructing the subjects to relax in a control posture and making no unnecessary movements.

All of the 15 subjects involved in this work are voluntary. They include students and lecturers of ages 12 to 40 years and are all intact and neurologically normal safe a blind subject.

The physical attributes of the alpha rhythm will be discussed in the followings.

2. Frequency

There is a striking constancy of the frequency of the approximately sinuisoidal EEG alpha rhythm. However, it does vary with time. At present, little is known on how it varies exactly. Carrie (1969) showed a significant positive correlation as high as +0.80 between mode location and alpha frequency. Modal alpha representation ranged from 16.6% to 2.5%. Modal height and wave length at the mode locations proved not to be correlated. Frost (1969) showed similar results. Poole and Taylor (1970) confirmed that the frequency content of the EEG at rest is derived, in part, from a range of inter-related frequencies rather than a narrow band and totally independent variables and frequency components.

A dominant peak is found in the frequency spectra of EEG recorded from normal adults around 10Hz, with time variations less than 1 Hz usually (Fig 2.5). The autocorrelative function of the same EEG record is also shown in an autocorrelogram plotted by the computer (Fig. 2.6). The greater the delay in correlating with itself, the smaller the autocorrelative function will be. To have a better understanding of the frequency of the alpha rhythm, it will be shown in later sessions this frequency is actually that of the extra-ocular muscle tremor which in turn is due to the neuromuscular delay in the stretch-reflex feedback loop. The frequency also varies over the scalp. This is expected as there are six eye muscles in each orbit which can generate the rhythm. Each muscle would be expected to produce tremor at a slightly different frequency and with a slightly different distribution of its potential field over the scalp, or either the substance of the brain. The circadian rhythm of the frequency variations will be discussed in Chapter six.

3. Bilateral differences

There were no two identical bilateral EEG records. They are always associated with a continuously changing phase-difference between them. Their frequencies always differ by 0.1 to 0.9 Hz. The waxing and waning phenomena of the waves are also not similar.(Fig. 2.7). Bilateral EEG amplitudes differ in such a way that those on the left hemisphere are larger than those on the contralateral side for more than half of the subjects studied who are right-handers. No significant differences were found for the two left-handers studied. The results suggest that alpha activities over the scalp are not generated by a single pacemaker. Those hypotheses concerning a single origin cannot explain this simple fact. The bilateral differences favour the hypothesis that alpha waves on each side are generated by the eye muscles on the same side of the head. A confirmation of this is given in later chapters by the effect of warming and cooling the orbits on the two sides separately. moreover eye muscle tremors are related to alpha waves on the same side of the head only (cf section 4.4). Any differences in the bilateral recordings are due to the effect that tremor in the two eyes differ in amplitude and phase.

4. waxing and waning

The alpha rhythms are not constant. Individual differences are also marked. Intervals of little or no alpha occur often. In fact, the alternation between alpha rhythms and little alpha is the most reliable feature of the occipital EEG. This is the waxing and waning property of the rhythm. The waves seem to be quite regularly 'discharged' in 'bundles' at a rate of 0.5 to 2.5 seconds each. The waxing and waning seems to promise a relationship between the alpha frequency and amplitude variation but no such relationships were found (Burdick 1968). A possible explanation here is that some forms of tremor at about 10Hz are modulating an electrical potential somewhere. The waxing and waning is a result of this modulation. It will be shown in section 2.7 that the waxing and waning property resemble very much that of physiological tremors. Are physiological tremors responsible for the modulation then? Experiments carried out in section 2.7 showed that finger tremor and alpha waves are not related but some other form of physiological tremor may be involved.

2.6 ALPHA RESPONSES

1. Eye-open and eye-close effects

The simple effect of eye-open and eye-close on EEG, discovered half a century ago, challenges many published theories and hypotheses on the origin of the alpha rhythm. It can be seen that the two conditions have different trends in the amplitude-duration plots (Fig. 2.9). The open circles (eye-close) rise up from a low magnitude at small durations increasing from 5μV to 60μV to a maximum at a duration of 90 to 100 msec whereas the arsterisks (eye-open) spread sidewards. It can be seen that the eye-close EEG has much larger amplitudes and a dominant frequency peak at 10 - 11 c/s as compared with the eye-open one. Their frequency spectra were plotted by computer and compared (Fig. 2.10). For the eye-open case, the delta rhythm is dominant and 2 sub-maximal peaks occur at the theta rhythm. The peaks are at 2, 5, and 7 Hz respectively. It is interesting to note that the magnitudes are inversely proportional to the frequencies of the respective rhythms. As for the eye-close condition, the alpha rhythm predominates with a maximal peak at 10 Hz and a sub-maximal peak at 8 Hz. The relative magnitudes of the other rhythms arranged in descending order are theta, delta, beta and gamma respectively. It is concluded that the beta and gamma rhythms are relatively unaffected whereas the dominant peak is shifted from 10Hz to 2Hz on eye-opening and the subnormal peaks from 8Hz to 5 and 7 Hz. Further, the theta rhythm has a larger amplitude on eye-opening.

It merits special mention that the term 'eye-open' is referred to visual fixation of the subjects during EEG recordings in a relatively bright environment and in a physiologically silent state.

2. Immediately after eye closure

The Bell's phenomenon that there is an increase in alpha activity immediately after eye closure has long been noted. Storm van Leeuwen and Bekkering in 1958 proposed the squeak phenomenon that the alpha rhythm may be as much as 2 Hz faster than the mean immediately after eyes closed. We observed that immediately after eye closure, there is an immediate and marked increase in amplitude of the alpha rhythm and sometimes a slight increase in frequency. In most cases, the wax spindle is initiated (Fig. 2.11). A slight increase in frequency from 11.15 Hz (normal average of the subject) to 12Hz in the first second after eye closure is observed in the record. A possible explanation for this is that eye closure is immediately accompanied by upward movement of the eyes. The effect of forcing the eyes upward will be discussed in section 2.6.4. We suppose a more probable explanation will be that the eye-muscle dynamic damping system is activated immediately after no visual fixation.

The activation causes a burst of tremors, which are more synchronous and larger than normal, that generates the alpha activities. This effect is also observed in finger tremors at the very beginning of the recordings. Besides, the introduction of a step perturbation to the muscle servo loop results in similar effects in physiological tremors.

3. Flash-induced alpha waves

Alpha waves can be induced by slowly repeated flashes (intermediate flash intensities) on subjects with eye closed (the flashes were not expected by the subjects). The cortical evoked response to photic stimulation was recorded with a neon stroboscope triggered either manually or automatically to allow for at least 2 seconds between flashes. The circuit is shown in Fig. 4.7. Immediately after the flash, alpha waves continue for about half a cycle unchanged until the gradual, sometimes partial, extinction of the spontaneous activity. After about two cycles' time, a new rhythmic response begins which resembles, as regards frequency, symmetry and changes with vigilance, the spontaneous alpha rhythm. This is known to be the "ringing" effect. The flash-induced alpha waves appeared to be more synchronous than the normal alpha waves and were of larger amplitude in general. But these waves only lasted for a few cycles. The eye-muscle servo-loop is supposed to be responsible. The two servo systems effecting dynamic damping of eye movement in the eye, namely, the visual and the eye-muscle ones, may be triggered to a quick alteration by the flash. Immediately after the flash, the eye-muscle servo is reactivated. On activation, the immediate effect is that tremors of larger amplitude and more synchronous nature are generated. These tremors then generate the concomitant alpha waves. Studies on physiological tremors in the next chapter confirmed this effect. Actually, flash-induced alpha waves resemble those found immediately after eye-closure as they are both generated by a similar mechanism. On the other hand, Barlow and Estrin (1971) proposed a different mechanism. They speculated the possibility of "reverberating circuits" causing the rhythmic after-waves but gave no evidence in support. Lippold (1973) proposed that the effect is due to synchronization of all the activities of the extra-ocular muscles. This may also be a contributing factor.

4. Forcing the eyes upward

The extreme upward position of the eye enhances alpha activity (Mulholland and Evans 1965, 1966; Dewan 1967; Fenwick 1969 in Evans and Mulholland 1969; Lippold 1973). In most cases of our studies, the abundance as well as the amplitude are enhanced. The frequency shows no marked changes. Alpha can also be produced by this effect in the eye-open condition in some subjects (including the author himself). It merits to emphasize that the subjects should attain the extreme upward position by forcing the eyes up and not merely a slight displacment upward. In one subject, with the dominant peak at 9Hz, showed an average amplitude increase of 41% (Fig. 2.12). The abundance of alpha increased up to approximately 95%. No marked change in dominant frequency peak was observed. These observations are curious in terms of cortical-origin hypotheses. Mulholland (1965) concluded that the orientation of the eyes may drastically alter the probability of alpha occurrence. His discoveries indeed disturbed the equanimity of the world of EEG in those days. Dewan (1967) explained this effect in terms of the tendency of the eyes to defocus and relax convergence when in the maximum upward position. Lippold (1973) explained it on the basis that upward eye rotation prevents the subject from seeing focussed images on his retina. A more probable explanation is that when the eye is forced upward, small rotatory movements produce changes in the standing potential at a point on the scalp in the occipital region, because the apparent solid angle of the sheet ocular dipole will vary (personal communications with Lippold 1977). It is found that these minute movements correlate quite well with the alpha waves recorded simultaneously, even though with eyes open. Other extreme positions of the eye, for instance, forcing the eye sideward were found to produce similar effects but on the average, not so marked as the upward extreme position of the subjects.

5. Mental tasks

Mental arithmetic produces a decrease in alpha activity in the eyes-closed conditions but not the eyes-opened condition. On the contrary, the mean frequency is slightly higher. As compared with the eye-opening effect, the decrease in alpha magnitude is smaller and that the dominant frequency peak increases slightly instead of shifting to the delta rhythms (Fig. 2.13). A series of ten experiments had been carried out for two subjects. On the average, the alpha amplitude decreased 46.0% and the alpha frequency increased 9.3%. Concentration on a task, memory of a familiar visual image and thinking also produce similar effects (Fig. 2.14). It is also found that greater amplitudes during eye-close condition implies a greater decrease caused by mental arithmetic or thinking. For experiments on thinking, the subjects were instructed to indulge on a problem always entangling themselves for ten minutes and then relax ten minutes during which they were instructed not to 'use' their brains. The cycle was repeated for several trials. It is found that some sorts of eye movement were present during the periods of thinking and the subjects were aware of that.

6. Hyperventilation

Hyperventilation results in amplitude increase and synchronization of alpha activities (Fig. 2.15). The activities wax during breathe-in and wane during breathe-out. After a certain period of continuous hyperventilation the results are similar. It is known that hyperventilation causes a marked loss of plasma carbon dioxide, a reduction of the carbon dioxide tension, a modest decrease in the blood sugar and results in cerebral vasoconstriction as well as relative ischaemia. These may all be factors contributing to the effect but we suggest that the sudden increase in cerebral oxygen uptake ($CMRO_2$) as well as cerebral blood flow (CBF) may be involved. The stretch-reflex feedback loop of the eye muscles entails a sudden increase in the overall gain of the loop. This in turn produces tremor of larger amplitude and better synchrony. Ingvar et al (1976) reported that a strong correlation was found ($r=0.78$, $P<0.001$) between EEG frequency indices and $CMRO_2$ of the hemisphere from which the EEG was recorded. The correlation exists for phenomena on the same side of the head only. This is in consensus with the eye-tremor hypothesis that occipital EEGs are correlated only with the oscillations in the stretch-reflex servo-loop controlling the eye muscles on the same hemisphere. Experiments were also carried out to investigate the effect of continuous hyperventilation. Subjects were instructed to breathe as hardly and deeply as he can for about one minute and records were then taken. An average of 58.03% amplitude increase was obtained.

7. Muscular effects

The effect of the sternocleidomastoid was investigated. It is known that when the head rotates to the left, the right sternocleidomastoid is in action and the left for rotating to the right. On the contrary, when the head tilts to the left, the left sternocleidomastoid is in action and the right for tilting to the right. Are these effects reflected in the occipital EEG recordings? When the head rotated to the side of the right shoulder, the right and left occipital alpha rhythms were found to increase by 115% and 47% respectively. When the head rotated to the left shoulder, the right and left alpha rhythm increased 45% and 114% respectively. The increases were 50% and 120% respectively for tilting the head to the right shoulder and 117% and 49% respectively for tilting to the left (Fig. 2.16). In addition, the alpha waves on the side with larger amplitude increase appeared to be much more spiky (muscle artefacts) than the side with lower amplitude increase. The frequency variations were found to depend on the degree of activations of the sternocleidomastoideus of the same side. These effects show a dominant side factor of the hemisphere on the EEG recordings. The activation of the sternocleidomastoideus on one side affects the occipital alpha recordings of one side only. The much smaller amplitude increase on the contralateral side is in turn due to the much less activation of the sternocleidomastoid of that side. This is why exactly the opposite result is obtained by rotating and tilting the head respectively. Obviously, this phenomenon is due to anatomical reasons and suggests that alpha waves and muscle action potential artefacts on the same side of cortex are related in some way.

Other muscular effects include pinching and clenching. Subjects were instructed to clench with their hands on an instrument (Lafa yette Instrument Co. Model No. 76618) which recorded the clenching forces in kilograms. The right hand and left hand clenching showed similar effects on both the right and left occipital recordings (Fig. 2.17). This confirmed that the dominant side factor of the hemisphere on EEG recordings exists only within the head region. Thus some muscular effects somewhere within the head must be responsible for the alpha rhythm. An average of 69% amplitude increase was obtained by clenching. The effect of pinching was found to be similar (Fig. 2.18). Occipital EEG with superimposed muscle action spikes during eye-close and eye-open conditions still showed marked amplitude differences (Fig. 2.19). Nevertheless, alpha activity was evoked during the eye-open condition. It was further noticed that a sharp action potential spike was superimposed on each alpha wave showing a close link between the two phenomena. The record was obtained by straining the eye muscles of a 'good-alpha' subject.

8. Alpha feedback

The technique will be discussed in full in section 4.7. An amplitude increase of about 50% as well as a better synchrony and abundance were obtained (Fig. 2.20).

The results show that one can control his own alpha strength by feedback training. According to the eye-tremor hypothesis, the subject is actually controlling his own eye-tremor strength. This is indeed the truth as physiological tremors can be shown to be controlled by feedback training also (Section 3.8).

9. Psychological variables

The effect of fear was studied. The subject was instructed to recall a nightmare that frightened him much. Several trials were repeated with control periods in between. An average amplitude decrease of 53.53% was observed. The frequency spectra remained fairly constant. The diminishing effect is more pronounced at the start of the stimulus and quickly recovers to normal (Fig. 2.24). An angry subject (made angry by scolding him) showed amplitude decrease and desynchrony of his alpha wave (Fig. 2.21). Some muscle action potential spikes could also be observed in his EEG record. Another subject was instructed to solve a puzzle. The Zeno's paradox stating that the fleet Achilles can never overtake a tortoise was given. The paradox suggests that suppose the tortoise is given a lead AB, by the time Achilles reaches B the tortoise will have moved some distance, say to C; when Achilles gets to C, the tortoise will be at D, and so on. At the time the subject solved the paradox, a frequency increase of 11.2% together with an amplitude increase of 50.45% were observed in his EEG record.

The alpha responses reveal some hints on the origin investigations and give some supports to the eye-tremor hypothesis. Apart from this, these characteristics had been demonstrated for alpha activity only. Whether they are the same or not for physiological tremors will be dealt with in the following section.

2.7 ARE PHYSIOLOGICAL TREMORS RESPONSIBLE FOR THE ALPHA ORIGIN?

The close resemblance of alpha rhythm and finger tremor has long been noted, in fact almost as soon as the first papers on the rhythm were published. Jasper (1936) struck by this resemblance, hypothesised that the tremor is directly caused by the electrical phenomena of the cortex. Travis and Cofer (1937), on the other hand, found that the tremor had a higher frequency than the alpha waves and concluded that they are unrelated. This conclusion was made less convincing by the findings of Jasper and Andrews (1938a) and Rubin (1938) that the pre-central region very often has another alpha rhythm than the occipital region. Jasper and Andrews (1938b) gave further support that both phenomena have similar changes during sleep and in attack of petit mal. This observation was confirmed by Gibbs, Gibbs and Lennox (1938). Significant positive correlations were found between occipital EEG and finger tremor, especially between the mean and 6 to 12 Hz dominants (Poole, Taylor, Sowerby and Poole 1966). Nevertheless, they admit that their findings were not universal to all age and clinical groups.

The similarity of finger tremor and alpha rhythm is striking (Fig. 2.22). They tend to have the same frequency in individuals and also a similar waveform showing the waxing and waning properties. Both phenomena show similar changes with age or development. Sleep and anaesthesia abolish both signals at the same time. Alerting responses produce similar effects on both phenomena. The abnormally slow tremor characteristic of Parkinson's syndrome (about 4 to 6Hz) is frequently reflected in the concomitant EEG records (England, Schwab and Peterson 1959).

Experiments were carried out to study both phenomena recording simultaneously. It was found that eye opening and closure have no effect on finger tremor. Besides finger tremor and alpha waves are to no extent similar when the eye was open (Fig. 2.23). On the other hand, prodding the finger produced damped trains of tremor waves of the same frequency but had no effect on the alpha waves (Fig. 2.24). It will be shown in section 4.6 that prodding the eye yields a strong phasic correlations between eye-tremor and alpha waves. No such phase-locking relationship was found for finger tremor. When a sphygmomanometer cuff of 190 mm Hg was applied to the left arm, ischaemia resulted. At the moment the cuff was inflated, a momentary increase of finger tremor frequency to about 12Hz was observed but no accompanying change was seen in the alpha activity (Fig. 2.25a). This shows that the two phenomenon are not frequency related. After two minutes of inflation, a marked decrease in amplitude, abundance and synchrony of finger tremor resulted, again without accompanying alpha changes (Fig. 2.25b). Thus, the two phenomena are not amplitude related. After the removal of the sphygmomanometer cuff for about one minute, tremor amplitude increased but desynchrony and irregularities were present still (Fig. 2.25c). The EEG recordings showed no related changes throughout. Hence it can be concluded that finger tremor and occipital alpha activities are not related in frequency, amplitude, abundance, synchrony and phase. This can also be observed in the frequency spectra (Fig. 2.8a) and crosscorrelogram (Fig. 2.8b) of the two phenomena recorded simultaneously. Finger tremor showed two dominant frequency peaks at 11 and 13Hz whereas alpha waves had only one dominant peak at 11Hz. Nevertheless, they are similar for all other rhythms. In the crosscorrelogram, they showed a small product moment correlation coefficient of 0.192 only. The attractive theory that alpha waves are originated in finger tremor activities or vice versa must be abandoned. Furthermore, it is found that the variation with age of alpha waves is very small compared to that with age of finger tremor. However, the similarities of alpha waves and physiological tremor in appearance as well as the same effects of anaesthetics, drugs and sleep on them should not be neglected. Other forms of physiological tremor may be involved.

2.8 ELECTROENCEPHALOGRAPHIC CORRELATES OF OCULOMOTOR FUNCTIONS

The close association between vision and the occipital alpha rhythm has been recognised for quite some time (Adrian 1943; Adrian and Matthews 1934; Berger 1930, Durup and Fessard 1935). Alpha activity is markedly reduced during ocular fixation and pursuit tracking (Mulholland 1968; Mulholland and Peper 1971). Mulholland in 1966 hypothesised that the alpha-activation cycle reflects the movements, accomodation and position of the eyes and in 1971 confirmed a tight relationship between oculomotor efferent commands and the occurrence of the occipital alpha rhythms. Plotkin et al (1976) came to the conclusion that there is very little doubt that there are some very close links between the occipital alpha rhythm and oculomotor processes. The most obvious fact is the effect of eye opening and eye closure (section 2.6.1). The Bell's phenomenon after eye closure (section 2.6.2), the 'ringing' effect of flash-induced alpha activity (section 2.6.3) and the extreme eye position as a means of alpha enhancement (section 2.6.4) suggest some close association between alpha activities and eye movements (section 2.4.3). Furthermore, we found that when the eyeball is pressed by soft cotton pads, alpha activities on the same side of the head as the depressed eye decrease considerably (Fig. 2.26). An average of 50 to 55% magnitude decrease was found. The pressing force need not be great and no phosphenes were produced. A considerable amount of desynchrony was also observed. The effects, magnitude decrease and desynchrony, were even more marked than those produced by mental tasks. A possible explanation might be in terms of ischaemia (an impairment of blood supply) of the extra-ocular muscle spindles abolishing the EOM tremor in the same manner as a blood pressure cuff abolishes finger tremor (section 3.8). This effect shows somehow the importance of the position of the eye on alpha activity.

Close links between occipital alpha and oculomotor variables have been demonstrated. We then proceed to find out these links. It has been demonstrated in the previous section that physiological tremors closely resemble alpha waves but no phasic relationships were found for finger tremor and occipital alpha.Other forms of physiological tremors may be involved. The close correlations between the alpha waves and oculomotor variables suggest the eye-tremor.

2.9 THE AXIAL, TRANSLATORY EYE MOVEMENT STUDIED

If mechanical oscillations of the eye around 10Hz could be demonstrated, the existing of certain form of physiological tremor in the eye can be confirmed. The vertical, horizontal and rotational eye movement did not display well-defined 10Hz tremor. Experiments showed that it is the axial, translatory movements of the eye that promises the 10Hz oscillations. The frequency spectrum and the autocorrelogram are shown in Fig. 4.1 and Fig. 4.2 respectively. Lippold (1970d) first reported recordings of this 10Hz oscillations but his technique of recording was found to be quite trouble-shooting. The records thus obtained are not very satisfactory too (see Fig. 2 in his paper). Thereupon, in order to verify his results, we deviced a new technique to record the eye-tremor by using diving mask and dynamic mikes (section 4.2). The technique was found to be simple and efficient. Records of the eye-tremor thus obtained show good correlations with the occipital alpha waves (section 4.4). The new technique thereby enables us to perform a detailed correlative study between the eye-tremor and the occipital alpha waves under different peripheral conditions (section 4.5). The axial, translatory movements of the eye in the optical axis are actually the summation of the tremors of the six extra-ocular muscles of the eye due to their anatomical structures. Well-defined and regular oscillations were readily obtained. This finding highlights the validity of the eye-tremor hypothesis. What is left and the most important of all is to show that these oscillations bore a constant phase relation to occipitally recorded alpha waves. Should the eye-tremor hypothesis be true, the two phenomena should also vary similarly under different conditions. A detailed correlative study between them is thus necessary and will be dealt with in full in chapter four. A significantly strong correlation was found and the eye-tremor hypothesis is confirmed. Moreover, the strong correlation exists for recordings from the same side of the head only. This is a very promising result since the optic nerve is distributed to both occipital lobes (the partial crossing of the optic nerve fibers in the optic chiasma is the basis of binocular vision). Hence if alpha activities on one side are affected by some physical alteration of one eye (on the same side) only, this cannot be explained in terms of neural connections, indeed cannot be explained in terms of electrical activity of the brain.

2.10 THE 10Hz OSCILLATIONS IN ELECTRO-OCULOGRAPHY

If the EOG records are studied carefully, oscillations at approximately 10Hz can be found during the eye-close conditions (Byford and Stuart 1959, Byford 1963). These oscillations can be seen to be phase-locked to the rapid component of the EOG (Byford 1964) and were labelled as '10c/s ocular tremor' by Byford. On the other hand, they are of very small amplitudes (comparable with that of EEG only) with the usual scales employed in EOG recordings (about 10 times that of EEG). Thereby they may be easily neglected or treated as artefacts. When a scale of 0.2 mV/100 divisions (Sanborn Recording Permapaper) is employed, the 10Hz oscillations are clearly seen in the EOG records (see chap. 5). Actually these waves resemble the alpha waves to certain extent. These findings indicate the electrical activity of the eye is ~~closed~~ closely linked with that over the scalp. A more detail investigation will be given in Chapter Five.

2.11 CONCLUSION

After a brief review of the history of electroencephalography, we are fully aware of the importance of investigating its origin. We studied some published theories and hypotheses together with some other published result and found support for the eye-tremor hypothesis which was first proposed by Lippold in 1970. Experiments were then carried out to study the alpha characteristics. These studies are based on several reasons. Firstly, they may reveal some hints of the alpha origin, and most of them are not completely known hitherto. A careful study of them is important in order to have a better understanding. Secondly, the mechanisms underlying these characteristics are not completely understood. Any proposed hypothesis must be able to explain at least some of these. It is found that many odd characteristics that cannot be explained by other hypotheses can be explained by the eye-tremor hypothesis. Thirdly, the properties and variations of the alpha waves must be known first in order to compare with the physiological tremors. If a phenomenon was found to vary with the alpha waves in a similar manner under all circumstances, the puzzle on the alpha origin would then be solved. On the way to find out this phenomenon we bore in mind that the validity of some of the published hypotheses must also be considered. Consequently, we studied the finger tremor. It is rather disappointing to find that, though very similar, the two phenomena are actually different from each other. A careful study of the alpha responses reveals that a strong correlation existed for the alpha activity and oculomotor functions. This suggests that some form of muscular tremor related to the eye may be involved. Lippold (1970d) first reported that a 10Hz oscillation can be recorded from the axial, translatory eye movement in the optical axis but his technique of recording as well as his results are not very satisfactory . we then deviced new techniques to record the eye-tremor and found that the tremor can simply be recorded by taping dynamic mikes to the corneal surface or even to the eyelids. Displacement up to 0.5mm can be detected. These findings certainly highlight the eye-tremor hypothesis and a detailed correlative study between the eye muscle oscillations and the alpha waves will be carried out in chapter four. Apart from this, a 10Hz oscillating component was also found in the EOG recordings. This suggests that the problem on the potential source contributing to the electrical activity recorded over the occipital regions may be solved. To conclude, the alpha origin was investigated experimentally in this chapter and a new problem is raised on the origin of the physiological tremors. Should the alpha waves be originated in the eye muscle tremors, the origin of these tremors must also be known. This will be dealt with in the next chapter.

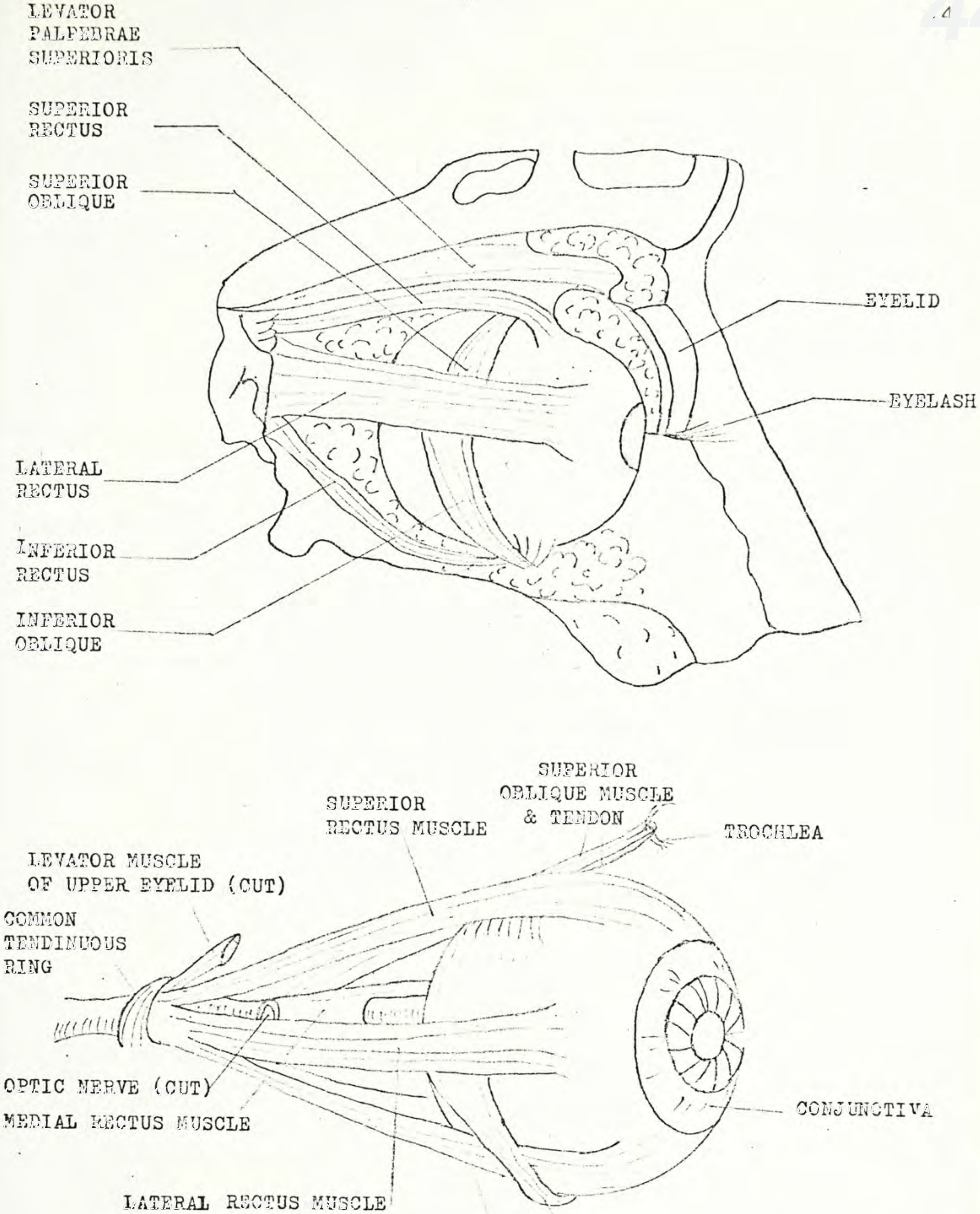


Fig. 2.1 (a) The extra-ocular muscles.

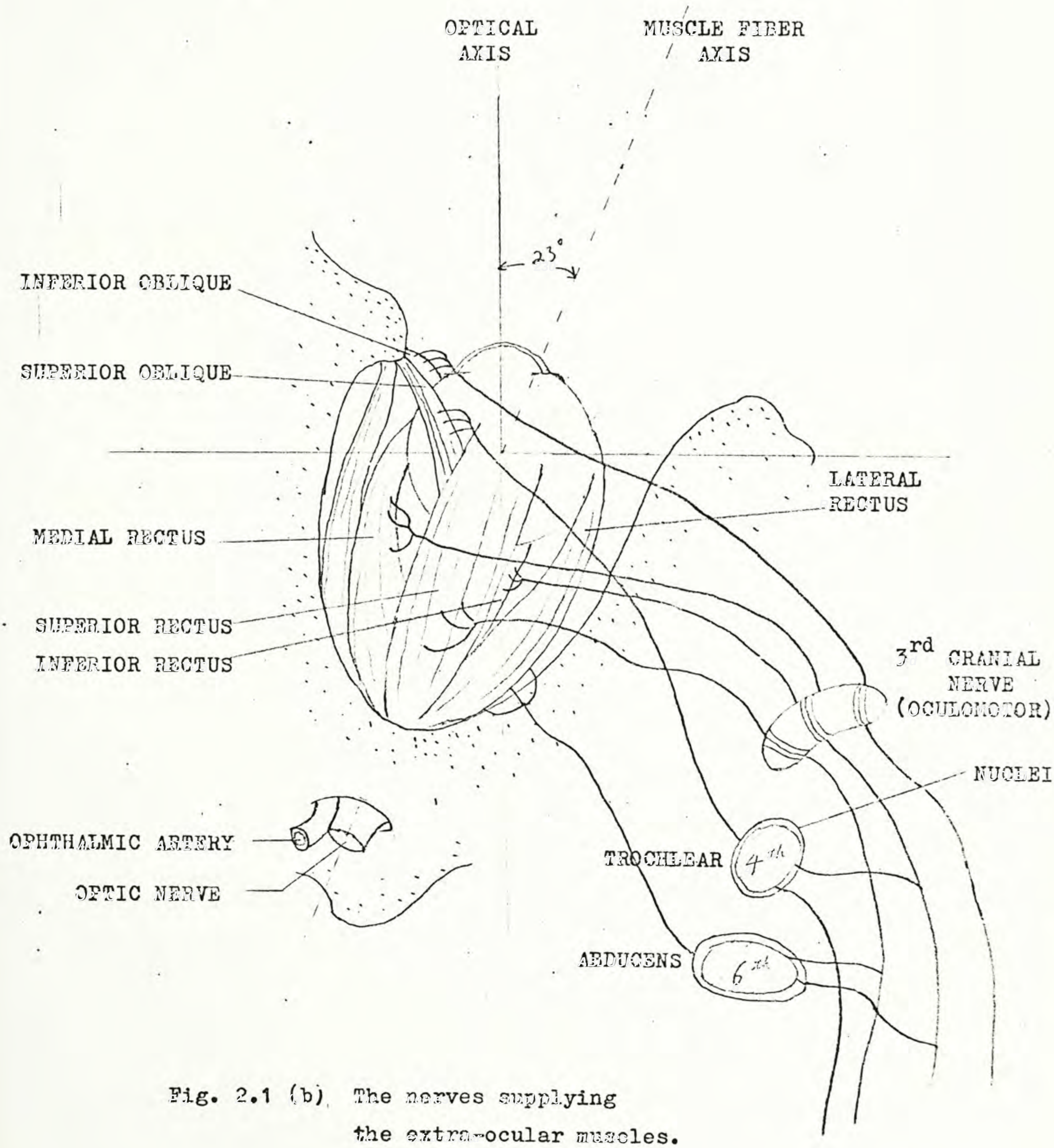
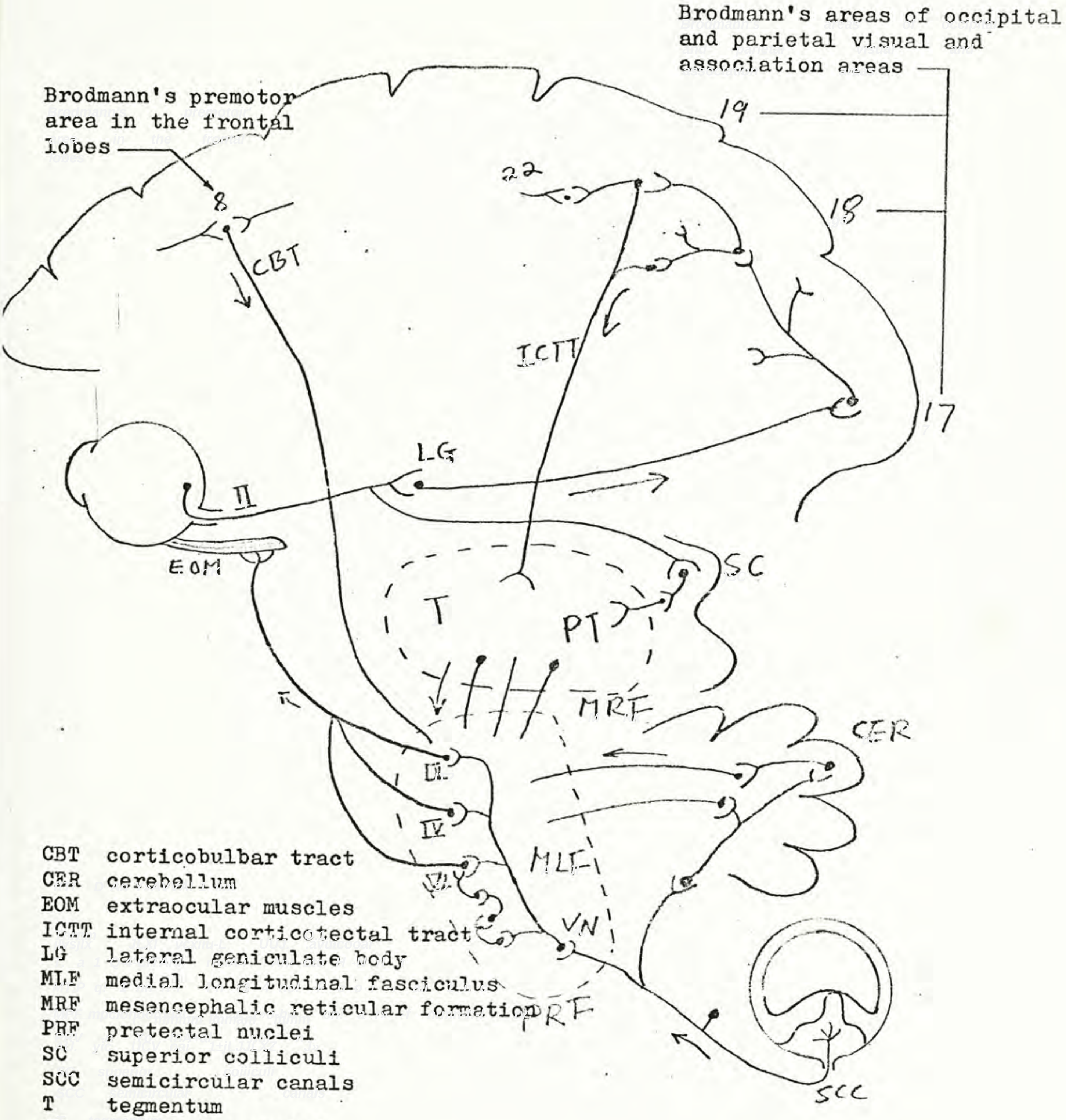
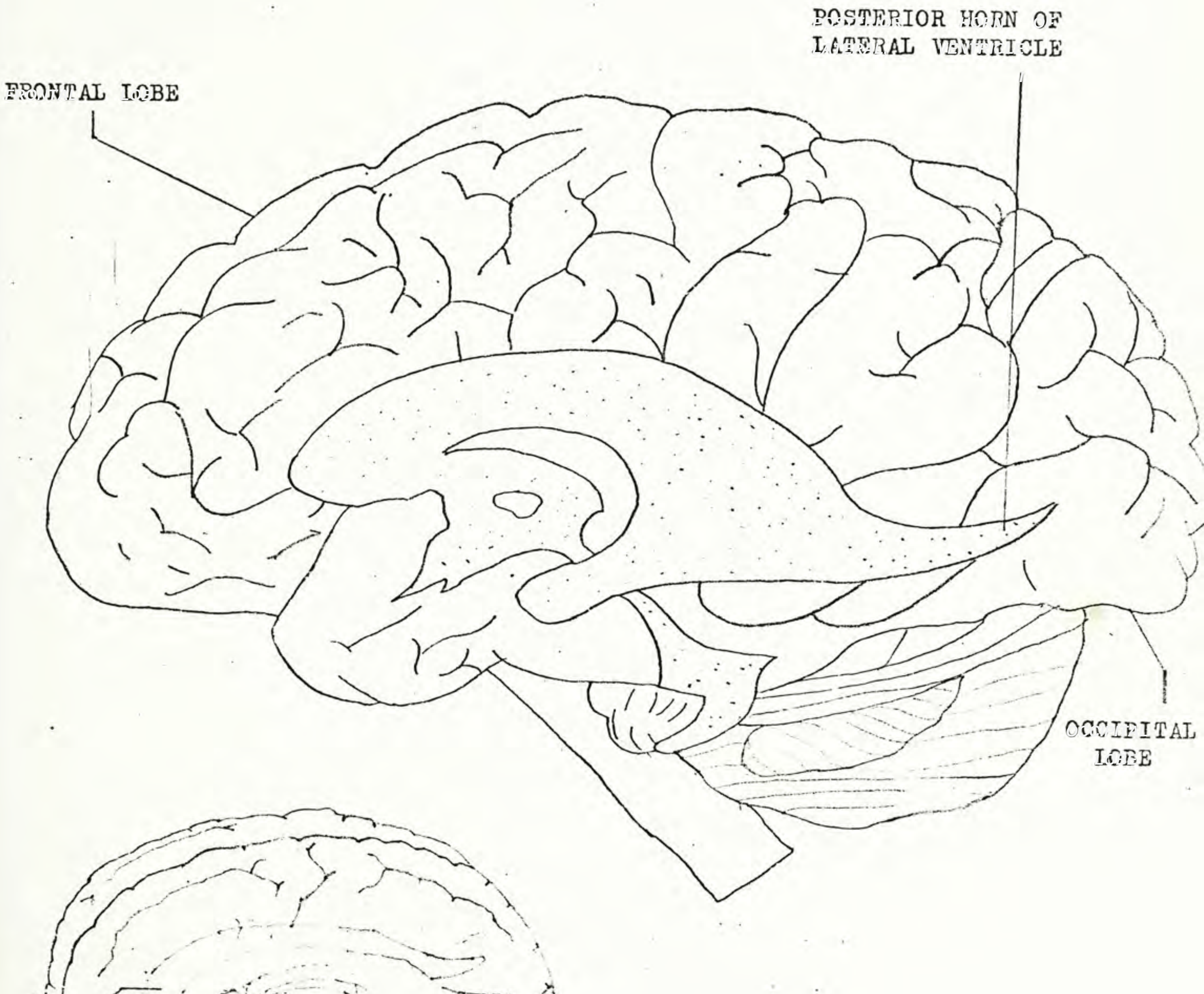


Fig. 2.1 (b) The nerves supplying the extra-ocular muscles.



CBT	corticobulbar tract
CER	cerebellum
EOM	extraocular muscles
ICTT	internal corticotectal tract
LG	lateral geniculate body
MLF	medial longitudinal fasciculus
MRF	mesencephalic reticular formation
PRF	pretectal nuclei
SC	superior colliculi
SCC	semicircular canals
T	tegmentum
VN	vestibular nuclei
II	optic nerve
III	oculomotor nuclei and cranial nerves
IV	trochlear nuclei and cranial nerves
VI	abducens nuclei and cranial nerves

FIG 2.2 A SIMPLIFIED PICTURE OF THOSE PORTIONS OF THE NERVOUS SYSTEM INVOLVED IN EYE MOVEMENTS. (FROM ROBINSON 1968)



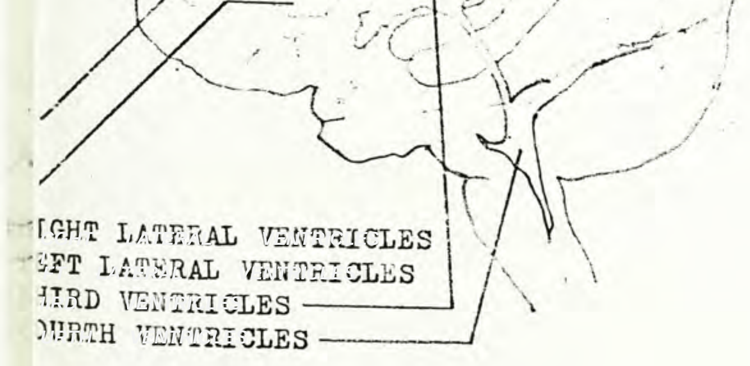


FIG 2.3a OUTLINE OF THE BRAIN SHOWING A LARGE CONTINOUS LOW IMPEDANCES PATH FROM THE ENDS OF THE EXTRA-OCULAR MUSCLES TO THE OCCIPITAL REGIONS ON EACH SIDE OF THE HEAD.

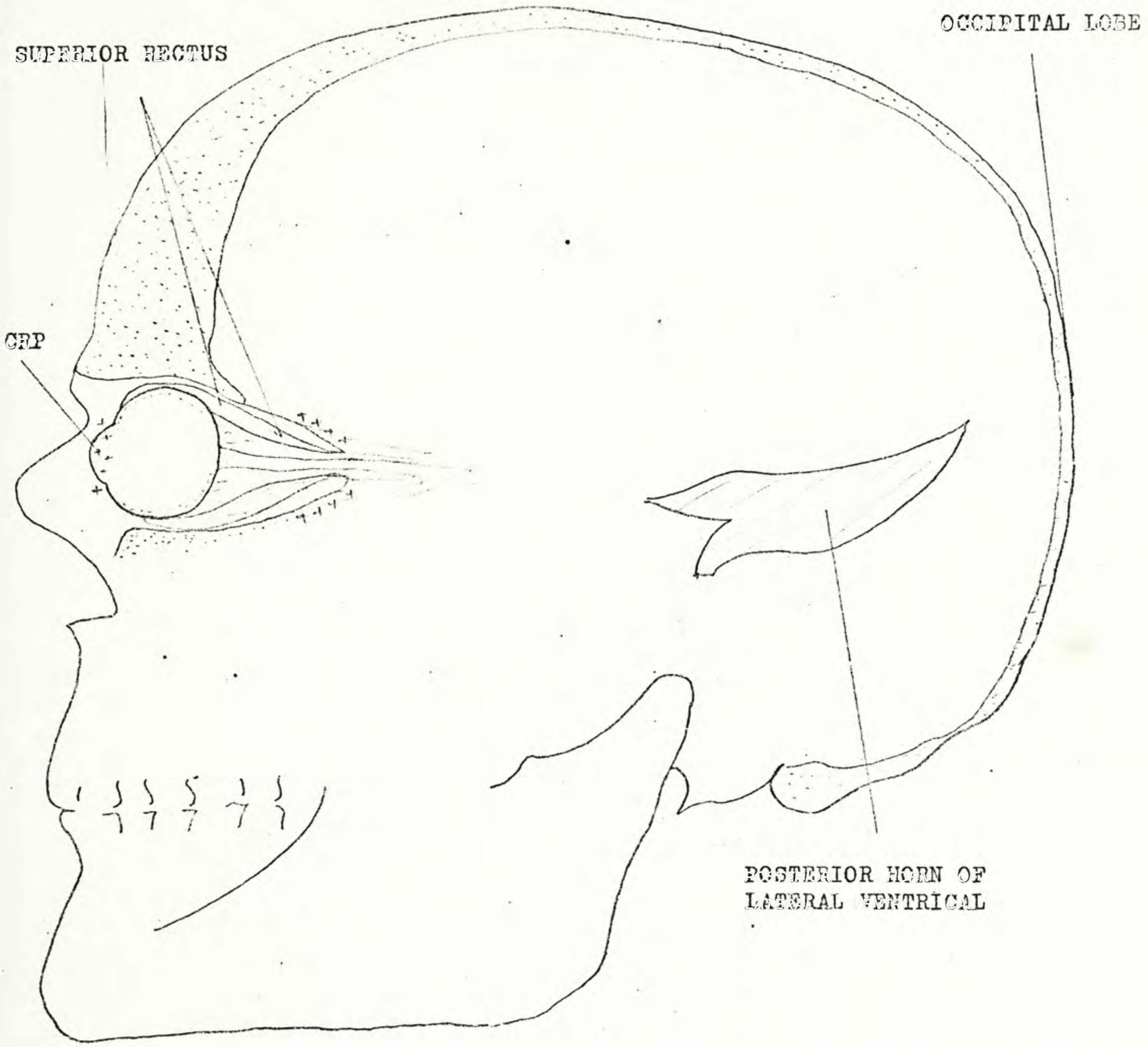


FIG 2.3b OUTLINE OF THE HEAD SHOWING THE EXTRA-OCULAR MUSCLES AND THE CORNEORETINAL POTENTIAL CONDUCTED ALONG THESE MUSCLES. FROM LIPPOLD (1973).

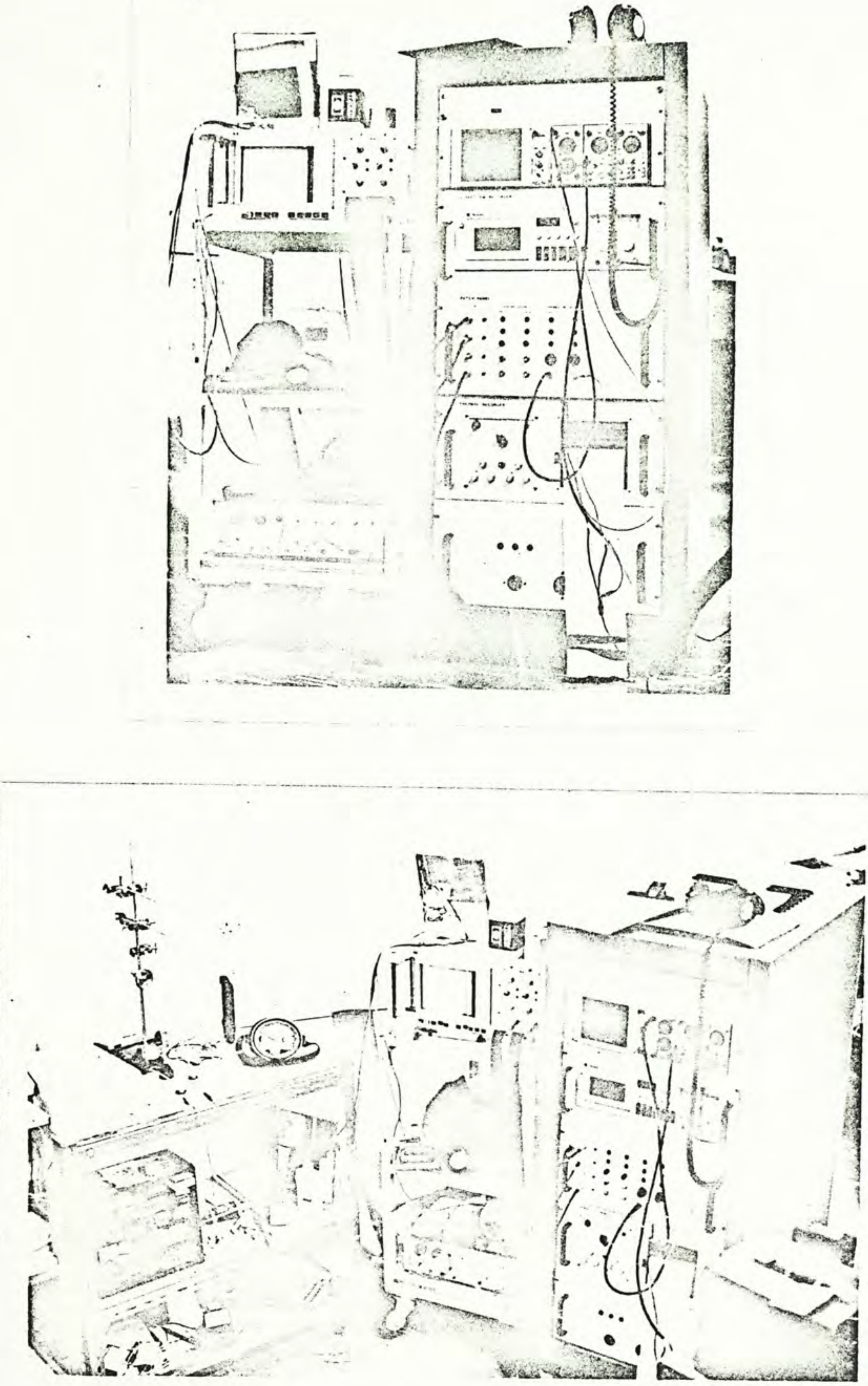


FIG 2.4 THE SET-UP : THE EEG MACHINE, THE TAPE RECORDING SYSTEM, THE STIMULUS GENERATOR, THE SET-UPS FOR FINGER TREMOR AND EOMT RECORDINGS.

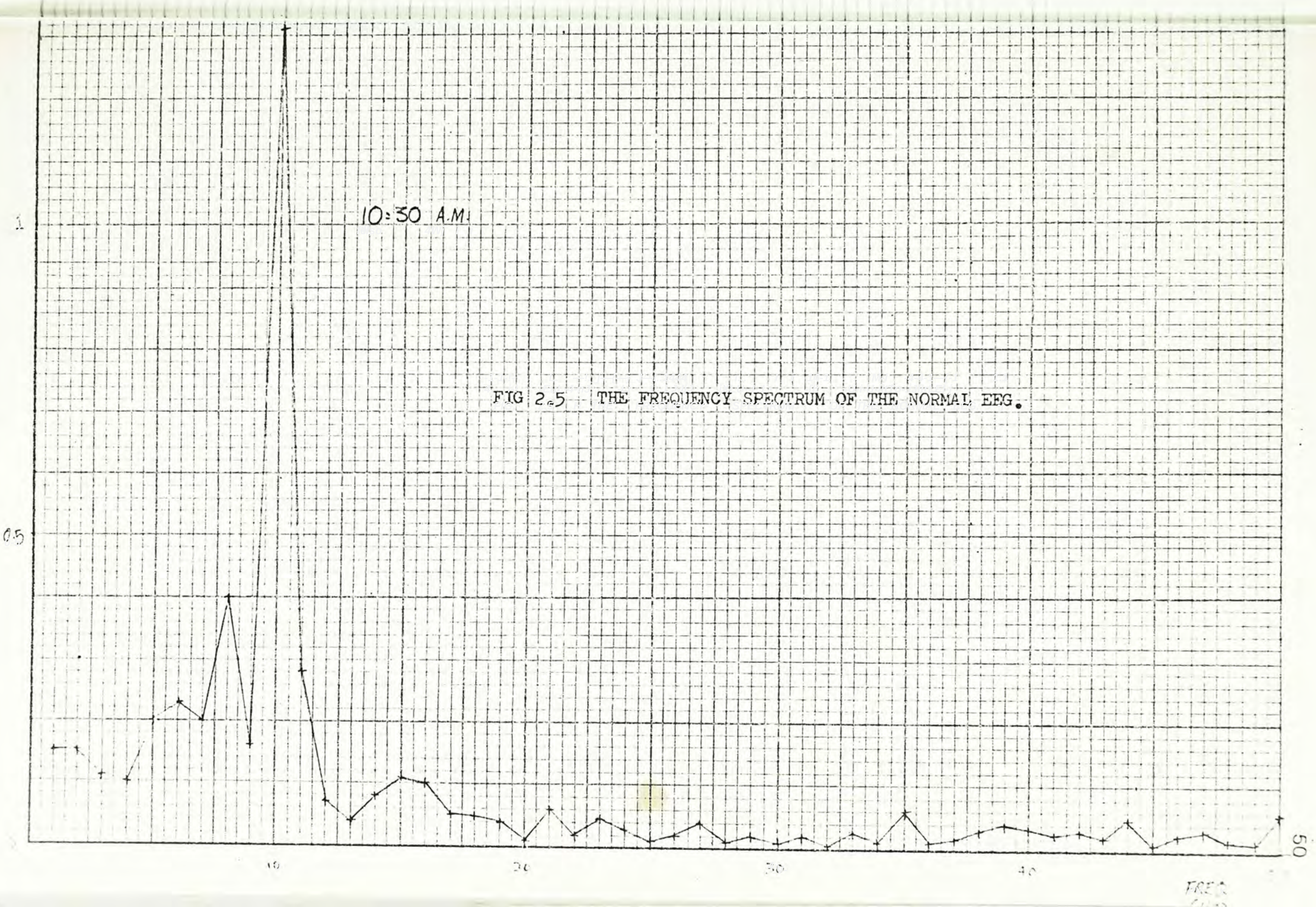


FIG 2.5 THE FREQUENCY SPECTRUM OF THE NORMAL EEG.

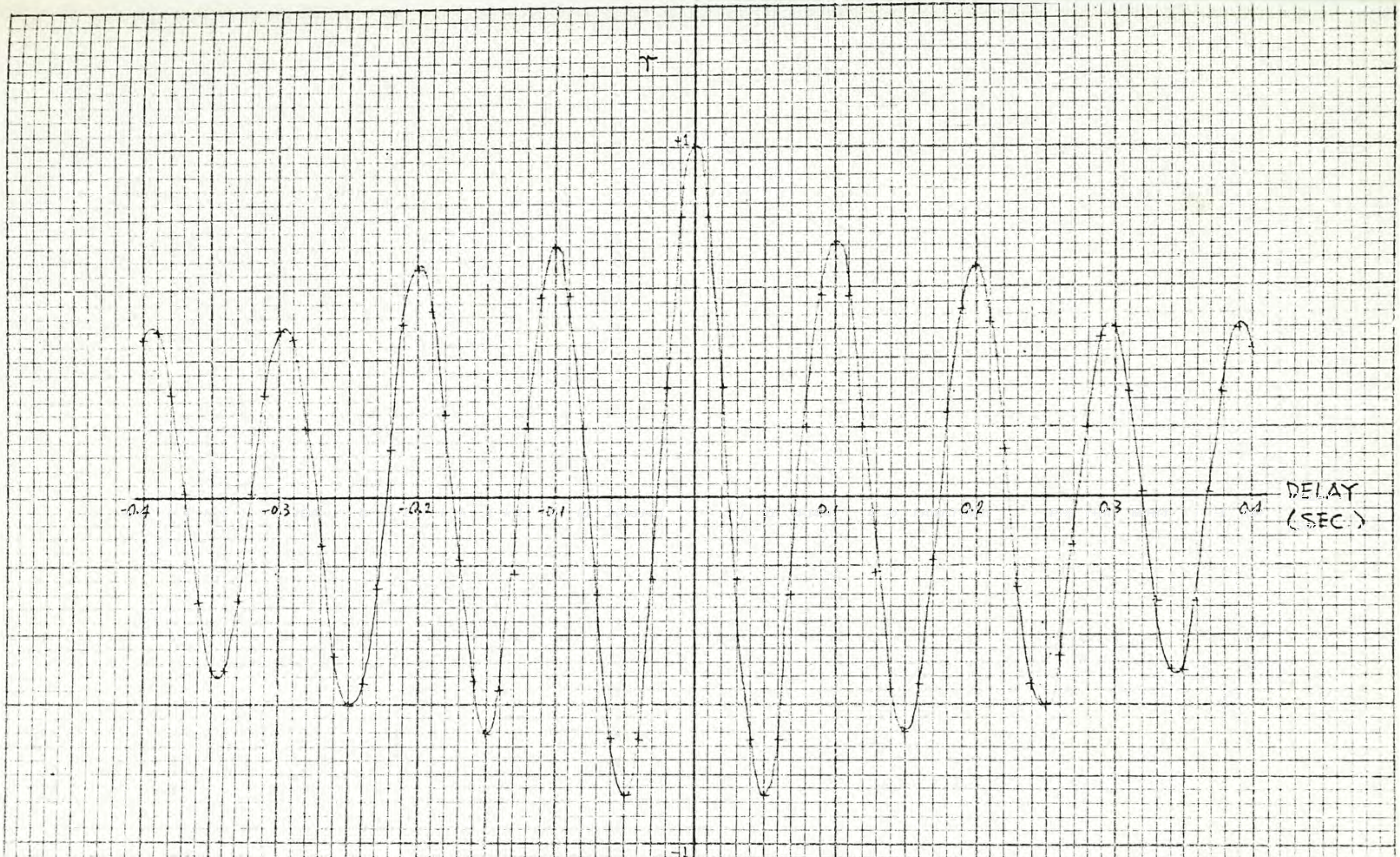


FIG 2.6 THE AUTOCORRELOGRAM OF THE NORMAL EEG.

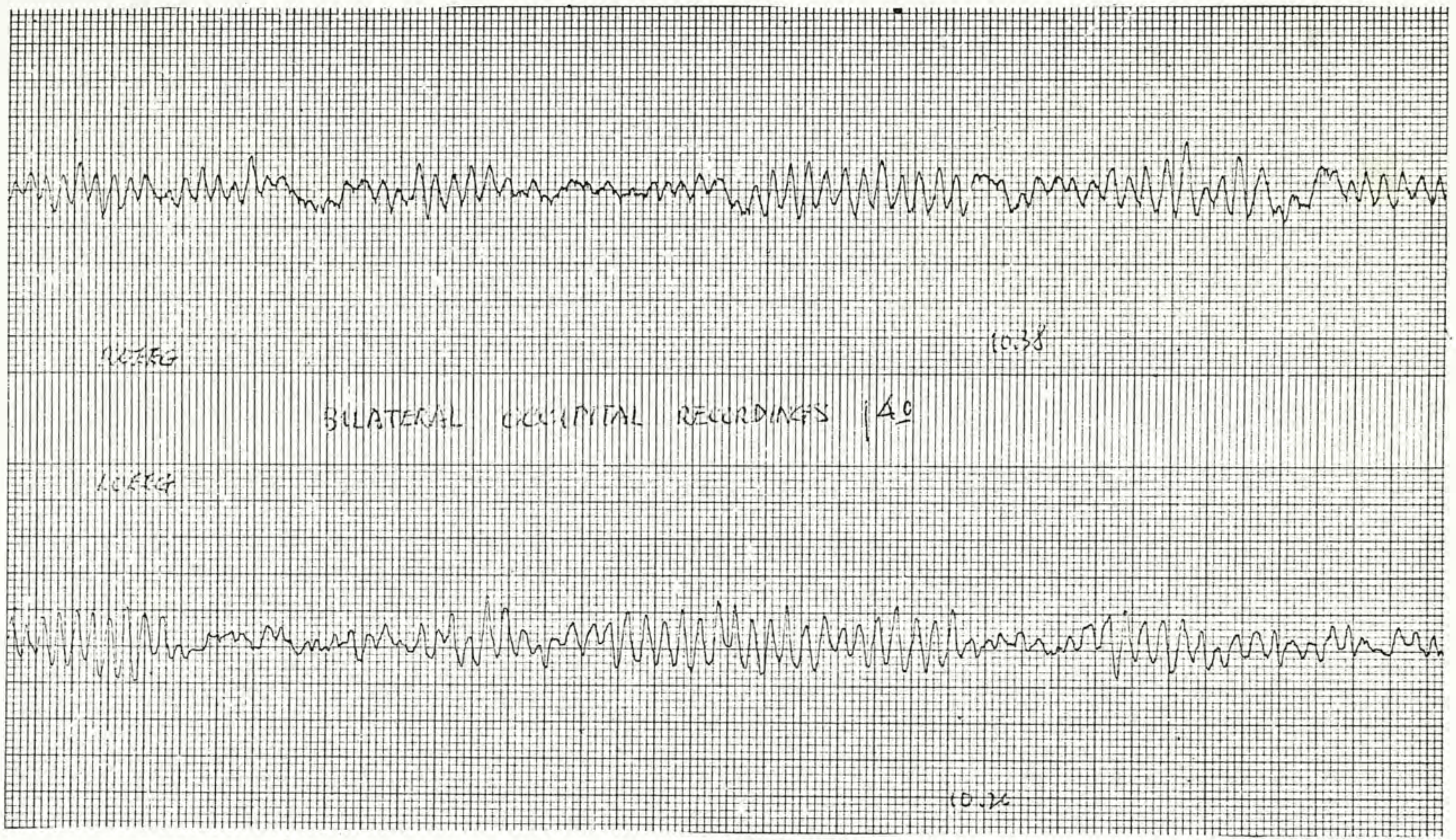


FIG 2.7 EEG RECORDINGS ON THE RIGHT AND LEFT OCCIPITAL REGIONS SHOWING BILATERAL DIFFERENCES. NOTE BOTH THE SIMILARITIES AND DISSIMILARITIES.

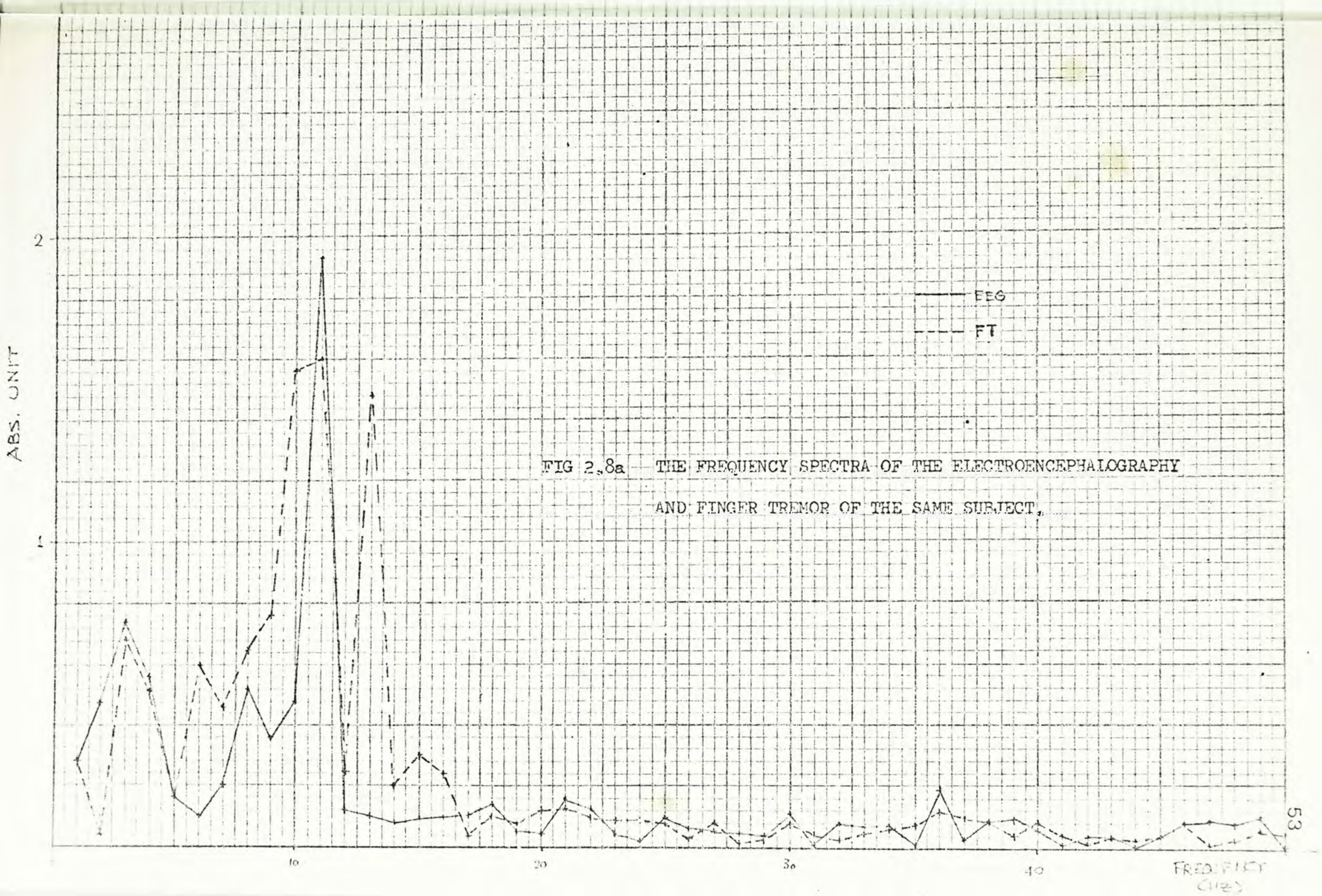


FIG 2.8a THE FREQUENCY SPECTRA OF THE ELECTROENCEPHALOGRAPHY AND FINGER TREMOR OF THE SAME SUBJECT.

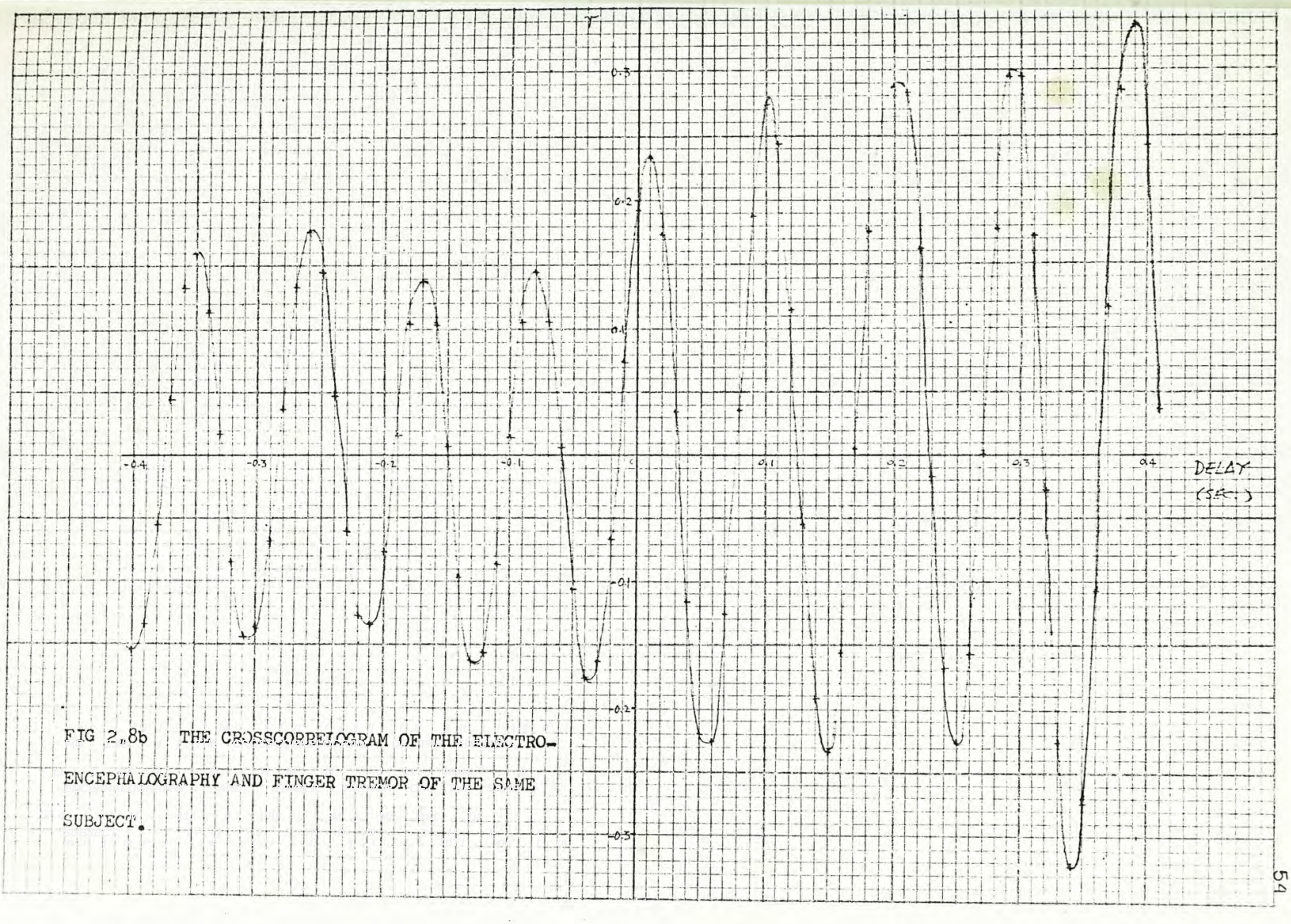


FIG 2.8b THE CROSSCORRELOGRAM OF THE ELECTROENCEPHALOGRAPHY AND FINGER TREMOR OF THE SAME SUBJECT.

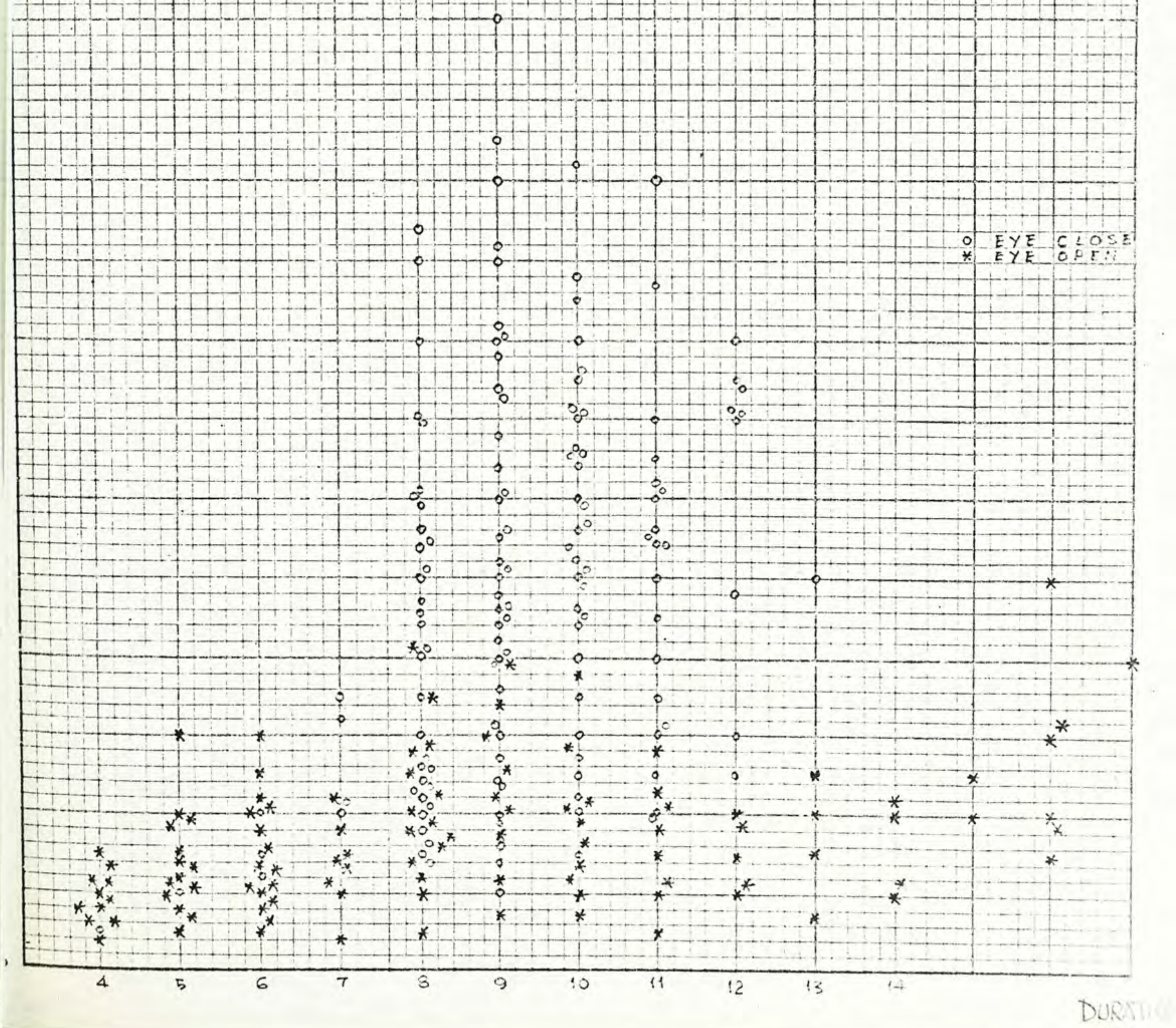


FIG 2.9 THE AMPLITUDE-DURATION CHARACTERISTICS OF THE OCCIPITAL ALPHA ACTIVITY DURING EYE-OPEN AND EYE-CLOSE CONDITIONS. NOTE THE TWO DISTINCT TRENDS.

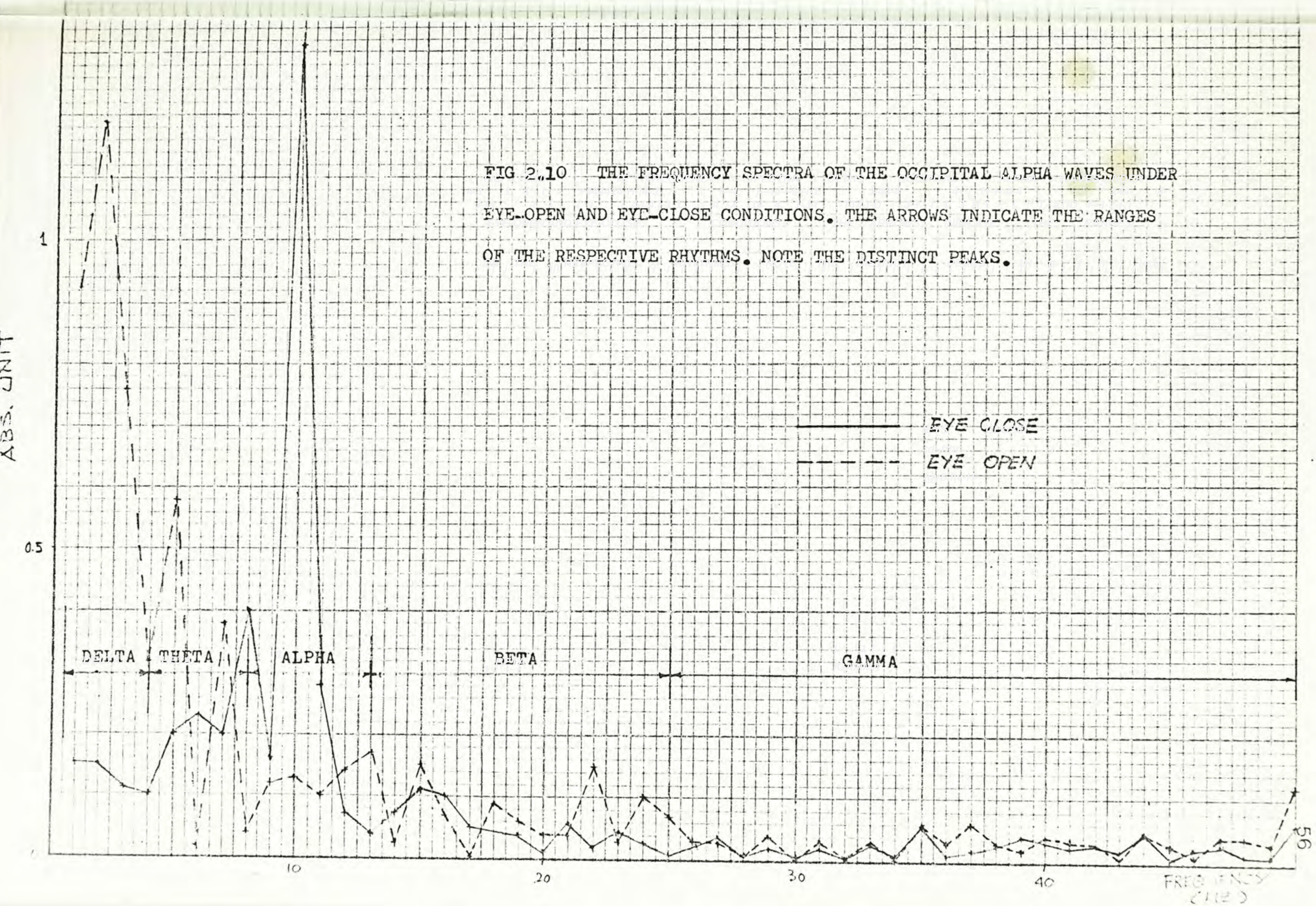


FIG 2.10 THE FREQUENCY SPECTRA OF THE OCCIPITAL ALPHA WAVES UNDER EYE-OPEN AND EYE-CLOSE CONDITIONS. THE ARROWS INDICATE THE RANGES OF THE RESPECTIVE RHYTHMS. NOTE THE DISTINCT PEAKS.

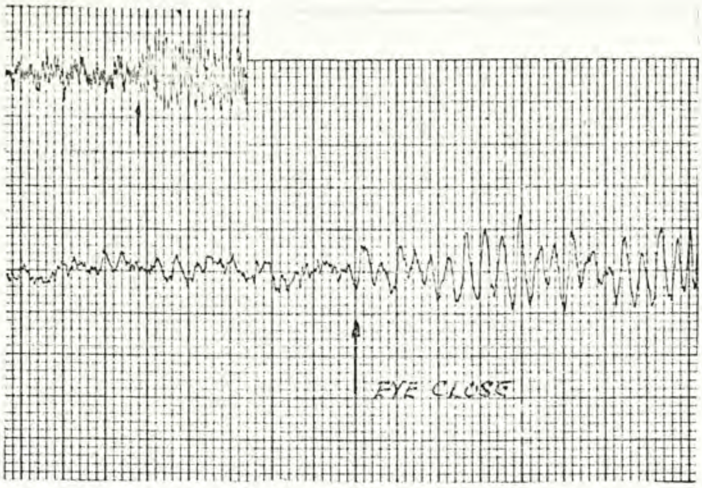


FIG 2.11 EFFECT OF IMMEDIATE EYE CLOSURE ON OCCIPITAL ALPHA RHYTHM. THE LEFT UPPER RECORD SHOWED A RECORDING WITH SPEED OF 5mm per sec (25 mm per sec FOR THE LARGER RECORD). NOTE THE BURSTS OF ALPHA ACTIVITY AND THE INITIATION OF THE WAX SPINDLE. A SLIGHT INCREASE IN FREQUENCY FROM 11.15 HZ TO 12 HZ IN THE FIRST SECOND AFTER EYE CLOSURE SHOULD ALSO BE OBSERVED.

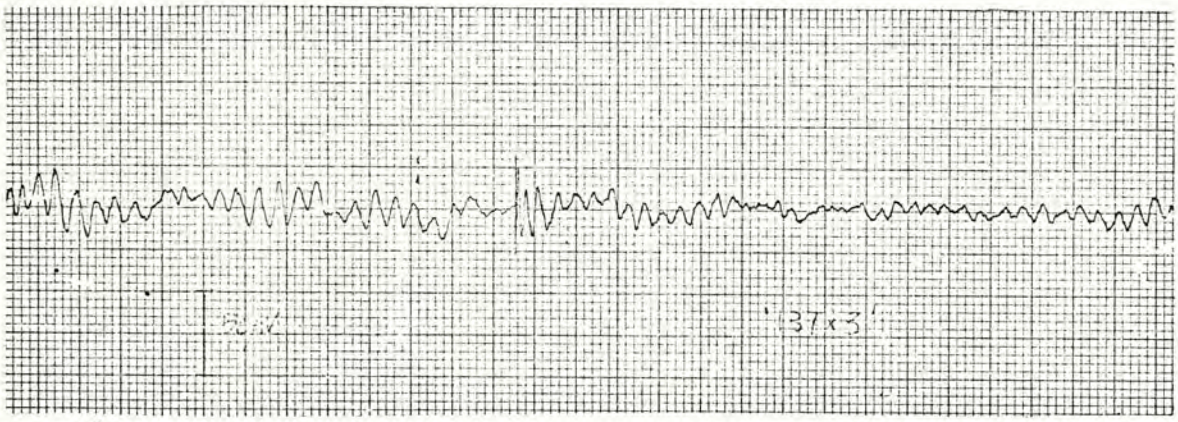


FIG 2.13 EFFECT OF MENTAL ARITHMETIC ON OCCIPITAL ALPHA. THE SUBJECT WAS ASKED TO CALCULATE THE PRODUCT OF 137x3 AND HE OBTAINED THE RIGHT ANSWER. NO REWARD WAS GIVEN.

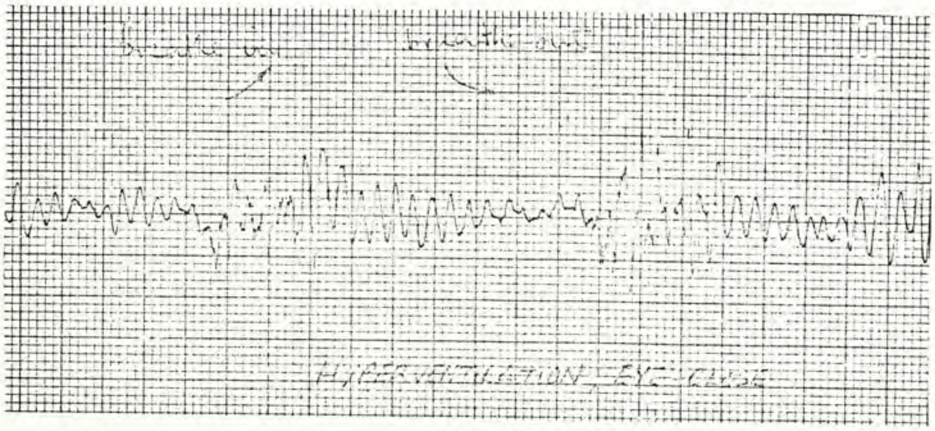


FIG 2.15 EFFECT OF HYPERVENTILATION ON ALPHA WAVES. NOTE THE WAVE CHARACTERISTICS DURING THE EFFECT.

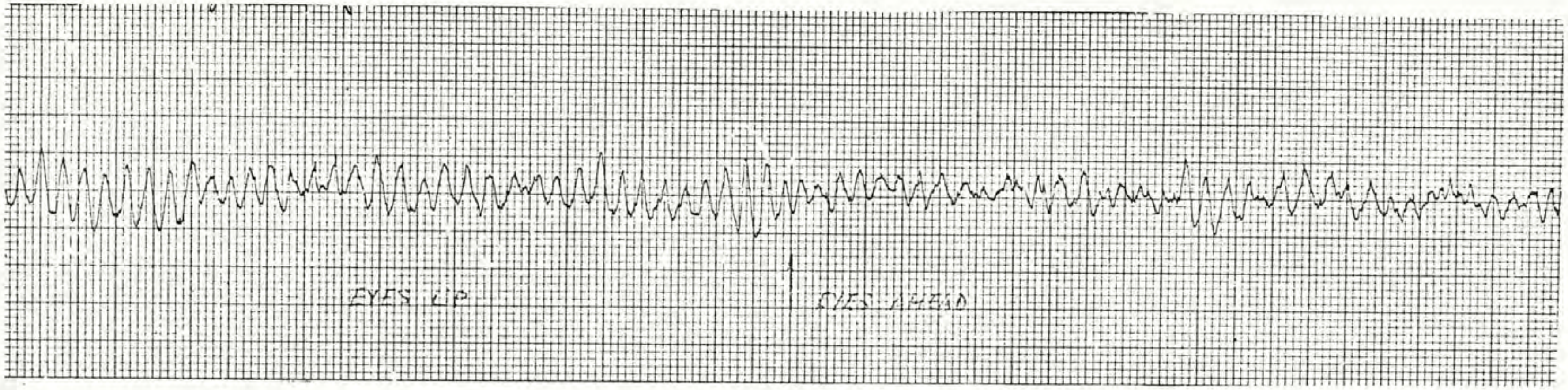


FIG 2.12 EFFECT OF FORCING THE EYE UPWARD ON ALPHA WAVES. NOTE THE INCREASE IN ABUNDANCE AND AMPLITUDE.

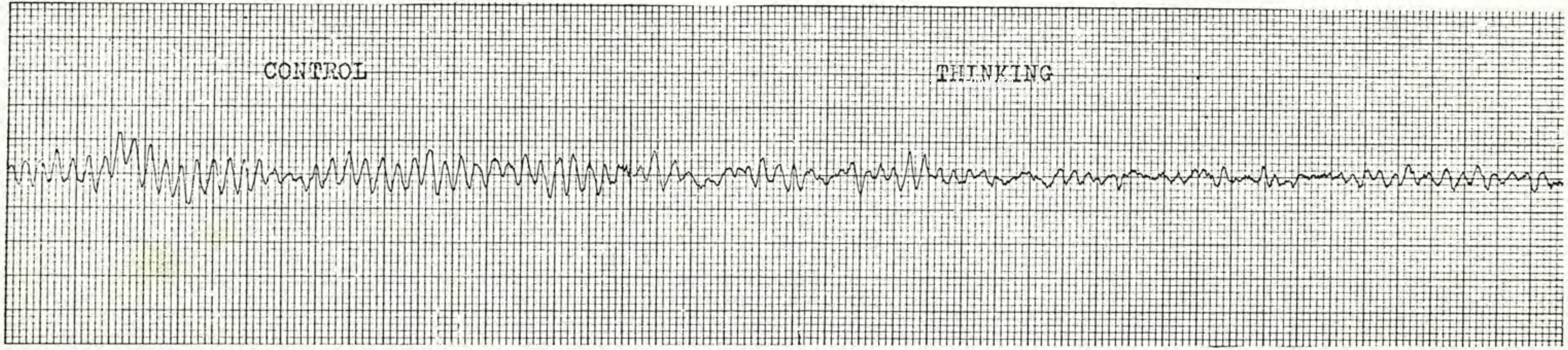


FIG 2.14 EFFECT OF CONCENTRATION OR THINKING OR MEMORY OF A FAMILIAR VISUAL IMAGE ON ALPHA WAVES.

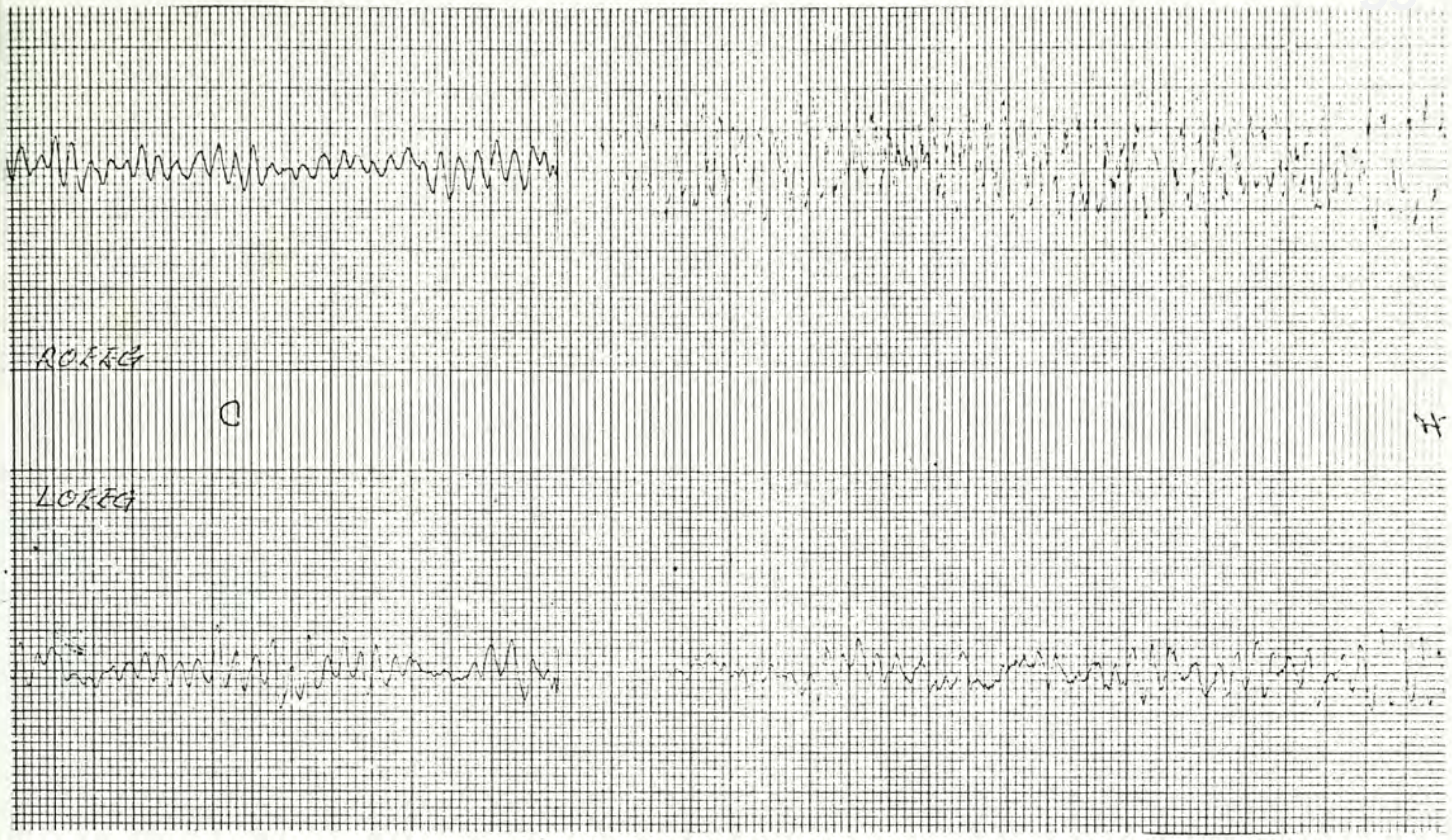


FIG 2.16 EFFECT OF ROTATING THE HEAD TO THE RIGHT SIDE ON THE RIGHT AND LEFT OCCIPITAL EEG RECORDINGS. NOTE THE SPIKY APPEARANCE OF THE RIGHT OCCIPITAL WAVES.

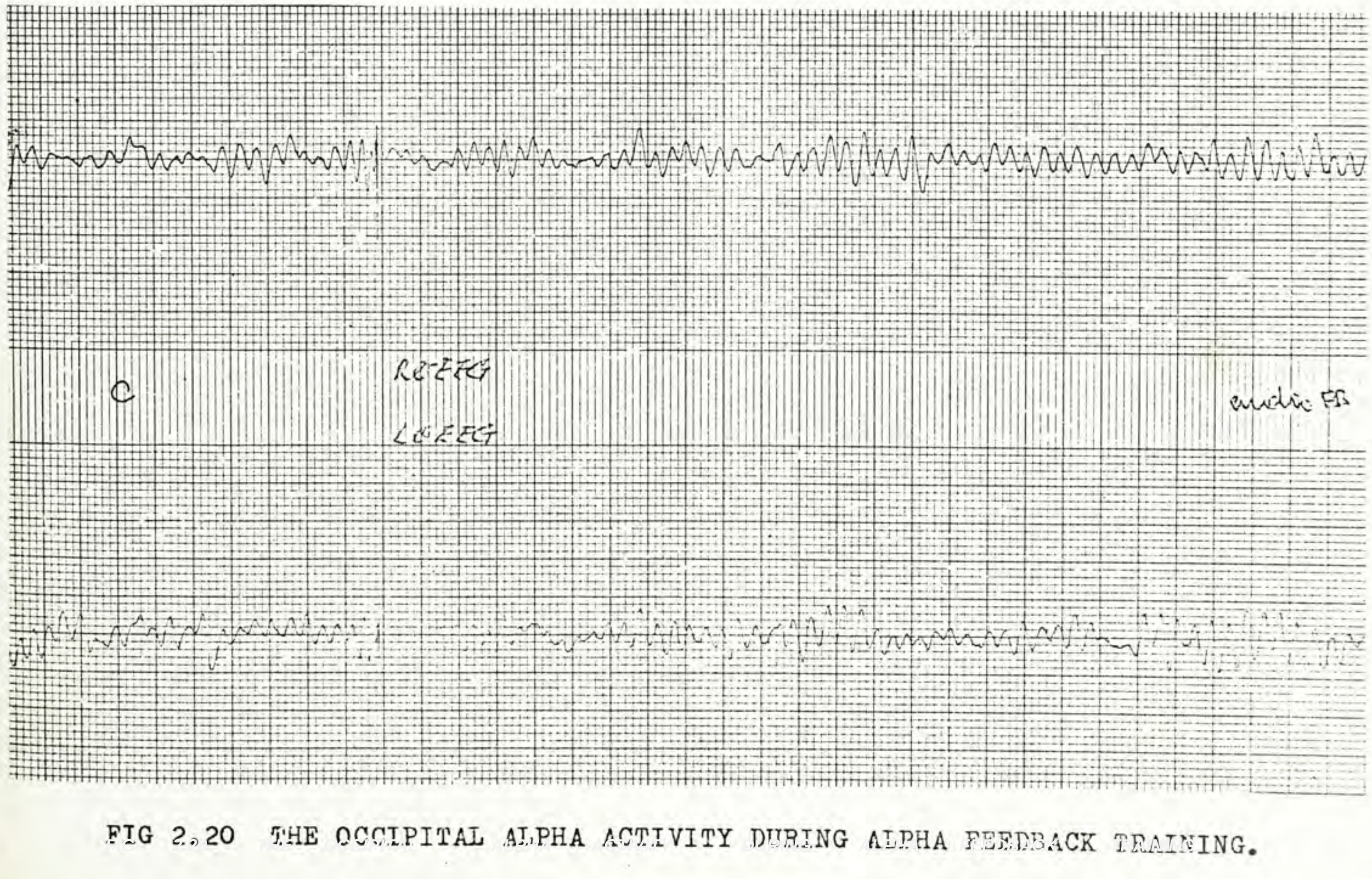


FIG 2.20 THE OCCIPITAL ALPHA ACTIVITY DURING ALPHA FEEDBACK TRAINING.

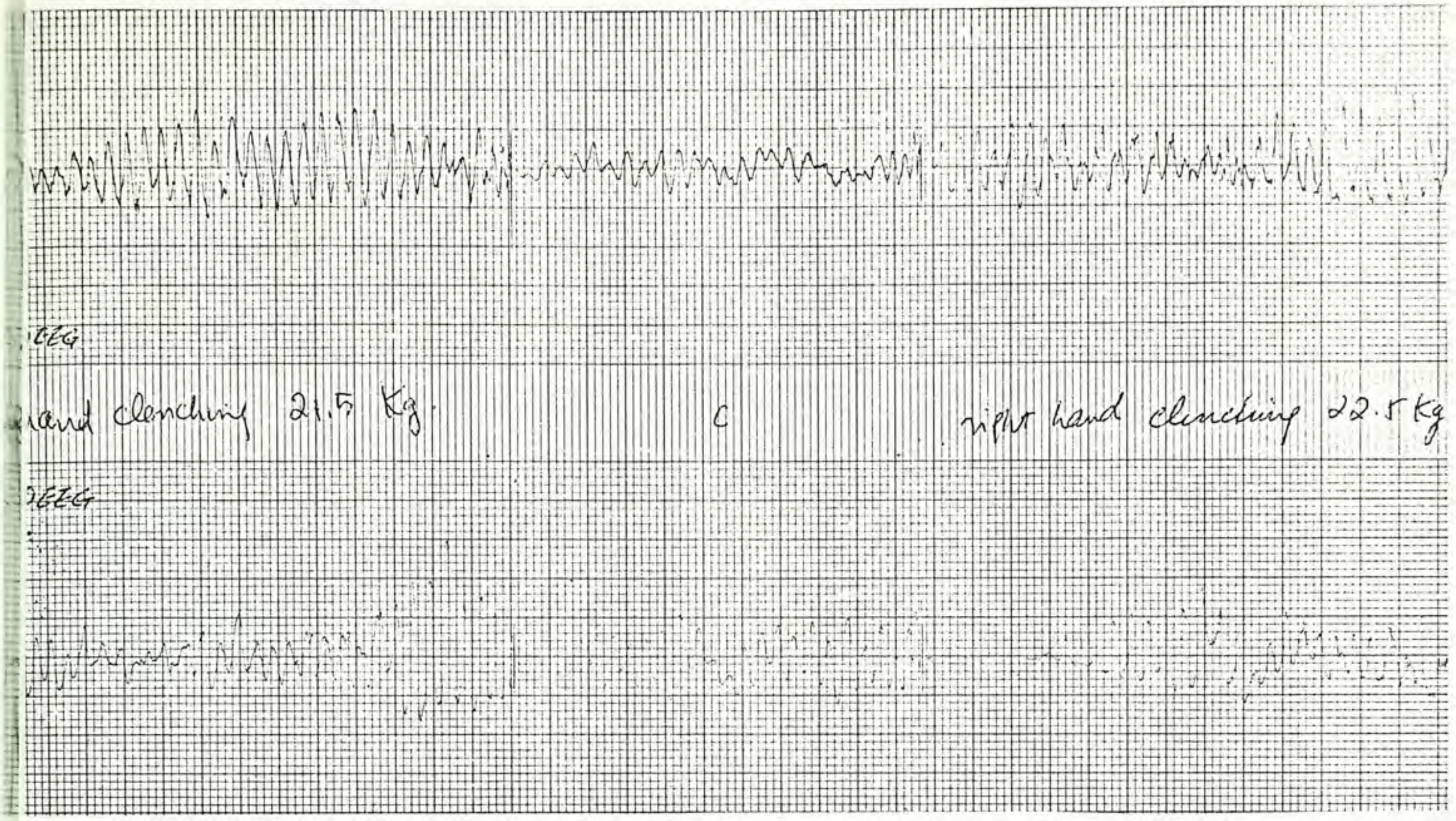


FIG 2.17 THE EFFECT OF CLENCHING ON OCCIPITAL ALPHA ACTIVITY. THE CLENCHING FORCE WAS ABOUT 22 Kgf.

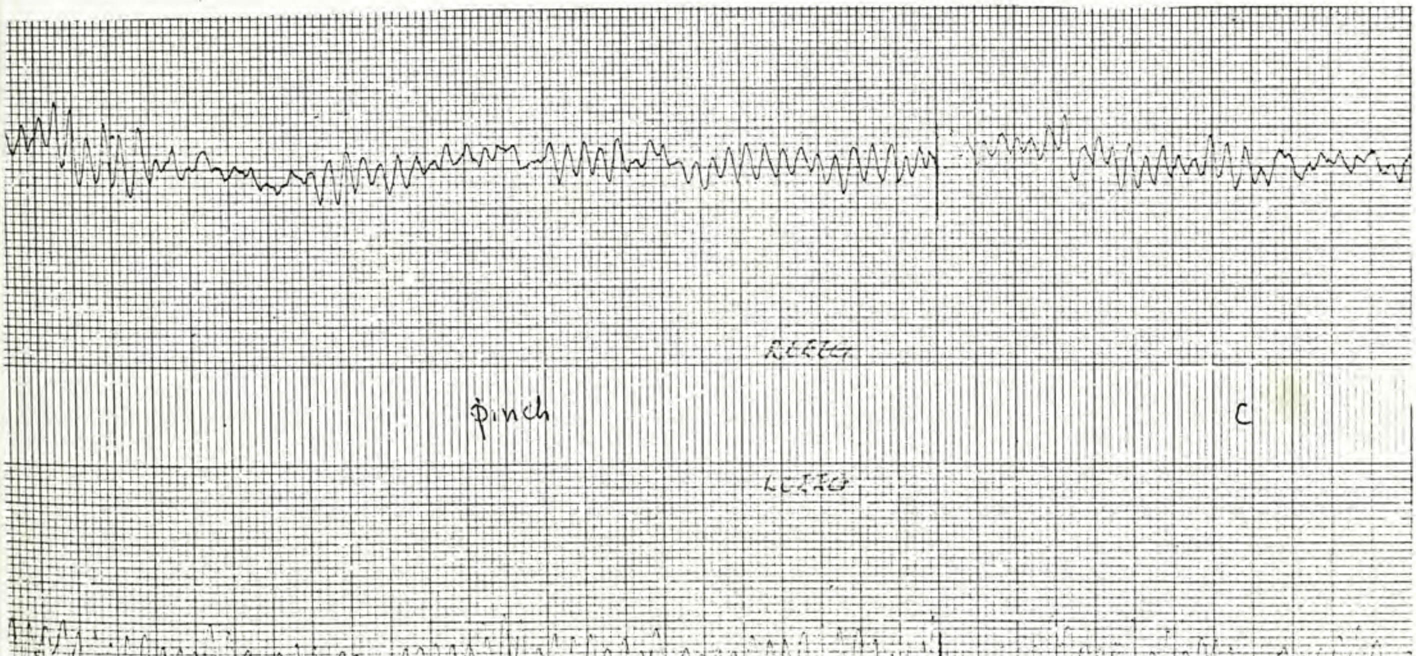


FIG 2.18 THE EFFECT OF PINCHING ON OCCIPITAL ALPHA ACTIVITY.

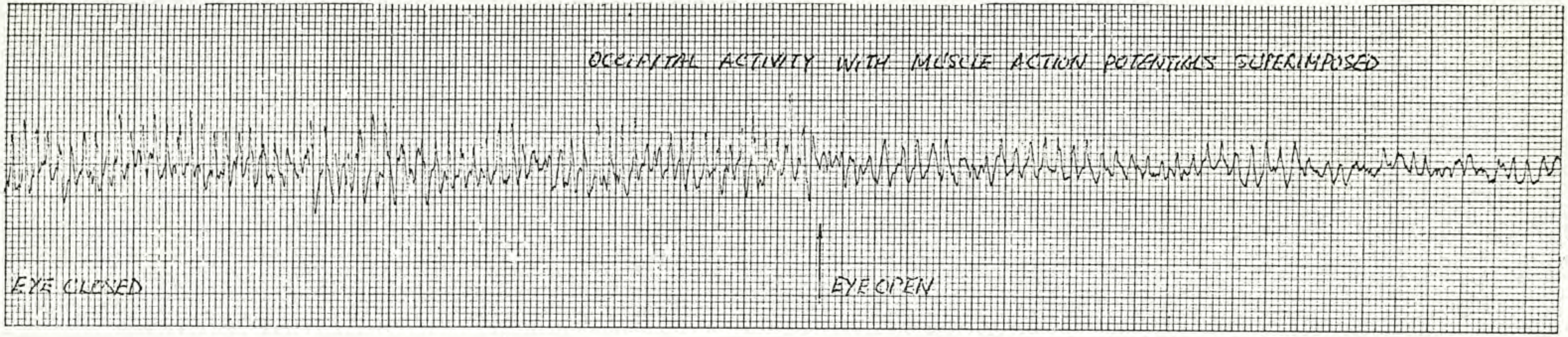


FIG 2.19 OCCIPITAL ALPHA RHYTHM WITH MUSCLE ACTION POTENTIAL SPIKES SUPERIMPOSED.

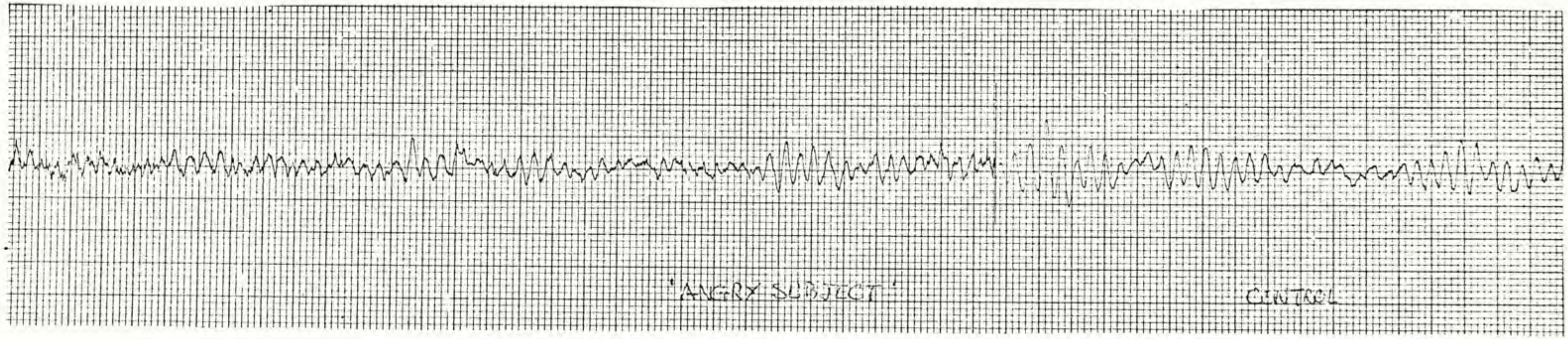


FIG 2.21 THE EEG RECORD OF AN 'ANGRY' SUBJECT.

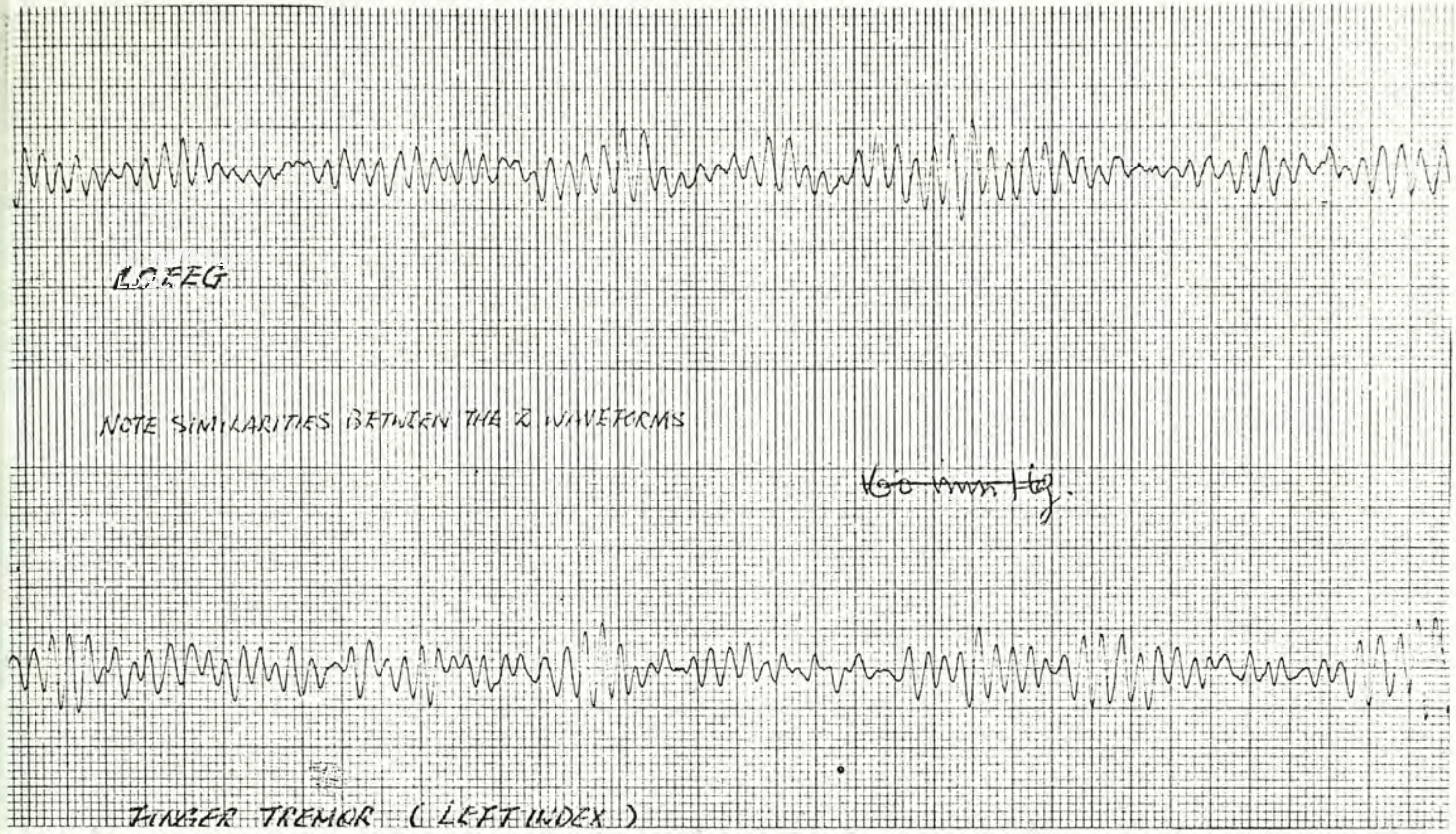


FIG 2.22 THE SIMILARITY OF OCCIPITAL ALPHA AND FINGER TREMOR.

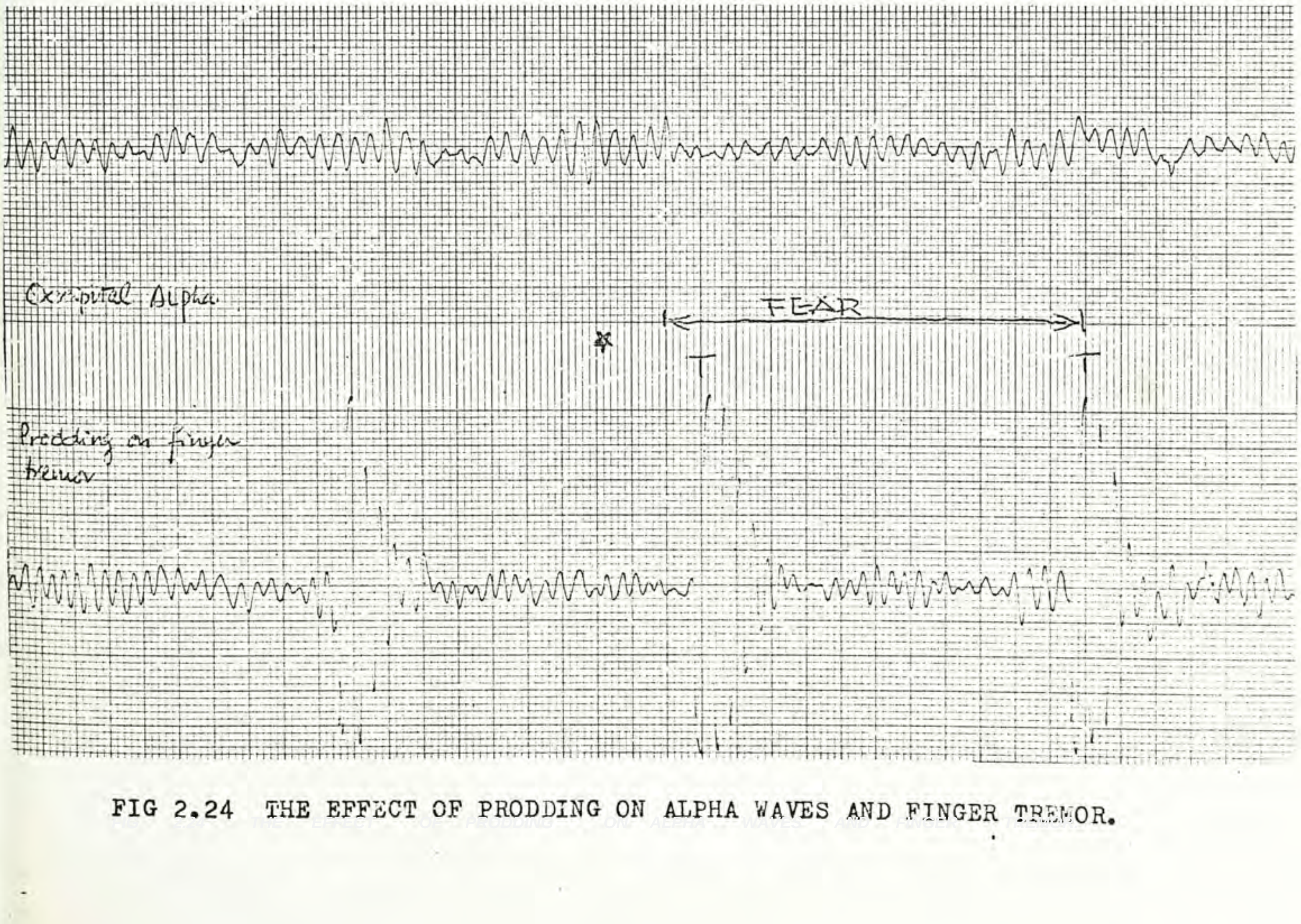


FIG 2.24 THE EFFECT OF PRODDING ON ALPHA WAVES AND FINGER TREMOR.

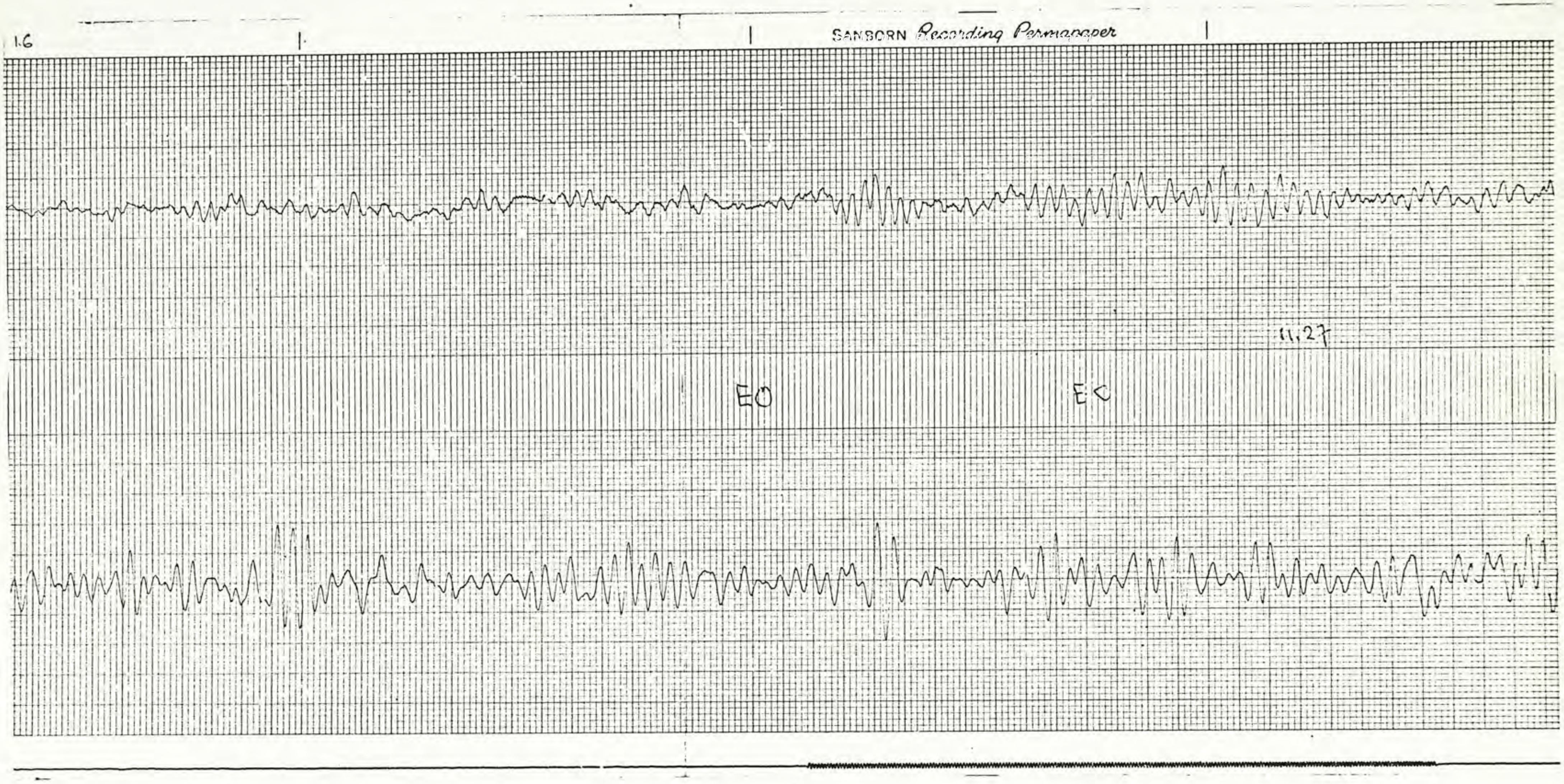
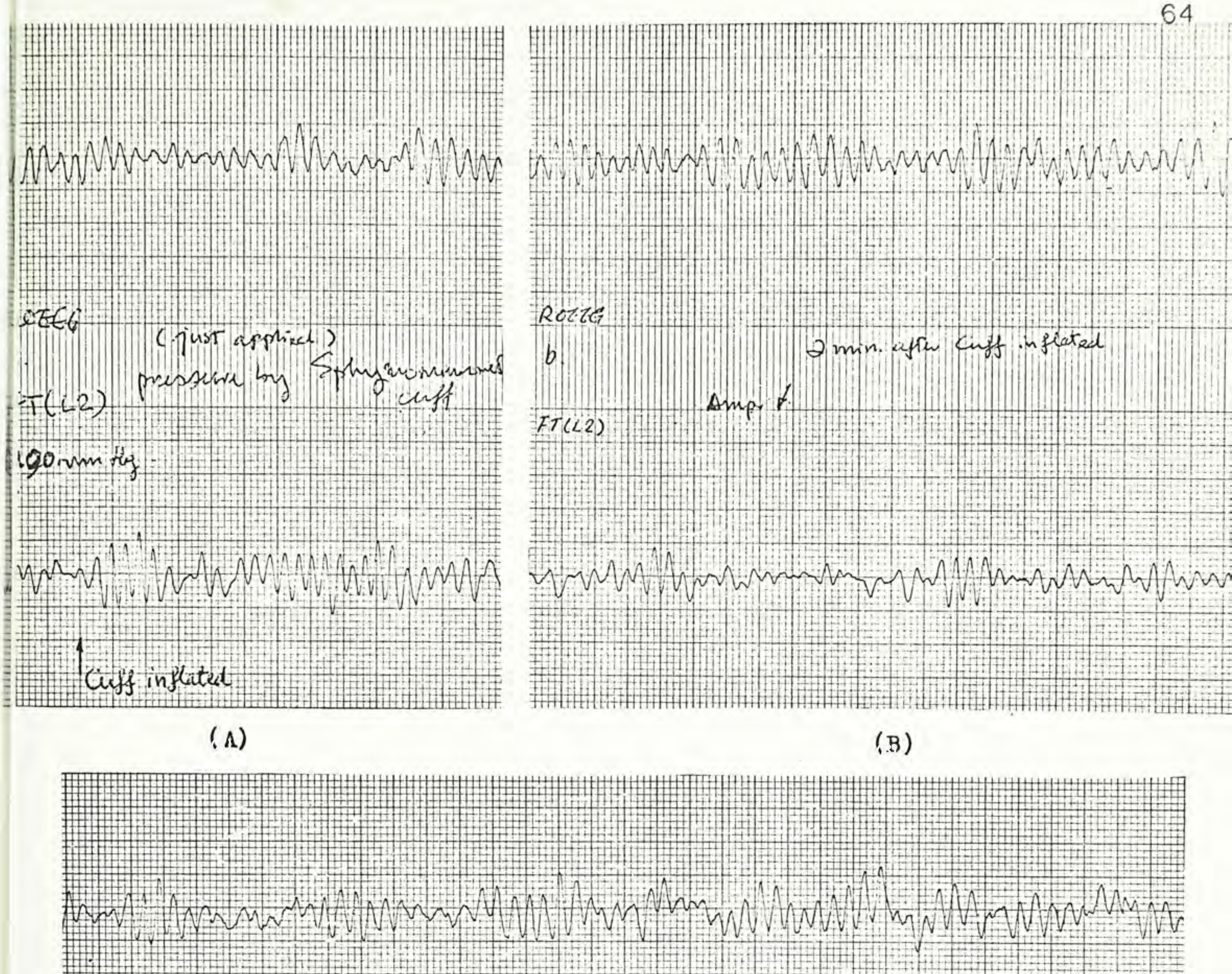


FIG 2.23 EEG ALPHA ACTIVITY AND FINGER TREMOR COMPARED UNDER EC AND EO CONDITIONS.



(A) (B)

(C)

FIG 2.25 EEG AND FT RECORDINGS (A) JUST AFTER, (B) 2 MIN AFTER A SPHYGMOMANOMETER CUFF WAS INFLATED AND (C) 1 MIN AFTER THE CUFF WAS REMOVED. NOTE THAT THE CHANGES IN THE FT WERE NOT ACCOMPANIED BY SIMILAR CHANGES IN ALPHA ACTIVITY.

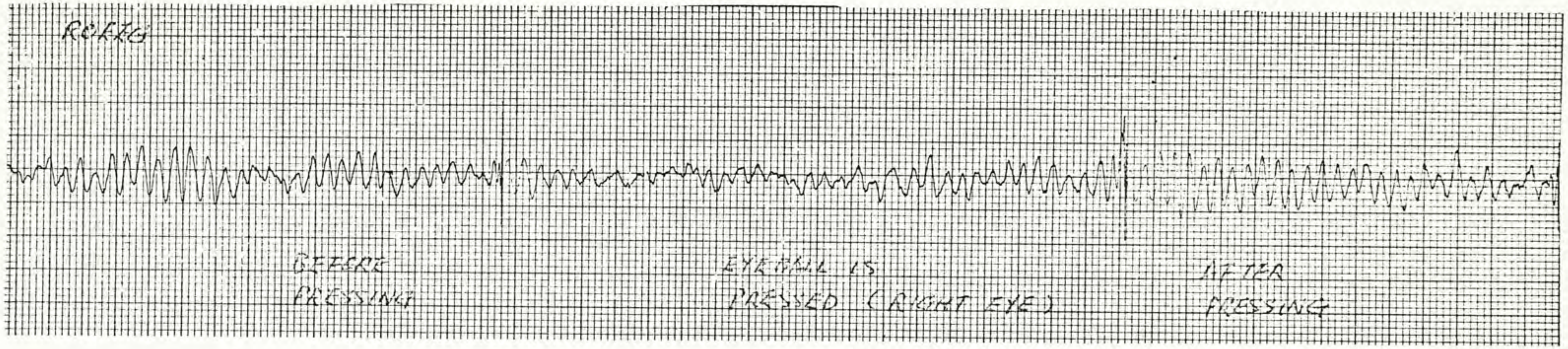


FIG 2.26 THE EFFECTS OF PRESSING THE RIGHT EYE BY SOFT COTTON PADS ON THE RIGHT OCCIPITAL ALPHA ACTIVITY. THE ALPHA WAVES BEFORE AND AFTER EYE PRESSING ARE SHOWN. NOTE THE MARKED DECREASE IN AMPLITUDE AND CONSIDERABLE DESYNCHRONY DURING EYE PRESSING.

CHAPTER THREE

ORIGIN OF PHYSIOLOGICAL TREMOR

3.1 HISTORICAL BACKGROUND

Physiological tremor accompanying voluntary muscular contractions has long been studied since 1886. The first recording of the tremor is usually credited to Schafer, Canney and Tunstall (1886). They clearly defined a 10 Hz rhythm in the mechanical record of the contractions of muscles and limb movements in normal human subjects. Unfortunately, they did not discuss the natural periodicity of their recording system and their results were regarded as artefacts by Haycraft (1890). Nevertheless, other authors using different recording systems verified the finding of the 10 Hz rhythm. Horsley and Schafer (1886) were later able to demonstrate a similar 10 Hz rhythm in the graphic records of the movements of monkeys following stimulation of the motor cortex, and descending motor pathways at various frequencies. They conclude, on the basis of their results, that the rhythmicity was originated at a spinal rather than a cortical level. Since 1886, various investigators confirmed the rhythmicity (Pelnar 1913; Wachholder 1928; Hultkrantz 1931).

3.2 OBJECTIVE OF INVESTIGATION

Schafer's observation, verified by other investigators, might be expected to throw light upon the organisation of voluntary movements. It then becomes necessary to enquire as to the origin of the rhythmicity. The human body, in order to survive in the continually changing environment, must be able to achieve and maintain internal stability. For instance, there are the response of the pupil to the intensity of illumination and the stretch-reflex servo action to maintain constant muscle length and an automatic gain compensation for altering load. These subtleties of design can even hardly be found in man-made servo mechanisms. However, little attention has been paid to the various nervous reflexes involved in these homeostatic mechanisms hitherto although such mechanisms are ubiquitous. This investigation is also important in revealing the alpha origin since the origin of physiological tremors must be known before a complete understanding of the occipital alpha activities can be achieved.

3.3 SOME PUBLISHED THEORIES AND HYPOTHESES

Among the first publications on physiological tremor, Horsley and Schafer (1886) hypothesised a spinal origin of the rhythmicity. Thereafter, many theories relating to the production of the tremor had been proposed but no documented evidence suggesting a single common origin for the tremor has been found. Two main schools of thought can be identified, namely, the physiological and the physical ones. The physiological school has suggested different areas of the central and peripheral nervous system or muscle as the possible origin of physiological tremor. The cortical origin of such tremor was first suggested by Jasper and Andrews (1938). They hypothesised that physiological tremor was originated in the cortical electrical activities. Nevertheless, this is proved unlikely in section 2.7. Halliday and Redfearn (1954, 1956, 1958) using an automatic frequency analyser for the study of physiological tremor in human subjects found a spectrum of tremor between 5 and 15 Hz but with peak frequency around 10 Hz. However they did notice that there was a variation in frequency from one examination to the next in the same person. The frequency spectral analysis of tremor in tabetic patients with marked alteration in proprioceptive sensibility indicated an absence of 10 Hz frequencies, as well as a change in frequency on loading, a response differing from that of the normal subject. They interpreted their data as supporting the contention that physiological tremor is due to oscillation around a spinal reflex arc and concluded that the changes noted in tabetic patients are the changes one would expect in the presence of a failing servo-loop mechanism. Lippold, Redfearn and Vuco (1957) and Redfearn (1957) confirmed that the tremor was due to the self-regulating mechanism of a servo-loop. Marshall and Walsh (1956) and Marshall (1959), on the other hand, viewed muscles as a band-pass filter that blocked the high frequency neural discharges and converted those below 15Hz to mechanical ripples. They also noted a slowing of tremor frequency with cooling of the extremity and believed this was due to a change in the muscle, thus altering its characteristics as a filter. At the same time, Hammond, Merton and Sutton (1956) also noted that local cooling of the forearm would reduce the frequency of physiological tremor but interpreted this as due to an altered servo-loop mechanism. A somewhat different view was advocated by Rohracher (1962), who suggested that the tremor was the permanently alternating muscular activity of a 'bio-seismic' process for maintaining the body heat because the tremor was found only in warm-blooded animals and changed with temperature. Another group of investigators favoured the hypothesis that the grouped discharge underlying the tremor beats were the result of chance synchronization of independent firing motor units (Fulton and Liddell 1925; Gordon and Holbourn 1949; Taylor 1962; Dietz et al 1976).

The physical or mechanical school of thought suggested tremor was a ballistocardiographic effect (Brumlik 1962; Van Buskirk and Fink 1962; Brumlik, Mier, Petrovick and Jemsen 1964; Wachs 1964; Yap and Boshes 1967). However, the data in support of the ballistocardiographic origin do not appear conclusive. Another hypothesis belonging to the same school is the mechanical resonance hypothesis which proposed that tremor was the result of a forcing applied to a peripheral resonance system (Stiles and Randall 1967).

3.4 THEORETICAL CONSIDERATION FOR THE STRETCH-REFLEX SERVO HYPOTHESIS

Halliday and Redfearn (1956, 1958) first postulated the servo-loop theory of tremor. They recorded and analysed the frequencies of finger tremor in eight patients (recorded photo-electrically from the right index finger) suffering varying degrees of deafferentation due to fabes dorsatis. Tabetic patients were divided into two groups, those without a 10 Hz rhythm and those with an increased rhythm. The absence of the rhythm is very clearly correlated with the degree of diafferentation as determined by clinical testing. In the case of the less severely deafferented tabetic patients, the increased rhythm is probably due to increased gamma activation of the remaining intact parts of the reflex arc (see Fig. 1, 2 and 3 of their paper in 1958). The results suggest that the integrity of the reflex arc is essential to the presence of the tremor rhythm and the rhythm is not a centrally determined one. The same result was obtained in experiments on the anaesthetized cat by Lippold, Redfearn and Vuco (1959). They showed that cutting of the dorsal roots coming from the limb, where tremor from its tibialis anterior muscle was recorded, abolished the 10 - 15 Hz tremor peak recorded before cutting. The servo-loop hypothesis is also supported by the fact that local cooling of the forearm would lower the frequency of finger tremor (Hammond et al. 1956; Lippold 1971). Lippold (1971) carried out a series of experiments aiming to interrupt and to modify the properties of the stretch-reflex servo mechanism to test the servo-loop hypothesis and found gratifying results confirming the hypothesis. Joyce and Rack (1971a, 1971b, 1974a, 1974b) showed support by investigating the effect of load and force on elbow tremor and the forces generated at the elbow joint in response to imposed sinuosoidal movements of the forearm. They concluded that the stretch reflex and the spring-mass system in the limb each have a filtering effect on spontaneous tremor, but when by adjustment of the load the natural frequencies of these two systems are brought close together and the stretch reflex has a high gain, a relatively large spontaneous oscillation develops. After a brief review of the published works in support, some background theories of the servo-loop hypothesis will be discussed in the followings.

1. The control of voluntary muscle movement

The muscle spindle is the key structure in the complex self-regulating mechanism for the control of movement of skeletal muscle. In voluntary movement a muscle can be made to contract by impulses reaching it by one of the two routes, namely, the direct and indirect pathway. The direct pathway is probably involved in sudden movements. Impulses from higher centres in cerebral cortex pass down large motor neurones of the pyramidal tract (the alpha route) to excite directly the lower motor neurones and then the motor units and lead to contraction of muscle (Fig 3.1). The indirect pathway, on the other hand, is probably for accurately controlled and fine movement and also for movements involved in maintenance of posture. Impulses from higher centres especially the cerebellum pass in small motor neurones to intrafusal muscle fibres in the muscle spindle (the gamma route). These contract and cause stretching of spiral sensory endings which then discharge an increased number of impulses along their different fibres into the spinal cord. This reflexly leads to the discharge of impulses in the lower motor neurone and contraction of muscle (Fig 3.1). The reflex arc that senses and controls the stretching of a voluntary muscle consists of the spiral sensory endings that signals the amount by which the muscle is stretched, the afferent nerve fibre that conveys the signal to the spinal cord and the motor neuron in the cord that in response sends a contraction-activating ~~spinal~~ signal to the muscle by way of the alpha efferent nerve. The properties of this feedback loop will be altered to investigate its effect on physiological tremor.

2. Why does a voluntary muscle contraction exhibit tremor?

The stretch-reflex servo-loop hypothesis postulates that physiological tremor arises as a hunting phenomenon in the stretch reflex arc. Underdamped servo-mechanisms are often prone to overshoot and to give rise to oscillations. One of the common features of most biological control systems is that they are underdamped. Critical damping, the desirable criterion to be achieved, is only obtained at the expense of speed. Excessive damping in the stretch reflex arc would inevitably slow the response to stimulation. Reflex action must therefore involve a necessary compromise between speed of response and a certain degree of overshooting or oscillation. Experiments were carried out to verify that physiological tremor is actually oscillation of the underdamped servo action of the stretch reflex arc. This oscillation is in turn due to the time delay in the various nerve pathways, and more important, in the muscles involved. The amplitude of the oscillations usually does not exceed two percent of the physiological range of movement of a limb and would certainly be tolerated in the interest of maintaining a fast response.

3.5 EXPERIMENTAL METHODS

Tremors can be recorded by position, velocity or acceleration transducers. The technique used in the studies involved chiefly the measurement of velocity with the commercially available dynamic ~~motors~~ mikes (Model no. 92CU2974 and 92CU2947, Poly Paks). The transducer is small ($1\frac{1}{8}$ X $\frac{1}{2}$ "), light (2 oz.) and has high impedance (20K ohm). Other techniques used include the multi-purpose variable impedance transducer (KD-2300-0.55U, Kaman), the temperature compensated linear differential pressure transducer (LX1601D, National) and the laser technique (He-Ne laser, SP-155, Spectra Physics). Preliminary tests were carried out to compare the different techniques and the dynamic mikes proved to be the best transducer. We appreciate the excellent performances of the dynamic mikes in recording physiological tremor but to our surprise, they are neglected by other investigators. The transducers used by most authors are acelerometers. They are certainly good transducers but are very expensive especially the miniature and piezoelectric ones. Thus cheap and efficient transducers would certainly be of great interest. With numerous experiments, we are able to show that the dynamic mikes gave reliable and well-patterned physiological tremor recordings. They are cheap, versatile, easily available and efficient. Their low frequency responses are excellent. What is more important, their price is only about three-hundredth of that of the accelerometers. The transducer also takes the advantage of introducing no dc components into the output signals as compared with the optical and variable impedance transducers.

Before recording, each subject was made familiar with the test situation in advance such that changes due to habituation were kept to a minimum. All studies were conducted in a large quiet room with the subjects sitting in a comfortable chair and relaxed as best as they can. Tremor was recorded from the index and middle fingers of both hands of the subjects consisting of the students and staff members of the department. They were instructed to adduct their arms at the shoulder and flex the elbow so that the pronated forearm lay comfortably and horizontally on a raised rigid surface supported up to the wrist level at the surface edge. The forearm was also fixated as a whole to exclude any extraneous movements. The hand, turning a right angle at the wrist joint from the forearm, hanged freely and vertically with the fingers facing downward. The dynamic mike was then positioned such that the tip of the freely hanging finger just touches its diaphragm (Fig. 3.2). The force to be exerted on the membrane is not very significant provided that it is not great enough to produce a depression on the whole membrane. The procedure is simple and easily adapted. Finger tremors recorded in this posture, with the dynamic mikes as transducers, were found to be reliable, regular and stable. However, again to our surprise, this simple posture discovered by us has not been used by other authors hitherto (to our best knowledge). The most common posture employed by other authors involves the strapping of accelerometers over the dorsal surfaces of the terminal interphalangeal joints of the index fingers with the subjects' wrist and fingers actively extended and the arm fully supported to the wrist. This posture had also been employed in some experiments but the results were found not so satisfactory as compared with our posture. The results lacked good regularity and stability such that some experiments on peripheral changes and servo-loop interruptions of the tremor seems not possible.

During recording, the outputs of the dynamic mikes were fed to the bioelectric amplifiers (HP8811A) and then recorded in the EMG recorder (HP7702B). A tape recording system was employed to modulate and record the signals in tapes for further analysis. Several methods of analysis had been used. They include analog, digital and interval analysis. For the analog techniques, circuits were built to filter the signals into different bands, to obtain the variance, mean, absolute mean, envelope, r.m.s. value of the signal etc. and for frequency to DC and phase difference to DC conversions. Digital methods involve computer manipulations and plotting of the frequency spectra and cross-correlograms as well as auto-correlograms. As for the interval analysis technique, the activity time, the frequency of occurrence, the amplitude distributions and other variations of each particular wave interval were studied.

When the effect of temperature change on physiological tremor was studied, a bath and circulator (Mod. No. 2095, Masterline Forma Scientific Co.) was used to provide a circulation of hot and cold water in some acrylic set-ups specially built for this experiment (Fig 3.3 a, b), two for the recordings on both hands and two for both feet. Finger tremors were recorded with the hanging posture safe that the whole forearm was immersed in cold or hot water whereas foot tremor was recorded at the hinged foot platform with the whole limb immersed. The effect of load and force on finger tremor was studied with a pulley system (Fig. 3.4). Weights and force were exerted at the wrist joint and the subject was instructed to maintain a constant posture against the weights or tension of the string for a period of about half a minute while the finger tremor was recorded. The procedure was repeated for different weights and tensions. Experiments on feedback studies were enabled by modulating the tremors to audible signals in the subjects' headphone. The modulator circuit will be shown in section 4.3 . The subject was trained to control his own tremor via the feedback signals.

Lippold (1970a) working on a series of experiments on finger tremor confirmed the stretch-servo theory. In his experiments, tremor was recorded in two ways; either by recording the force of contraction or by recording the displacement of the finger. The first method involved a strain gauge which recorded the force of extension of the forefinger or middle finger as it was maintained in the raised position against a predetermined load. Visual feedback by displaying the output of the strain gauge bridge circuit on an oscilloscope was coupled to the subject to monitor and control his force of voluntary contraction such that the tremor amplitude would be directly proportional to contraction strength. This method suffers from four drawbacks. Firstly, visual feedback must be involved which certainly affects the tremor. Secondly, the complexity in the control mechanism is difficult to adapt and attention always plays a part which is not desired. Thirdly, dc components were introduced into the output signals and fourthly, recordings must be taken with the eyes open and distinct vision. The second method employed by Lippold was to interrupt a parallel beam of light falling upon a phototransistor with the freely extended middle finger (the same method used by Halliday and Redfearn in 1956 and 1958). Their subjects were required to keep the shadow of their fingernails as close as possible to a fiducial ~~Fudicial~~ mark to introduce no ~~us~~ voluntary movements which had to be avoided in this recording method. Their second method again suffered from the same drawbacks as in the case of the first one save that no visual feedback was involved. Due to their shortcomings, we had to device new technique to overcome these difficulties and the technique of recordings with the dynamic mikes ~~units~~ and the 'hanging' posture proved to be very successful. This enabled us to verify the findings of Halliday and Redfearn as well as that of Lippold. Using the technique, we were able to obtain reliable recordings of physiological tremor under different experimental requirements to verify the stretch-servo hypothesis.

3.6 IS IT A LOCAL EFFECT?

An experiment was carried out to verify that physiological tremor is not a local phenomenon at the recording site but an effect accompanying voluntary muscular contractions.

1. method and material

   The multi-purpose variable impedance transducer (KD-2300 -0.5SU, Kaman) with a small sensor (3mm dia.) was employed in the experiment for two reasons. There is no direct contact with the muscle surfaces and the sensing area is small. Besides, the transducer can be fixed with respect to the finger such that movements other than that of the recording site are eliminated. A tube made of transparent materials is designed to house the finger and the transducer rigidly and comfortably (Fig. 3.5) such that there is no relative displacement. The target is a thin film of silver (6mm dia.) made by evaporating eight layers of silver on a temperature resistant plastic sheet (to obtain an optimum thickness) and then separating them apart. Recordings were made with the silver target stuck to the finger tip by double-sided adhesive. The arrangements is shown in Fig. 3.5.

2. results and discussions

   No tremor was recorded in the experiment, in fact, no output other than noise (less than 0.5μV) could be observed. This simple experiment thus verifies that tremor is not an intrinsic effect of the muscle surface at the recording site but is muscular oscillation accompanying voluntary muscular contractions when one tries to keep a finger in a given posture.

3.7 EXPERIMENTAL STUDIES ON FINGER TREMOR

Experiments were carried out in this section to study the general characteristics of finger tremor. These experiments had been done for the alpha waves and their results for tremor may be of great help either as a comparison with alpha activity and eye-tremor (see chapter 4) or as a support for the stretch-servo hypothesis. Some of the characteristics have not been studied before and some were found to have different results from other investigators. As a whole, they agree well with the hypothesis. The new technique of recording (dynamic mike and the 'hanging' posture) was employed throughout the experiments.

The frequency spectrum of the tremor is characterised by a dominant peak at 10 Hz and a sub-maximal peak at 1Hz (Fig. 3.6). The delta rhythm is much more dominant in the tremor than in the EEG waves whereas other rhythms are similar. The autocorrelogram of the tremor is characterised by a gradual decrease of the product moment correlation coefficient with increasing time lag in a similar manner as the EEG alpha waves (Fig. 3.7).

Tremors recorded at different locations are similar but not identical. We have not been able to find relations between the phase of tremor in different parts of a limb though they are very similar in appearance. This is in consensus with the stretch-servo hypothesis. The finger tremors recorded at the left index and the right index fingers simultaneously are shown in Fig. 3.8. No phasic relationship was observed and the correlation coefficient was found to be 0.171 only.

It has been shown that the waxing and waning phenomenon is similar in physiological tremor and alpha waves. Would this suggest that the waves are actually very slow waves (below 2 Hz) carried by 10 Hz sinuisoidal oscillations? Simple experiments showed that this is not probable by filtering out the envelope of the waves (Fig. 4.10d) and analysing it. We found that the envelope is similar to random fluctuations and its frequency is to no extent stable or regular. In addition, no 10Hz sinuisoidal oscillations without waxing and waning had been recorded anywhere in the body. Thus the envelope hypothesis had to be abandoned. The waxing and waning property is probably due to the 'hunting' phenomenon of the stretch-reflex arc. Instability in this servo-loop, which is responsible for controlling muscle length and tension, results in oscillations. When it oscillates, the loop gives rise to repetitive, rhythmical nerve discharges, which in turn are apparent as the mechanical oscillations of tremor. This system has a finite delay in its operation and hence under certain circumstances it will go into oscillation. Experiments were carried out to show that it can be induced to oscillate by a brief mechanical stretch of the muscle. The frequency of such oscillation produced in the stretch reflex arc is the same as that of physiological tremor. When the muscle of the subject is cooled by immersing either his forearm or his leg in cold water, the twitch of the muscle when stimulated, is prolonged. As the twitch time is the most dominant factor in the delay of the stretch reflex arc, the frequency of physiological tremor thus recorded were also found to be lower. It merits special mention here that it is the delay in muscle responses (the twitch-time) and not the delay in the various nerve pathways that contribute dominantly to the overall delay in the reflex arc. The most common objection raised to the servo-loop hypothesis stating that, the changes in the neural conduction velocity by drugs or other procedures are not significantly reflected in the physiological tremor recordings, should observe the above points.

The followings are some studies in the characteristics of finger tremor hoping to reveal some hints on the origin of physiological tremor and to show support to the abovementioned mechanisms.

1. Some general studies: muscle action potential and loop delay

   In order to show that the mechanism of generation of tremor does involve neural mechanism and is not simply the result of mechanical resonance of the finger, it is possible to record muscle action potectrals responsible for the contraction maintaining the finger in a certain posture. Lippold, Redfearn and Vuco (1957) showed that in the case of spontaneous tremor in many different accessible muscles in the human body that groups of action potentials occur with a frequency of 8 to 12 Hz and that they do synchronise with tremor. Lippold (1970a) confirmed the result by showing that groups of muscle action potentials recorded from the skin of the forearm over the extensor digitorum communis are in phase with tremor following prodding. Response of groups of muscle action potentials to sinuisoidal stretching at about 10Hz of a single afferent fibre from an annulo-spiral ending within the gastrocnemius muscle of anaesthetized cat also showed strong phasic relationships (Lippold 1970a). The result suggested that physiological tremor involves stretch receptor activation in phase with it.

We recorded muscle action potentials from surface electrodes on the skin of the forearm of the subject over the extensor digitorium communis simultaneously with finger tremors from the subject's left index finger tip in the 'hanging'posture following single prodding at the nail of the same finger. The action potential groups and the tremor waves thus recorded showed strong phasic correlations that each wave was roughly aligned with a group of action potentials and their maxima conicided when the tremor waves were inverted upside down. The results confirmed Lippold's findings and supported that physiological tremor is nerve-generated and not associated with muscular mechanical resonance. In fact, the resonant frequency of the finger in the unloaded flaccid state is known to be 30Hz, greatly different from that of normal tremor.

The delay in the servo-loop comprises the time taken for the muscle fibre to contract after receiving the activating signal from the spinal cord and the time for the spindle to respond to the subsequent relaxation. The reflex time (for instance, that of the leg) is about 30 msec whilst the delay due to the developing twitch is characteristically about 150 msec (Lippold 1973). The frequency of tremor will thus not depend upon, to any appreciable extent, conduction time in the reflex arc. Thereupon, any changes altering the muscle delay should also affect the tremor frequency. Experiments on cooling, warming, loading, fatigue and prodding which change the twitch-time of muscle showed related changes of the tremor frequency. Thus, the delay in the muscle response dominates the overall delay in the reflex-arc. This implies that the extra-ocular tremor will have about the same frequency as tremor in the limb though their neural pathways are different. Experimental results conformed to this. It also explains why tremor in children is slower than in adults though the nerve conduction time is expected to be shorter in the former (their reflex arc is smaller in dimension). The answer is simply that twitch-time in children is appreciably prolonged. In fact, it shows some hint to our findings that those of our subjects with faster reaction times had on the average a higher tremor frequency and alpha frequency than the others.

When knee-jerk test which involves the knee-jerk reflex arc are applied to finger tremor recordings, no marked effect was observed. This is simply because that only the quadriceps muscle is effected when the tendon of the muscle is tapped firmly below the knee. It explains why tremor recorded at different parts of the body is different (no phase relationship). The muscle and muscle delay involved in producing the tremor are different.

2. oculomotor variables

It has been demonstrated that eye-open and eye-close conditions have no effect on finger tremor. This section is intended to find out whether other oculomotor varialbes affect tremor or not. The subjects were instructed to perform several types of eye movements including saccadic, vergence, smooth pursuit, comparatory and fixation either with eyes open or close during finger tremor recordings. The amplitude and regularity of tremor seemed to decrease slightly but no other changes were observed. On the whole, no marked changes resulted for all the subjects. The slight decrease in amplitude and regularity is probably due to the 'attention' of the subject towards the different eye movement tasks. The Bell's phenomenon that there is an increase in alpha activity immediately after eye closure was not observed in case of finger tremor. The 'ringing' effect of the flash-induced alpha waves did not hold for finger tremor too. The subjects were then instructed to force the eyes to extreme positions (upward and sideward) under eye-open and eye-close conditions, and when they were familiar with the procedures, finger tremors were recorded. The frequency spectra as well as the average amplitudes were found to be unchanged either with eyes open or eyes closed.

The effect of visual feedback was studied. Sutton and Sykes (1967) found that depriving a subject of visual information about the position of his limb abolished or greatly reduced the amplitude of the dominant peak in the frequency spectrum of physiological tremor. Merton, Morton and Rashbass (1967) with the same experimental arrangement as Sutton and Syke (subject holds a short, stiff, vertical joystick with the finger tips of his right hand and attempts to press to the left with a constant force which is recorded by a strain gauge and is made to deflect the spot of a cathode ray tube watched by the subject)confirmed that the peak frequency (they found to be 9Hz) is determined by visual feedback and hypothesized that the fundamental mode of oscillation (they expected to be 3 Hz) corresponds to an oscillatory tendency with π radians of phase shift round the visual feedback loop and the higher peaks (including the 9Hz peak) are separate modes of oscillation with 3π, 5π and 7π radians phase shift. Their finding is rather obscure and Dymott and Merton (1967) later in the year were able to produce good 9Hz peaks in runs with the eye shut by slightly altering the mechanical conditions of the task. The hypothesis that the 9Hz peaks are visually determined is doubted.

Their experimental arrangements were totally different from those employed in our investigations and it was therefore of considerable interest to know whether finger tremor recorded in our 'hanging' posture would be affected or not. We found that visual feedback has no effect or at least no marked effect on our finger tremor recordings. The dominant peak around 10 Hz were confirmed to be not visually determined. Thus the hypothesis that the dominant peak of frequency involves activity in the larger visual feedback loop seems unacceptable.

On the other hand, visual acuity appears to play a part in determing tremor levels. Lippold (1973) showed a strong association between resting normal tremor amplitudes, and visual defects, in a large group of students. In particular, he found hypermetropia to be associated with above-normal tremor amplitudes. He explained the result on the basis that hypermetropes are continually employing more than normal muscle tone to compensate for their disparity between accomodation, and convergence and that this tends to irradiate thus leading to an increase in tremor in many other irrelevant muscles.

3. mental tasks

Subjects were instructed to perform mental calculations of the product of two 2-digit numbers. A series of ten trials had been carried out for two subjects with control periods in-between during which they were instructed not to 'use' the brain and to relax. The mental calculation periods each lasted for about one minute whilst the control periods were ten minutes each to ensure a complete 'blank' state of mind. We found that during mental calculation periods, 'bundles' of tremor waves occured relatively more steadily. On the average, an amplitude decrease of 31.5% and a frequency increase of 9.67% accompanied mental calculations. The interval distribution plot shows similar profiles for the two periods except a peak shift from 90 msec wave interval to 80 msec and a sudden increase in the 60 msec wave interval during mental calculation (Fig. 3.9). The amplitude distribution plot shows a complete shift of the whole profile towards lower amplitude ranges and a submaximal peak at 1.6 mV during the mental task (Fig. 3.10). The maximal peak is also shwifted from 1.3 mV to 0.7 mV during the task. Finally the amplitude-duration relationships of the tremor waves during the two periods have different trends (Fig. 3.11).

We are not able to find any published works or literature on the effect of mental tasks on physiological tremor. What we obtained and presented here is simply an effect similar to that in case of the alpha rhythm and this effect can easily be repeated by any others with our arrangements. This similarity between physiological tremor and alpha rhythm (the effects of mental task on both phenomena) has not been noted hitherto .

4. Jendrassik's reinforcement

A simple maneuver called "Jendrassik's reinforcement" is known to produce a general enhancement of reflex action by way of activation of the muscle spindles' motor fibers. The mechanism is that an increase in the gamma tone to a muscle and hence an increase in gamma firing enhances the coupling between muscle spindles and extra-fusal fibers. Thereby the resultant afferent discharge with each tremor cycle is both increased and earlier in phase. This leads to tremor being enhanced and sometimes also raised in frequency (Lippold 1971). The manoeuvre consists in gripping one hand with the other and holding on while attempting to pull them apart. Applying this test, we obtained a most gratifying increase in the overall amplitude of physiological tremor. An average amplitude increase of 56.67% was found. The effect of the manoeuvre on tremor suggests that when any muscle is strongly contracted voluntarily, tremor in other muscle is at the same time increased. This is expected to be the effect of increased fusimotor outflow irradiating to other muscle groups. The result, which verifies that of Lippold, again supports the stretch-servo hypothesis.

We have already noted that tremor can be increased and we found that tremor can also be decreased as Lippold in 1971 suggested. The arm of a subject was rested in a splint to immobilize its muscles for several hours. A significant reduction in the amplitude of the tremor in that limb was observed. This may involve the same mechanism affected by a strong contraction, but this time in reverse. The period of inactivity may result in a decrease in fusimotor tone. Thus, it can be seen that tremor amplitudes can be increased or decreased by altering the fusimotor tone and thus the 'loop gain' of the stretch-servo. According to the servo-loop hypothesis, a large loop gain implies a greater amplitude and a small one implies a decreased amplitude.

5. Hyperventilation

Lindqvist (1941) found that the cortical potentials are slowed down in a marked degree during hyperventilation whereas finger tremor keeps its frequency unchanged. Thereafter, we found no literature or published works describing the effect of hyperventilation on physiological tremor except quoting this results. There seems to be no more query on the topic but we found that more works should be done. Firstly, Lindqvist's finding that cortical potentials are slowed down during hyperventilation is found to be untrue (section 2.6.6). No marked changes in the frequency of the alpha rhythm during hyperventilation as well as after continuous hyperventilation were observed. Secondly, his techniques of recording and equipments are crude as compared with nowadays. Experiments were carried out in a similar manner as described in section 2.6.6. We found that hyperventilation affects both phenomena roughly in a similar manner. An amplitude increase resulted with the frequency remaining roughly unchanged for both cases. This new discovery is in consensus with our supposition that the sudden increase in oxygen uptake and blood flow may be involved in the amplitude increase (Section 2.6.6) by increasing the gains of the stretch-reflexes.

6. muscle effects

When the subject clenched his hand with the clenching force recorded by an instrument (Model no. 76618, Lafayette Instrument Co.), we found that the finger tremor recorded from the other hand increased with increasing clenching force until maximum was reached. Amplitude increase could also by achieved by the act of pinching (Fig. 3.12) on the subjects' limbs. Similar muscular actions produced the same effect too. These are expected to be the effect of increased gamma tone to a muscle and hence an increase in fusimotor outflow irradiating to other muscle or muscle groups according to the stretch-servo hypothesis. The increase in the resultant afferent discharge with each tremor cycle (they are demonstrated to be in phase in section 3.7.1) leads to enhanced tremor.

7. Psychological variables

Psychological factors (anxiety, arousal, fear, angry and worry) seem to have no marked effects on finger tremor amplitudes and frequencies. The frequency spectra and amplitude distribution plots were found to be similar under different the psychological states. On the other hand, sudden stimuli, a sudden loud sound made by dropping some heavy equipments on the ground, caused sn instantaneous increase in tremor amplitudes. The effect only lasted for a few cycles (Fig. 3.13).

3.8 ALTERING LOOP PROPERTIES OF THE STRETCH-REFLEX SERVO-LOOP

Lippold (1971) verified the stretch-servo hypothesis by three experimental approaches:

1. opening or interrupting the servo-loop at a suitable point.

   If tremor originates in the stretch-reflex-arc, its abolition following cutting the reflex-arc at any point will serve as a decisive test.
2. changing the parameters and properties of the loop

   The overall delay (chiefly due to muscle) in the loop determines the tremor frequency whilst the gain of the loop determines the tremor amplitude. Experiments were designed to alter the loop delay as well as the loop gain.
3. introducing various inputs, such as step functions, into the loop.

   If the loop is in an underdamped condition, a step function perturbation introduced into the closed loop will bring the oscillations in the loop to be in predictable phase relation with the input step.

These are three excellent experimental approaches to alter the loop conditions of the stretch-servo in order to verify the stretch-servo hypothesis. We will follow these to verify Lippold's findings with our recording techniques and arrangements and with some extra or new experimental evidences.

1. opening or interrupting the servo-loop

(a) cutting the reflex-arc on the afferent side

If the reflex-arc is cut on the efferent side, all activities of the muscle simply abolish. Nevertheless, voluntary movement can still occur if only the afferent side is cut, but the feedback mechanism and hence damping of the movement is absent. It happens that certain patients are afflicted with an afferent interruption: tertiary syphilis of the central nervous system sometimes abolishes the conduction of impulses by the afferent nerve. Lippold (1971) found that these patients generally show no sign of the oscillation peak around 10 Hz when a muscle was stretched. Halliday and Redfearn (1958) working on patients suffering varying degrees of deafferentation due to tabes dorsalis found no 10 Hz rhythm and that this absence was clearly correlated with the degree of deafferentation. Lippold et al. (1959) also showed the abolition of the rhythmical tremor peak in anaesthetized cat by cutting the afferent nerve experimentally (Fig. 3.14). Their results are certainly very strong evidences in support of the stretch-servo hypothesis.

(b) applying sphygmomanometer cuff

A sphygmomanometer cuff inflated to above the systolic pressure leads to ischaemia when applied to the upper arm of the subject. This causes impairment of the sensitivity of the muscle spindles. According to the servo-loop hypothesis, this impairment and hence ischaemia should reduce the loop gain of the reflex-arc and even may reduce it to levels below that required to sustain oscillation. This effect of ischaemia on finger tremor was first studied by Halliday and Redfearn (1954). They found that a sphygmomanometer cuff, just above the elbow, inflated to between 150 and 200 mm Hg, led to the depression of the amplitude of tremor at all frequencies within about 1 to 2 min. In many of their subjects, tremor was abolished after 3 or 4 min. When the cuff was removed, tremor returned within about 1 min. and regains the control amplitude in usually less than 5 min. Lippold (1970a) confirmed their findings by inflating an arterial cuff on the upper arm. He found in addition that at the instant of inflation, a momentary increase of normal tremor amplitude usually occurred, presumably as a result of the readjustments in posture made by the subject. After 1 to 2 min., the tremor record showed a continual decline in amplitude but a small increase in frequency of the 8 - 12 Hz component. All frequencies of tremor appeared to be affected by ischaemia. He also concluded that the stretch-reflex threshold and the maximum force of a voluntary contraction are unaltered during the first 5 min. of ischaemia until ischaemic paralysis develops after then.

We found slightly different results from our own arrangements. The effects of ischaemia on finger tremor was studied by inflating a sphygmomanometer cuff at 200mm Hg on the subject's upper arm. At the moment of inflation a momentary increase of finger tremor frequency to about 12 Hz was observed (Fig. 2.25a) and was accompanied by a better synchrony as well as a momentary increase of abundance. This implies an instantaneous change of the loop gain and the overall loop delay at that particular moment and is expected to be effect of increased fusimotor outflow, due to any muscle strongly contracted voluntarily, irradiating to other muscle groups. The effect, however, is only momentarily. After two minutes of inflation, a marked decrease in amplitude, abundance as well as synchrony of the tremor resulted (fig 3.15). The amplitude distribution plot shows a marked amplitude decrease of 89.44% (from 2.71 to 0.286 mV) , that is, tremor after cuff inflated for 2 min. is only about one-tenth of that before cuff inflation. The peak in the plot shifts from 2.1 mV to 0.3 mV during ischaemia (Fig. 3.16) and the maximum amplitude decreased from 6 mV to 1.2 mV. The wave interval histogram of finger tremor during ischaemia with a peak at 80 msec is shown in Fig. 3.17. Similar profiles for both the control and cuff conditions are seen in the interval distribution plot

(Fig. 3.18). They both peak at 80 msec and their average frequency are 10.996 and 11.398 Hz respectively. There is a slight increase of 3.66% in frequency during ischaemia. The amplitude-duration relationships of finger tremor of the two conditions are shown in Fig. 3.19. Two distinctly different trneds are observed with the 'cuff' points (the asterisks) all falling to the bottom of the graph. The ischaemic tremor of the left index finger was also compared with the normal tremor recorded at the right index finger simultaneously. The duration-wave number plot of both tremors recorded simultaneously shows different trends (Fig. 3.20). The ischaemic tremor tends to fluctuate to a larger degree in the graph than the normal tremor and thus has a poorer synchrony (more dispersive in nature).

After the removal of the sphygmomanometer cuff for about one minute, tremor amplitude gradually increased but desynchrony and irregularities were present still (Fig. 2.25c). If on the other hand, a venous cuff of 70mm Hg is applied or the radial nerve just above the elbow is compressed, no reduction in tremor could be observed. It follows that the muscle spindles are likely to be implicated. Any impairment of the normal blood supply to a muscle resulted in its spindles giving a sustained high frequency discharge with a concomitant reduction in sensitivity to stretch (Matthews 1933). Lippold, Nicholls and Redfearn (1960) lent support to the views that cessation of the circulation to a muscle spindle will almost abolish its response to stretch. Thus, it can be concluded that:

(i) the overall delay in the servo-loop and thus the frequency is roughly unaffected by ischaemia (only 3.66% increase),

(ii) tremor is not reduced by venous cuff and nerve block' but greatly diminished to only one-tenth of normal by arterial cuff.

(iii) the effect of ischaemia on finger tremor is equivalent to changing the loop gain of the stretch-servo by rendering the muscle spindles insensitive to stretching.

2. changing the parameters and properties of the loop

a. altering the overall delay in the servo-loop

Lippold et al. (1957b) first studied the effect of cooling a muscle by flowing cold water through a bin while the subject stands upright with his leg immersed wholly in the bin and recording tremor of the limb simultaneously with the electromyogram (EMG) for the determination of twitch times (see Fig. 1 of their paper). They found that cooling the muscle slowed the tremor while warming it or stretching it in certain circumstances, increased the frequency. They ascribed these effects to alterations in the physical properties of the muscle changing the interval between an external or internal disturbance and the reflex response to it. They also found that the frequency of the action potentials bursts progressively decreases on cooling the muscle concomitantly with the mechanical record of tremor.

We repeated their experiments with the set-up shown in Fig. 3.3b and obtained similar results. Cooling the leg caused a reduction in both tremor frequency and amplitude and progressively less rhythmical bursts of action potentials. In view of the fact that cooling lengthens the twitch time very considerably without greatly altering the reflex time, this additional delay in the muscle between arrival of motor nerve impulses and excitation of muscle stretch receptors set up by the lengthening again of the muscle after its twitch must be largely mechanical in origin. The fact that the muscle twitch-time largely determines the frequency of tremor is verified in the case of human leg.

But what will happen in the case of finger tremor? No literature on the topic has been found hitherto. We designed a set-up which can measure finger tremor in the 'hanging' posture with the dynamic mike and with the forearm wholly immersed in flowing water at the desired temperature (Fig. 3.3a). A bath and circulator was used to provide a circulation of water at temperatures from 0° to 50°. Finger tremor was recorded at the left and right index finger under three conditions: cold (10°C), hot (47°C) and room temperature (26°C). A series of experiments were done and the average of the results taken.

The activity time -- frequency plot (activity time here designates that of a particular frequency in sec, see section 4.3.3) displays obvious differences in characteristics between the three conditions (Fig. 3.21).

The 'cold' characteristic showed 6 peaks at 4.17, 5, 6.25, 8.33, 10 and 12.5Hz with the dominant one at 8.33Hz. The 'hot' characteristic showed, on the other hand, a mono-peak at 12.5Hz only. The normal characteristic (room temperature) had 3 peaks at 8.33, 10 and 12.5Hz with the peak at 12.5 Hz dominating. It is obvious that the dominant peak shifted from 12.5Hz (normal and hot condition) to 8.33Hz under the cold condition and that the condition is characterised by multi-peak and low frequency. The hot condition is characterised by mono-peak and a shift to high frequencies from the normal condition.

Distinct characteristics are also observed for the three conditions in the amplitude distribution plot (Fig. 3.22). The characteristic of the cold condition peaks at 2.1 mV. The normal and 'hot' characteristics resemble very much but the cold one is obviously shifted to the lower amplitudes. Nevertheless, the normal one is double-peaked (2.1 mV, 3.6 mV) whereas the hot one is only mono-peaked.

The frequency and amplitude of finger tremor under the three conditions are tabulated in Fig. 3.23. The percentage are compared with the room temperature values.

	ROOM TEMP (26° C)	HOT (47° C)	COLD (10°C)
FREQ(HZ)	11.0	12.66 (15.1%)	8.08 (26.55%)
AMP(mV)	2.71	2.53 (6.62%)	1.03 (62.02%)

Fig. 3.23 Temperature effects on finger tremor

The activity time - duration histograms of finger tremor under the three conditions are shown in Fig. 3.24 a, b, c. Their characteristics are clearly defined. The amplitude-duration relationship of tremor waves of the three temperatures are shown in Fig. 3.25 and Fig. 3.26. Fig. 3.25 shows the relationship of the tremor waves simultaneously recorded at the left index finger immersed in room temperature water and at the right index finger immersed in 10°C water. Two distinct trends can be seen with the points recorded at 10°C spreading towards larger intervals. The arrangement was then reversed with the left forearm immersed in 10°C water and the right one immersed in 47°C water. Similar results are again obtained (Fig. 3.26). As compared with the tremor waves at 47°C, there is an amplitude decrease of 59.33% and a frequency decrease of 36.18% in those recorded at 10°C.

After the left forearm left the 10°C water and immersed in 26°C water, both the frequency and amplitude of the tremor waves gradually recover to normal in about 5min (Fig. 3.27). It is interesting to note that they both increase in the same manner and same proportion.

The results of temperature effects on finger tremor presented here are in support of the servo-loop hypothesis. Cooling on lengthening the muscle twitch-time lowers tremor frequency by 26.55% and warming on shortening the twitch-time increases tremor frequency by 15.1%. These results can hardly be interpreted by any other hypotheses.

b. altering the loop gain or the system's sensitivity

Just as the tremor frequency could be changed by altering the delay interval, the tremor amplitude could also be changed by modifying the system's sensitivity or the loop gain. The signal generating muscle spindles offered an opportunity for such modification. Any manoeuvre activating the fusimotor nerve fibres innervating the spindles should increase their firing rates and hence enhance the sensitivity of the entire reflex arc. The enhancement of tremor amplitude by the Jendrassik's manoeuvre (section 3.7.4) and other muscular effects (section 3.7.6) serves as a proof.

Muscle action potentials during voluntary activity show a tendency towards grouping of action potentials. Lippold et al. (1957b) showed that this tendency is increased by local fatigue, by extension of the muscle either passively or during its active contraction, and by previously voluntary contraction. Fatigue of a single muscle or the whole body was found to increase tremor amplitude accompanied by a slight increase in frequency (Lippold, Redfearn and Vuco 1960).

We obtained similar results by recording finger tremor in the 'hanging' posture in subjects before and after several hours of continuous exercise. This is expected to be due to increased fusimotor activation during fatigue as in the case of Jendrassik's manoeuvre.

The effect of load and force on finger tremor again supported the hypothesis. Several investigators have, with different results, studied the effect. Bishop, Clare, and Price (1948) and Robson (1962) studied forearm clonus in man with the addition of mass and found little or no change in the frequency. Perkins(1945) found that increasing the moment of inertia of either the semitendinous or the quadriceps muscle of a shivering cat consistently decreased the frequency of shivering. Halliday and Redfearn (1956) showed little or no change in the 9Hz finger tremor frequency recorded from 46 normal people with loads of 50 and 100 g. However, their frequency spectra did not include frequencies below 5Hz and above 15Hz. Marshall and Walsh (1956) reported little or no change in the 8-12 Hz band of hand tremor upon increasing the moment of inertia whilst Hamoen (1962) reported a decrease. Randall and Stiles (1964) found no change in the 9Hz peak of finger tremor with added mass, but did report finding a reduction of the 15 to 30Hz band with increments of 5 g. Stiles and Randall (1967) reported that adding mass to the whole hand lowered the frequency of the 9Hz spectral peak and that the relationship between tremor frequency and added mass was consistent with that for a second-order underdamped system. Joyce and Rack (1971a) reported that during voluntary flexion of the arm against a spring the spontaneous tremor that occured changed in both frequency and amplitude with changing spring stiffness. They (1971b) found also that the frequency and amplitude of tremor were changed when the subject exerted a constant force against a series of different springs and concluded that if this tremor is a product of stretch reflex activity, then the gain of the reflex probably increases with increasing muscle force. Joyce and Rack (1974) confirmed that the filtering function of the limb with its stretch reflex probably plays an important part in the control of normal movement and tremor.

Our results come out to be quite similar to those of Joyce and Rack out of the so many but we worked on finger tremor instead of elbow tremor. We studied the effect of force on finger tremor with the set-up shown in Fig. 3.4. Different masses were added to the pulley system which exerted a corresponding force tending to pull the finger away from the diaphragm of the dynamic mike. The subject was instructed to maintain the 'hanging' posture while the finger tremor from the left and right index fingers were recorded.. Any possible loops of visual feedback was avoided by instructing the subject to look ahead during the experiment. Joyce and Rack(1974) had to employ visual feedback for the subject to maintain a constant flexing force against a spring and this may alter the tremor characteristics. In fact, they were troubled with a steady growth in tremor which could be as much as 2 to 3 times larger at the end than at the beginning of a 20 sec period. This is forbidden in our recordings. A two minute interval was allowed for the subject to relax between each change of force, up to eleven such records at different forces were made in one session. The experiment was repeated on different days. a 20sec epoch of each recording at different forces was analysed.

The result is shown in Fig. 3.28. With the increase of the force applied to the finger, we found that the tremor amplitude attained a roughly monotonic increase to reach a maximum amplitude at a force of 0.45N. The tremor also became more regular and synchronous as the force increased. An average increase of $1.313A_o$/Kgf was obtained where A_o is the average amplitude at zero load and equals 1.22mV. Contradicting to some of the published works, the frequency was also found to change as the force changed. In fact, the frequency altered in a rather puzzling manner. It can be seen in Fig. 3.28 that the frequency increased roughly in a zig-zag way, with the first peak at 0.1N and a second peak at 0.45N while the first minima occurred at 0.05N and the second at 0.3N. Rack (personal communications, 1977) suggested that this complicated result we obtained is probably due to the fact that increasing muscle force will be associated with an increase in stiffness which would tend to increase the natural frequency of the system while the added inertia would tend to decrease it. A combination of these effects may result in the zig-zag curve in our recordings. We think a more probable explanation would be that it is not the stiffness of the mechanical system in the limb but the timing of the stretch reflex that is responsible for the frequency change. Evidence is gained from the findings that patients with Parkinson's disease in whom there is rhythmical activity at 3 to 5 Hz exhibit a tremor at this frequency eventhough the limbs are loaded in such a way that gives them a higher natural frequency of oscillation (Joyce and Rack 1974).

The increase in tremor with increasing force can be explained on the basis that loading increases the gamma excitation to the muscle spindle and hence enhances the sensitivity or the loop gain of the stretch-reflex. The result is again in support of the stretch-servo hypothesis.

3. introducing various inputs into the loop

Some investigators concluded that physiological tremor is a ballistocardiographic effect (Van Buskirk and Fink 1962; Brumlik 1962; Brumlik et 1964; Wachs 1964; Yap and Boshes 1967). Nevertheless, the data in support of the ballistocardiographic origin do not appear conclusive. Tremor recordings of the same subject at different heart rates did not show corresponding changes. In addition, arterial cuff inflated above the systolic pressure (the heart pulse is excluded) did not abolish tremor for a certain time. On the other hand, we did find the heart pulse superimposed on tremor recordings by tying the finger with a string in such a way that the heart pulse can be strongly felt. This is in fact due to the introduction of a mechanical stimulus into the servo-loop.

The introduction of a step perturbation into the loop can be achieved by means of a mechanical prod. Lippold (1970a, 1971) had done a thorough and complete study on the topic and we found no extra result other than his findings. we succeeded in verifying his results with our own arrangements. The results can be summarised as follows.

Tremor waves could be induced by prodding(2mm. 30msec) and were phase-locked to the mechanical impulse in an underdamped servomechanism (indicated in averaged recordings). The prod-induced tremor waves lasting for a few cycles had larger amplitudes but same frequency as compared with the normal ones. They can be theoretically either mechanical or neurological in origin. Simple experiments showed that they are nerve-generated. Warming or cooling the muscle or applying an arterial cuff inflated to well above the systolic pressure produced the same results on prod-induced tremor waves as the normal ones. Bursts of action potentials were phase-locked to the prod-induced oscillations as they did in normal physiological tremor waves. It is also interesting to note that the amplitude of the prod-induced waves tended to increase after 3 to 4 cycles and then gradually decreased to normal after a few more cycles, indicating that energy was somehow being fed into the system and thus giving further support to the idea that the prodding initiated a process involving nerve activity. These results yield further support to the servo-loop hypothesis. Moreover, when the prods were applied in phase with the tremor waves, tremor was enhanced and when applied out of phase, tremor was suppressed for a few cycles (Fig. 3.29).

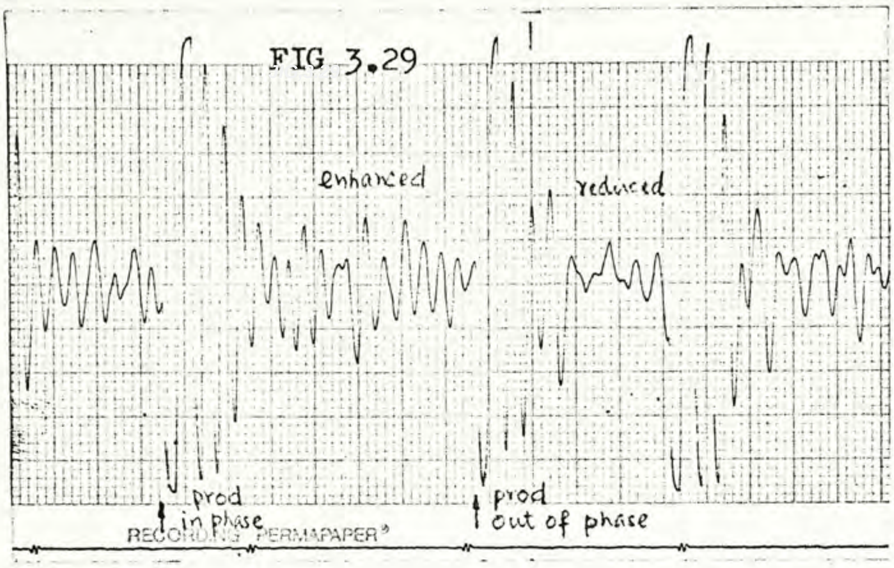


FIG 3.29

Fig. 3.29 The reduction of tremor with an out-of-phase prod and enhancement with a prod in phase with the tremor waves during a random-prodding experiment. Time mark appeared every second.

3.9 CONCLUSION

The stretch-servo hypothesis is verified experimentally. The results can be summarised as follows:

1. Finger tremor was recorded by a new transducer and a new posture. The excellence and reliability of the new arrangement were fully appreciated.

2. Tremor is not a 'local' phenomenon but oscillation accompanying voluntary muscular contractions. It peaks at 10Hz and 1Hz with the former dominating. It waxes and waves due to the 'hunting' phenomenon of the stretch-reflex arc. Bursts of action potentials were phase-locked to the tremor waves.

3. Various oculomotor variables had no effect on finger tremor except visual acuity.

4. Mental tasks diminished tremor with a slight increase in frequency.

5. Jendrassik's reinforcement and other muscular manoeuvres enhanced tremor and sometimes increased its frequency. This suggests that any muscle strongly contracted voluntarily increases fusimotor outflow irradiating to other muscle spindles and hence enhances tremor.

6. An amplitude increase with frequency roughly unchanged occurred during hyperventilation and after continuous hyperventilation.

7. Psychological variables had no marked effects on tremor.

8. Cutting the reflex-arc on the afferent side abolished or greatly reduced tremor.

9. The overall delay, chiefly due to the muscle twitch-time and not the reflex time, in the stretch-reflex servo-loop determines the tremor frequency whilst the system's sensitivity or the loop gain determines the tremor amplitude.

10. A sphygmomanometer cuff, inflated to well above the systolic pressure (200mm Hg) and cutting off the blood supply to muscle, greatly reduced tremor. The frequency is roughly unchanged since the overall loop delay is not significantly affected. Venous cuff and nerve 'block' did not reduce tremor. The effect of ischaemia is that loop gain is altered by rendering muscle spindles insensitive to stretching.

11. Cooling the limb lowered tremor frequency whilst warming the limb raised the frequency. This happens because the muscle twitch-time was lengthened on cooling, and shortened on warming. The amplitude was also greatly reduced on

cooling and only slightly decreased on warming. The effects were demonstrated for both the leg and the hand.

12. Fatigue of muscle enhanced physiological tremor with a slight increase in frequency.

13. Tremor increased monotonically as the force applied to the finger was increased until a maximum was reached at 0.45N. The rate of increase was $1.515A_0$/Kgf, (A_0 = 1.22 mV, amplitude at no load). The frequency increased in a zig-zag manner, peaking at 0.1N and 0.45N.

14. Prod-induced tremor waves are nerve-generated. They were affected similarly by warming or cooling the muscle or applying an arterial cuff as in the case of normal physiological tremor. Bursts of action potentials were also phase-locked to the prod-induced oscillations. In-phase prods enhanced tremor whereas out of phase prods suppressed tremor. The prod-induced tremor was phase-locked to the mechanical input and hence represented oscillations in an underdamped servomechanism.

In light of the experimental results obtained, we would like to consider the possibility of other published hypotheses:

(a) local phenomenon of the muscle?

Marshall and Walsh (1956) and Marshall (1959) viewed muscles as a band-pass filter that blocked the high frequency neural discharges and converted those below the tetonic fusion frequency (around 15Hz) to mechanical ripples. Objection to the servo-loop theory was raised because of the lack of parallelism between tremor frequency and spinal reflex latency. We have demonstrated that it is the muscle twitch-time instead of the spinal reflex latency that dominates the overall loop delay and hence determines the tremor frequency. Hence, a lack of parallelism is expected. Secondly, factors affecting the tetanic fusion frequency, for instance, fatigue that lowers it much, should also alter tremor frequency. Fatigue does not slow tremor. In fact, it raises the frequency slightly and enhances tremor considerably. Thirdly, their hypothesis cannot explain the phase-locking between action potential bursts and tremor waves or the prod-induced oscillations. Fourthly, stimulation of a muscle through its nerve at increasing frequency showed progressive smoothing of the response without any increase in the 10Hz tremor (Lippold at el. 1957). Lastly, patients suffering from Parkinsonism in whom there is rhythmical activity at 3 to 5 Hz exhibit a tremor at this frequency eventhough the limbs are loaded in such a way that gives them a higher natural frequency of oscillation (Joyce and Rack 1974). Hence the band-pass filter hypothesis seems implausible. Any other hypotheses concerning purely muscular mechanisms must also be able to explain the above point.

(b) cerebral origin?

Struck by the striking similarity between alpha waves and physiological tremor, Jasper and Andrews (1938) propounded the hypothesis that tremors are originated in the electrical activities of the brain. The two phenomena tend to have the same frequency in individuals and similar waveforms showing the waxing and waning property. They change similarly with age, development, alerting responses, sleep and anaesthesia and are similar in patients suffering from Parkinson's disease. Nevertheless, oculomotor variables had no effects on tremor while influencing alpha waves significantly. The two phenomena are to no extent similar when eyes are open. No phasic relationships between them can be found anyway. Prodding and inflating a sphygmomanometer cuff had no effects on alpha waves while affecting tremor considerably. Hence, the two phenomena are actually two independent ones. Consequently the hypothesis had to be abandoned. Furthermore the evoked tremor around 10Hz, in experimental animals with the peripheral end of the spinal cord cut, by stimulating the cut end electrically at a wide range of frequencies, exclude the possibilities of a feedback loop incorporating the motor cortex or subcortical motor systems. The effects of warming or cooling the muscle or cutting off the blood supply to it also prove the cerebral origin unlikely.

(c) spinal origin?

The excluding of the cerebral origin and that physiological tremor is nerve-generated suggest a simple and attractive hypothesis that tremor may be originated by the spinal cord. A group of investigators favoured the hypothesis that the grouped discharges underlying the tremor beats were the result of chance synchronization of independently firing motoneurones (Fulton and Liddell 1925; Gordon and Holbourn 1949; Taylor 1962; Dietz 1976). The hypothesis, though attractive, can hardly explain the frequency changes brought about by warming and cooling the muscle unless some rather curious afferent, temperature sensing pathway from it to the motoneurone pool was found. Furthermore a different hypothetical pathway would have to exist, this time proprioceptive in nature, in order to explain for the prod-induced tremor waves. Moreover, the different effects of the arterial and venous cuff could also be hardly explained.

Conclusively speaking, no better explanation can be put forth to the results found than the stretch-servo hypothesis. The hypothesis is well supported by the experimental studies discussed in this chapter. Having settled the problem on the origin of physiological tremor, which would mean the same origin for the extra-ocular muscle or eye tremor, we then proceed to the comparative and correlative studies of alpha waves and eye tremor recorded simultaneously in the hope that they can be shown to vary in the same way under all circumstances.

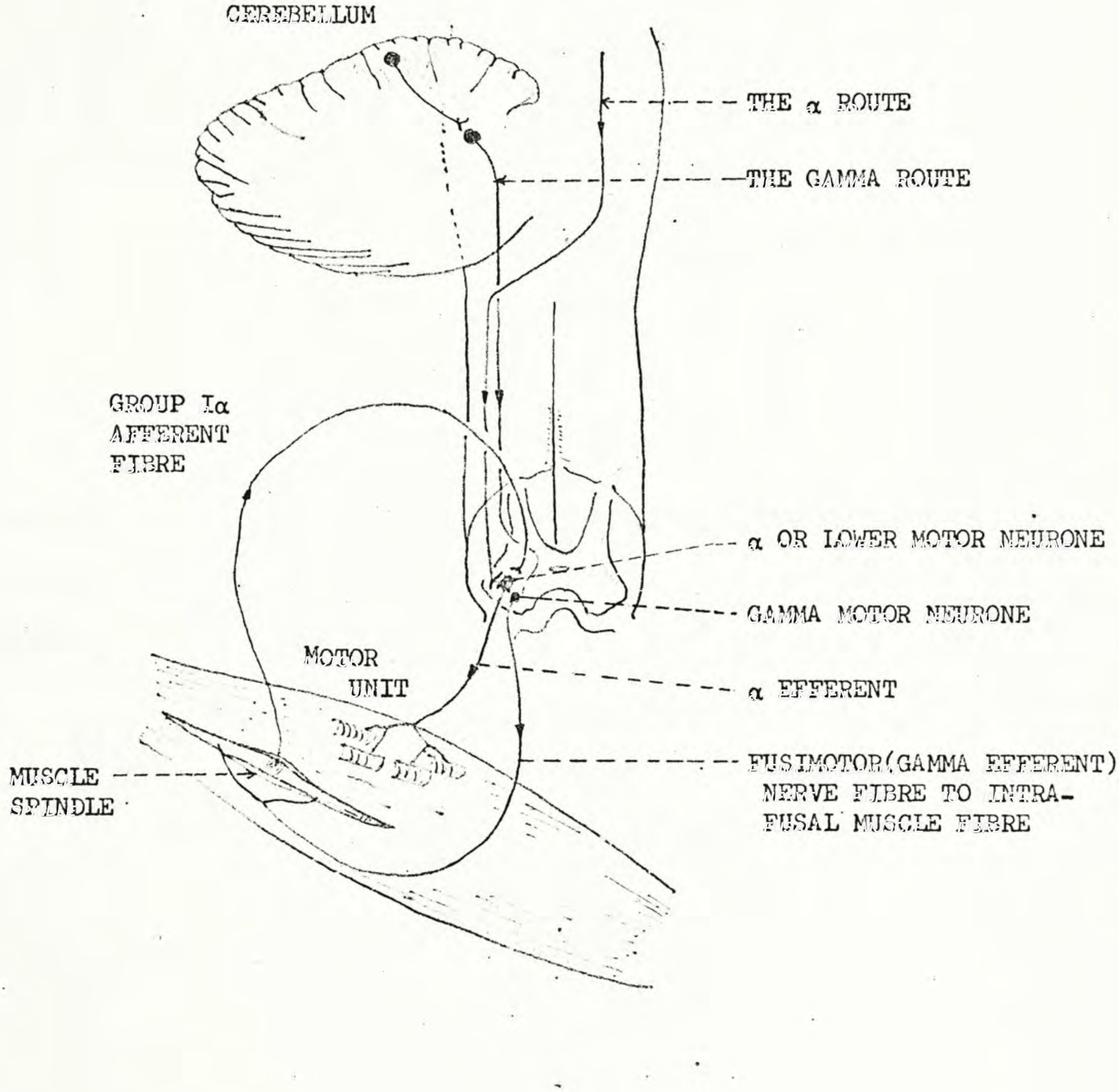


FIG 3.1 THE CONTROL OF VOLUNTARY MUSCLE MOVEMENT.

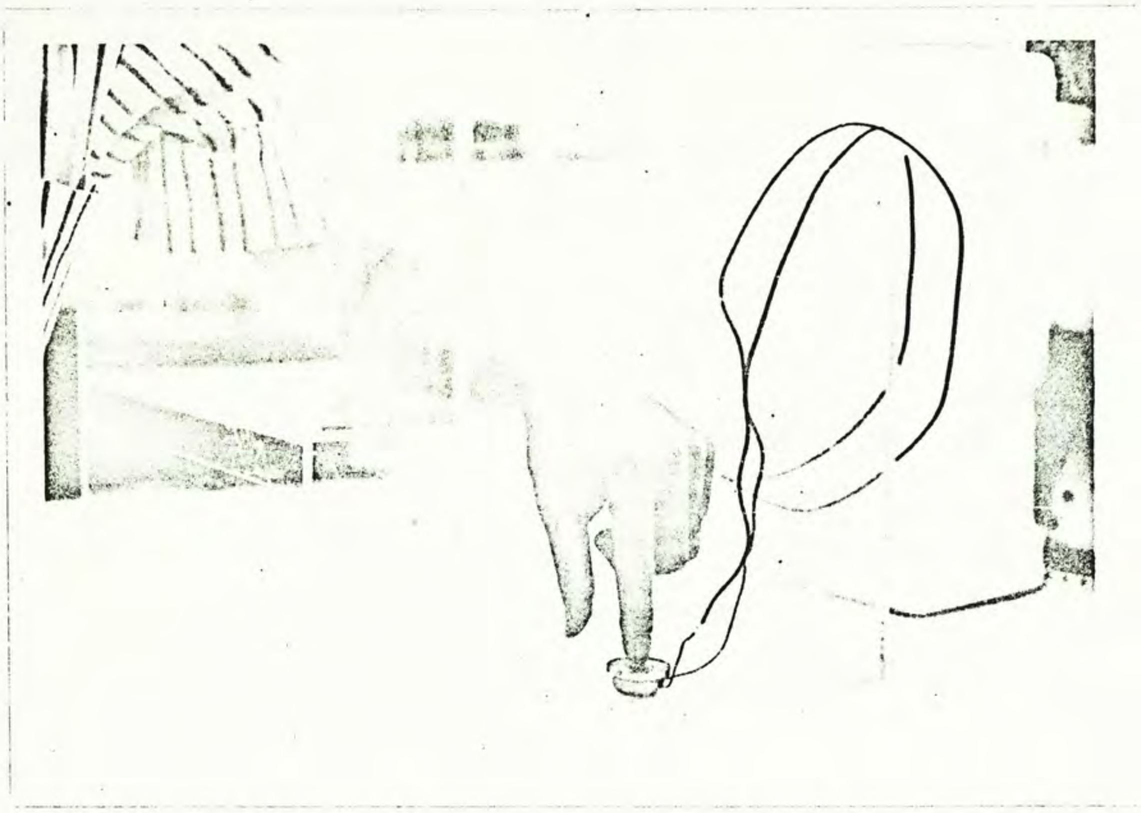


FIG 3.2 and 3.3a THE 'HANGING' POSTURE FOR THE RECORDING OF FINGER TREMOR . FOR THE STUDY OF TEMPERATURE EFFECTS, COLD AND HOT WATER IS CIRCULATED IN THE SET-UP

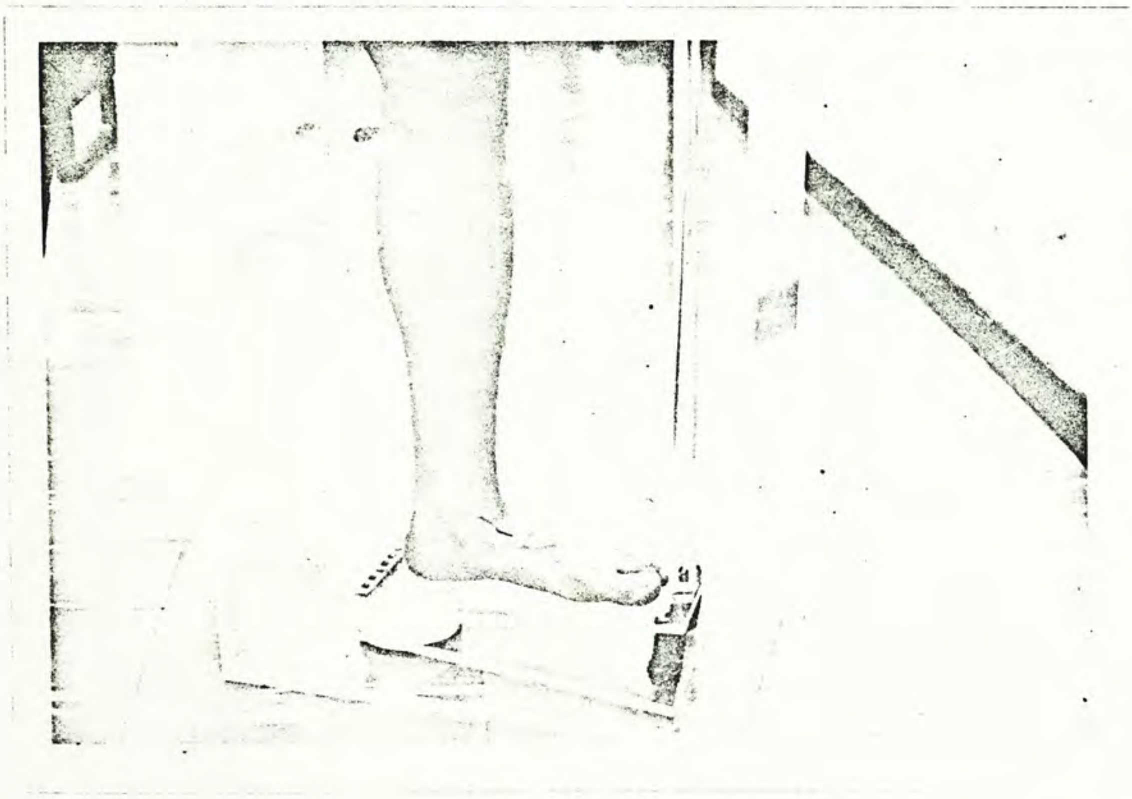


FIG 3.3b THE RECORDINGS OF TREMOR FROM THE FOOT IN COLD AND HOT WATER.

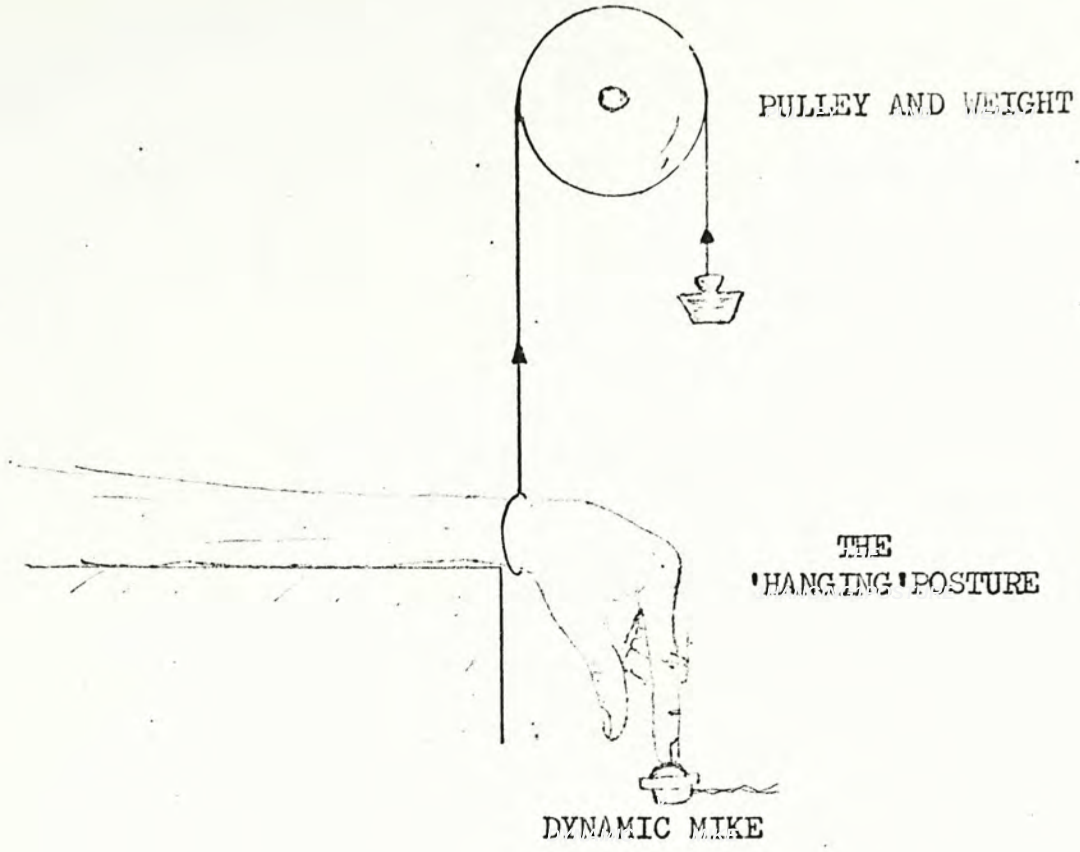


FIG 3.4 THE SET-UP TO STUDY THE EFFECT OF FORCE ON FINGER TREMOR.

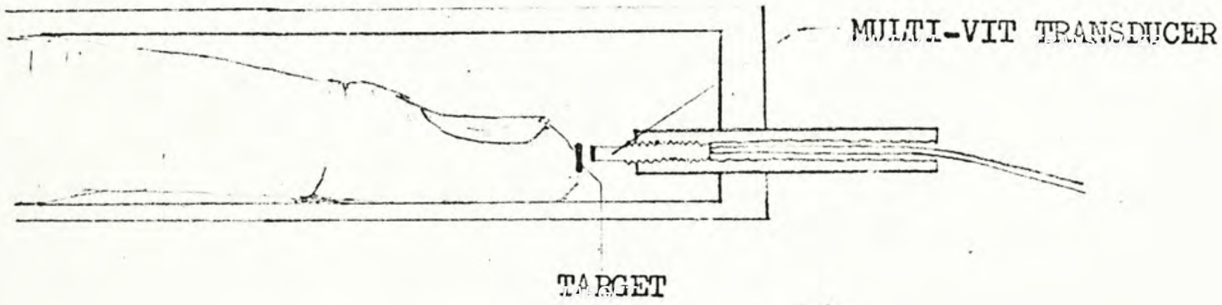


FIG 3.5 THE MULTI-VIT SET-UP FOR THE TEST OF THE LOCAL EFFECT.

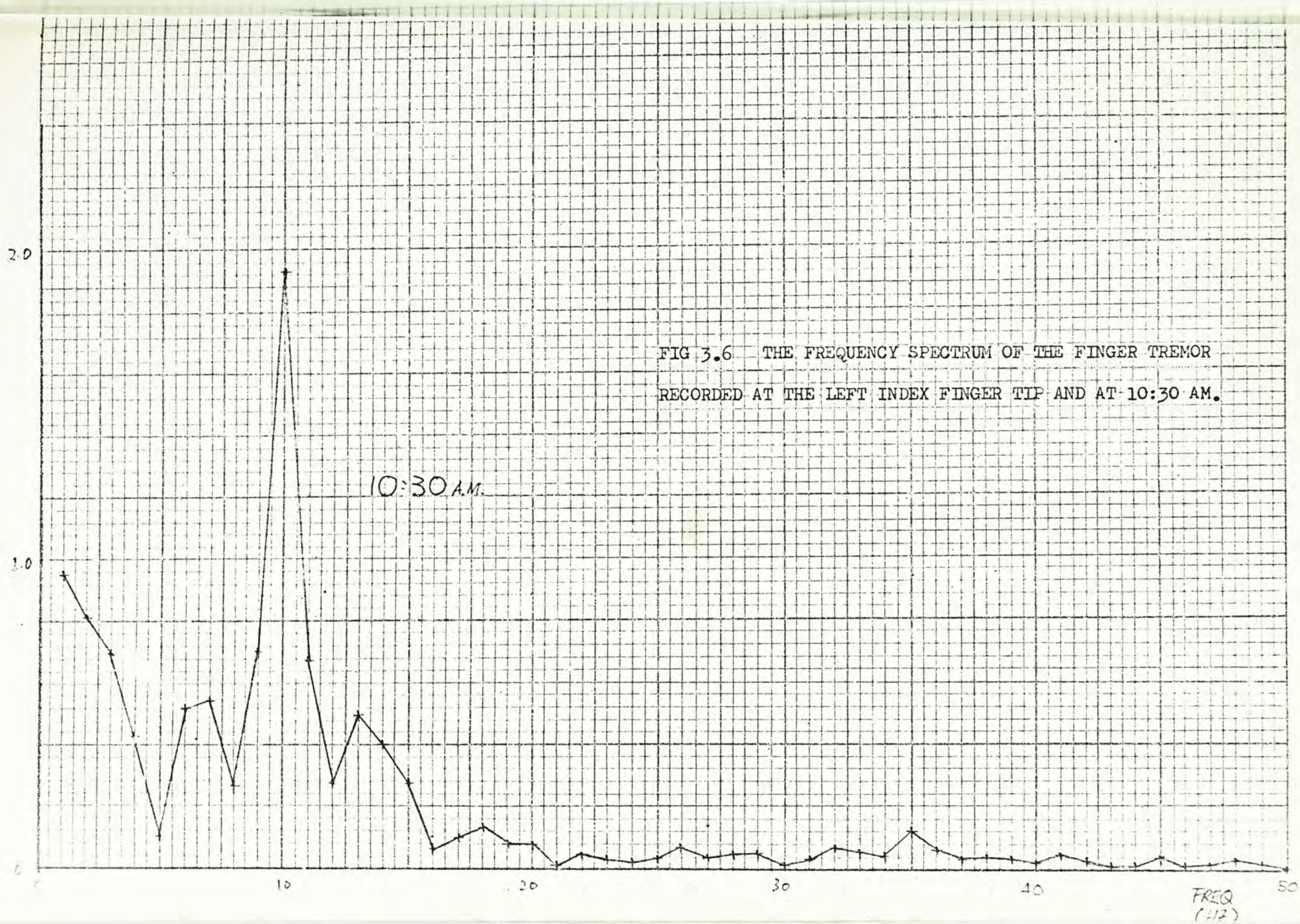


FIG 3.6 THE FREQUENCY SPECTRUM OF THE FINGER TREMOR RECORDED AT THE LEFT INDEX FINGER TIP AND AT 10:30 AM.

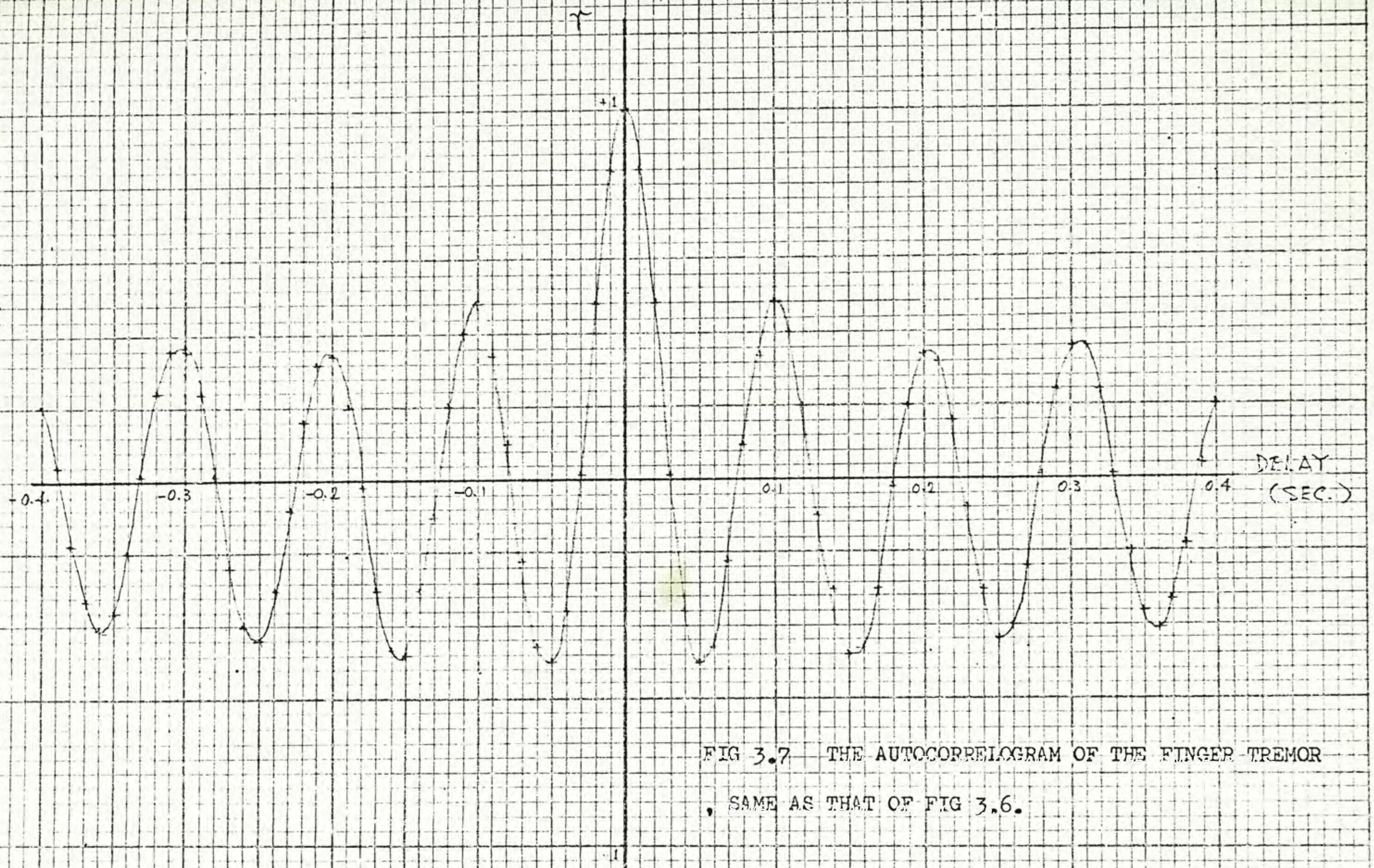


FIG 3.7 THE AUTOCORRELOGRAM OF THE FINGER TREMOR , SAME AS THAT OF FIG 3.6.

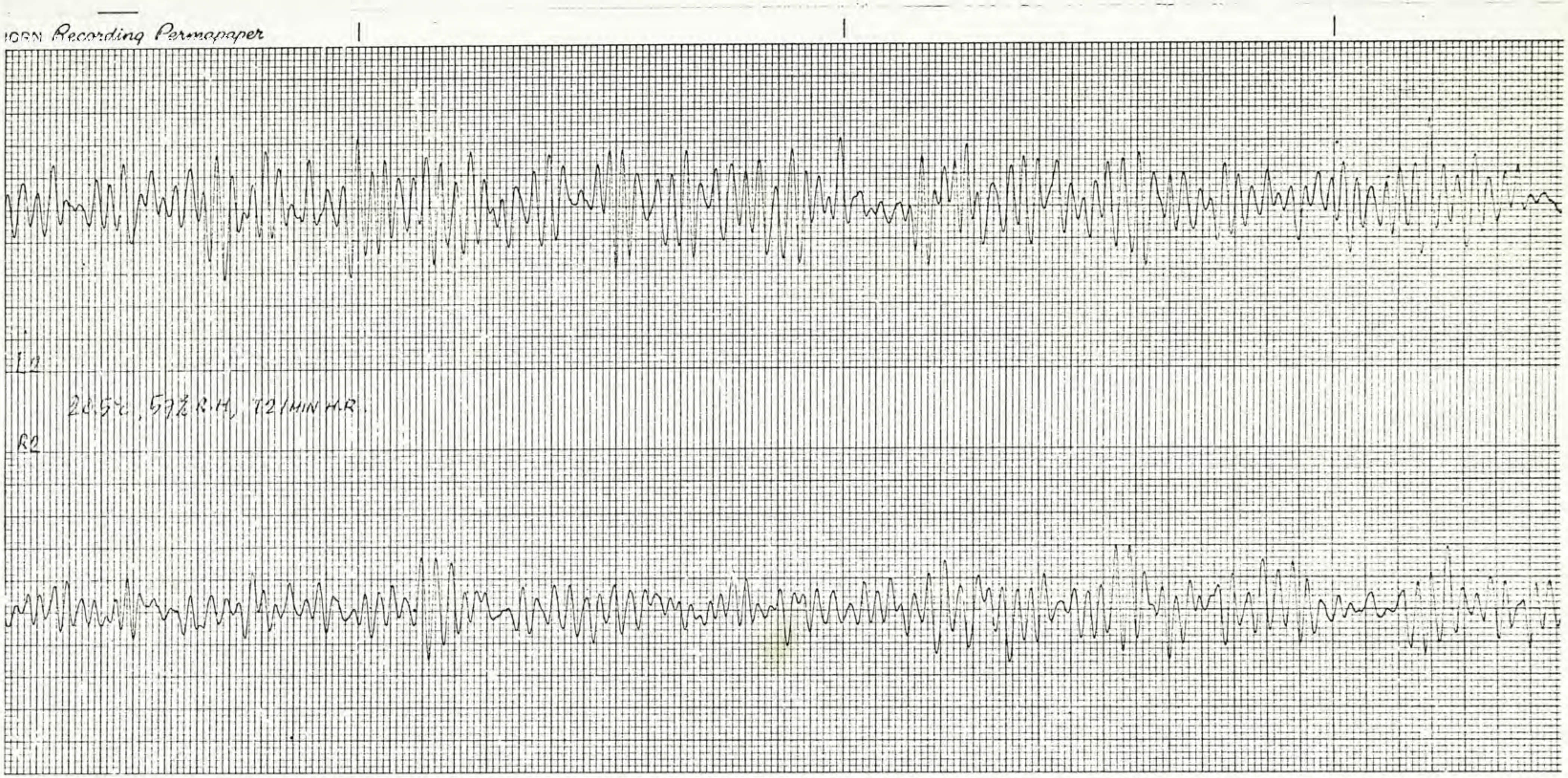


FIG 3.8 FINGER TREMOR RECORDED AT THE LEFT INDEX (UPPER CHANNEL) AND RIGHT INDEX (LOWER CHAN.) FINGERS SIMULTANEOUSLY. DYNAMIC MIKE AND THE 'HANGING' POSTURE WERE EMPLOYED.

5 LARGE SQUARE = 1 SEC.

FIG 3.9 THE INTERVAL DISTRIBUTION PLOT OF THE CONTROL PERIODS AND THE MENTAL CALCULATION PERIODS.

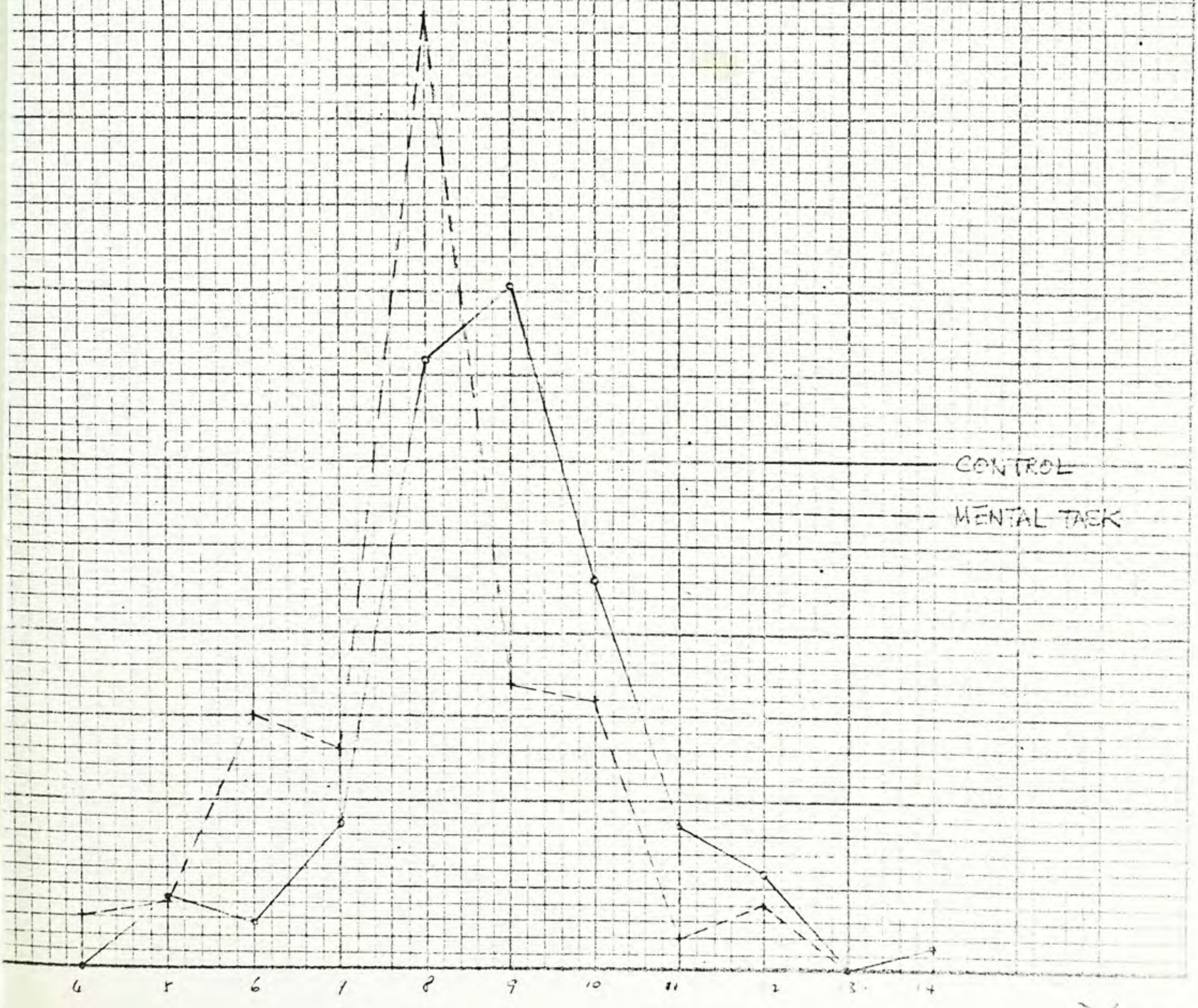


FIG 3.10 THE AMPLITUDE DISTRIBUTION PLOT OF THE CONTROL PERIODS AND THE MENTAL CALCULATION PERIODS.

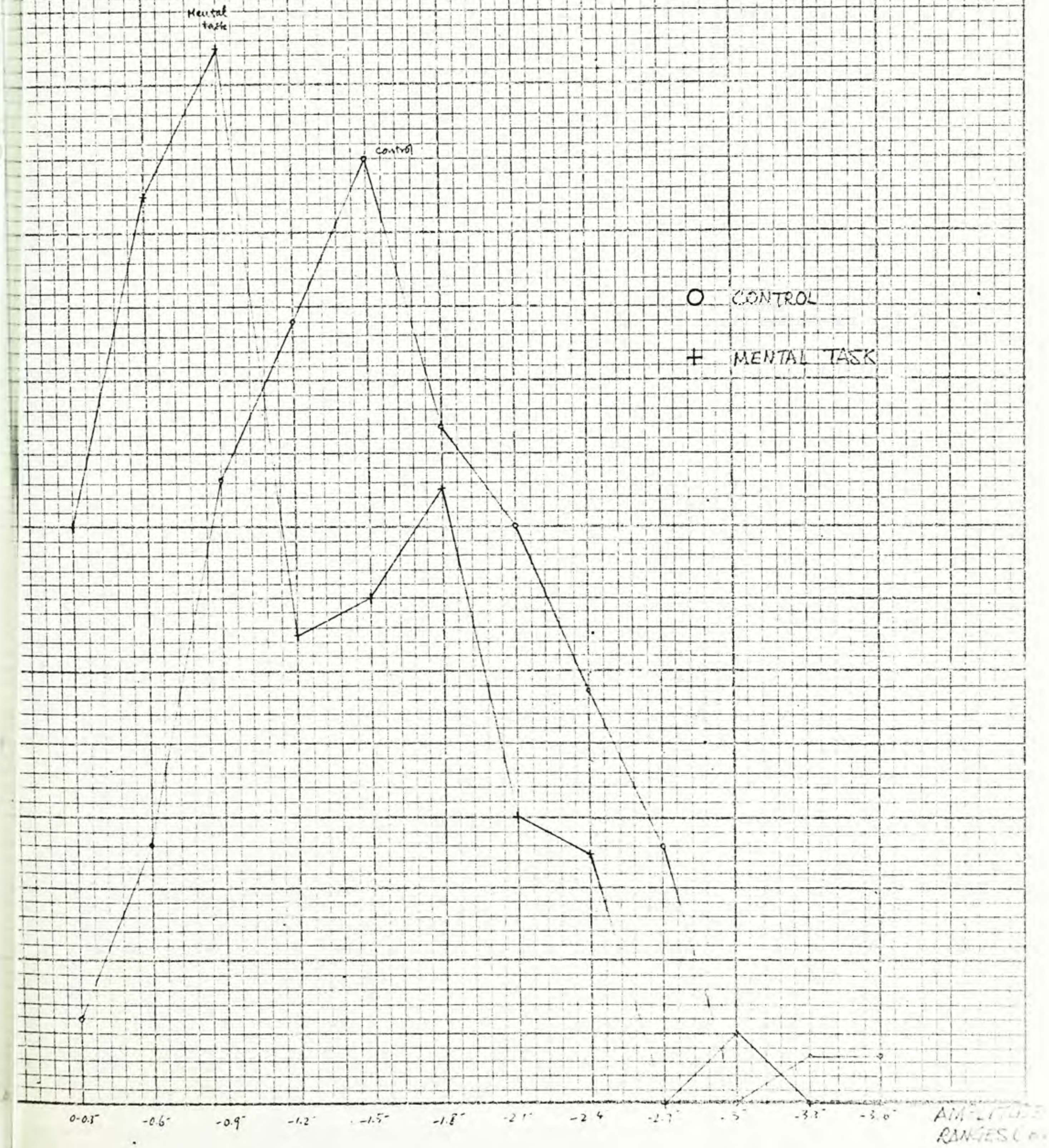
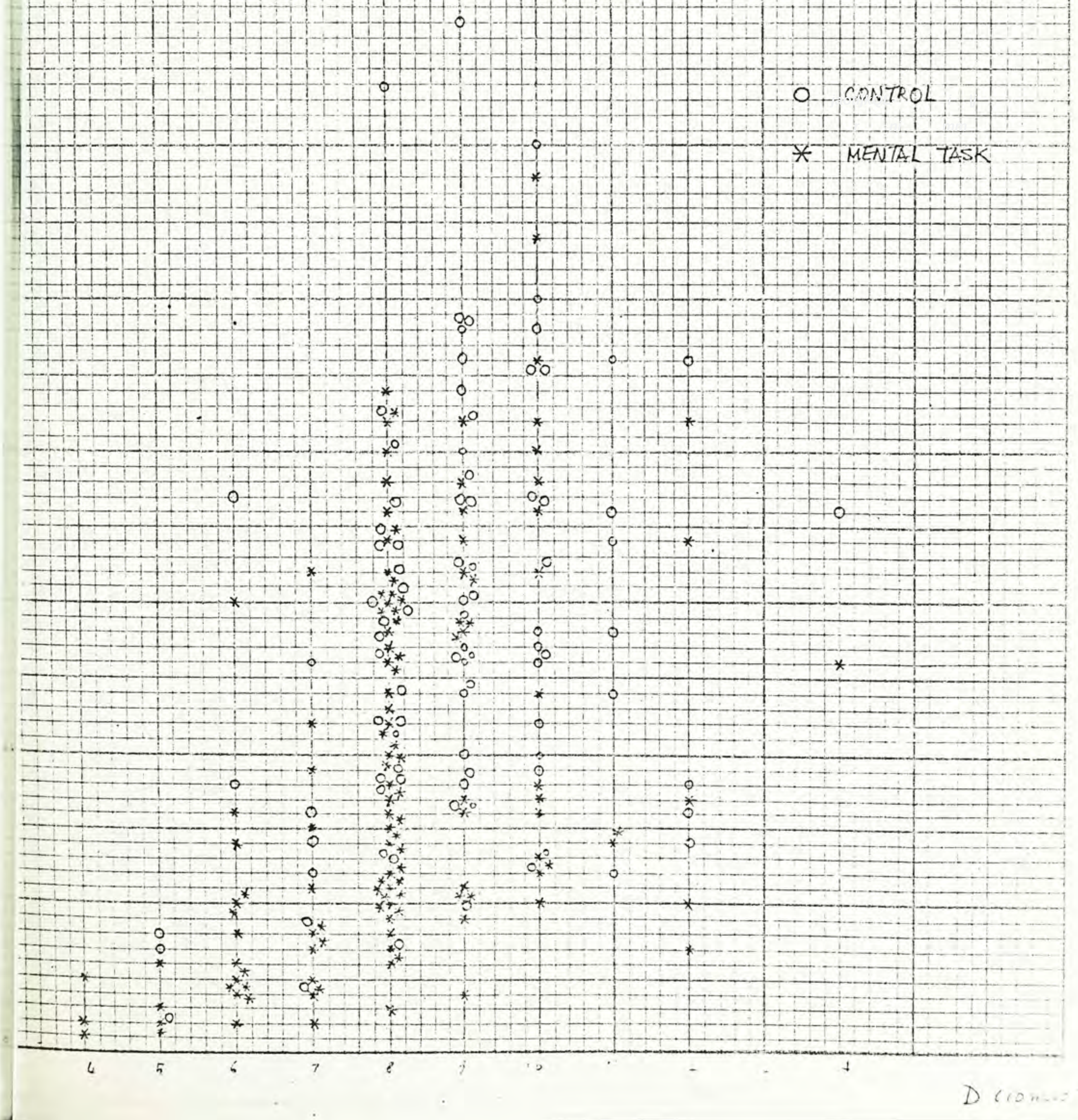


FIG 3.11 THE AMPLITUDE-DURATION PLOT OF THE CONTROL PERIODS AND THE MENTAL CALCULATION PERIODS.



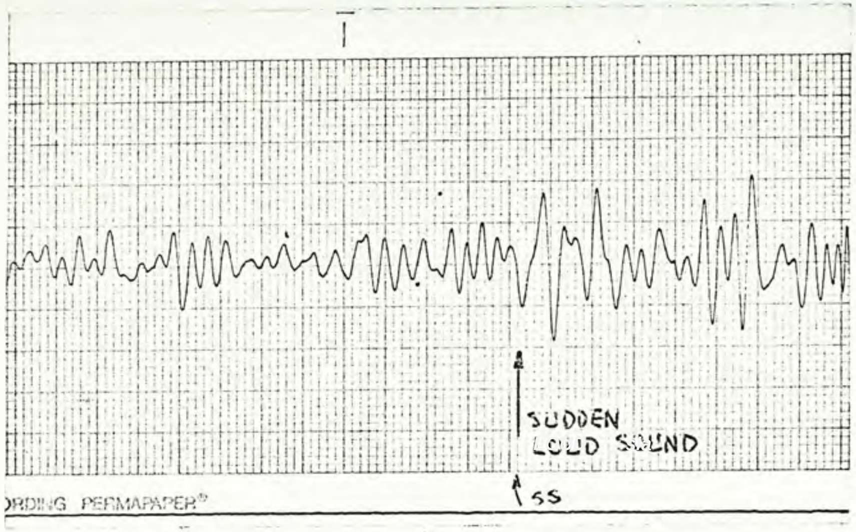
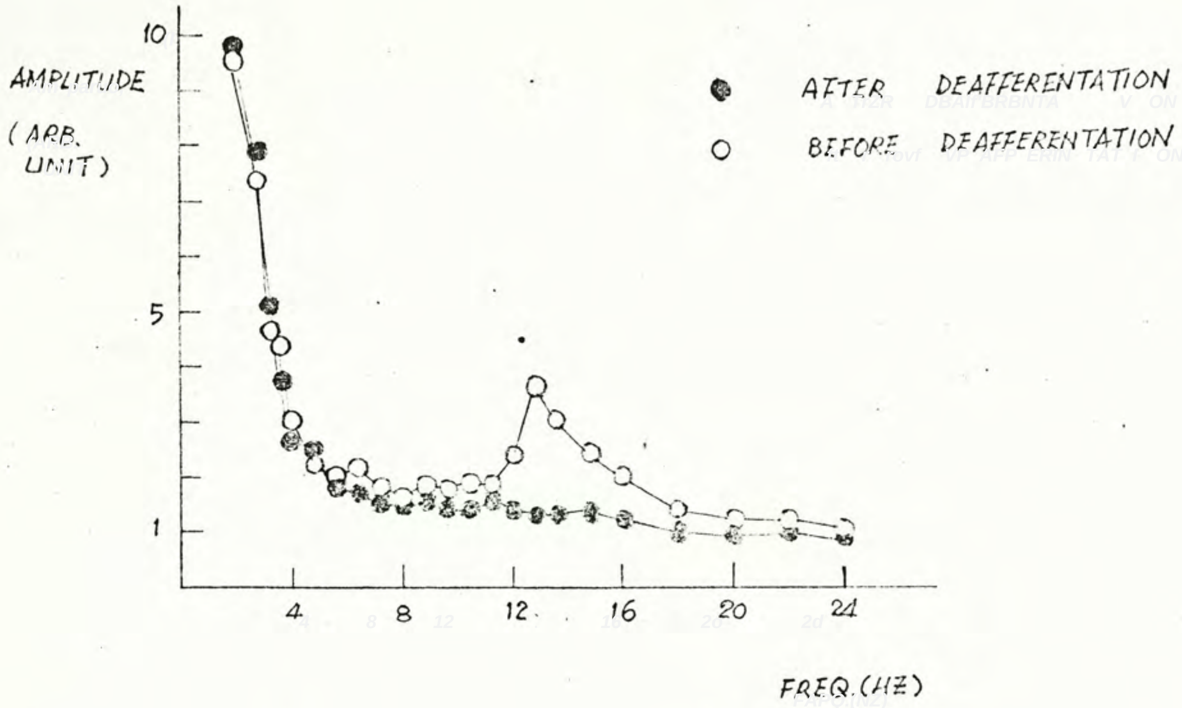


FIG 3.13 THE EFFECT OF A SUDDEN LOUD SOUND ON FINGER TREMOR.

FIG 3.12 THE EFFECT OF SKIN PINCHING ON FINGER TREMOR.



<u>FIG. 3.14</u> FREQUENCY SPECTRA DERIVED FROM TIBIALIS ANTERIOR TENSION RECORD IN ANAESTHETIZED CAT. THE PEAK AT 13 HZ IS ABSENT AFTER DEAFFERENTATION BUT THE OTHER FREQUENCY ACTIVITY REMAINS. (From Lippold *et al* 1959)

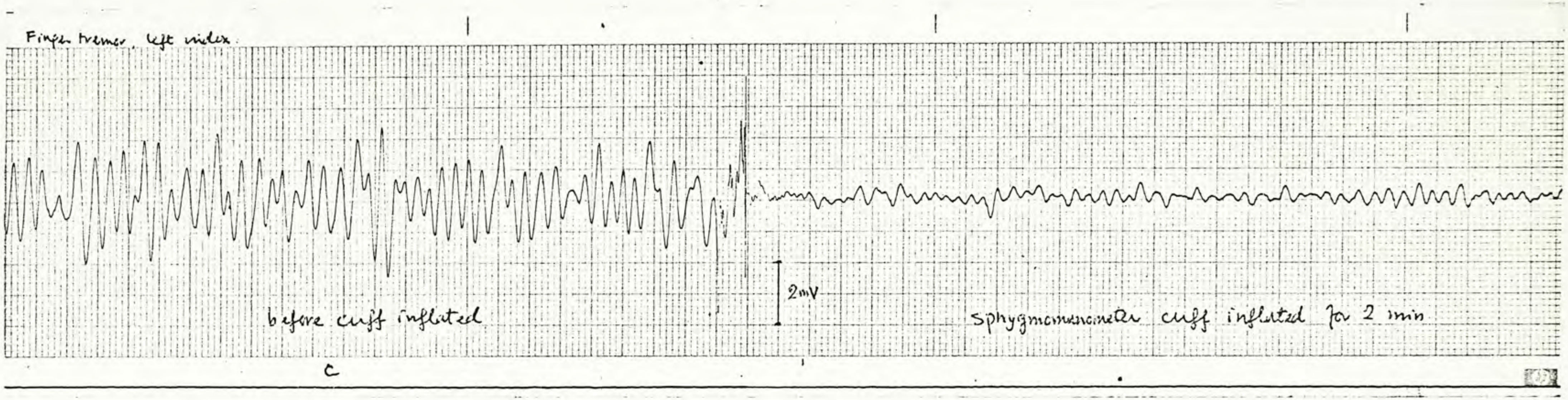


FIG 3.15 FINGER TREMOR RECORDED BEFORE AND AFTER A SPHYGMOMANOMETER CUFF WAS INFLATED. THE TREMOR AMPLITUDE DECREASED TO ABOUT ONLY ONE-TENTH AFTER CUFF INFLATION . 5 LARGE SQUARES = 1 SEC.

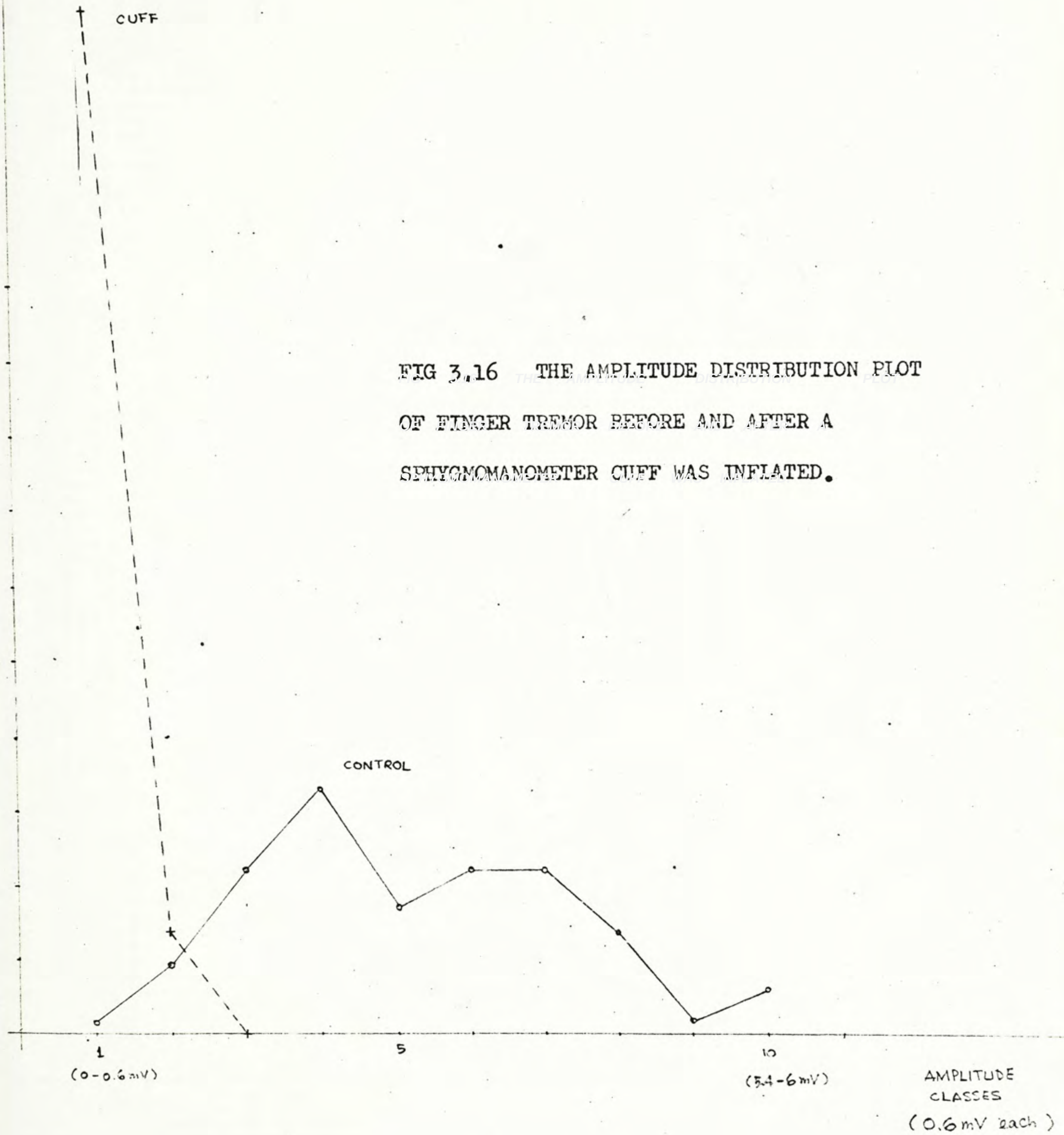


FIG 3.16 THE AMPLITUDE DISTRIBUTION PLOT OF FINGER TREMOR BEFORE AND AFTER A SPHYGMOMANOMETER CUFF WAS INFLATED.

FIG 3.17 THE WAVE INTERVAL HISTOGRAM OF FINGER TREMOR DURING ISCHAEMIA.

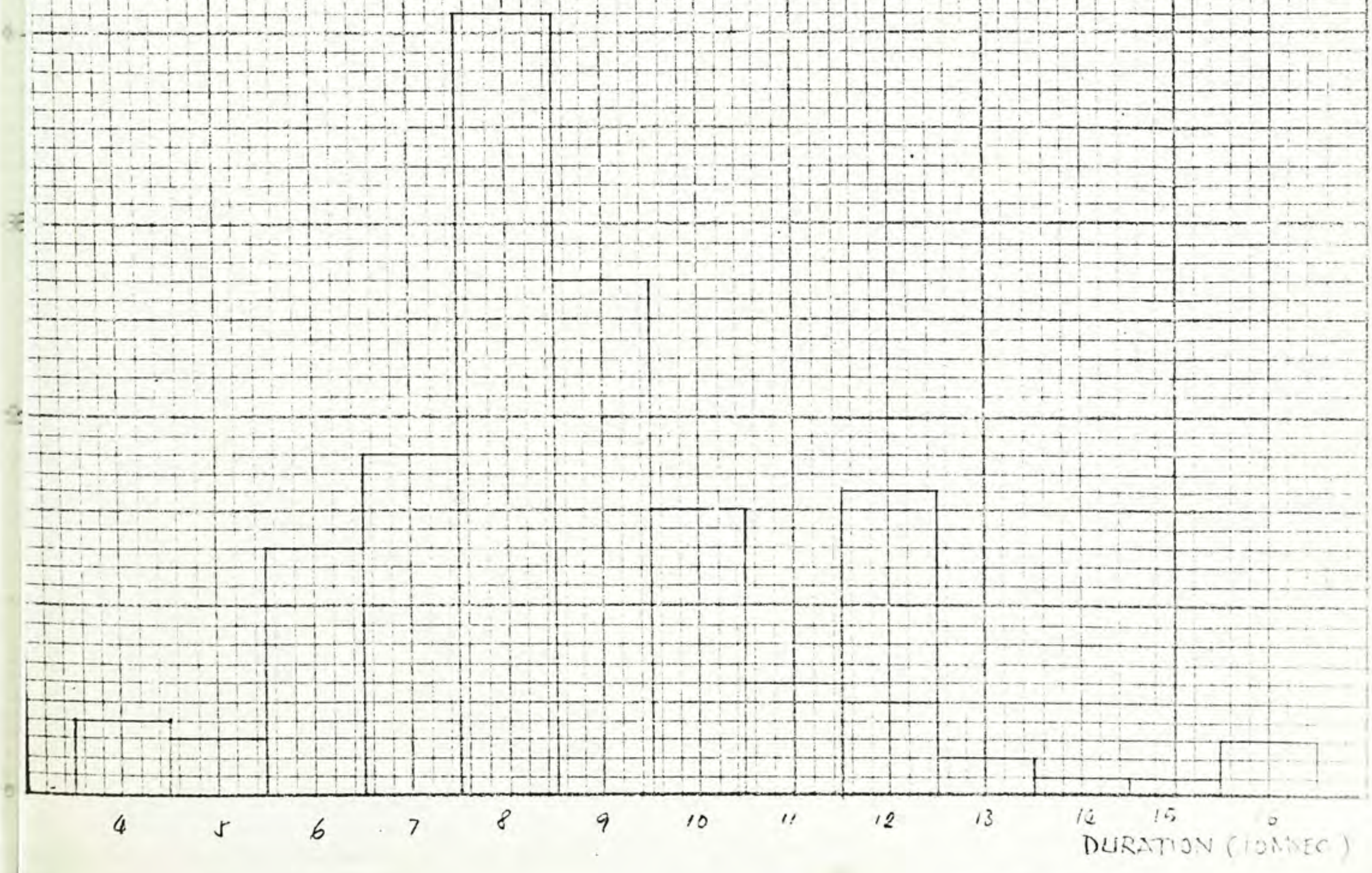
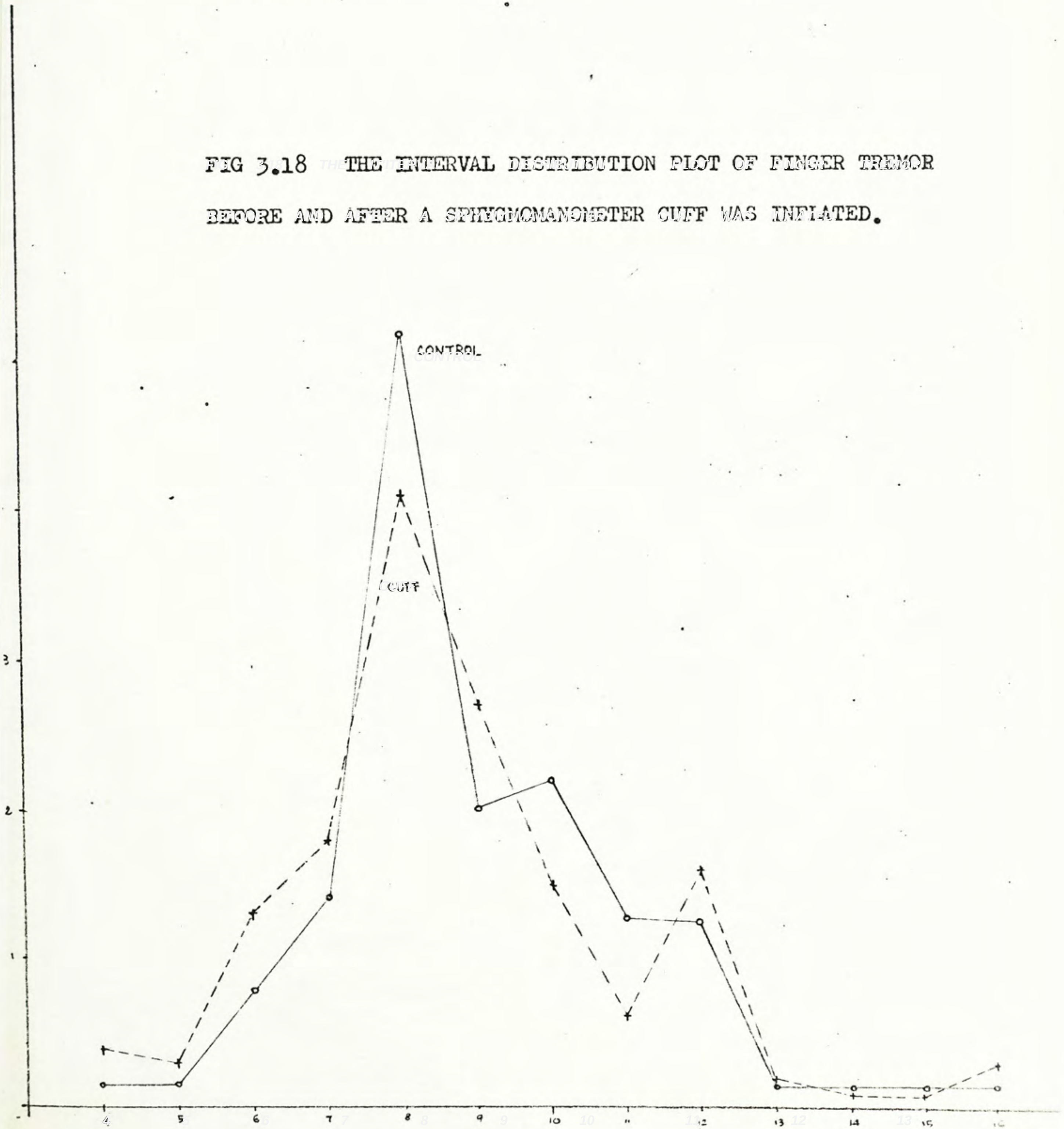


FIG 3.18 THE INTERVAL DISTRIBUTION PLOT OF FINGER TREMOR BEFORE AND AFTER A SPHYGMOMANOMETER CUFF WAS INFLATED.



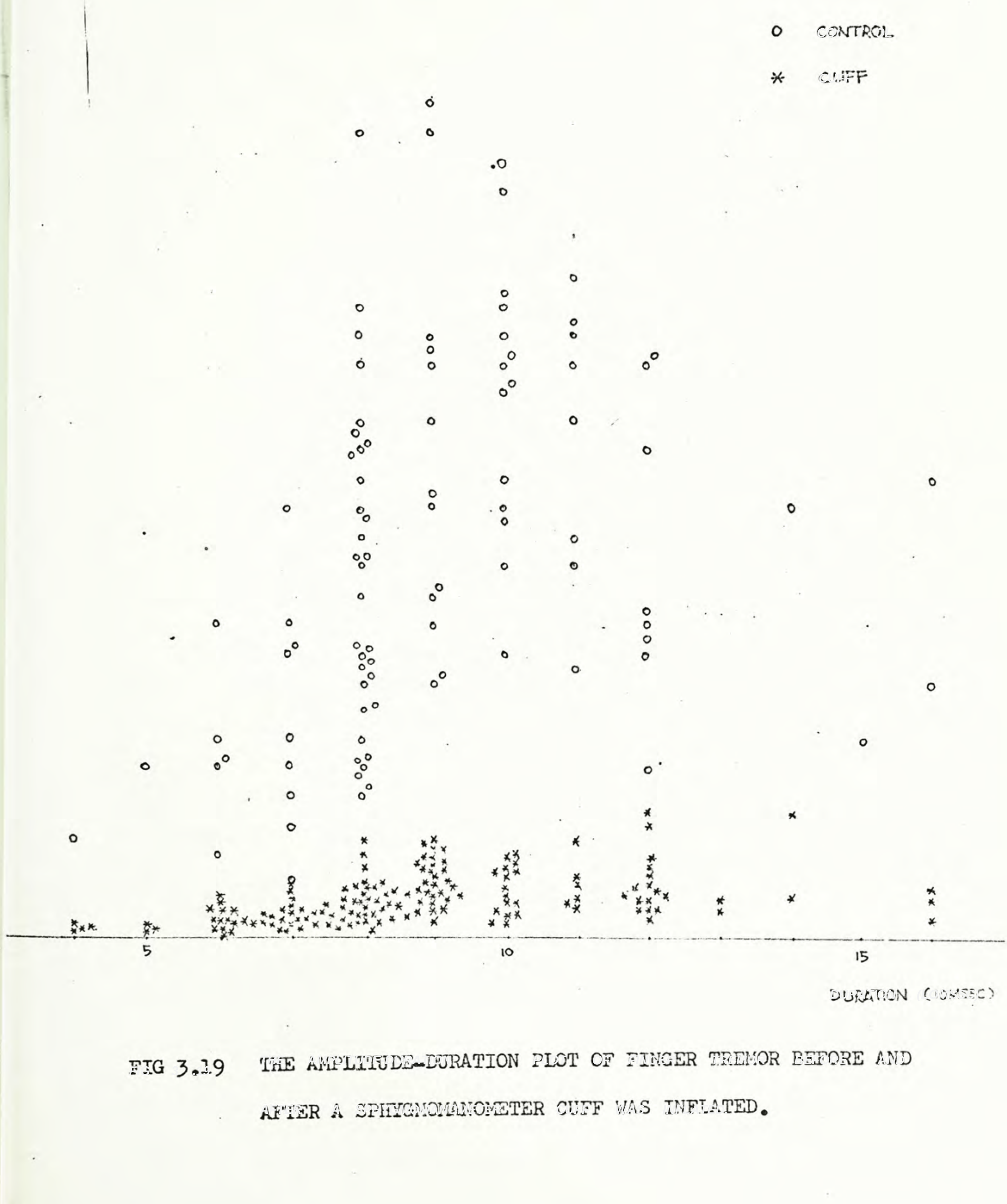


FIG 3.19 THE AMPLITUDE-DURATION PLOT OF FINGER TREMOR BEFORE AND AFTER A SPHYGMOMANOMETER CUFF WAS INFLATED.

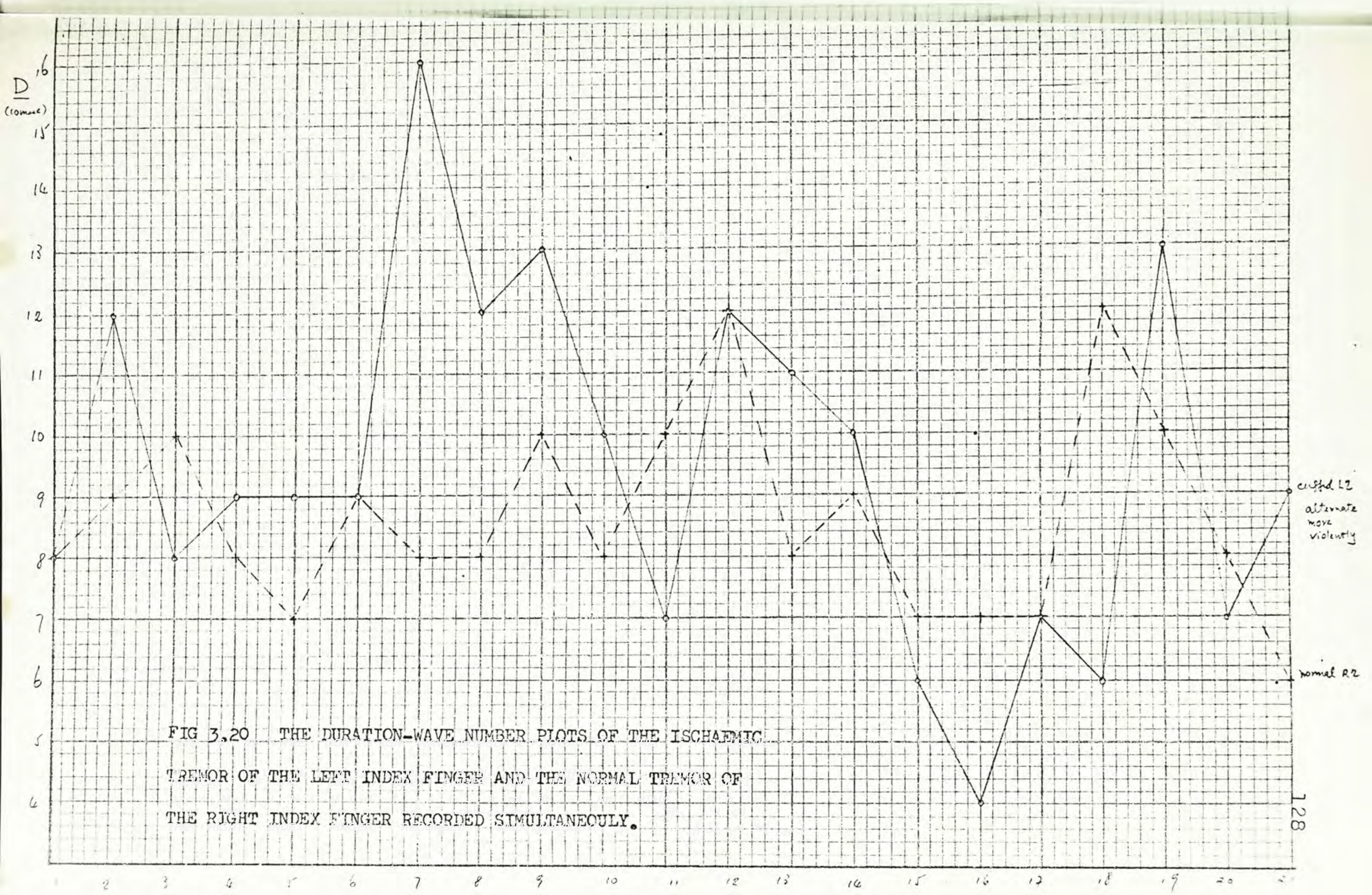


FIG 3.20 THE DURATION-WAVE NUMBER PLOTS OF THE ISCHAEMIC TREMOR OF THE LEFT INDEX FINGER AND THE NORMAL TREMOR OF THE RIGHT INDEX FINGER RECORDED SIMULTANEOULY.

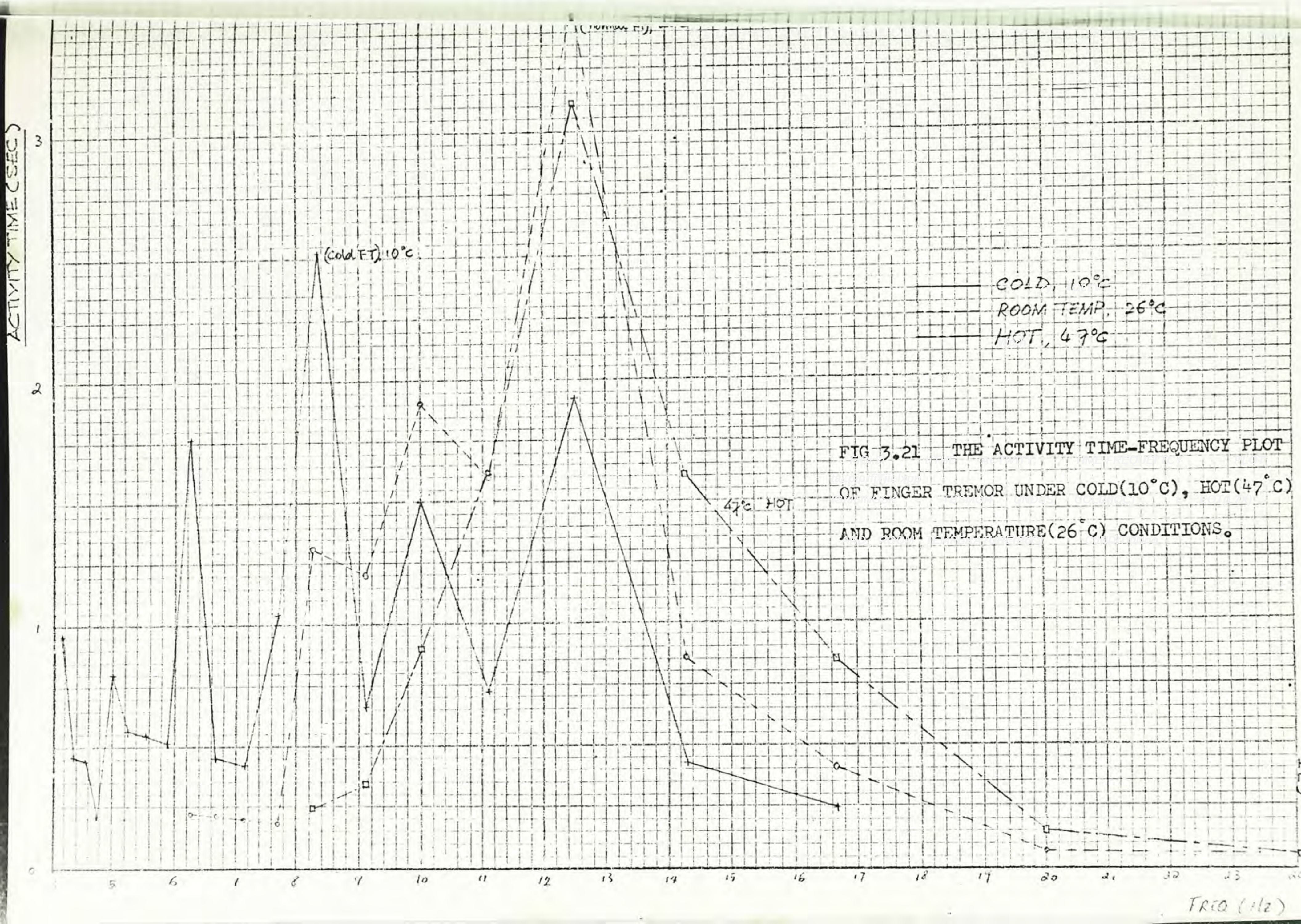


FIG 3.21 THE ACTIVITY TIME-FREQUENCY PLOT OF FINGER TREMOR UNDER COLD(10°C), HOT(47°C) AND ROOM TEMPERATURE(26°C) CONDITIONS.

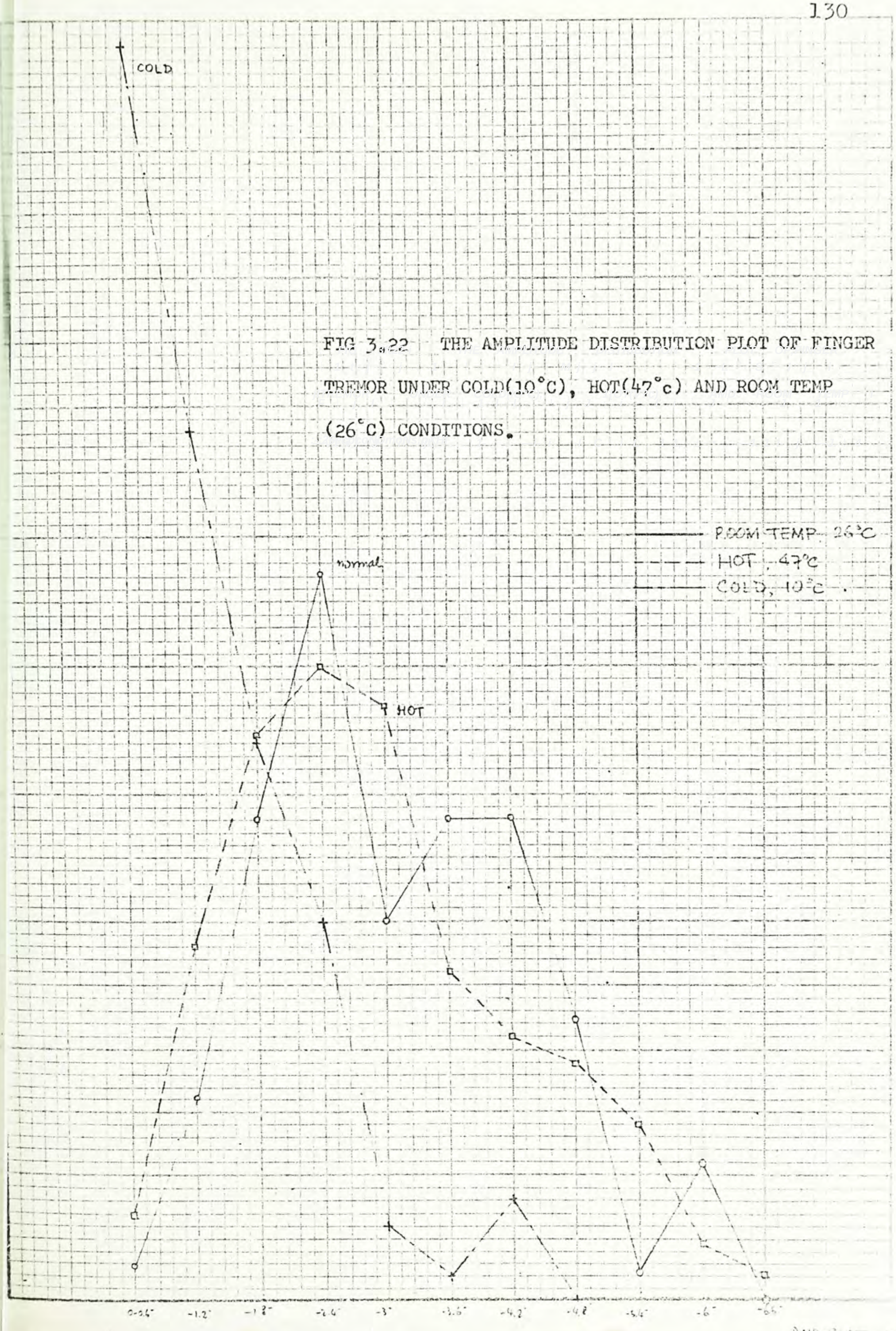


FIG 3.22 THE AMPLITUDE DISTRIBUTION PLOT OF FINGER TREMOR UNDER COLD(10°C), HOT(47°c) AND ROOM TEMP (26°C) CONDITIONS.

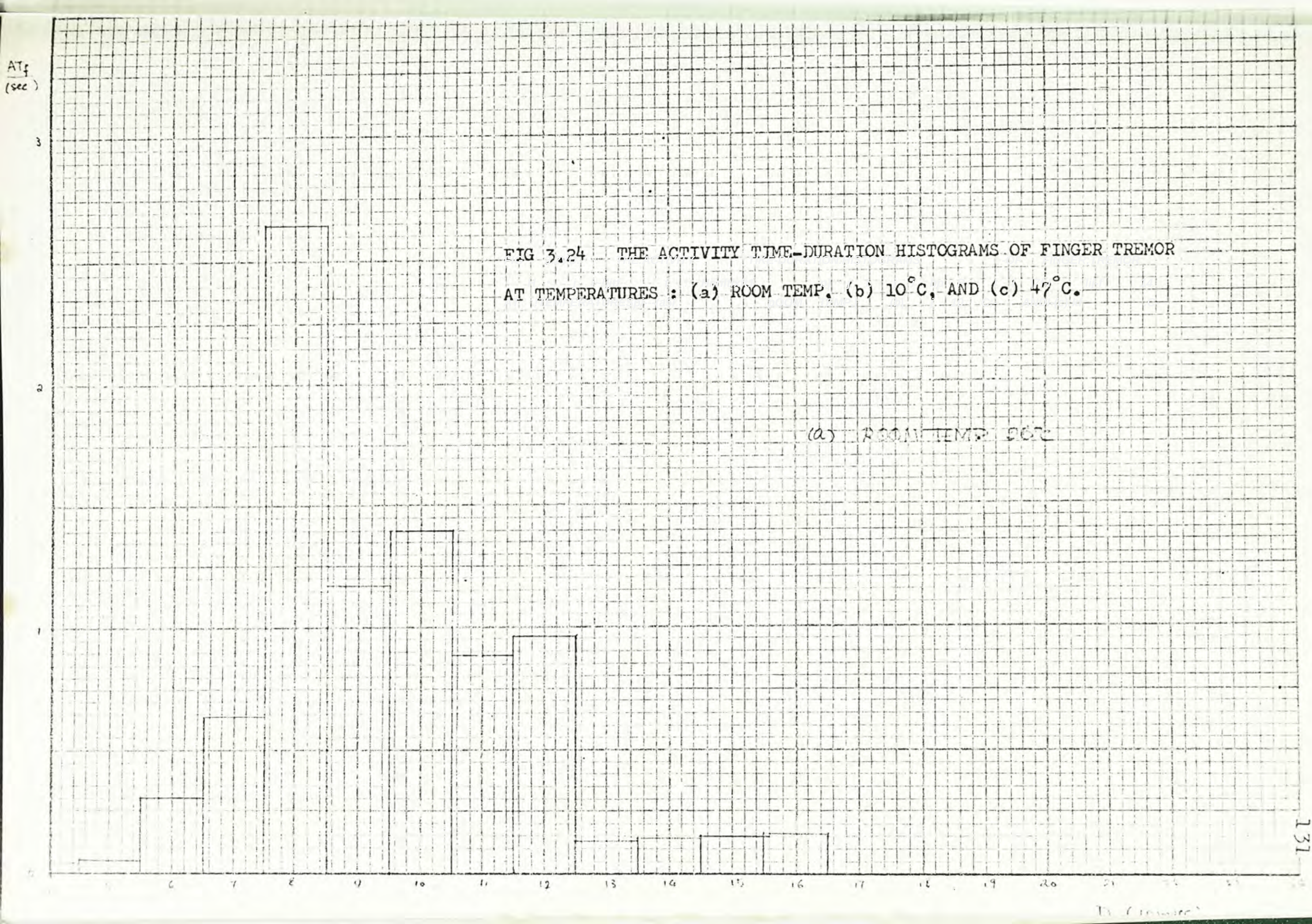


FIG 3.24 THE ACTIVITY TIME-DURATION HISTOGRAMS OF FINGER TREMOR AT TEMPERATURES : (a) ROOM TEMP. (b) 10°C, AND (c) 47°C.

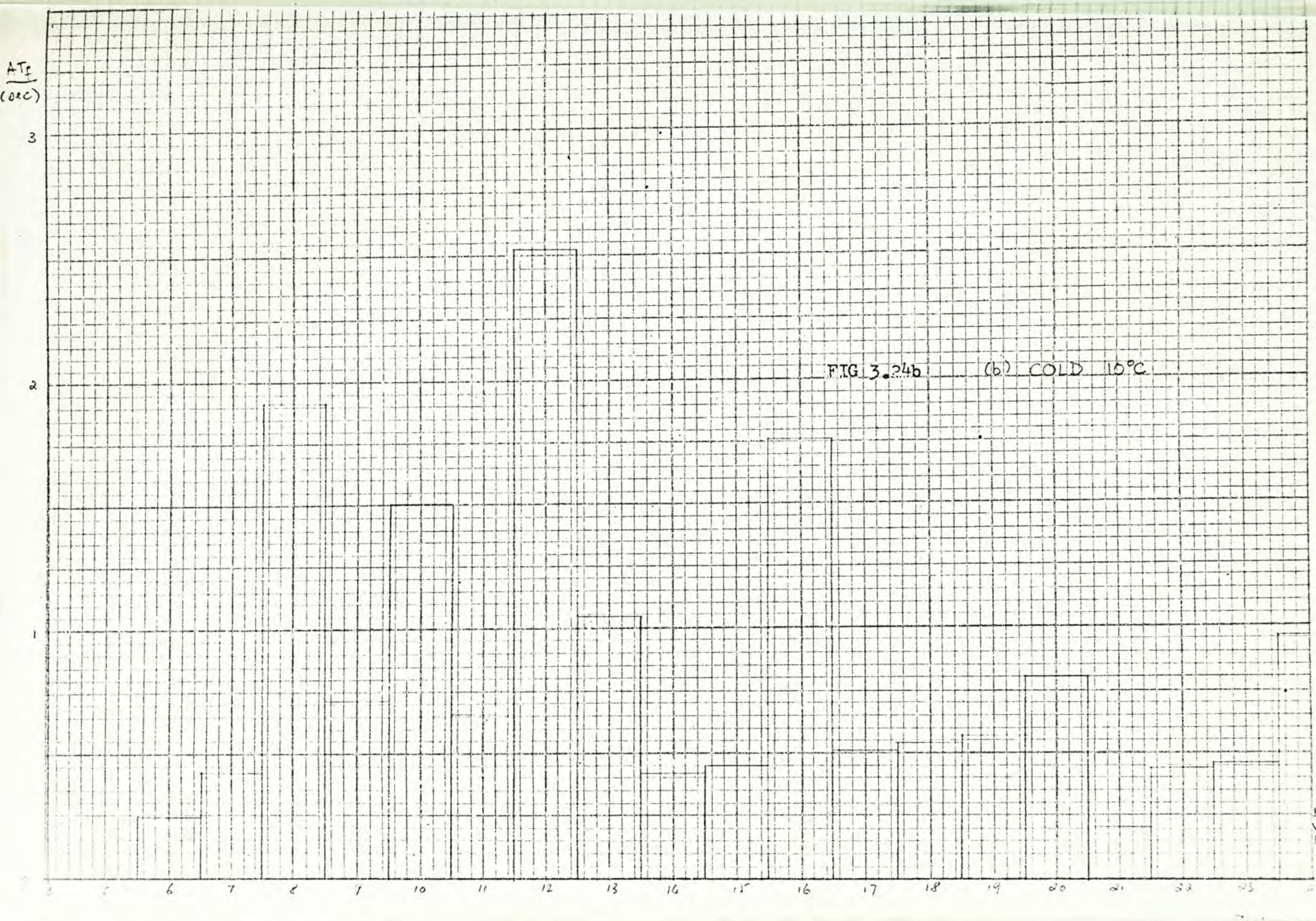


FIG 3.24b (b) COLD 10°C

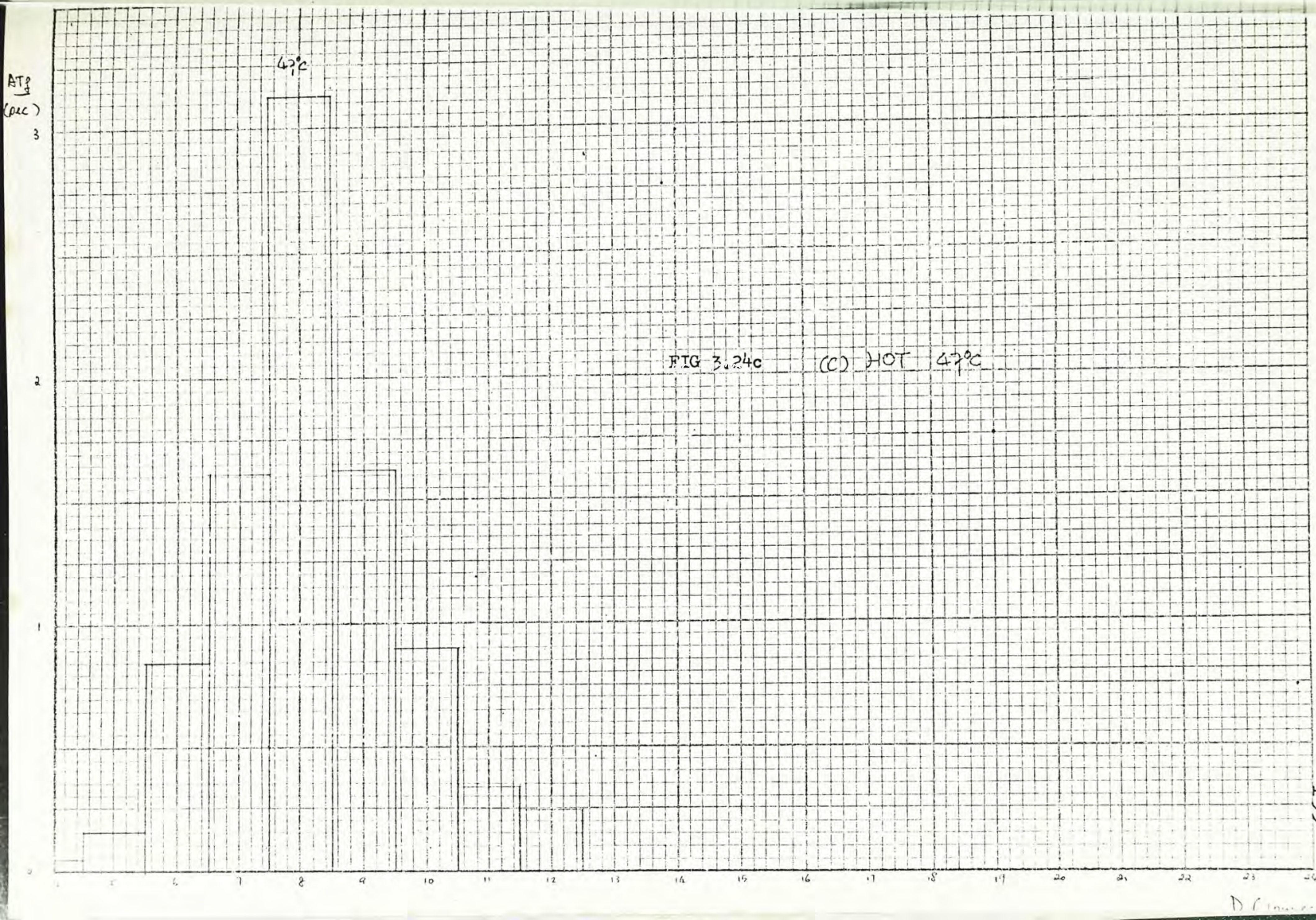
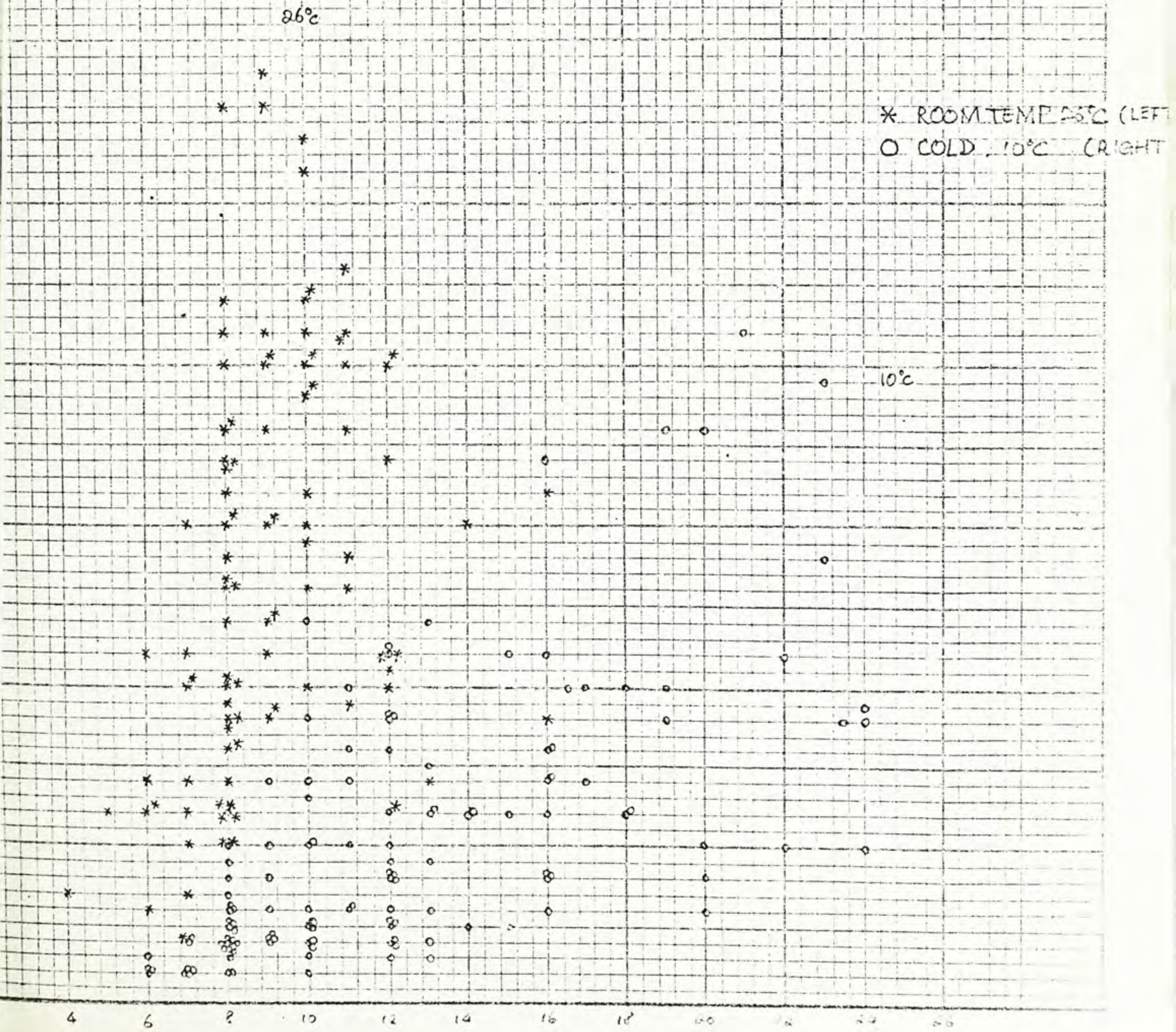


FIG 3.24c (C) HOT 47°C

AMP/DURATION FOR FT AT 26°c + 10.5°c

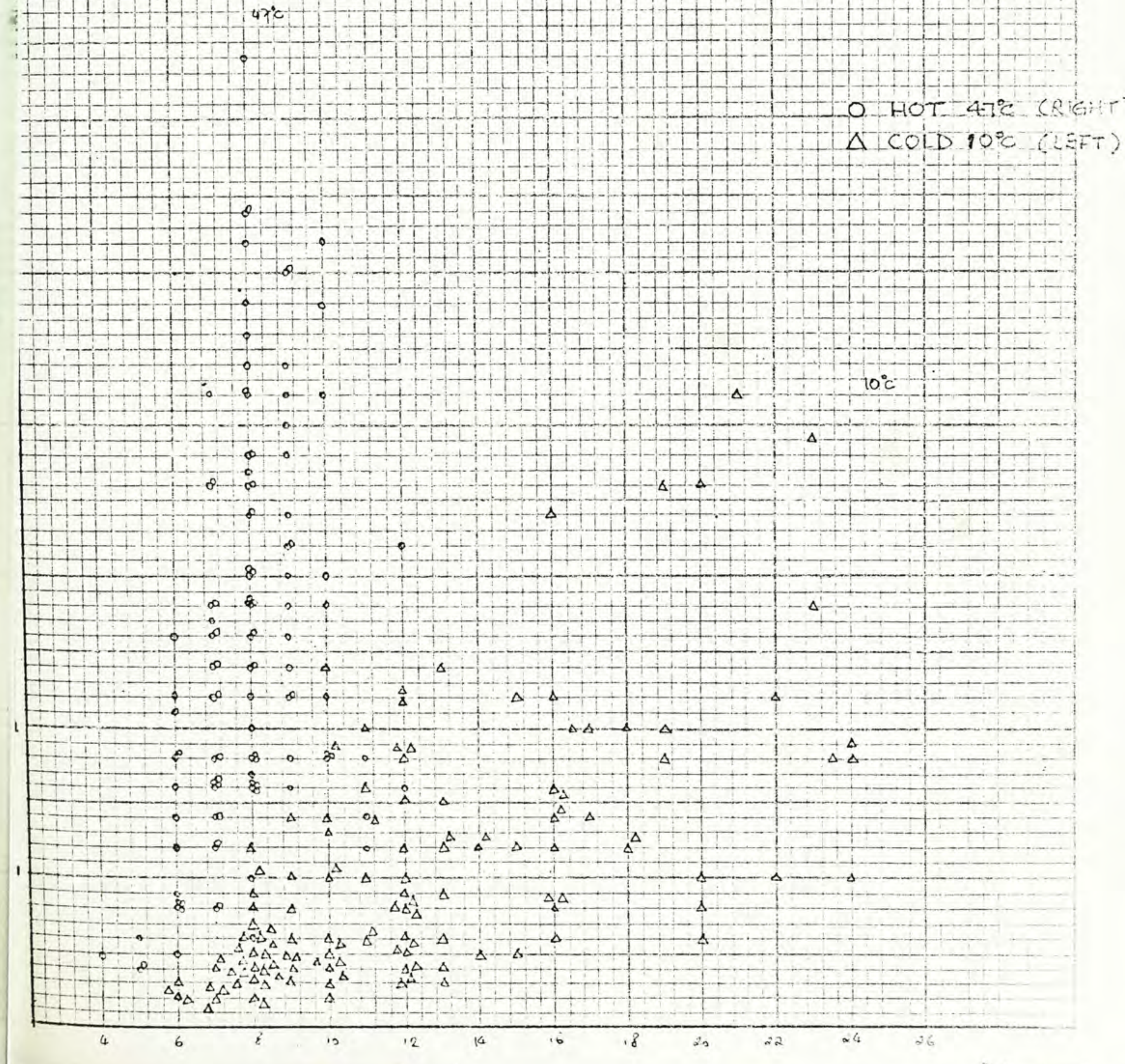
(2 different Hands)

FIG 3.25 THE AMPLITUDE-DURATION PLOT OF FINGER TREMOR RECORDED SIMULTANEOUSLY AT THE LEFT INDEX FINGER IMMERSED IN 26°C WATER AND AT THE RIGHT INDEX FINGER IMMERSED IN 10°C WATER.



D ([illegible])

FIG 3.26 THE AMPLITUDE-DURATION PLOT OF TREMOR WAVES RECORDED SIMULTANEOUSLY AT THE LEFT INDEX FINGER IMMERSED IN 10°C WATER AND AT THE RIGHT INDEX FINGER IMMERSED IN 47°C WATER.



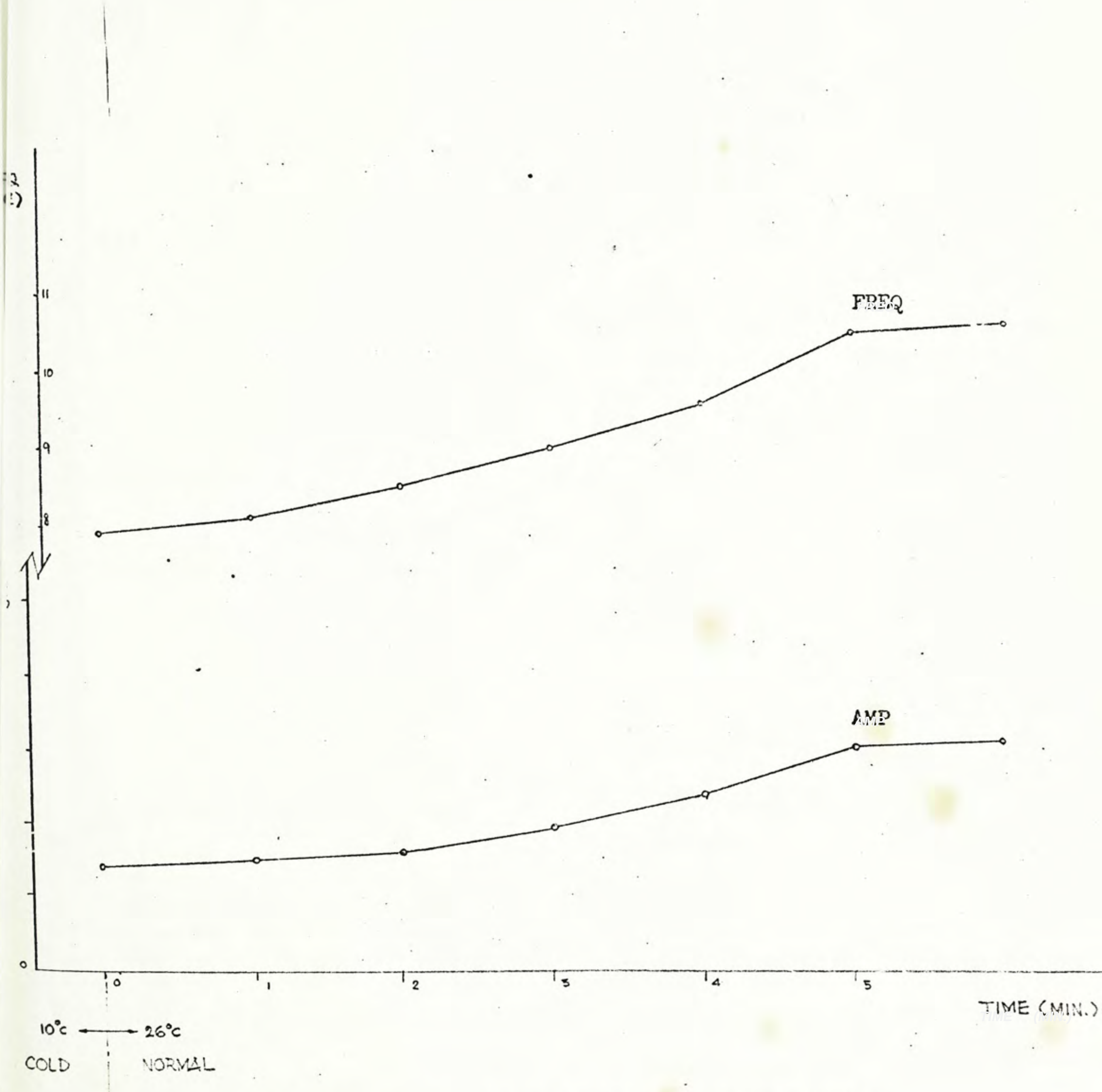


FIG 3.27 EFFECT OF TEMPERATURE ON FINGER TREMOR : THE FREQUENCY AND AMPLITUDE OF FINGER TREMOR GRADUALLY RISED TO NORMAL AFTER THE LEFT FOREARM LEFT THE COLD WATER.

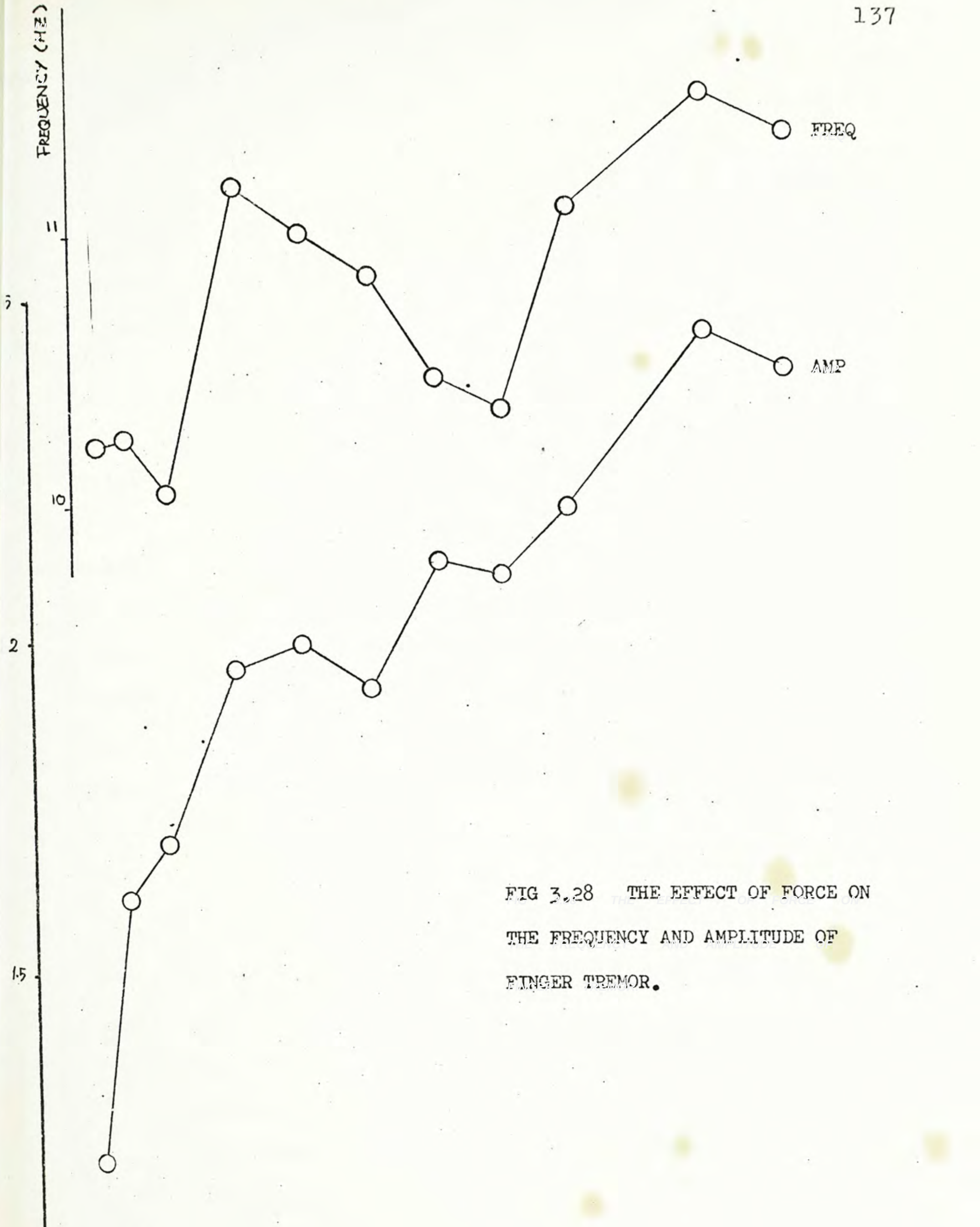


FIG 3.28 THE EFFECT OF FORCE ON THE FREQUENCY AND AMPLITUDE OF FINGER TREMOR.

CHAPER FOUR

T

COMPARARIVE AND CORRELATIVE STUDIES OF EEG AND EOMT

4.1 THE EXTRA-OCULAR MUSCLE TREMOR (EOMT)

The extrinsic ocular muscles are peculiar among the human voluntary muscles in their sensitiveness. They are small in size and uniform and their fibres run the full length of the muscle. There seems no reason to suppose that the extra-ocular muscles differ in any fundamental way from other voluntary muscles as far as the functions of the stretch-servo are are concerned; actually, since there is a ~~nich~~ much richer supply of stretch receptors and their associated nerve fibres in these muscles, one might well suppose that these functions are more rather than less, highly developed than in other muscles.

Cooper and Daniel (1949) reported that more than 47 muscle spindles in a single human extrinsic eye muscle were found with comparable numbers in all the other five. Cooper, Daniel and Whitteridge (1951) further found that eye muscle spindles are organs exquisitely sensitive to stretch. The stretching of human eye muscles increased the afferent discharge in the oculomotor nerve (Cooper etal 1955, Fillenz 1955).

Thus the control mechanisms of these muscles much resemble those of other skeletal muscles.

Whitteridge (1959) demonstrated the existence of a fusimotor system in eye muscles just as that in all other skeletal muscles. He reported a linear relationshop between muscle stretch and afferent discharge frequency and fusimotor stimulation increased the slope of the muscle spindle to stretch. Donaldson (1960) futher reported that the small fusimotor fibres constitute about 30% of the motor nerve to the eye muscles. The fusimotor activation thus plays a dominant part in extra-ocular muscle control, and may even be more important than in other skeletal muscles.

There is now no dispute that human extra-ocular muscles are profusely supplied with muscle spindles, fusimotor innervation and an afferent pathway leading back to the oculomotor nuclei (Alpern 1962). This suggests the existence of a stretch-reflex in extra-ocular muscles. Nevertheless, eye muscles differ from postural muscles in that no external forces are applied to the eye (the eye is not subject to disturbances by external forces) and hence the fusimotor system and muscle spindles need not function in such a way to make the muscle follow and correct length changes in the spindle due to variable external forces applied (i.e. to maintain a given posture). On the other hand, eye movements are exceedingly accurate and highly damped. The control of eye movements therefore requires an extremely sophisticated servo-loop damping. Evidences for this damping were given by Fender (1964 a,b) and Robinson (1964). It is thus clear that the servo-loop of extra-ocular muscles functions only during their activity and the function is to provide damping for eye movements. Hence their responses to stretch would not be expected. Finally, Lippoid (1971) proposed the control of eye movements is achieved by two systems. One is a feedback involving the visual cortex and retina to control eye position and some eye movements. The other is a muscle stretch-reflex servo-loop acting via spindles and control the position of the the eye in relation to the bony orbit when the eyes are closed, or more precisely, when no visual fixation occurs. The resting length of the extra-ocular muscles must be kept constant at an appropriate level by some servomechanism to maintain the globe in its correct position within the bony orbit. If not, the eyeball may hang out of the orbit, or be tightly drawn in against the bone, because the six eye muscles are its only attachments. When the eyes are opened and a sharp image is present on the retina, fixation via the visual cortex will inhibit the operation of any purely muscular reflex mechanism. On the other hand, with the eyes closed, the retinal-visual connections for controlling eye position are broken and the only way in which eye position can be maintained will be by the operation of the muscle servo-loop.

Extra-ocular muscle tremor emanates from this muscle servo-loop in exactly the same way as other physiological tremor is originated. It has been demonstrated that physiological tremor arises as a result of the 'hunting' phenomenon of the stretch-reflex servo-loop. The overall loop delay determines the tremor frequency and the system's sensitivity determines the tremor amplitude. The same effects should hold for eye tremor according to the stretch-servo hypothesis. This proved to be the case . Studies on the extra-ocular muscle tremor yielded the same results as other physiological tremors did under various circumstances. Warming and cooling the extra-ocular muscles produced the expected results. When a step perturbation was introduced into the servo-loop mechanism of the eye muscles by prodding the eye, phase-locked oscillations at the tremor frequency could be easily demonstrated. The extra-ocular muscles, when fatiqued by instructing the subject to concentrate on reading continuously for several hours or to move his eyeballs from side to side until the eye muscles are 'tired' or to watch a TV film, produced enhanced tremor. In addition, Pinelli (quoted in Lippold 1973) found that a patient with nystagmus rectatorius, disorders of the eye, had very large occipital potentials synchronised with the nystagmus. The greatly increased 'hunting' in the patient's eye muscle servo-loop enhanced eye tremor and thus indirectly the occipital alpha waves. Thereupon, it can be concluded that extra-ocular tremor is originated in exactly the same way as the stretch-servo hypothesis postulates.

The tremor has a characteristic peak at 10Hz, similar to that of finger tremor and alpha rhythm(fig.4.1). It has submaximal peaks at 3 and 7Hz, in the delta and theta range respectively. The beta and gamma ranges are insignificant. The autocorrelogram of EOMT is shown in fig 4.2. A gradual decline of the product moment correlation coefficient with increasing delay and the well-shaped characteristic can be observed. Both the frequency spectra and the autocorrelation plots show that alpha rhythm, finger tremor and EOM tremor are actually very similar in their characteristics. Inasmuch as finger tremor and alpha waves were shown to be independent events in section 2. , the EOM tremor and the alpha rhythm suggest themselves for a detailed comparative and correlative study under various experimental conditions. Supposing gratifying results were obtained, many odd properties of the alpha waves, for instance, the effect of eye-closure and eye-opening, could be explained. When the eyes are closed, and their reflex connections to maintain eye position inthe visual pathways are cut. EOM tremor arises as a result of this servo action and the concomitant alpha waves thus appear at the occiput. When the eyes are open with a sharp image on the retina, fixation via the visual cortex will inhibit the operation of this muscle servo-loop. Eye position is controlled by a visual feedback loop involving the visual cortex and the retina. Hence, EOM tremor is 'blocked' and the alpha waves recorded at the occiput suffer from the same outcome. This simple phenomenon of eye-open and eye-close can hardly be explained by any other hypothesis.

4.2 RECORDING TECHNIQUES

Ten voluntary subjects, either students or members of the staff of the University of ages 12 to 40 years and are all intact and neurologically normal, were involved in the experiments. They were all familiar with the experimental situation in advance. Experiments were carried out in a large quiet laboratory with the subjects sitting comfortably in a padded chair and relaxed. No visual or audio feedback was allowed.

The techniques employed in the experimental studies involved chiefly the measurement of EOM tremor with the dynamic mikes (Model no. 92CU2924 and 92CU2947 Poly Paks) and the recording of EEG alpha activity with the oscillographic recording system (HP 7702B) and the bioelectronic amplifier (HP 8811A). A tape recording system consisted of the cassette deck and the modulator-demodulator circuits was employed to record the outputs of the EEG machine in tapes for analysis. The technique of recording EEG is described in section 2.5.1.

Recording of EOM tremor resembles that of finger tremor except the arrangements at the respective recording sites. The distinctions of the dynamic mikes in recording physiological tremor have been described. The same holds for eye tremor. To our surprise, no investigators happen to discover this simple technique in recording eye movements, to our best knowledge up to now. The transducer is small, light, cheap, efficient and versatile as compared with those used by other investigators. It is also advantageous in introducing no d.c. components and noise into the output signals as in the case of optical methods.

The axial, translatory eye movements in the optical axis were recorded since the horizontal, vertical and rotational ones did not produce well-defined 10 Hz oscillations. The resultant tremor of the six extrinsic ocular muscles will result in a 10 Hz oscillation chiefly in the longitudinal ocular displacement. Thus EOM tremor can be recorded in the axial, translatory eye movement.

The diaphragm of the dynamic mike was tapped directly to the corneal surface or over the eye-lid to record this movement or eye tremor. The subject must wear contact lens when the corneal surface is touched upon directly by the membrane (cleaned by cleaning and soaking solution and then washed thoroughly with wetting solution) of the dynamic mike. The eyelid must also be pulled up by the adhesive tape sticking to it in order not to interfere with the recordings. No anaesthesia of the cornea was required. When recorded over the eye-lid, that is, with closed eye, the procedure would be even much simpler, as simple as that of finger tremor.

The dynamic mikes were mounted flexibly on a diving mask (Fig 4.3) and could be adjusted in three planes by screwing and sliding. Accurate longitudinal adjustments were achieved by the mounting shown in Fig 4.4. Thus the dynamic mikes could be located safely and accurately over the recording site for all the subjects. The diving mask was employed because any extraneous movements other than the eye movements would be eliminated. In addition, the mask ~~in~~ is comfortable and familiar to the subjects. This set-up has several advantages :

(i) the procedure is simple and precise, the result is repeatable and reliable and the set-up is flexible and comfortable.

(ii) there are no harm and ~~difficulties~~ discomfort for the subject, he can relax and adapt easily.

(iii) diurnal studies, long-time recordings and experimental studies under various peripheral changes, for instance, eye-open and eye-close. were possible.

(iv) noise-free and artefacts reduced to a minimum, tremor of both eyes can be recorded simultaneously.

When the effect of warming or cooling the orbits on EEG alpha waves was studied, a bath and circulator was used to provide a circulation of hot or cold water in a large goggle worn by the subject (Fig 4.5). The orbits could be warmed or cooled separately and together by the set-up shown. The experiment should be repeated for several days to obtain the average result. Experiments on feedback studies were enabled by modulating the tremors and alpha waves to audible signals fed back to the subject via headphone. The subject was trained to control his own alpha and eye-tremor over a long period of time. Polarising current (0.5-1.5 mA) through the orbit by locating the electrodes over each orbit and just beneath each eyebrow.

Lippold (1970d) first recorded the eye movements in the optical axis of the eye and found that 10 Hz oscillations of the eye occur concomitant with alpha waves. The correspondence between the two phenomena he obtained with his own recording techniques was quite good but not good enough to give a strong support for the eye-tremor hypothesis (see Fig. 2 of his paper) Recordings under various experimental requirements were also difficult. He recorded eye-tremor by a silicon strain gauge fitted to a bar firmly attached to the subject's forehead. A small nylon probe fitted to the gauge recorded eye movement by lightly pressing on the cornea. Prolonged application of the nylon probe tended to leave a small indentation in the cornea and only disappeared after several hours. He initially applied local anaesthesia to the subject's conjuntiva but later abandoned this. This method suffers from several shortcomings. Firstly, the indentation left in the cornea is certainly unfavourable. Secondly, recordings with eyes closed are not efficient with the strain gauges. Thirdly, the mounting is not flexible and stable and finally, diurnal studies as well as long-time recording are difficult. Another method employed by Lippold was the optical one. A bright beam of light was shone obliquely into the subject's opened eyes and recorded by a detector on the other side. The method is too crude to yield a reliable result as extraneous movements of the other parts of the body can hardly be avoided.

Due to the shortcomings of these methods, we had to design new techniques to overcome these difficulties and the technique of recording with the dynamic mike and the diving-mask mounting proved to be very successful. The EOM tremor thus recorded occurs concomitant with and resembles alpha rhythm strikingly. This enabled us to investigate Lippold's findings and give further supports to the eye-tremor hypothesis with our own technique.

4.3 METHODS OF ANALYSIS

The alpha waves and tremor waves were recorded in tapes for analysis. They can be treated in three different ways : analog, digital and internal analysis.

1. Analog approach

The tape recording system comprises the modulator, tape recorder, demodulator, filters and amplifiers (Fig 4.6). The carrier frequencies are 3.3 K and 1.5 KHz respectively. The signals can be recorded either direct or frequency modulated.

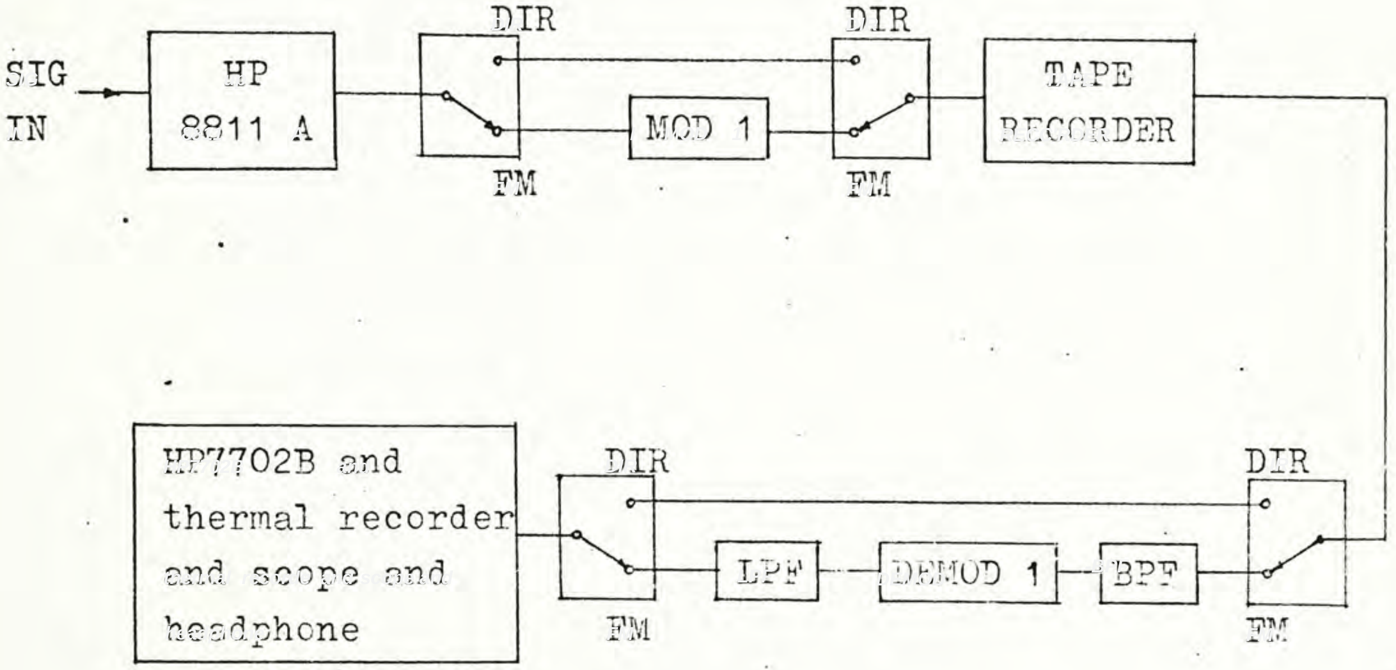


Fig. 4.6 The Recording System (showing one channel only)

Audio, stroboscopic and electrical stimuli are generated by the circuit shown in Fig. 4.7. The duration and intensity of the stimuli can be varied to the desired values.

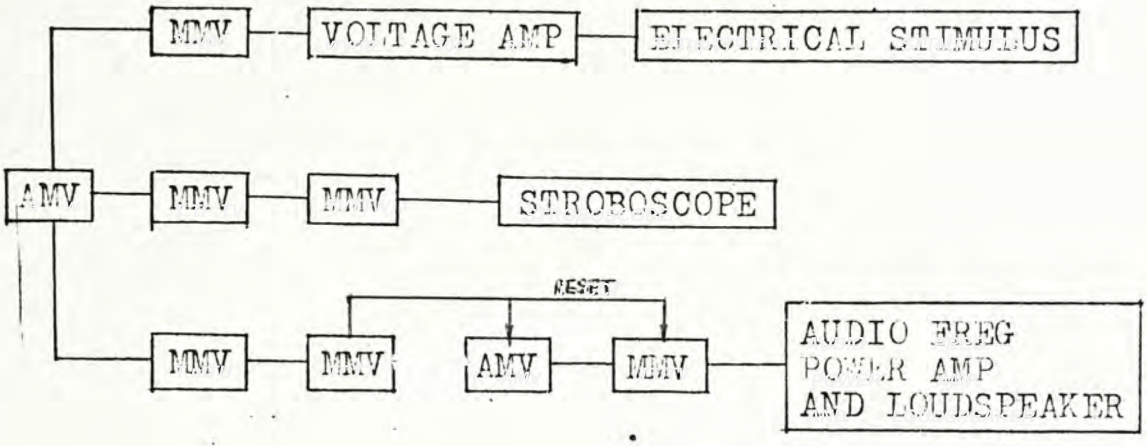


Fig. 4.7 Generation of the various stimuli

For the analysis of the signals, several circuits were built to analyse their frequency, phase-difference, variance, average, rms and absolute values (Fig. 4.8). The circuits were designed to operate in the frequency and amplitude range of the

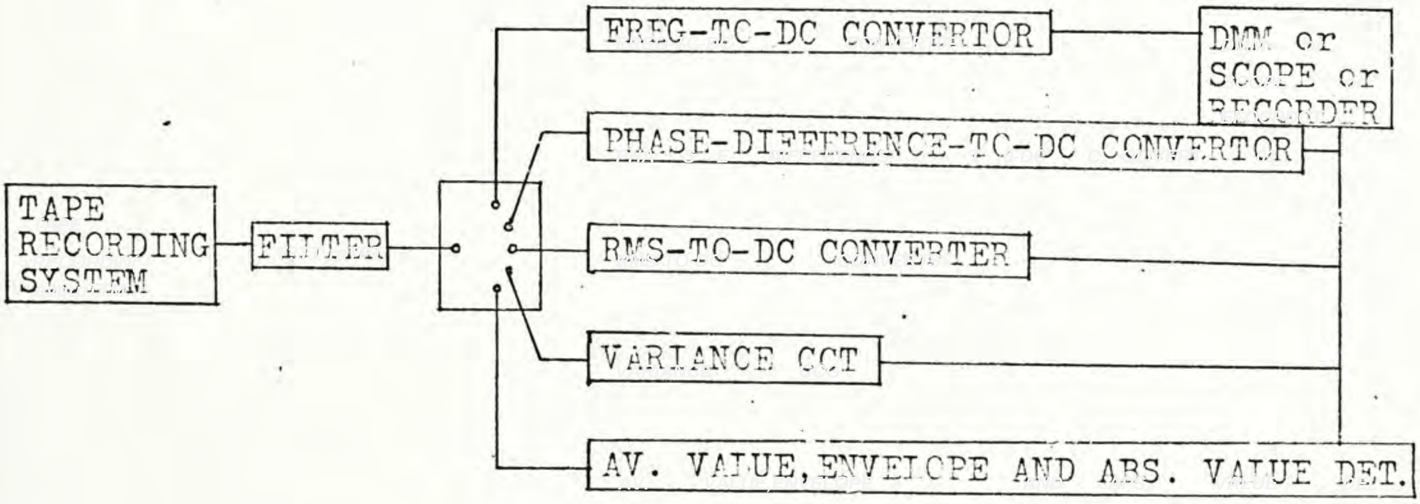
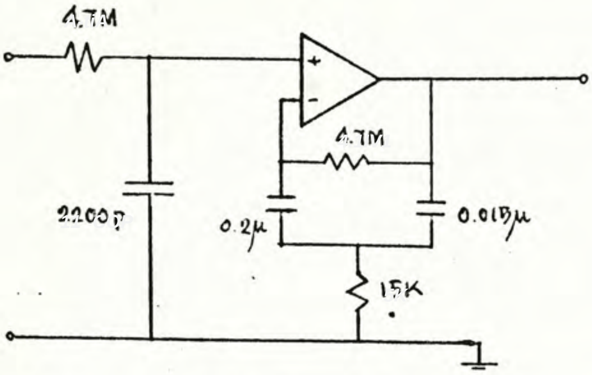


Fig. 4.8 ANALOG ANALYSIS CIRCUITS

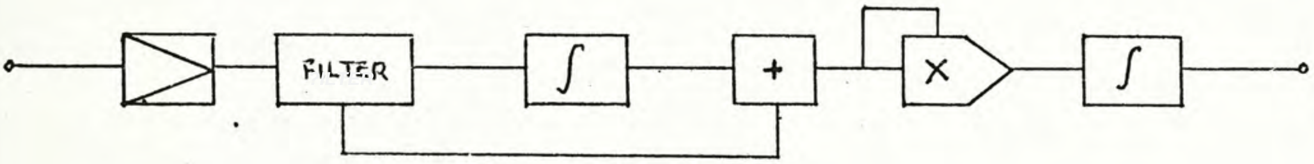
alpha waves and physiological tremor. The bandpass filters (Fig. 4.9a) were often used in the circuits to suppress signals other than the alpha range (8-13Hz). While the frequency and phase of the signals were recorded directly and the statistical variance was taken as an appropriate index of the signal amplitude (Fig. 4.9b).



(a) BPF gain magnification = 70

$$\frac{\text{mag. at 50 Hz}}{\text{mag. at 10 Hz}} = 0.07$$

range = 8 - 13 Hz



(b) Variance measure

Fig. 4.9 The bandpass filter and the variance measure circuits

The outputs of the analog analysing circuits are illustrated in Fig. 4.10.

2. Digital approach

The electroencephalographic data are most widely treated by statistical analysis . Two methods were employed in our present study : the method of correlation coefficients and of frequency analysis, for the acquisition of accurate and useful knowledges of the phenomena. They possess their respective characteristics and it would be a more satisfactory description of the statistically "fluctuating phenomena" to bring the two together under combined consideration. By virtue of the correlation function , the status with regard to the phenomena of time variation expressed in the elementary waves is more definitely shown, and that the stand of the frequency distribution of the amplitudes of the waves is conveniently studied by virtue of the frequency spectrum. In the case of alpha waves and physiological tremor, the autocorrelation function may appear slightly simpler while the frequency spectrum obtained hereby is often rather complicated in structure. Moreover, autocorrelation analysis, unlike epoch analysis of frequency, computes information about the EEG voltage-time record throughout the whole length of the sample simultaneously. It seeks to find whether any amplitude fluctuations occurring in the EEG recordings are related in any consistent way to those that have come before them. Nevertheless, frequency spectrum carries far beyond simple and yet clear descriptions.

Whilst autocorrelation compares a phenomenon with itself displaced in time. corsscorrelation compares two different phenomena to determine the strength of the association between them and is thus important in the present work. The respective programmes to generate the crosscorrelation functions, frequency spectra and autocorrelation functions are illustrated in Appendix I a and b. Examples of the respective plots are shown in Fig. 4.16, Fig. 4.1 and Fig. 4.2. Apart from this, the programmes also evaluate the variance, average amplitude and the base-line of the phenomena. In order to obtain a cross-correlation function independent of the phenomena amplitudes, their products are divided by the products of the standard deviation ~~derivation~~ of the phenomena. The normalised crosscorrelogram thus obtained maximizes at +1 and minimizes at -1 and has a basic repetition frequency of that of the phenomena. The product moment correlation coefficient (r) will be positively large for good correlation (i.e. approximately in phase) and negatively large for approximately out of phase. The common test of statistical significance applied to the estimations of r is the Student's t-test. To carry out the test, we first evaluate r and derive from it the quantity t given by :

$$t = \frac{r\,(n-2)^{\frac{1}{2}}}{(1-r^2)^{\frac{1}{2}}}$$

which is precisely a Student's t with n-2 degrees of freedom and can be referred to tables on Student's t-distribution. If we had a sample containing 102 observation-pairs, i.e. with 100 degrees of freedom, then only values of r that were greater than +0.164 or less than -0.164 would be significant at the

10 per cent level (p= 0.10, probability of observing r).

3. Interval or Period analysis

The analysis of the EEG and physiological tremor in the time domain has not enjoyed the popularity of that in the frequency domain. Nevertheless, apart from its simplicity and low cost, period or interval analysis requires no untoward assumptions regarding the nature of the signal analysed. Chief among the assumptions inherent in the frequency-based techniques is the assumption of periodicity. Period analysis, by contrast, treats the consecutive waves in an EEG record as a series of aperiodic phenomena to be described and analysed independently of each other (Saltzberg *et al* 1957). The earliest attempts in period analysis employed manual methods whilst a few investigators have found them still to be useful nowadays (Fujimori *et al* 1958; Sulg 1969; Surwillo 1963, 1971). They demonstrated that interval histograms obtained from computer period analysis are highly correlated with those derived from manual methods.

In period analysis, most methods are limited to the measurement of major period, or the half-wavelength intervals defined by the baseline crossings of the raw record. Inasmuch as baseline crossings are sensitive to shifts in DC level (Fig. 4.11), major period determinations can be contaminated by large-amplitude and low-frequency artefacts and baseline sway. Owing to this , we use peaks and troughs in the EEG and tremor records as the reference points for determining wave intervals and amplitudes instead of zero crossings (Fig. 4.11).

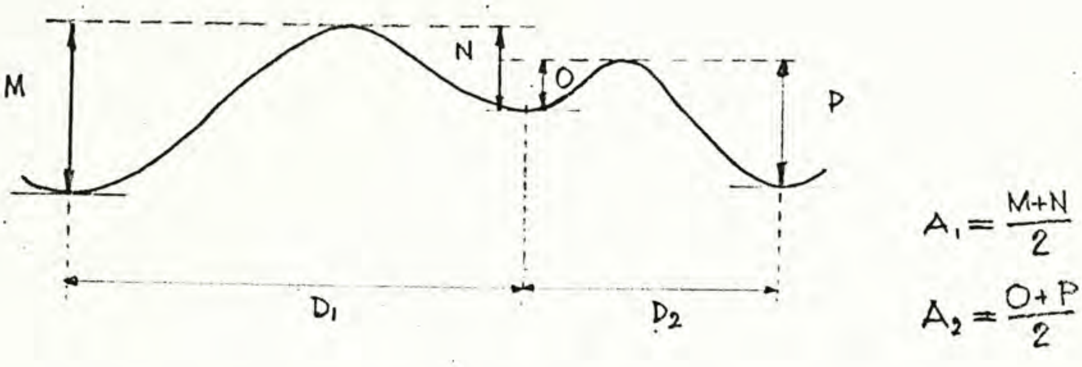


Fig. 4.11 Evaluations of wave durations and amplitudes

Usually, a 20 sec epoch of EEG or tremor record was analysed in our studies. Artefact-contaminated samples were excluded. Several plots were generated in this approach. The interval distribution histogram plots the frequency of occurrence (n) against the wave duration (D) or the frequency class. Activity time (AT) studies, on the other hand, evaluate the time occupied by all measurable waves in one frequency class or wave duration to be known. The interval distribution and activity time plots of normal physiological tremor are compared in Fig. 4.12 and Fig. 4.13. Their differences in the higher frequency or smaller duration ranges are distinct. The activity time studies are credited because fast waves cannot be considered to have the same neurophysiological significance as slow waves. Both plots can be taken as representing the frequency content and distribution of the phenomina under study. Aside from the frequency characteristics, the amplitude content of the phenomena was studied by the amplitude distribution histogram (Fig. 3.22). The mean, median, mode and other measures were computed and described in statistical terms. The amplitude-duration plots relate the frequency and amplitude content of the phenomena (Fig. 3.26). These plots are significant because they always show particular trends for EEG and tremor under different experimental conditions. In order to show the similarities, particularly the phase correlations, between two phenomena, the duration-wave number characteristics, the phase differences and the accumulative average duration-wave number characteristics were plotted. These plots are particularly important to show the correlations between alpha waves and EOM tremor.

4.4 ALPHA WAVES AND EOMT

Supposing the eye-tremor hypothesis is true, there should be an intimate phasic, frequency and amplitude relationship between the alpha waves and the EOMT. They should also show similar changes under different tests. This proved to be the case. Two typical records of the two phenomena recorded simultaneously are shown in Fig. 4.14 and fig. 4.17. The similarities between the two phenomena are obviously striking. 20 sec epochs of the records were treated by the digital and the interval analysis approach respectively.

In the digital approach, the frequency spectra of the two phenomena show very similar profiles (Fig. 4.15). They both peak at 11Hz and have sub-maximal peaks at 1Hz. The delta, theta, alpha, beta and gamma rhythms are all alike for both phemomena. Their crosscorrelation coefficient shows a high value of +0.711 at zero delay (Fig. 4.16). The values of r are maintained at large values even at large delays which indicate a very good correlation between the phenomena. It merits to mention here that the alpha waves and EOM tremor are best correlated at zero delay(r maximum) and not at a delay of 50 msec as found by Lippold (1973). Actually, we found that in most of our studies, the two phenomena were in phase. This is likely because if alpha waves are generated by extra-ocular tremor, they should be occurring concomitantly and simultaneously, i.e.they should be approximately in phase. Any phase differences between them could only be explained by complicated and sophisticated pathways during their interactions. Anyhow, they are here shown to bear a constant phase relationship with phase difference approaching zero.

The interval analysis of the two phenomena is also gratifying. In the interval distribution plot, both show a dominant peak at 0.08 sec (duration) and a sub-maximal peak at 0.1 sec and are very similar indeed (Fig. 4.18). Their similarity is further shown in the duration-wave number plot (Fig. 4.19). The two profiles follow closely at small and large durations and even at abrupt changes (at wave numbers 5-8 in the figure). The duration variations of the phenomena are also shown to follow each other very closely in a well-patterned manner (Fig. 4.20). Aside from their striking similarity in appearance, they are actually varying with time in the same way . The well-shaped accumulative average duration vs wave number plot confirms this. Their phase differences are illustrated in the phase histogram (Fig. 4.21). More than 70 per cent of the observations have phase differences less than 10 msec. If they are two independent phenomena, how can all these be achieved ?

4.5 EXPERIMENTAL STUDIES OF BOTH PHENOMENA RECORDED SIMULTANEOUSLY

The correlation between the two phenomena is promising under normal conditions. Their variations with various peripheral conditions were then investigated. Supposing a strong correlation exists for all the tests, the eye-tremor hypothesis will thus be verified.

1. Oculomotor variables

A very attractive result appeared when the two phenomena were recorded under EO and EC conditions . This fundamental property of the alpha activity (maximum when EC and blocked when EO) is well known but only the eye-tremor hypothesis out of the so many can give a satisfactory explanation to it. However, the explanation is only valid when the eye-tremor also exhibits the same characteristics concomitantly. This proved to be the case. The eye-tremor is maximum when EC and blocked when EO, occurring concomitantly with the alpha waves. Similar profiles are also observed in their respective frequency spectrum. The dominant peaks for both occur at 10Hz when EC and at 2 Hz when EO. Their amplitude-duration plots are also similar with two district trends for the EC and EO conditions.

The Bell's phenomenon that there is a marked increase in alpha activity immediately after eye closure was also observed in the case of eye-tremor. The amplitudes are enhanced together with a slight increase in frequency. In addition, their waxing spindles were always initiated. The possible mechanism has already been discussed in section 2.6.2.

While alpha waves are induced by stroboscopic flashes, the same happens for EOM tremor. The "ringing effect" was also observed in the case of eye-tremor. Immediately after the flash, tremor waves continued for about 50 msec until a diminish of the spontaneous activity. After about 200 msec, the flash-induced wave trains appeared and lasted for about ten cycles. Both the phenomena were synchronised by the flashes and this synchronization indicates a close relationship between them. A possible explanation by the eye-tremor hypothesis is proposed in section 2.6.3.

The act of forcing the eye to its extremities produced a similar enhancement of the amplitudes as well as the abundance of both phenomena. In a series of fifteen experiments, an average of 63.68% and 64.43% amplitude increase as well as 16.2% and 16.4% frequency increase were observed for alpha waves and tremor respectively by forcing the eye upward. Forcing the eye to the right extreme or left extreme produced similar results but not so marked as the upward extreme.

When the eyeball rolls from one extreme to another, it was found that the eye deflections emerged in the eye-tremor recordings appeared to trigger both the alpha and tremor waves. Immediately after the eye deflection, both waves appeared concomitantly in waxing 'spindles'. The effect is only a momentary one and everything is normal again therafter.

Moreover, the effect of eye movements on alpha waves has also been noted by other investigators. Cooper <u>et al</u> (1974) reported that ocular tremor when EC of anxious patients and those with nystagmus, slow oscillatory movements during drowsiness, eyelid flutter accentuated by eye closure and REM during sleep were all reflected in EEG recordings as artefacts. Nevertheless, they were only treated as artefacts by other investigators. We found that single prods and imposing repetitive sinuisoidal or square-wave proddings on the eye produced alpha waves phase-locked to the prods. This effect is similar to that of prodding on finger tremor but it is the alpha waves that is affected this time. A close relation between the axial eye movement (that producing eye-tremor) and the waves is thus confirmed.

As a whole, the close resemblances of alpha waves and EOM tremor for the various oculomotor variables and that of alpha activity and axial eye movement for various proddings are strongly supporting the hypothesis. These intimate linkages between mechanical phenomena occuring at the eye and the electrical activities at the occipital scalp region are certainly mysterious for other hypothesis.

2. Mental task

Mental arithmetic and thinking were found to decrease the alpha activity and eye-tremor by a similar extent under the EC conditions. The EO conditions appeared to have no influence. During mental calculations, the subjects were instructed to perform a multiplication of two double-digit numbers. An average amplitude decrease around 40% were found for both phenomena. While some showed an increase and some a slight decrease in frequency, the average is a 5% increase for the phenomena. For experiments on thinking, the subjects were instructed to indulge on a problem, a matter or a puzzle (for instance, the Zeon's paradox in 2.6.9) for ten minutes and then relax ten minutes to 'blank' their minds. The cycle was repeated and an average result similar to that of mental calculation was obtained. It is interesting to find that even mental tasks produce similar effects on the two phenomena.

3. Other studies

Hyperventilation and ~~continuous~~ prolonged hyperventilation were found to enhance the amplitude and synchronization of both phenomena in a similar manner. During the tests, subjects were instructed to breathe as hardly and deeply as they can for one minute during and after which the alpha and eye-tremor records were obtained. An average of about 55% amplitude increase was found for both. The phenomena gradually returned to normal in about another minute in a similar way.

Other studies include the followings. Knee-jerk tests produced no influence on them. Fear reduced the amplitudes of both phenomena and similarly for anger. Sudden audio stimuli (by dropping something on the ground with a loud sound) enhanced both amplitudes by about 60% and increased the frequencies by about 20%. Nevertheless, the effect only lasted for a few cycles.

On the whole, the alpha activity and the EOM tremor were found to be nicely correlated throughout these general experiments. We are getting very close to the eye-tremor hypothesis now and a further step would be to alter the loop parameter of the ECM servo-loop. According to the hypothesis, both the ECM tremor and the alpha activity should be influenced and altered in the same way if the servo-loop properties were changed. If this happens to be the case, we can conclude that the hypothesis is well supported by the experiments discussed in the present work.

4.6 ALTERING LOOP CHARACTERISTICS OF THE ECM SERVO-LOOP

In the study of the origin of physiological tremor, we employed three approaches to alter the loop properties of the stretch-reflex servo-loop to test the stretch-servo hypothesis. These three approaches are certainly appropriate in the present case, they are:

1. interrupting the loop at a suitable point
2. changing the parameters of the loop
3. introducing various inputs, such as step functions into the loop

The existence of the servo-loop in the extrinsic ocular muscles has been identified in section 4.1. The characteristics of these loops can certainly be changed as in the case of physiological tremor to study their effects on the occipital alpha activity and ECM tremor.

1. interrupting the loop: pressing the eyeball

It is found that pressing the eyeball produced similar effects on the alpha activity as inflating a sphygmomanometer cuff on finger tremor. This can be explained in terms of an imparement of blood supply to the extra-ocular spindles abolishing the eye tremor in the same manner as a blood-pressure cuff abolishes finger tremor (Lippold 1970). This in turn causes impairment of the sensitivity of the extra-ocular spindles and thus a reduction in the overall loop gain of the ECM servo. A decrease of ECM tremor and hence alpha activity thus results. During the experiment, the side of the subject was pressed by soft cotton pads for about half a minute during which records of EEG from both sides of the head were recorded. It is gratifying to find that the EEG of the same side of the pressed eye was affected to a larger extent. This again contradicts any possible neural mechanisms. Usually, alpha waves were depressed in about ten seconds after the press and recovered to normal in about half minute after the release of pressure on the eye. The applied pressure need not be large and no phosphenes should be produced.

2. changing the loop gain and loop delay

It is confirmed in section 3. 8. 2 that the delay in the loop determines the tremor frequency whilst the gain of the loop determines the tremor amplitude. Thus, by altering the loop delay and loop gain, consequent changes in amplitude and frequency should be observed in the occipital alpha activity, if the eye-tremor hypothesis is true. This is proved to be right.

a. altering the loop gain

i) Jendrassik's reinforcement

Alpha waves and ECM tremor were both enhanced by Jendrassik's reinforcement and other muscular effects including pinching and clenching. This is interesting as manoeuvres occurring at the limbs affect both phenomena inside the head to a similar extent. The manoeuvre activating the gamma nerve fibers which innervate the spindles increases their firing rates. The increased fusimotor outflow irradiates to other muscle groups and hence the ECM tremor is enhanced. This shows that whenever a muscle is strongly contracted by voluntary action, tremor in other muscles is also enhanced. The increase in extra-ocular muscle tremor results in a similar increase of occipital alpha activity. They were found to increase by about 50% on the average of 30 trials. Pinching and clenching were also found to enhance both phenomena by a similar extent and in the same way as the Jendrassik's manoeuvre.

ii) Fatigue of extra-ocular m uscles

Fatigue of eye muscles was found to increase the occipital alpha activity. It has been demonstrated in section 3. 8. 2b that fatigue of a muscle enhances its tremor amplitude. This should be also true for the extra-ocular muscles. Hence, fatigue of these muscles should lead to an increase in the alpha waves. This proved to be the case. The extra-ocular muscles were fatigued by instructing the subject to concentrate on reading continously for several hours or to move his eyeballs from side to side until the eye muscles are 'tired' or to watch a TV film. The frequency spectra of the alpha activity before and after such actions are shown in Fig. 4.22. The marked increase in the dominant peak after fatigue of eye muscles can clearly be seen. Nevertheless, there is no considerable difference in all other frequencies, that is only the alpha rhythm is affected and not the other rhythm . This is a nice result in support of the interactions between the alpha rhythm and eye muscles and not the other cortical potentials.

b. altering the loop delay: warming and cooling the orbits

It has been pointed out in section 3. 8. 2a that cooling a muscle on lengthening its twitch-time lowers its tremor frequency and warming on shortening the twitch-time (i.e. the loop delay) increases the tremor frequency. We therefore expect the eye muscle tremor and hence the alpha waves to exhibit similar changes in frequency by warming or cooling the orbits. We found that this is true. Alpha frequency could be varied between 9 to 12 Hz by cooling (5°-10°C) and warming (42°-45°C) the orbits (and this the extra-ocular muscles) respectively. The result obtained is similar to that of Lippoid (1970d).

We developed a relatively simple technique to support Lippold's results. The set-up is shown in Fig 4.5. A bath and circulator was used to provide a controlled superfusion of orbital regions with cold (5°-10°C) or hot (42°-45°C) water inside the large 'goggle'. The arrangements were found to introduce no discomfort to the subject. There is no water leakage in the large 'goggle' and no negative pressure is necessary. The experiments were carried out in the following sequence: 1) cooling and warming both orbits respectively, 2) cooling one orbit while warming the other, and 3) the reverse of (2). The results are shown in Fig. 4, 23, and Fig. 4, 24 respectively. It was found that when both orbital regions were cooled from 24°C to 5°C, the frequency of the alpha rhythm decreased, on the average, 1.75 Hz (16.28% decrease). When the temperature of the orbital regions were then raised to 45°C, an average alpha frequency increase of 2.1 Hz (23.20% increase) was obtained. Experiment two was then done on a subject. When the left orbital region was warmed to 43.5°C and the right one cooled to 9°C from the room temperature of 24°C, it was found that the alpha frequency of the warmed side raised 0.75 Hz and that of the cooled side decreased 1.1 Hz. The folow of warm and cold water was now reversed so that the left eye was at 9.5°C and the right one was at 42°C, the alpha frequency of the left side decreased 2.15 Hz while that of the right side increased 1.4Hz.

It is difficult to conceive an explanation for such frequency shifts based on the synchronous beating of the occipital cortical neurones. Nevertheless, the eye-tremor of the time delay in the extra-ocular servo-loop which is altered by the warming and cooling of the eye muscles. In addition, as the optic nerve is generally distributed to both occipital lobes, it is not possible to explain the effects localizing to one side of the hemisphere on in terms of neural mechanisms. No control is actually required in this experiment since Lindsley in 1974 reported that when the body temperature is elevated by fevers or artificially by diathermy treatments, the alpha frequency is elevated by 1 or 2 Hz and similarly it may be lowered by severe cooling.

3. introducing various inputs into the loop

   a. Polarization of the orbits

   Lippold (1973) described an ingenious method to increase the occipital alpha activity by passing a small polarizing current through the orbit. We repeated his experiment by placing the electrodes just below each eye-brow (positive) and on the palm (reference). A polarising current of 0.5 to 1.5 mA generated by a battery of 18V and a resistance box was passed between these electrodes. The currents were gradually increased to the desired value (different for each subject) from zero and good electrode-skin contacts were prepared such that the subject felt no discomfort. If not, the subject would suffer much and would not stand the experiment. After about half an hour, the alpha activity could be observed to increase. The increase is chiefly located in the alpha rhythm and less for the other rhythm.

   Better synchrony also resulted. The alpha activity gradually returned to normal after about an hour which depended on the time of current passage. This experiment shows that alpha rhythm can be enhanced by passing current through the eye which serves as an augmentation of the CRP of the ~~size~~ eye and thus the electrical potentials of the alpha waves are increased.

b. prodding the eyeball

In section 3. 8.3, it has been demonstrated that finger tremor could be induced by prodding (2mm, 30msec.) and were phase-locked to the mechanical input as in an underdamped servomechanism. The prod-induced tremor waves lasting for a few cycles has larger amplitudes but same frequency as the normal ones. Alpha waves would thus be expected to be induced by prodding the size in exactly the same manner as physiological tremor supposing the eye-tremor hypothesis is true. Lippold (1973) using averaging techniques, was able to show that the occipital waveforms generated by prodding would summate. This indicates the alpha waves induced by single prods were phase-locked to the mechanical input. Besides, they were found to have the same frequency as the normal waves and appear to have a better synchrony. However, prodding the other parts of the face other than the eye showed no such results (control experiment). When repetitive sinuisoidal proddings were applied to the subject's eye in the optical axis, the occipital potential waves were found to bear a constant phase relation to each prod. This synchronizing effect was also observed for repetitive square-wave prods. The alpha waves, clearly phase-locked to the various mechanical stimuli applied at the eye, are almost certainly the electrical concomitant of the ECM tremor. The proddings inducing phase-locking tremor waves of the eye muscles produced similar effects on the alpha waves. This is certainly a support of the eye-tremor hypothesis.

The experiments on altering the ECM servo-loop characteristics finished with most gratifying results. Occipital alpha activity was shown to vary with the various tests as expected by the eye-tremor hypothesis. Thus, it is quite safe to conclude here that the hypothesis is well supported by the experiments carried out in this chapter.

4.7 THE ROLE OF THE STERNOCLEIDOMASTOID

EMG arising in the neck muscles has long been considered as contaminations of the EEG records. They are ignored as muscle potential artefacts and hence their effects have not been clearly investigated. We found that both the alpha waves and EOM tremor are actually affected in an interesting way by the sternocleidomastoid. It is known that when one sternocleidomastoid acts, it tilts the head towards the shoulder of the same side and it also rotates the head so as to carry the face towards the opposite side. Inasmuch as the occipital alpha activity is affected by eye-tremor of the same side of head only, it will be interesting to find that the sternocleidomastoid has a similar effect too.

Subjects were instructed to rotate and tilt their heads during alpha and tremor recordings, relaxation periods of half minute each were allowed between each motion of the head. An average of 20 sets of results were obtained. When the head rotated to the right side, or tilted to the left side, the right and left occipital alpha waves and eye-tremor increased by about 116% and 50% respectively. Contrariwise, when the head tilted to the right side or rotated to the left side, the right and left occipital alpha and eye - tremor increased by about 47% and 115% respectively, Furthermore, the occipital alpha activity on the side with larger amplitude increase appeared to be much more spiky. These effects show an interaction dominated to one side of the head only as in the case of eye-tremor. Activation of a sternocleidomastoideus affects alpha waves and ECMT on one side of the hemisphere only whereas the much smaller amplitude increase on the contralateral side is in turn due to smaller activation of the other sternocleidomastoideus. This accounts for the exactly opposite results obtained by rotating and tilting the head respectively. It is exciting to find that the eye-tremor accompanies the alpha activities closely throughout all these changes. The two phenomena still show great similarities during the activations of the sternocleidomastoid (Fig. 4.25). The crosscorrelogram showed a considerable correlation between them ($r = 0.53$, $t = 9.84$) but a less well-shaped profile as in the normal case (Fig. 4.26). In addition, the maximum value of r is shifted from zero delay to a delay of -0.09 sec. The respective frequency spectra of EEG and ECMT both illustrate a dominant peak at 12 Hz and similar profiles at other rhythms (Fig. 4.27a, b) during neck turns. Their activity time-duration plots also show similar profiles and a dominant peak at 80msec (Fig. 4.28).

The relations between activation of the sternocleidomastoid and occipital alpha activity may be likely to suggest that the muscle action potentials in the sternocleidomastoid are summated or synchronized in some way during the eye muscle oscillations and thus are reflected in the scalp as alpha waves. Nevertheless, this is found to be unlikely since neck muscles do not vary in their contraction strength (or the tremor they display)with visual factors such as EO and EC. It will be shown in Chapter 5 that it is the CRP that is the source of the potential for the alpha activity. The sternocleidomastoid is thus unlikely to be responsible for even part of the alpha phenomenon but its activations show an interesting interaction on both the EEG alpha activity and the EOMT. Furthermore, this also serves as a test for the correlations between the two phenomena. A positive result again is obtained.

4.8 ALPHA TRAINING : EFFECTIVE FOR OCCIPITAL ALPHA AND EOMT?

Ever since Kamiya (1968) reported that subjects could learn to suppress or enhance the amount of alpha activity when receiving continuous feedback information, there has been much controversy over the strategies used by subjects to achieve alpha control and how do these strategies result in alpha control. The aspect of occipital alpha feedback training that has generated the greatest popular interest is the notion that this training induces a pleasant, quasi-meditational state of consciousness, known as the alpha experience. Of special interest here is the hypothesis that alpha feedback induces this phenomenological state by increasing the occipital alpha activity, which is purported to be directly associated with the 'alpha experience'. Frequently cited in support of this view are the increase in alpha strength during transcendental meditation (Wallace 1970) and the induction of 'alpha experience' during alpha enhancement training (Brown 1970; Nowlis and Kamiya 1970). However, reports from other laboratories do not conform to this simple and direct relationship between occipital alpha and the 'alpha experience' (Plotkin _et al_ 1976; Prewett and Adams 1976; Regestein _et al_ 1974; Walsh 1974).

In our study, with our experiments carefully controlled, we found that a subject when trained over a considerable period of time did show alpha enhancement by audio feedback. The subject was made familiar with the experimental conditions and procedures and must be relaxed without any sign of anxiety before the experiment which was carried out in a large quiet room without any disturbances. Audio feedback was achieved by the circuit shown in Fig. 4.6 The subject received continuous feedback information concerning his brain wave activity via the headphones. He was instructed to enhance his alpha activity and the increase in the alpha density is characterised by a certain nice sound in this headphone. We found that he can enhance his alpha activity by as much as 30% while the frequency spectrum remains unchanged. He reported certain oculomotor process during his feedback training. The training procecure comprises the followings : (1) it is explained to him that there are two control loops for the eye, namely, the feedback loop involving the visual cortex and the retina activated by visual fixation as well as the EOM servo-loop activated when no visual fixation was present (EC), (2) he then learns to activate the EOM servo-loop to enhance alpha under EC condition and (3) the training is carried out in dark and bright environment. His alpha enhancement is thus a result of the self-regulation of the gain of the EOM servo-loop. It is found that in order to activate the EOM servo, the procedure is somewhat similar to the training of not to look or not to have any visual fixation. In addition the training is found to be much more difficult in dark environment than the bright one. This is probably due to the fact that it is more difficult to control the act of visual fixation and no visual fixation in the dark which implies the environment is completely blank to the subject. These results are certainly in consensus with the eye-tremor hypothesis and may serve as some clues for the controversy over the strategies used by the subject to achieve alpha control and how these strategies result in alpha control. Our suggestion is based on some published works. Mulholland and Peper in 1971 had reported that autoregulation of the alpha rhythm by alpha feedback training is likely to be mediated by learned control of oculomotor and lens adjustment processes. However, we suggest that the alpha enhancement is more likely due to the trained control of the activation of the EOM servo-loop.

We have demonstrated that alpha training is effective in increasing alpha activity, but what about EOMT? It will be interesting to find that the EOMT can also be increased by the same procedure as alpha training. This is indeed true. We found that the same subject also exhibits enhanced EOMT by exactly the same training procedure, but this time listening to his tremor waves instead of the alpha waves. The enhancement is similar to that of the alpha activity. This result is certainly gratifying and the eye-tremor hypothesis is further supported by it.

4.9 CONCLUSION

The eye-tremor hypothesis is verified experimentally. The results can be summarised as follows :

1. The extra-ocular muscles are profusely supplied with muscle spindles and fusimotor innervations. There exists a servo-loop in the eye muscles. EOM tremor emanates from this servo-loop in exactly the same way as the stretch-servo hypothesis postulates.
2. EOM tremor was recorded by a new technique comprising the dynamic mike and its mountings in a diving mask. The excellence and reliability of this technique were fully appreciated.
3. To meet with all the properties of the waves and tremor, three different approaches (analog, digital and interval analysis) were employed in the analysis of the phenomena. They were found to be very successful.
4. A correlation study of the alpha waves and EOMT revealed their striking similarity. A very close frequency,

amplitude and phasic relationship was found. They were also shown to vary with time in the same way.

5. The close resemblance~~s~~ of alpha waves and EOMT for the various oculomotor variables (EO and EC, Bell's phenomenon, stroboscopic flash-induction, forcing the eye to extremities and eye rolling) and that of alpha activity and axial eye movement for various proddings are strongly supporting the hypothesis.
6. Other studies including mental task, hyperventilation and psychological factors also reveal the nice correlation between the two phenomena.
7. The EOM servo-loop was modified in various ways to study its effect on alpha activity. Modifications include interruptions, changing loop delay (reoponsible for tremor frequency) and loop gain (responsible for tremor amplitude) and introducing various inputs into the loop (corresponding changes in tremor).
8. Pressing the eyeball depressed alpha waves (similar to inflating an arterial cuff on finger tremor).
9. Jendrassik's and other muscular manoeuvres enhanced EOMT as well as alpha waves by a similar extent. Fatique of EOM also increased alpha activities.
10. Warming and cooling the orbital regions increased and decreased the alpha frequency respectively. When one orbit was cooled whilst the other was warmed simultaneously, the frequency of the alpha waves was lowered on the same side of the cooled eye and raised on the warmed side.

11. Passing small polarization currents (0.5-1.5 mA) through the orbit increased occipital alpha activity.
12. Various modes of prodding the eye produced alpha waves phase-locked to the mechanical inputs.
13. Activation of a sternocleidomastoid enhanced EOMT and alpha waves of the same side of the head similarly. Exactly opposite results were obtained by rotating and tilting the head respectively. EOM tremor was found to accompany alpha activity closely throughout all modes of sternocleidomastoid activations.
14. Alpha training was found to be effective for both occipital alpha and EOMT by audio feedback. Both phenomena could be enhanced and the enhancement was more efficient in a bright environment. A possible mechanism involving the trained control of the activation of the EOM servo-loop is proposed.

In light of the experimental results obtained, alpha waves and EOMT were very similar indeed and varied in the same way under the various tests as expected by the eye-tremor hypothesis. The verifications put forth to the hypothesis are all clear-cut and well-supported. Whether or not the hypothesis is true, one must accept that it is very difficult, if not impossible, to explain all these observations in terms of other hypotheses. A very strong evidence in support of the hypothesis is that occipital alpha activity entails corresponding changes when the properties of the EOM servo-loop are modified or altered. This can only be explained by a very close linkage between the alpha activity and the eye-tremor. A question will thus be raised; is it possible that the eye-tremor is generated by the occipital alpha activity instead of the reverse. This proved to be implausible as a step-wise displacement of the eyeball produced a damped train of tremor waves first (as demonstrated in the case of physiological tremor) before bringing forth the induced alpha oscillations. The reverse is absurd. Other alternations of the EOM loop characteristics, for instance, warming and cooling the orbits and pressing the eyeball, also confirm that the alpha activity emanates from the EOM tremor since changes in the parameters of the EOM servo-loop bring about corresponding changes in the alpha waves. On the whole, the close correlation between alp-ha waves and EOM tremor demonstrated in this chapter strongly supports that the alpha rhythm of the human EEG is in reality the electrical concomitant of EOM tremor. Thus, our next and last goal will be to find out the potential source for these cortical potentials which would be modulated by the EOM tremor and reflected in the occipital scalp region as alpha activities.

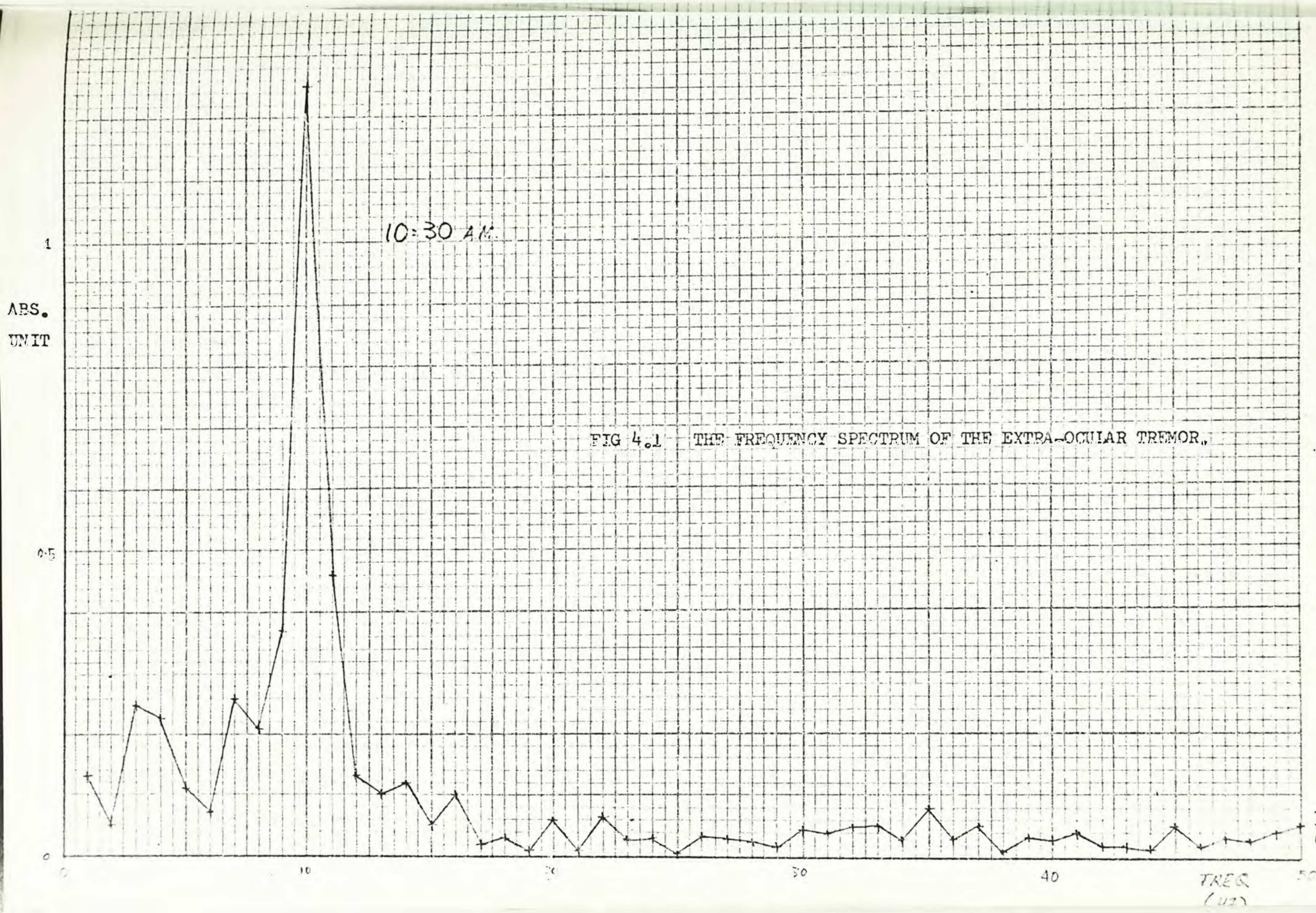


FIG 4.1 THE FREQUENCY SPECTRUM OF THE EXTRA-OCULAR TREMOR.

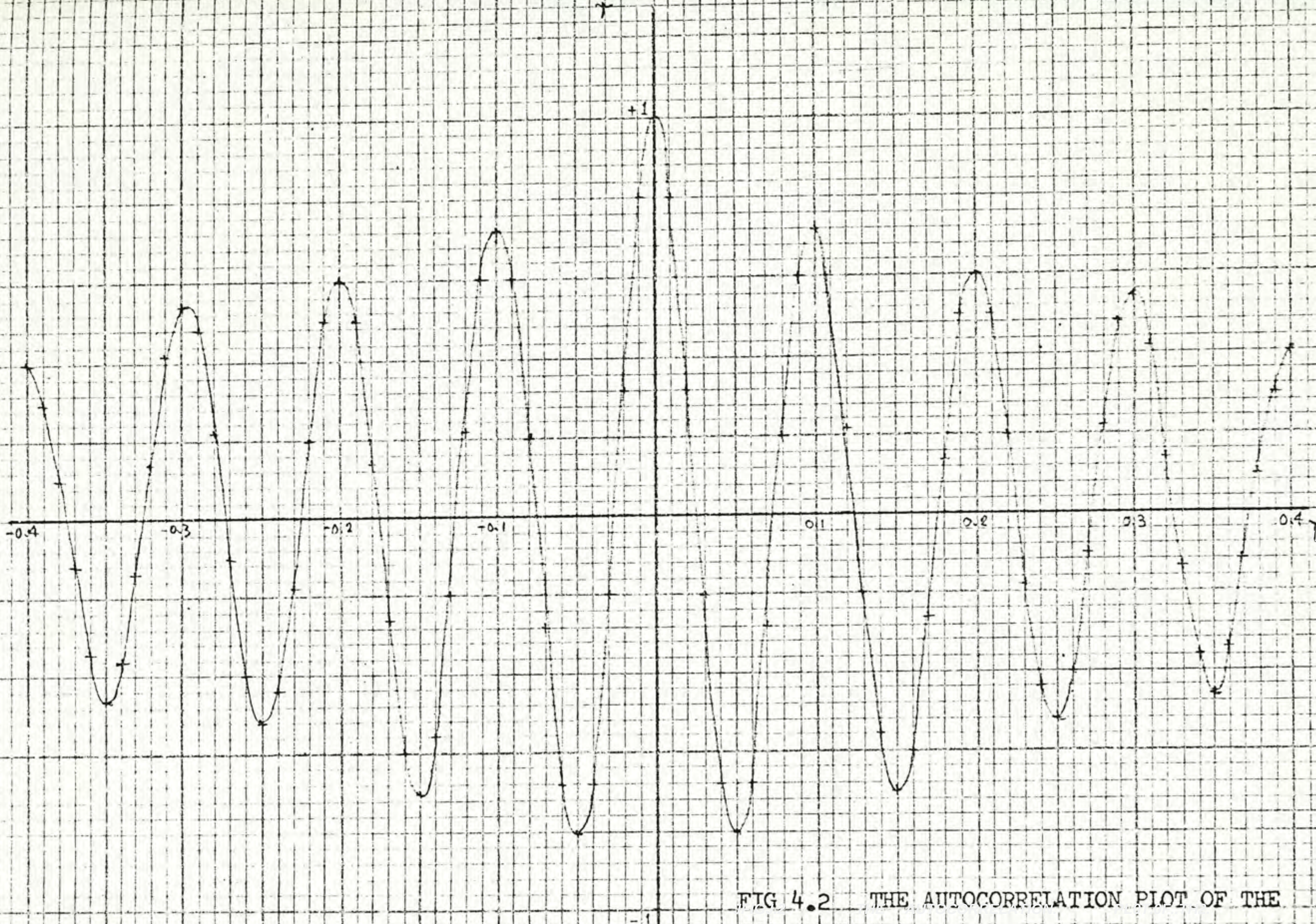


FIG 4.2 THE AUTOCORRELATION PLOT OF THE EXTRA-OCULAR TREMOR.

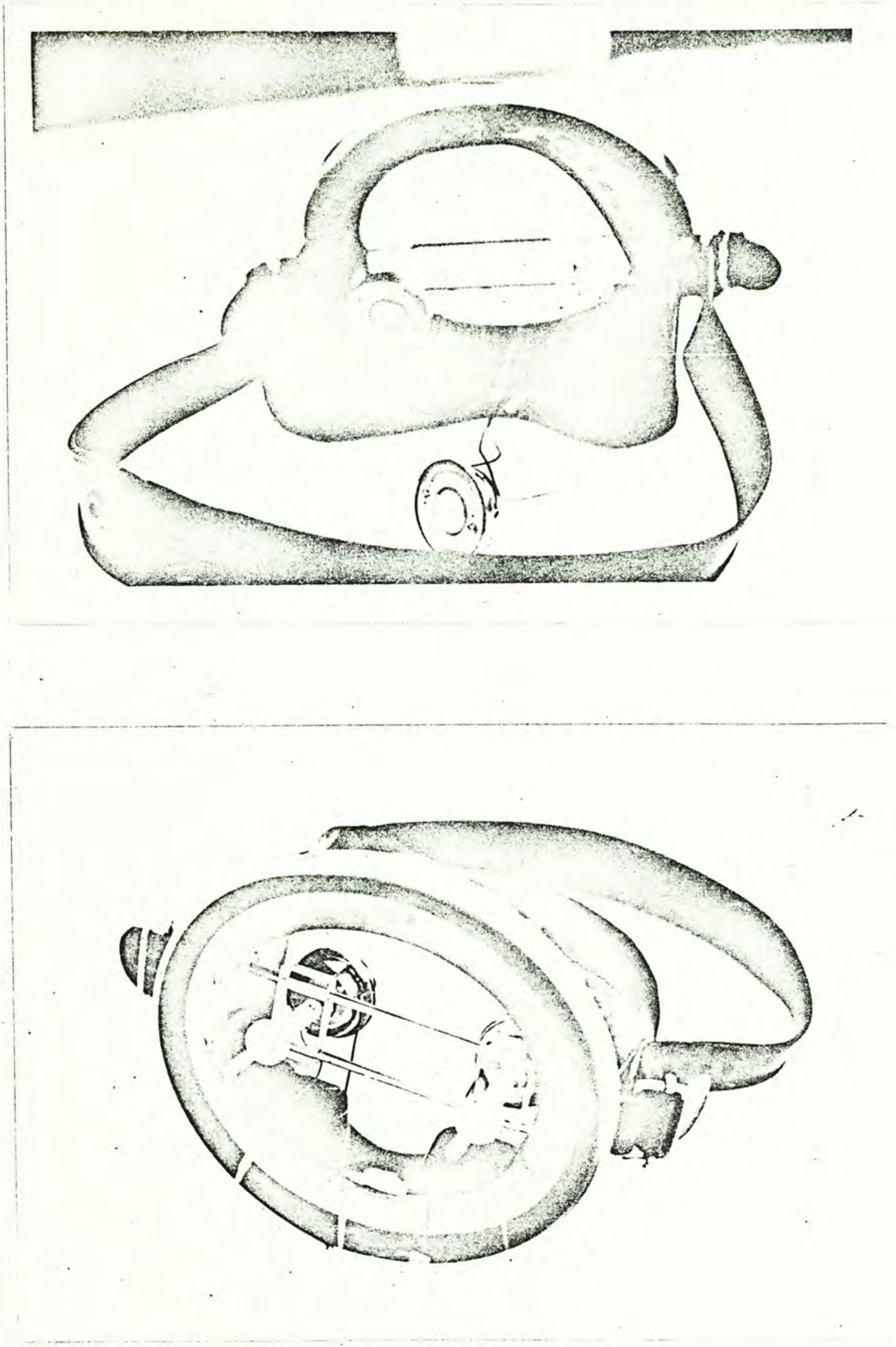
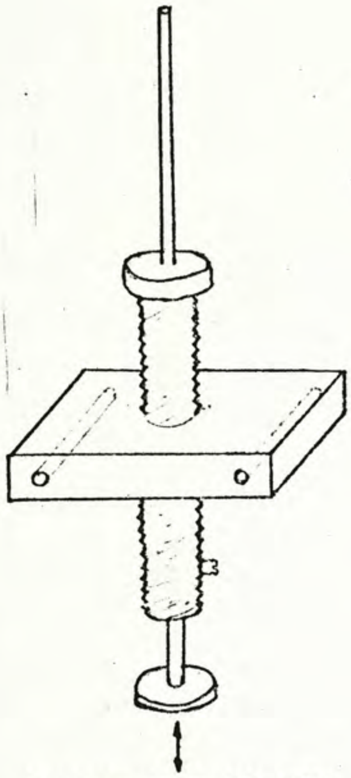
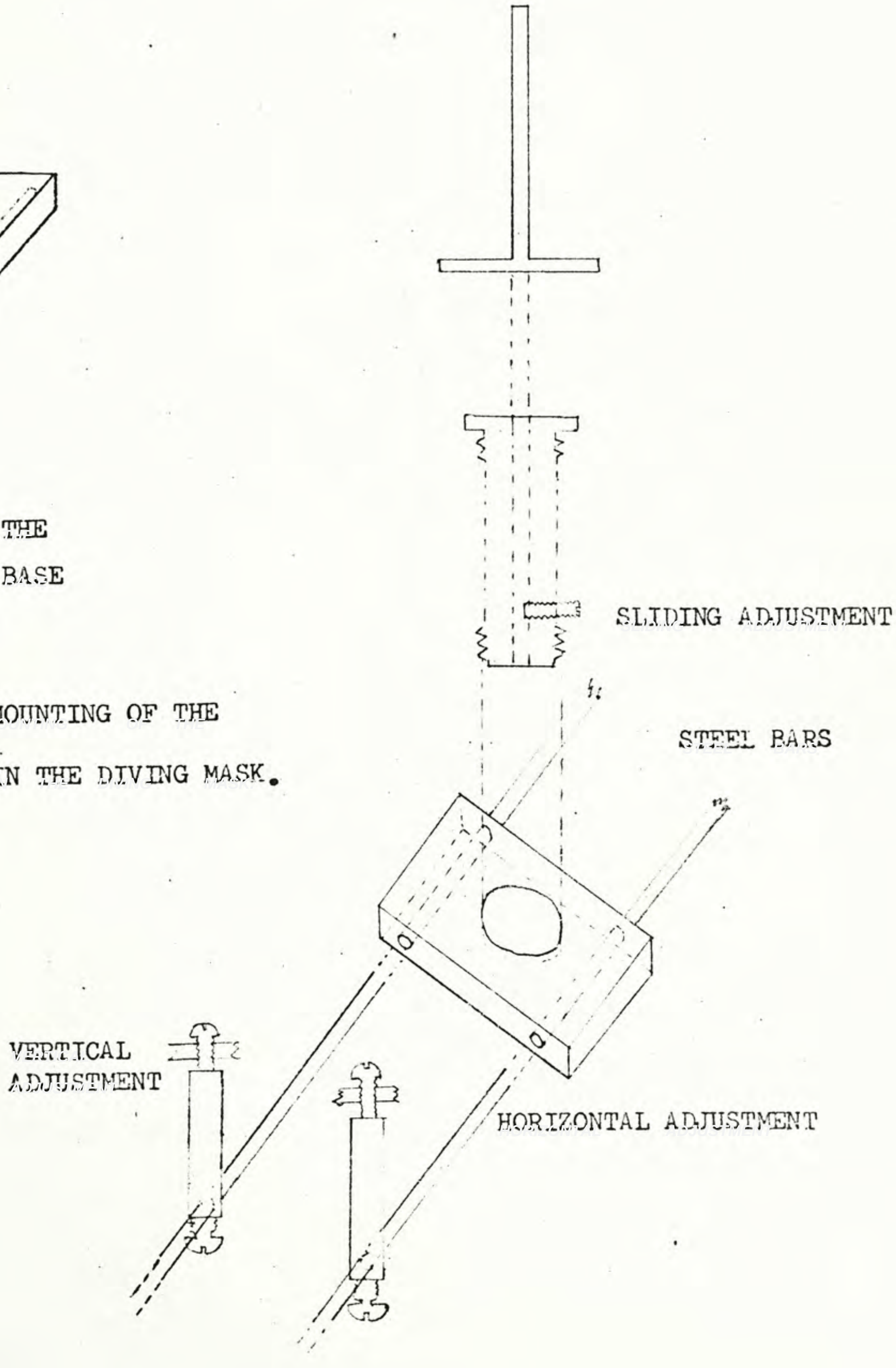


FIG 4.3 THE DYNAMIC MIKES AND THEIR MOUNTINGS IN THE DIVING MASK. THEY CAN BE ADJUSTED TO ANY DESIRED POSITIONS FOR EYE-TREMOR RECORDINGS.



ATTACHMENT OF THE
DYNAMIC MIKE'S BASE

FIG 4.4 THE MOUNTING OF THE
DYNAMIC MIKE IN THE DIVING MASK.



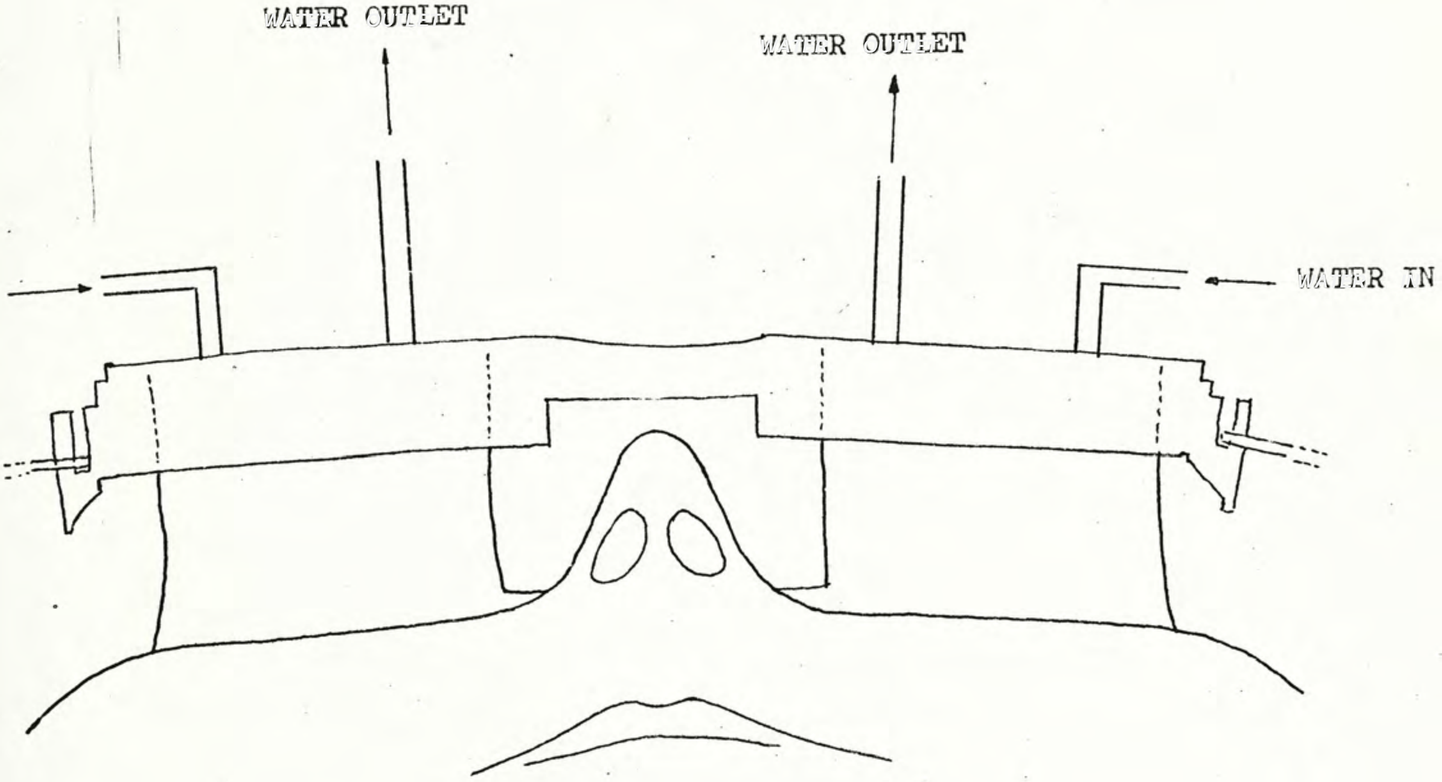


FIG 4.5 EXPERIMENTAL SET-UP TO WARM OR COOL THE ORBITS SEPARATELY OR TOGETHER. THE SET-UP COMPRISES MAINLY A 'LARGE GOGGLE', WHICH IS WATER-TIGHT.

Fig 4.10 Outputs of the analog analysing circuits

A :	chan 1	Right Occipital EEG	0.2v/div.	
	chan 2	Variance	20mV/div.	speed 0.2 sec/div

B :	chan 1	Right Occipital EEG	0.2v/div.
	chan 2	Freq-to-DC values	5v/div.
	speed	0.1sec/div.	

Note that the period of each wave is shown for both the slow wave and the alpha bundle and note their differences.

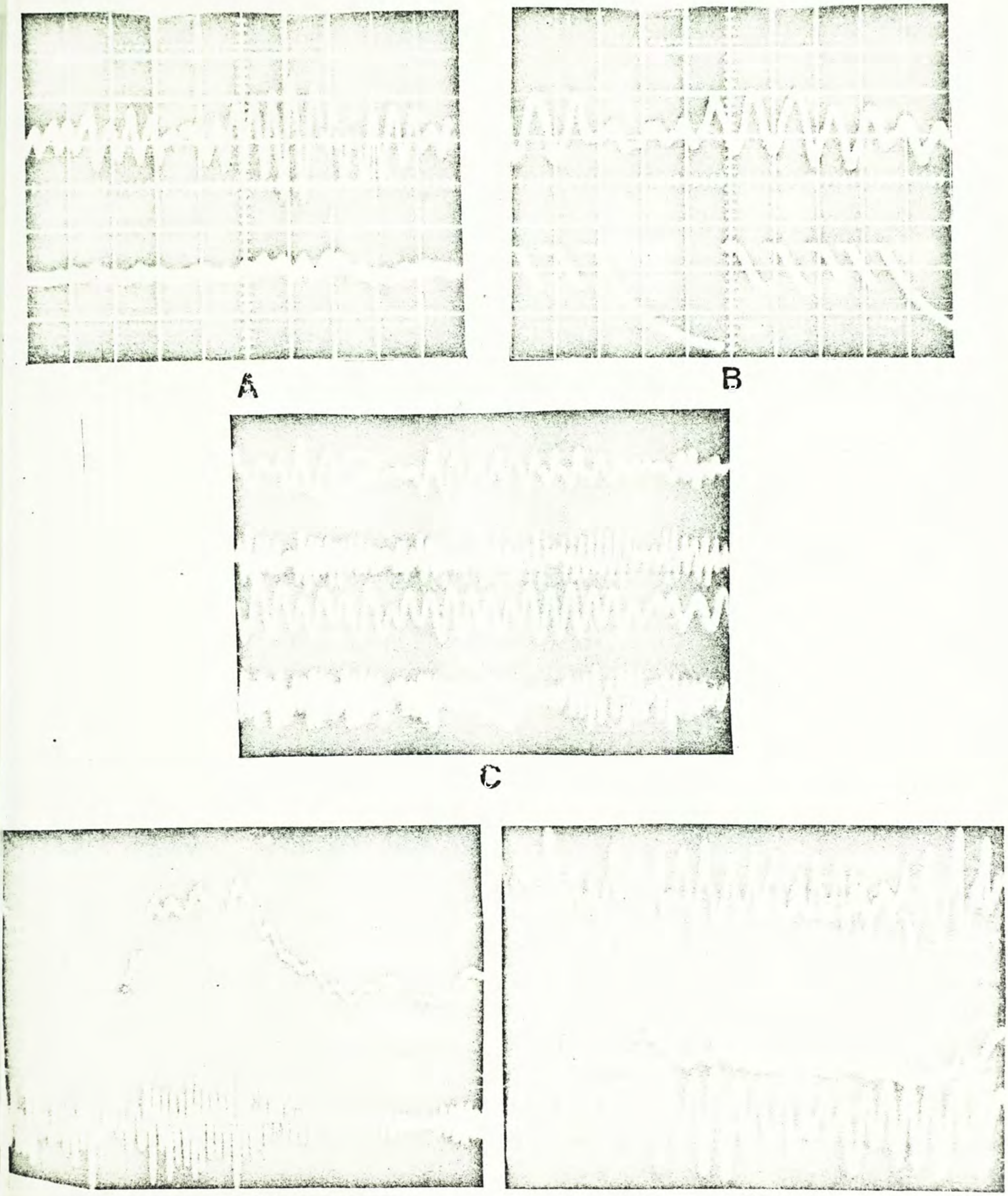
C :	chan 1	Right Occipital EEG	0.5v/div.
	chan 2	Right Occipital EEG	0.5v/div.
	chan 3	EOMT, right eye	1v/div.
	chan 4	EOMT, right eye	1v/div.
	speed	0.2sec/div for chans 1 and 3	
		0.5sec/div for chans 2 and 4	

Note the strong phasic relationships and the resemblance in their waxing and waning.

D :	chan 1	Average value	0.1v/div.
	chan 2	EOMT, right eye	0.5v/div.
	speed	0.5sec/div.	

Note the envelope of the signal is readily seen.

E :	chan 1	Right Occipital EEG	0.2v/div.
	chan 2	Phase-difference-to-DC values	1.5v/div.
	chan 3	EOMT, right eye	0.5v/div.
	speed	0.2sec/div.	



A

B

C

D

E

Fig 4.10 Outputs of the analog analysing circuits

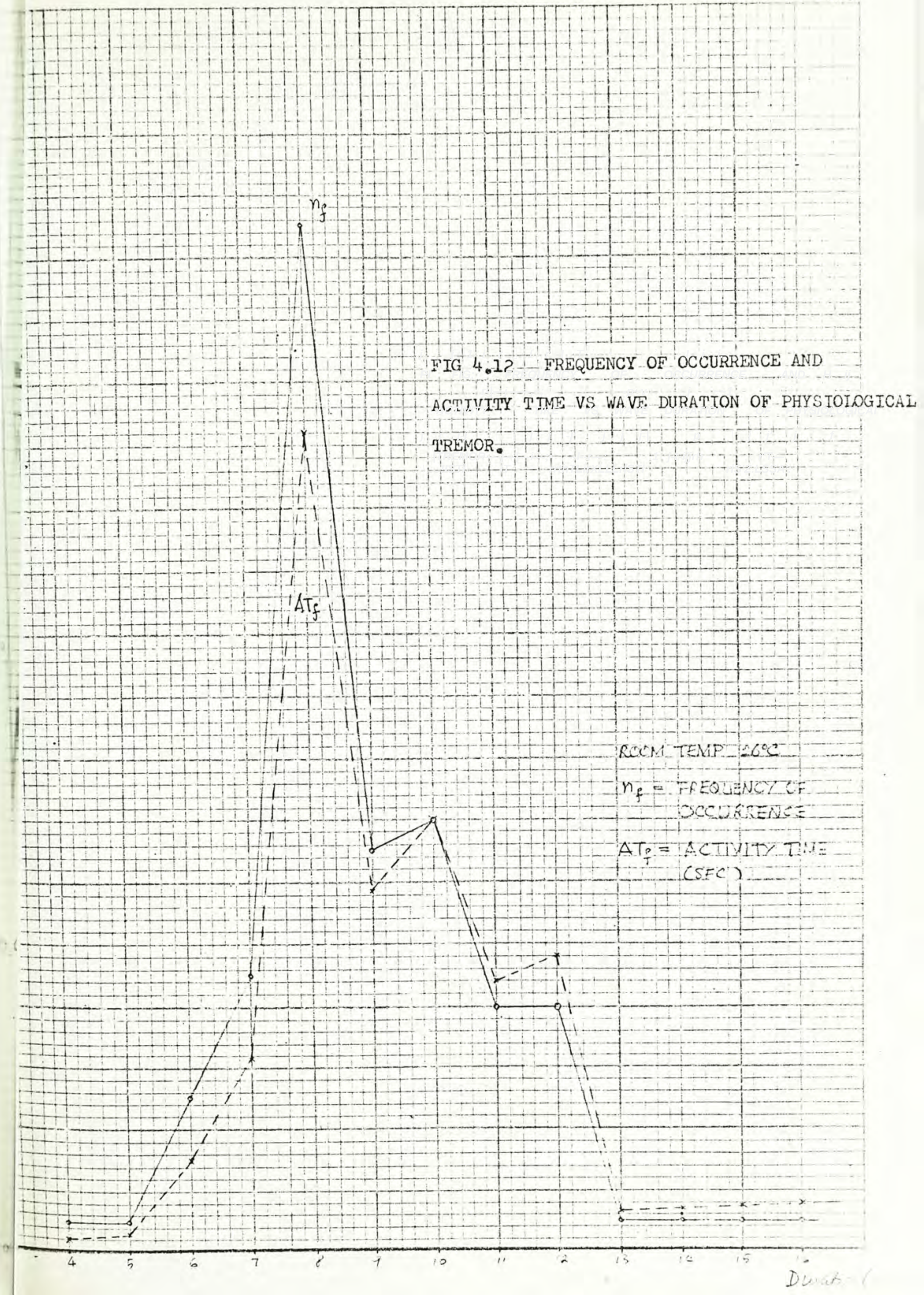


FIG 4.12 FREQUENCY OF OCCURRENCE AND ACTIVITY TIME VS WAVE DURATION OF PHYSIOLOGICAL TREMOR.

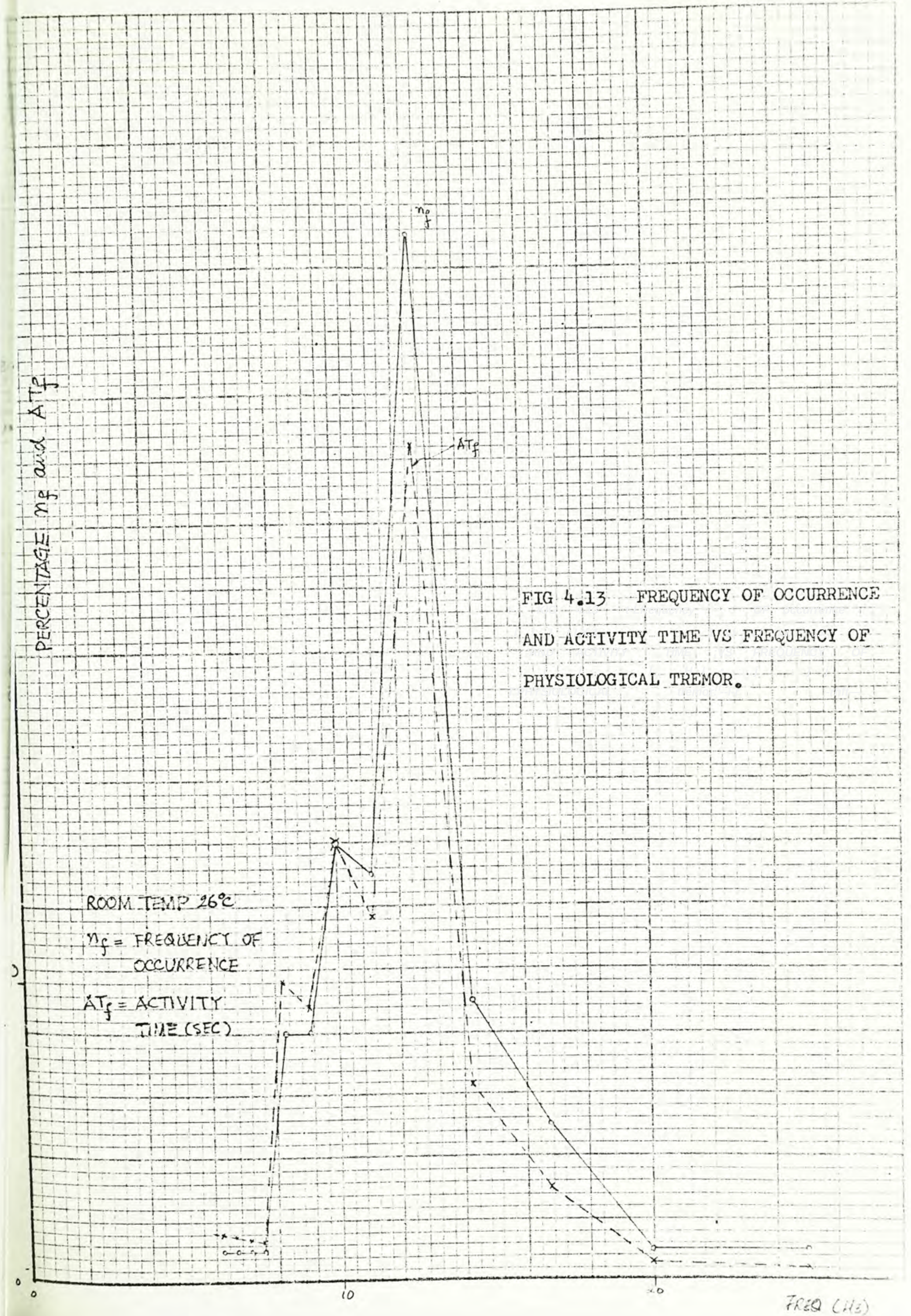


FIG 4.13 FREQUENCY OF OCCURRENCE AND ACTIVITY TIME VS FREQUENCY OF PHYSIOLOGICAL TREMOR.

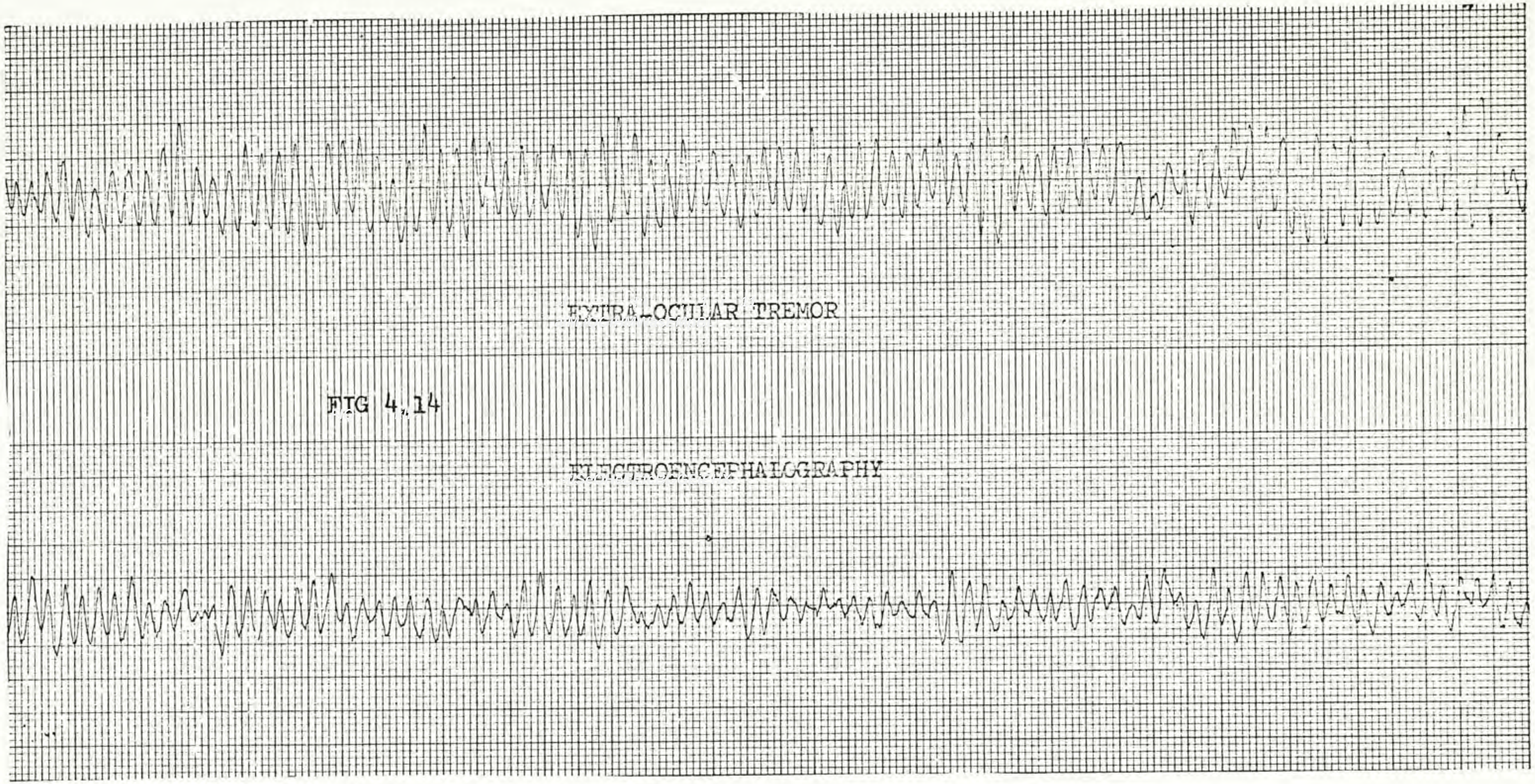


FIG 4.14

FIG 4.14 ALPHA ACTIVITY AND EXTRA-OCULAR TREMOR OF THE SAME SUBJECT RECORDED SIMULTANEOUSLY, 5 LARGE SQUARES = 1 SEC.

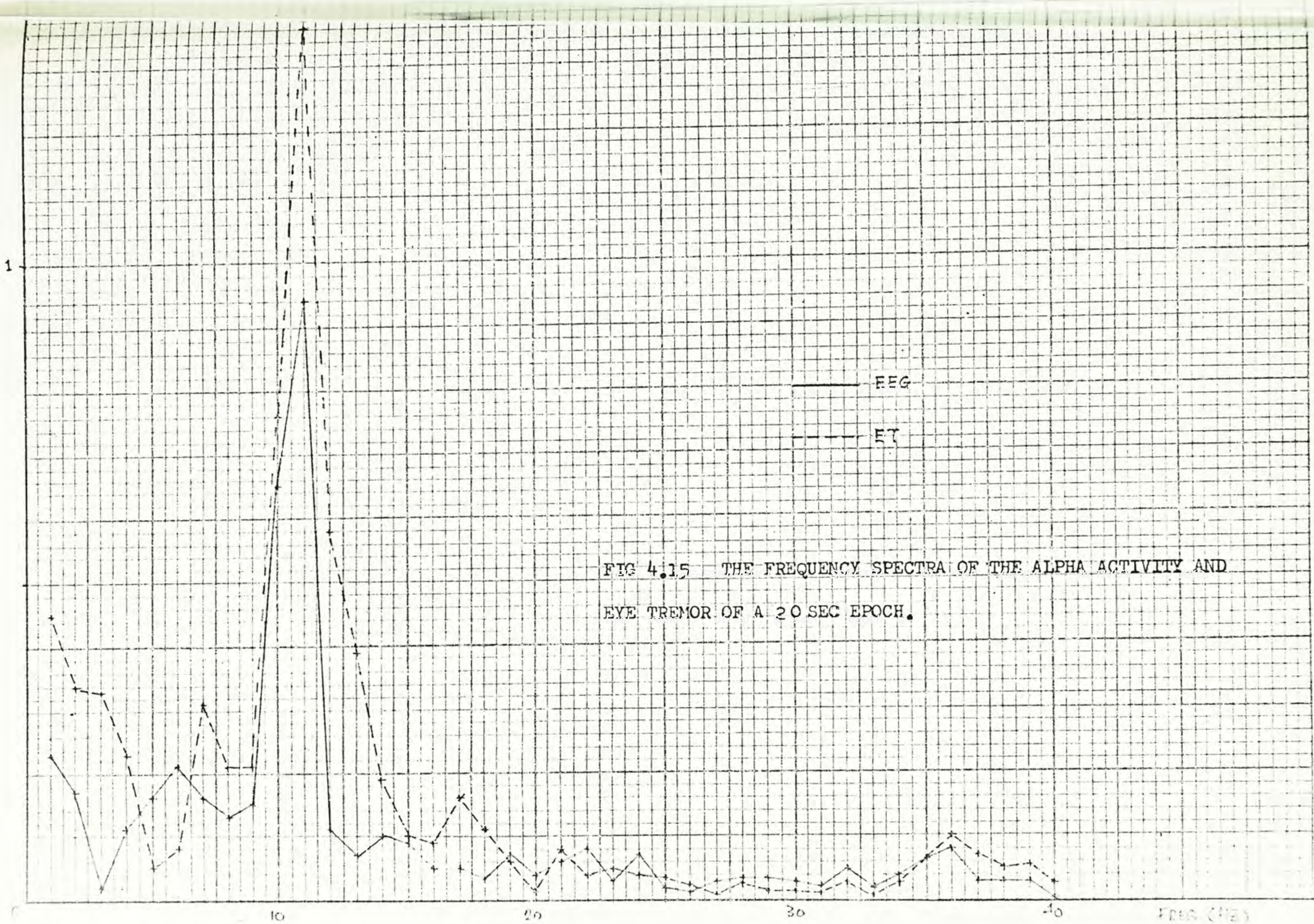


FIG 4.15 THE FREQUENCY SPECTRA OF THE ALPHA ACTIVITY AND EYE TREMOR OF A 20 SEC EPOCH.

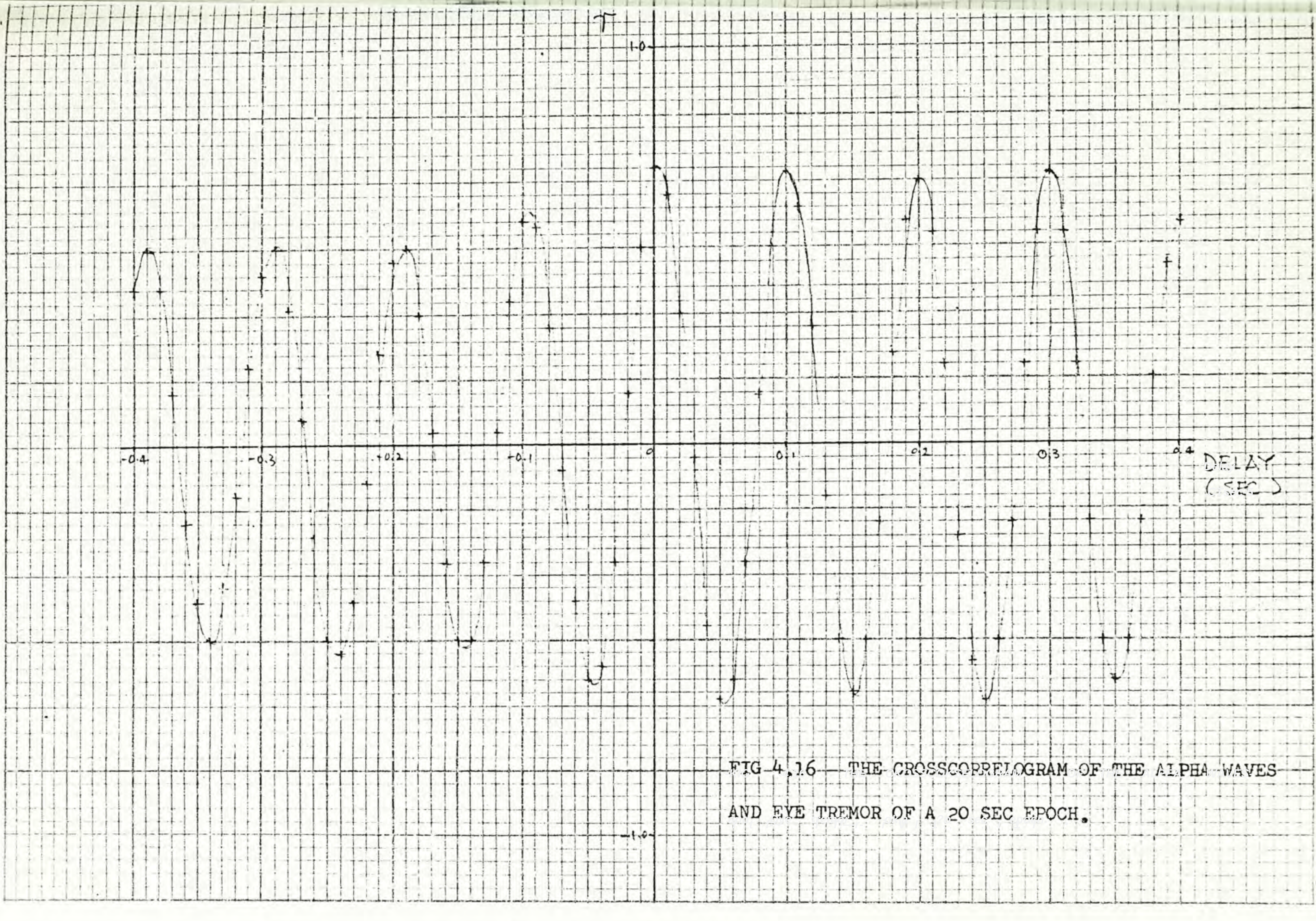


FIG 4.16 THE CROSSCORRELOGRAM OF THE ALPHA WAVES AND EYE TREMOR OF A 20 SEC EPOCH.

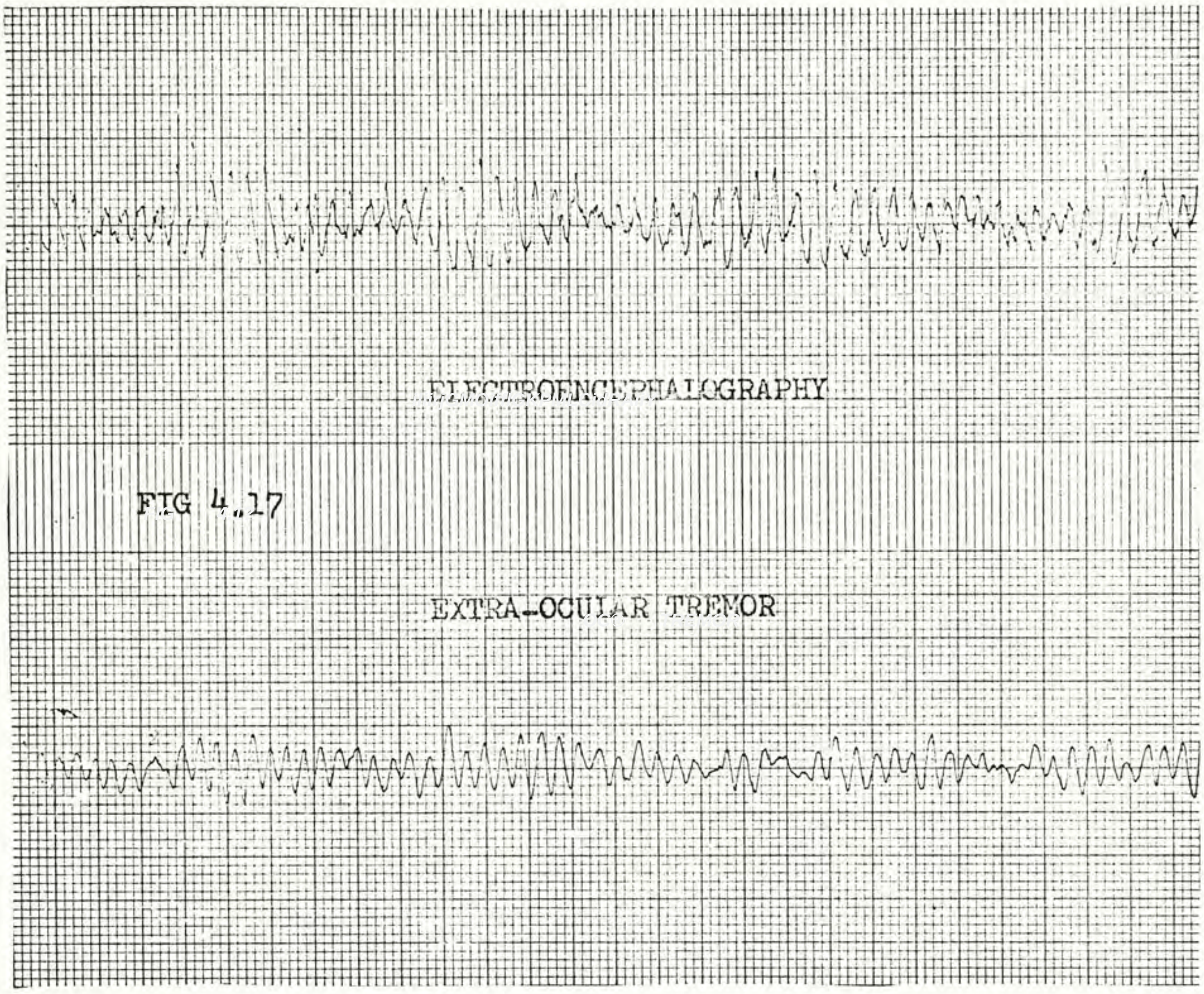
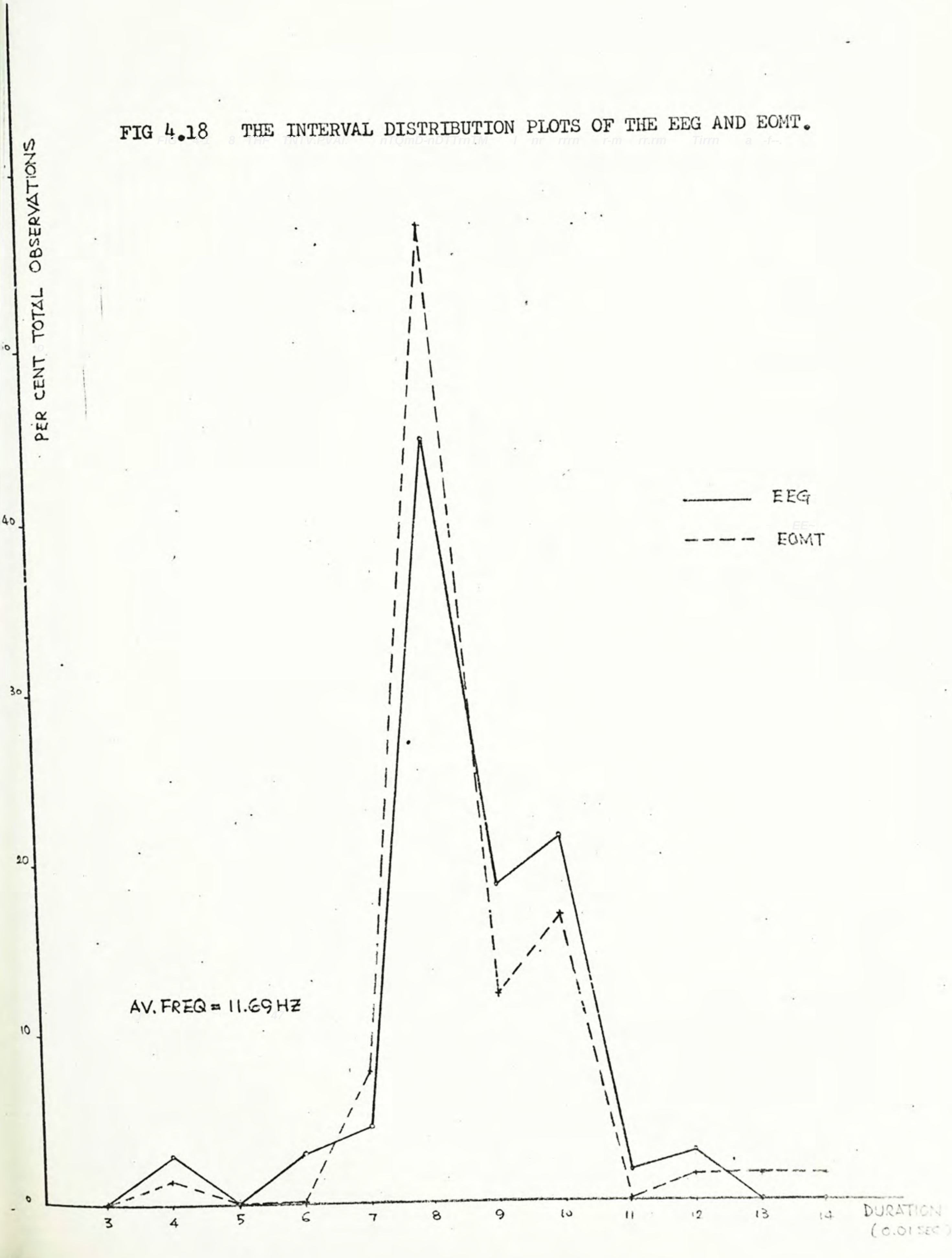


FIG 4.17 COMPARISION BETWEEN THE RIGHT OCCIPITAL ALPHA WAVES AND THE EXTRA-OCULAR TREMOR IN ANOTHER SUBJECT. 5LARGE SQUARES = 1 SEC.

FIG 4.18 THE INTERVAL DISTRIBUTION PLOTS OF THE EEG AND EOMT.



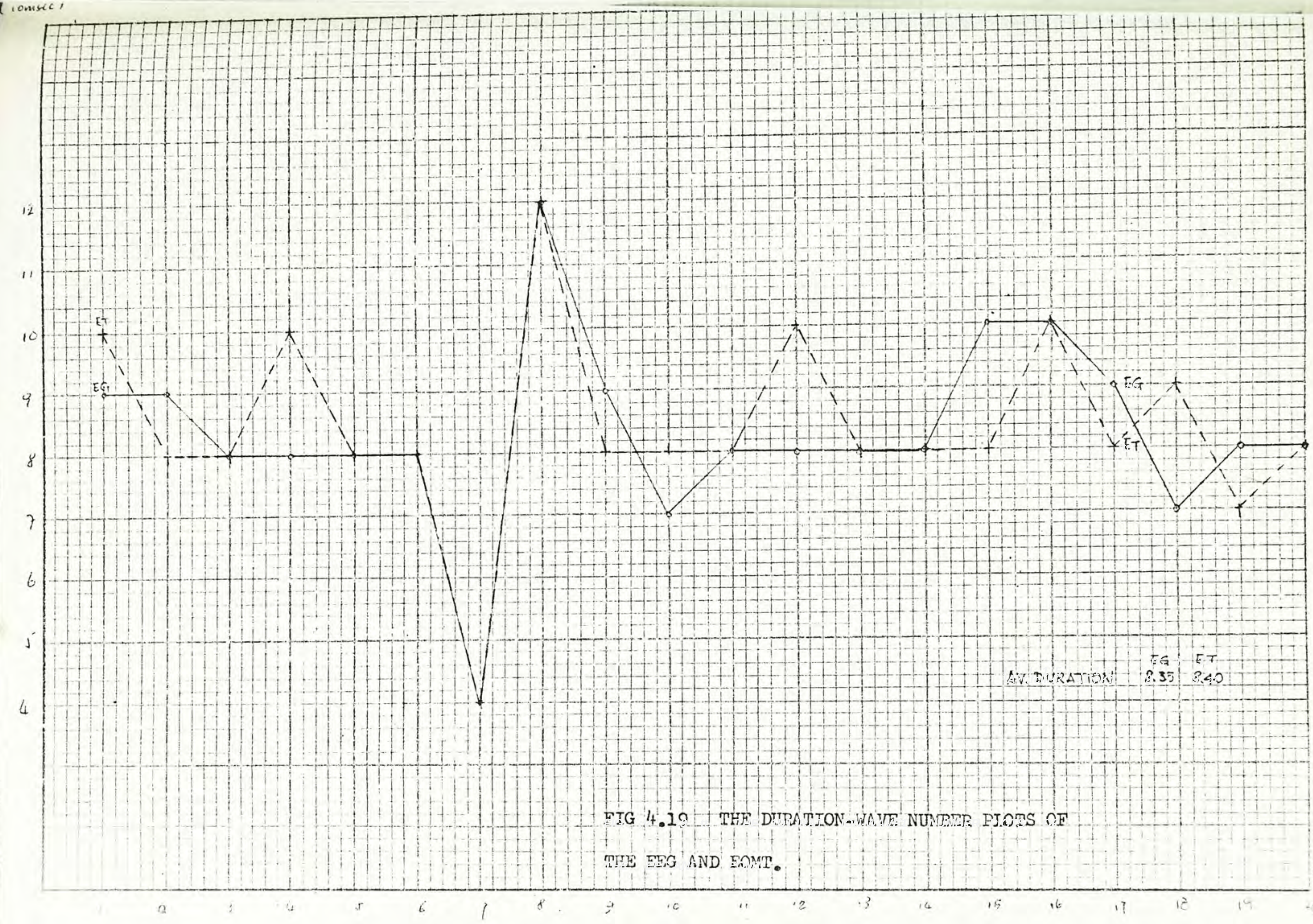


FIG 4.19 THE DURATION-WAVE NUMBER PLOTS OF THE EEG AND EOMT.

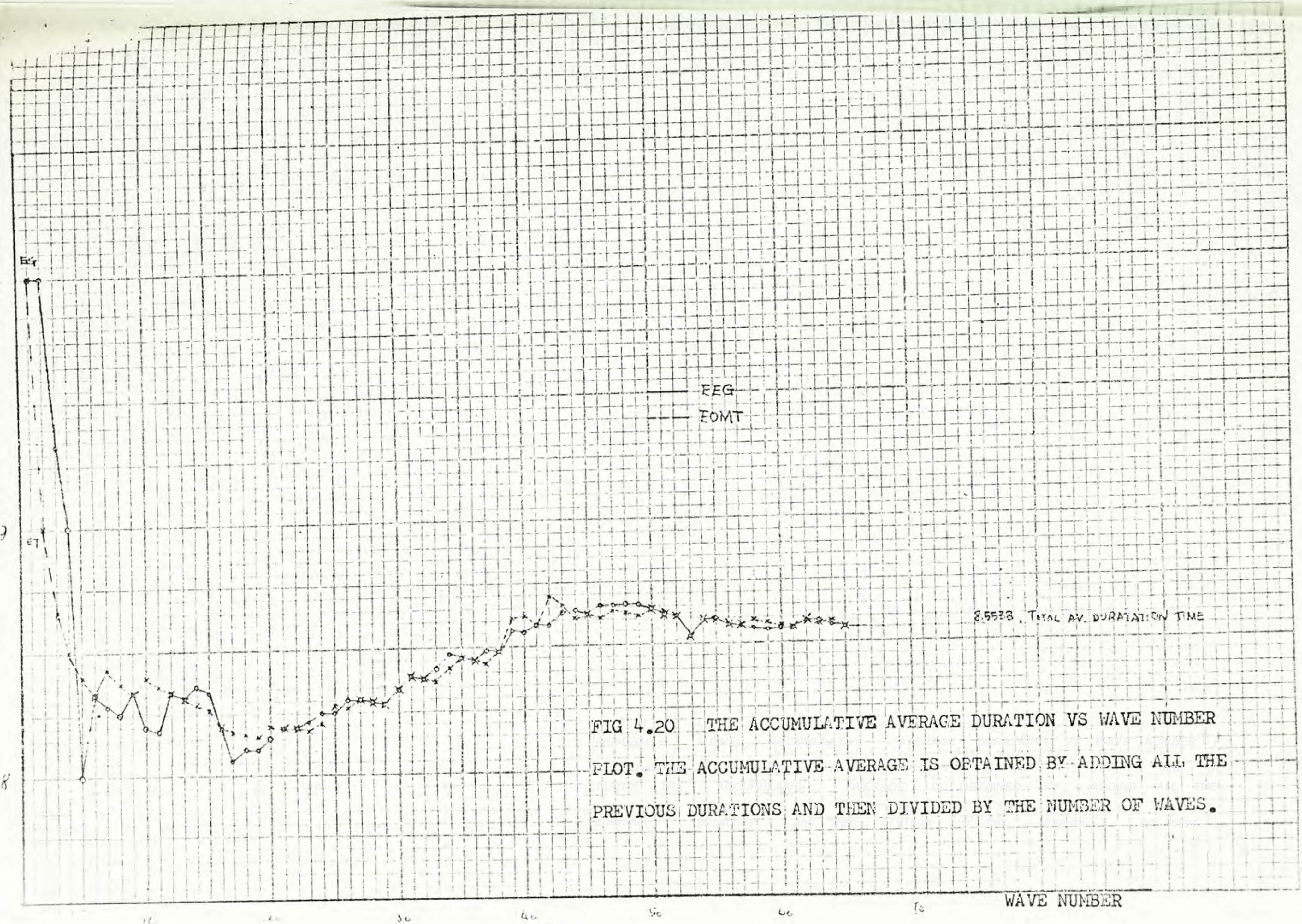


FIG 4.20 THE ACCUMULATIVE AVERAGE DURATION VS WAVE NUMBER PLOT. THE ACCUMULATIVE AVERAGE IS OBTAINED BY ADDING ALL THE PREVIOUS DURATIONS AND THEN DIVIDED BY THE NUMBER OF WAVES.

FIG 4.21 THE PHASE DIFFERENCE HISTOGRAM, INDICATING THE PHASE DIFFERENCES BETWEEN THE ALPHA WAVES AND THE EXTRA-OCULAR TREMOR.

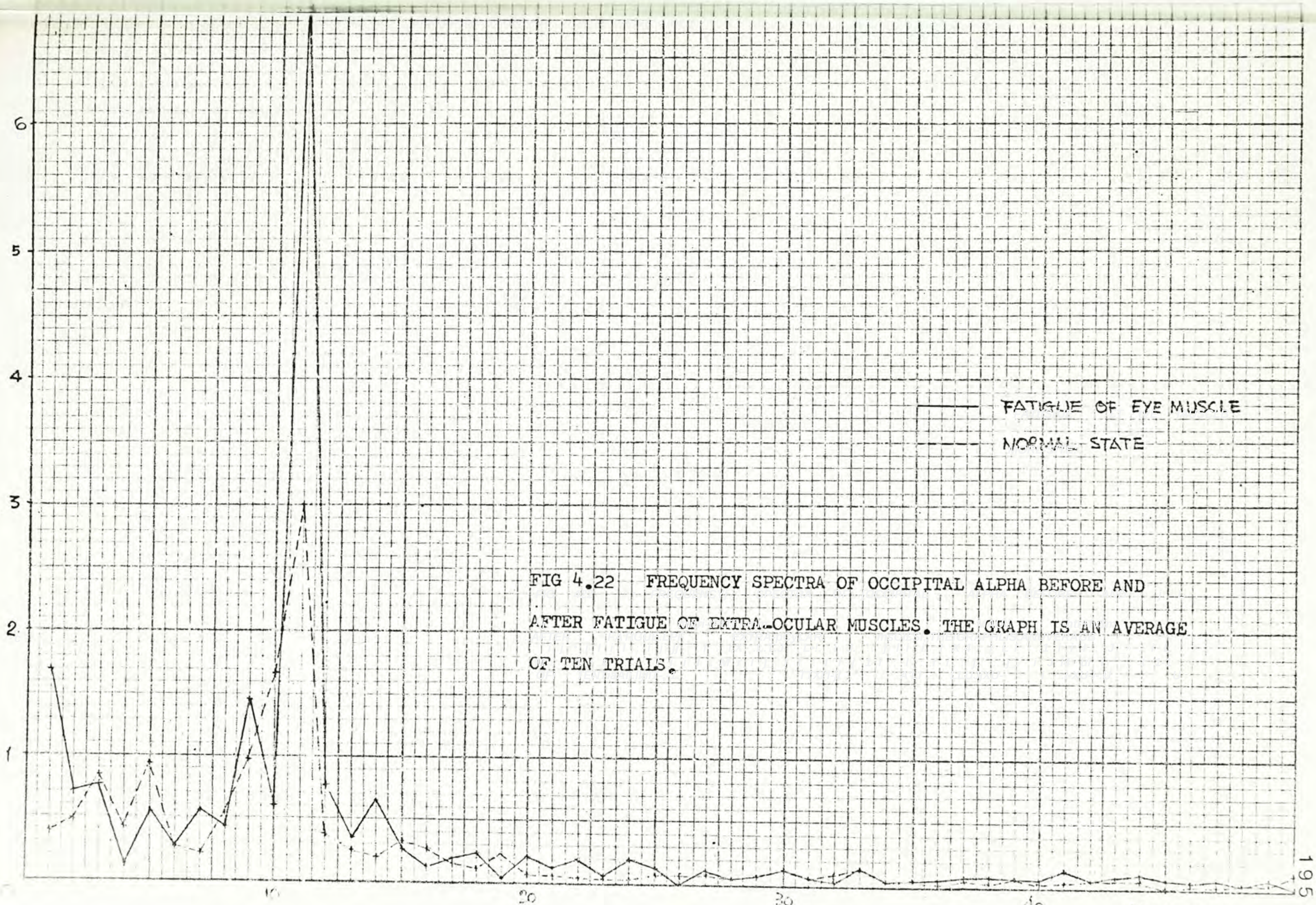


FIG 4.22 FREQUENCY SPECTRA OF OCCIPITAL ALPHA BEFORE AND AFTER FATIGUE OF EXTRA-OCULAR MUSCLES. THE GRAPH IS AN AVERAGE OF TEN TRIALS.

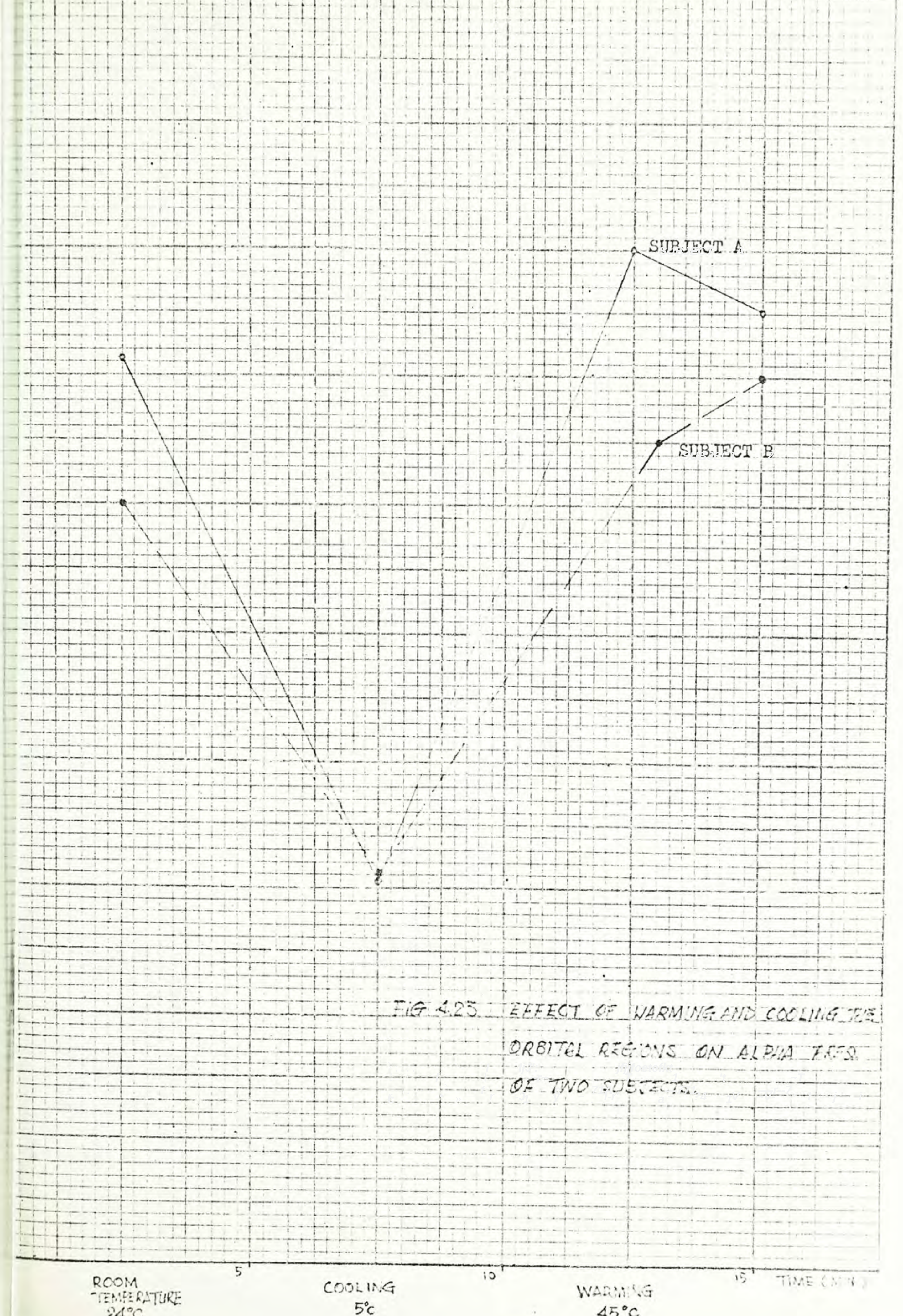


FIG 4.25 EFFECT OF WARMING AND COOLING THE ORBITAL REGIONS ON ALPHA FREQ. OF TWO SUBJECTS.

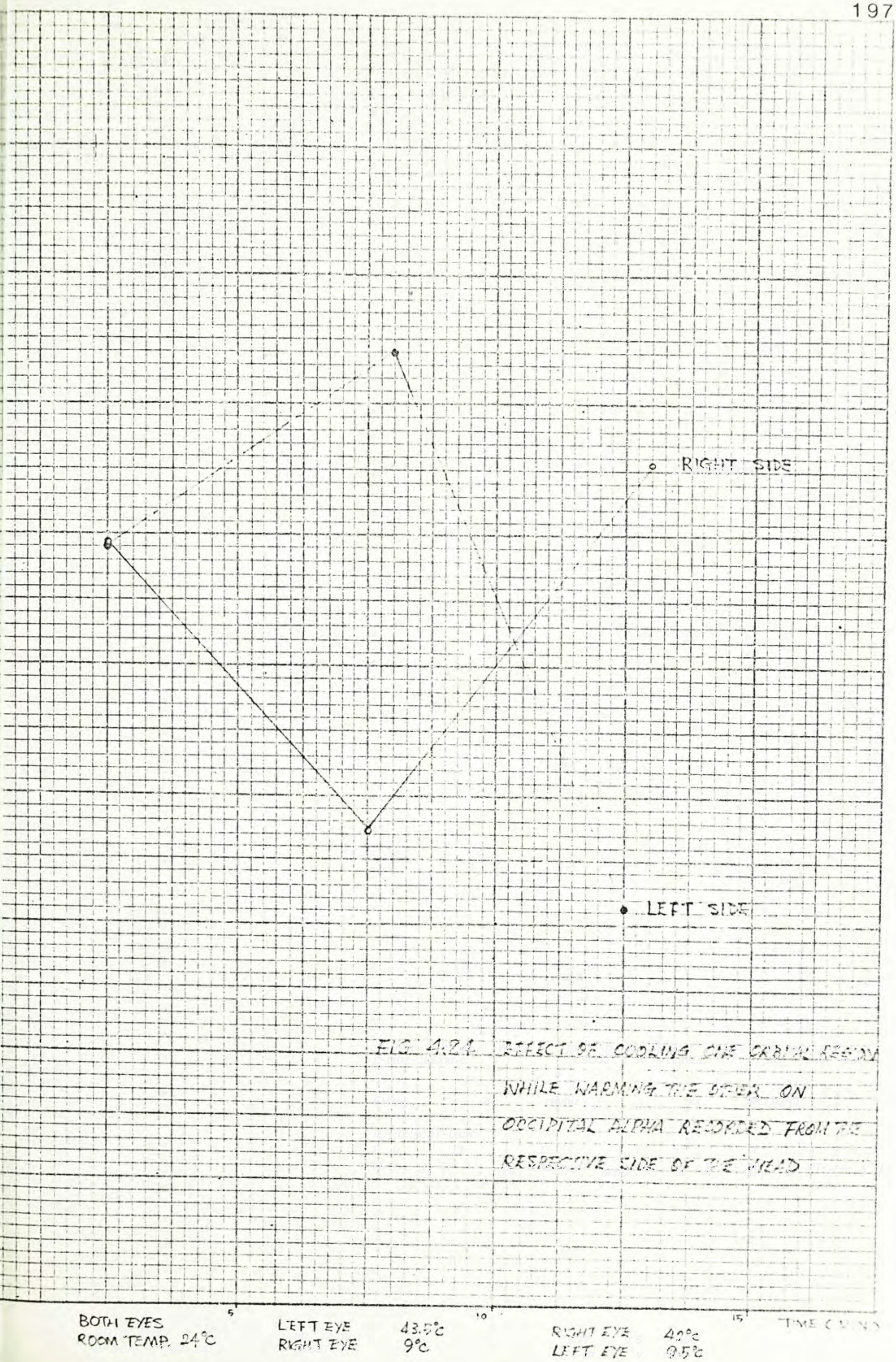


FIG. 4.24 EFFECT OF COOLING ONE ORBITAL REGION WHILE WARMING THE OTHER ON OCCIPITAL ALPHA RECORDED FROM THE RESPECTIVE SIDE OF THE HEAD

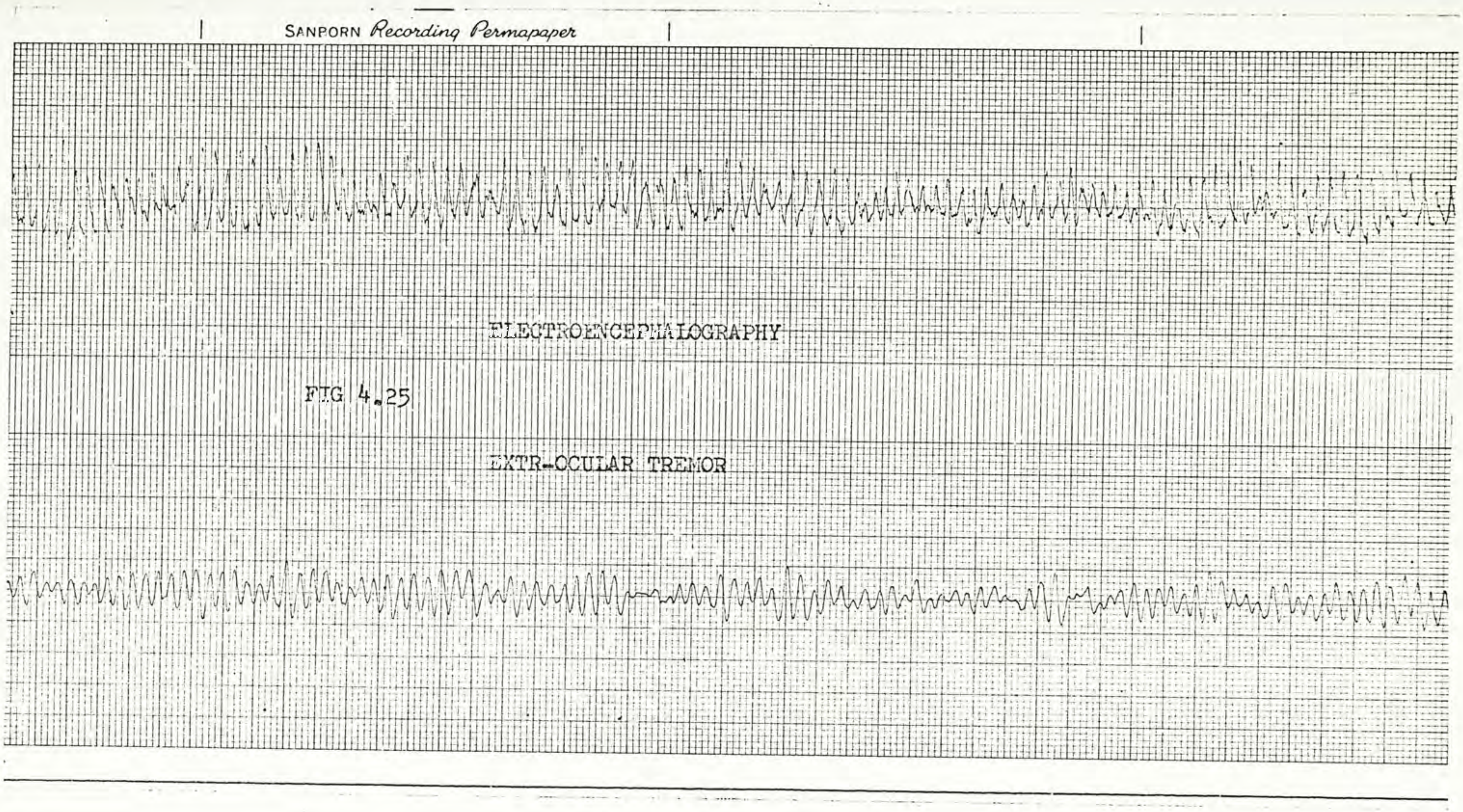


FIG 4.25 EEG AND EOMT RECORDINGS DURING ACTIVATION OF THE STERNOCLEIDOMASTOIDEUS. THE RECORD WAS OBTAINED WHEN THE SUBJECT TURNED HIS HEAD TO THE RIGHT SHOULDER. CHANNEL 1 IS THE RIGHT OCCIPITAL EEG AND CHANNEL 2 IS THE RIGHT EYE TREMOR. 5 LARGE SQUARES = 1 SEC.

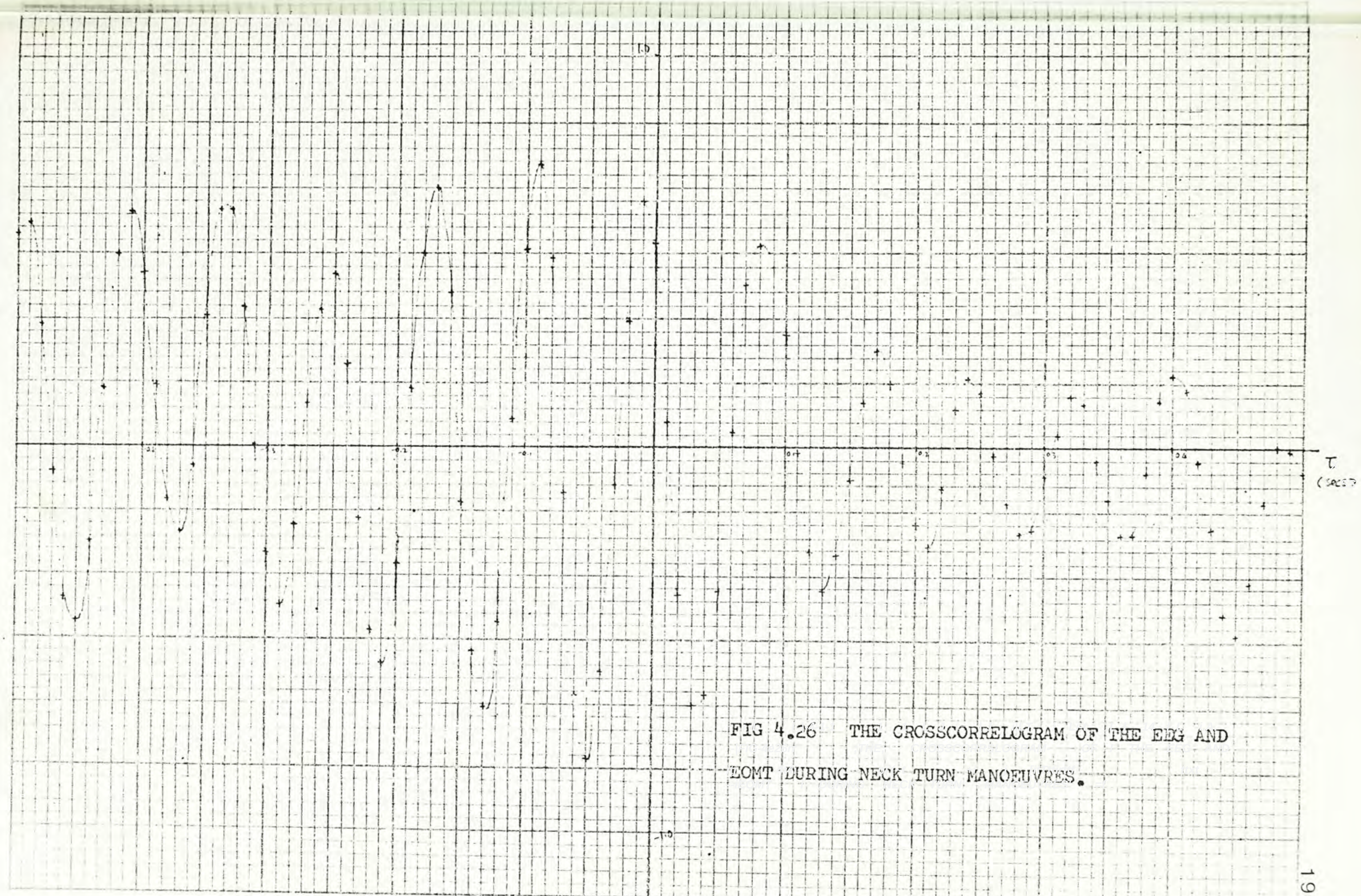


FIG 4.26 THE CROSSCORRELOGRAM OF THE EEG AND EOMT DURING NECK TURN MANOEUVRES.

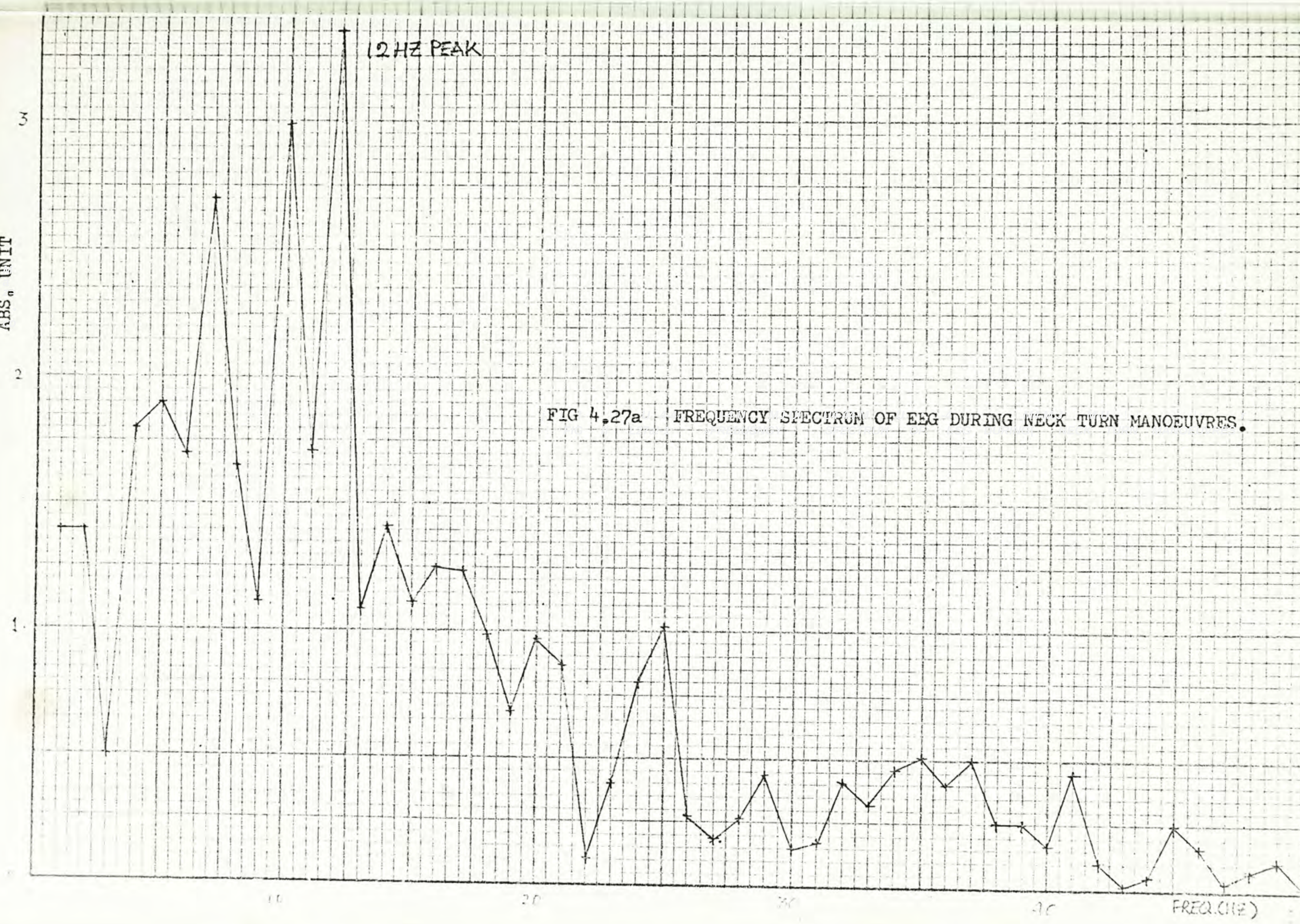


FIG 4.27a FREQUENCY SPECTRUM OF EEG DURING NECK TURN MANOEUVRES.

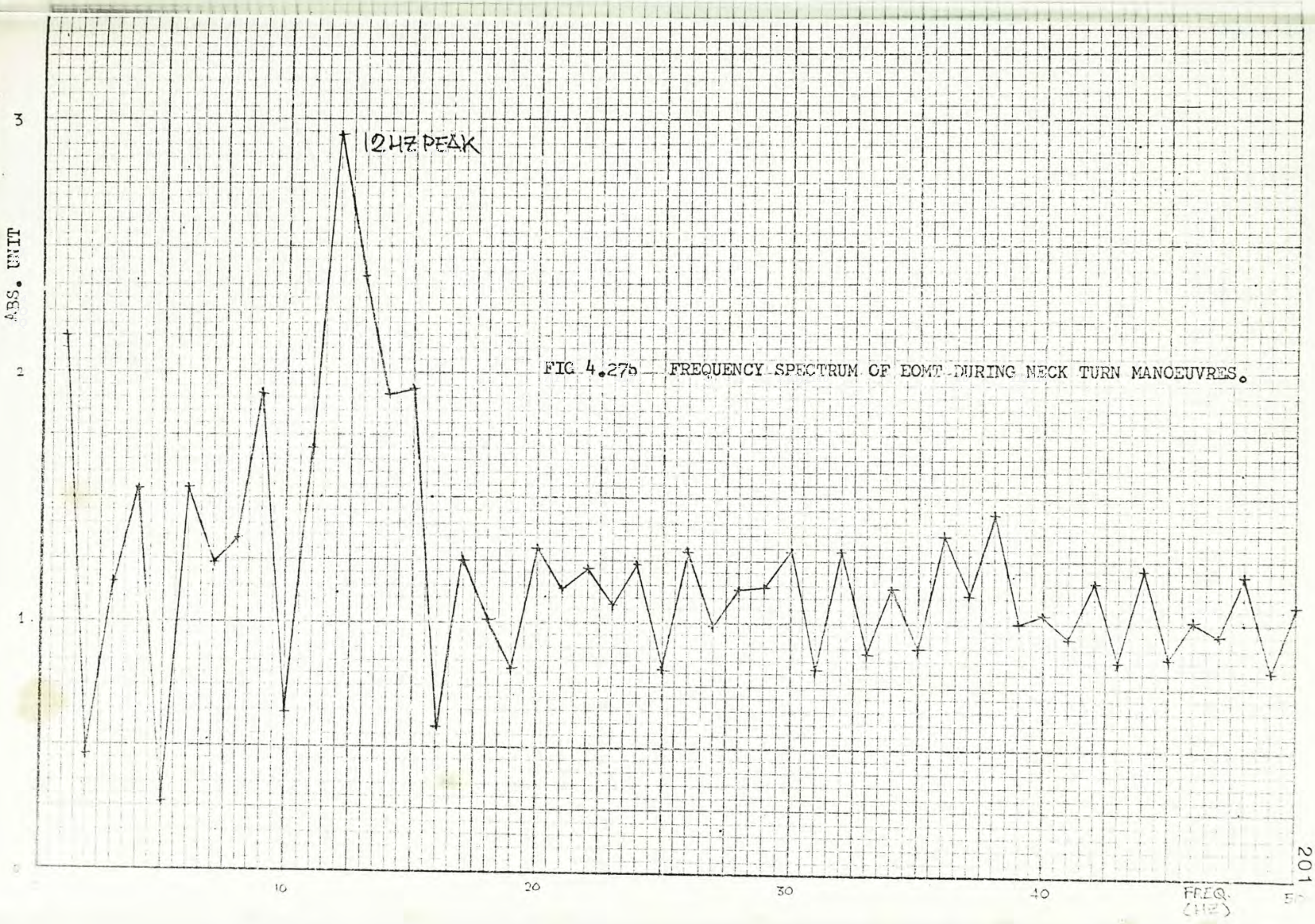


FIG 4.27b FREQUENCY SPECTRUM OF EOMT DURING NECK TURN MANOEUVRES.

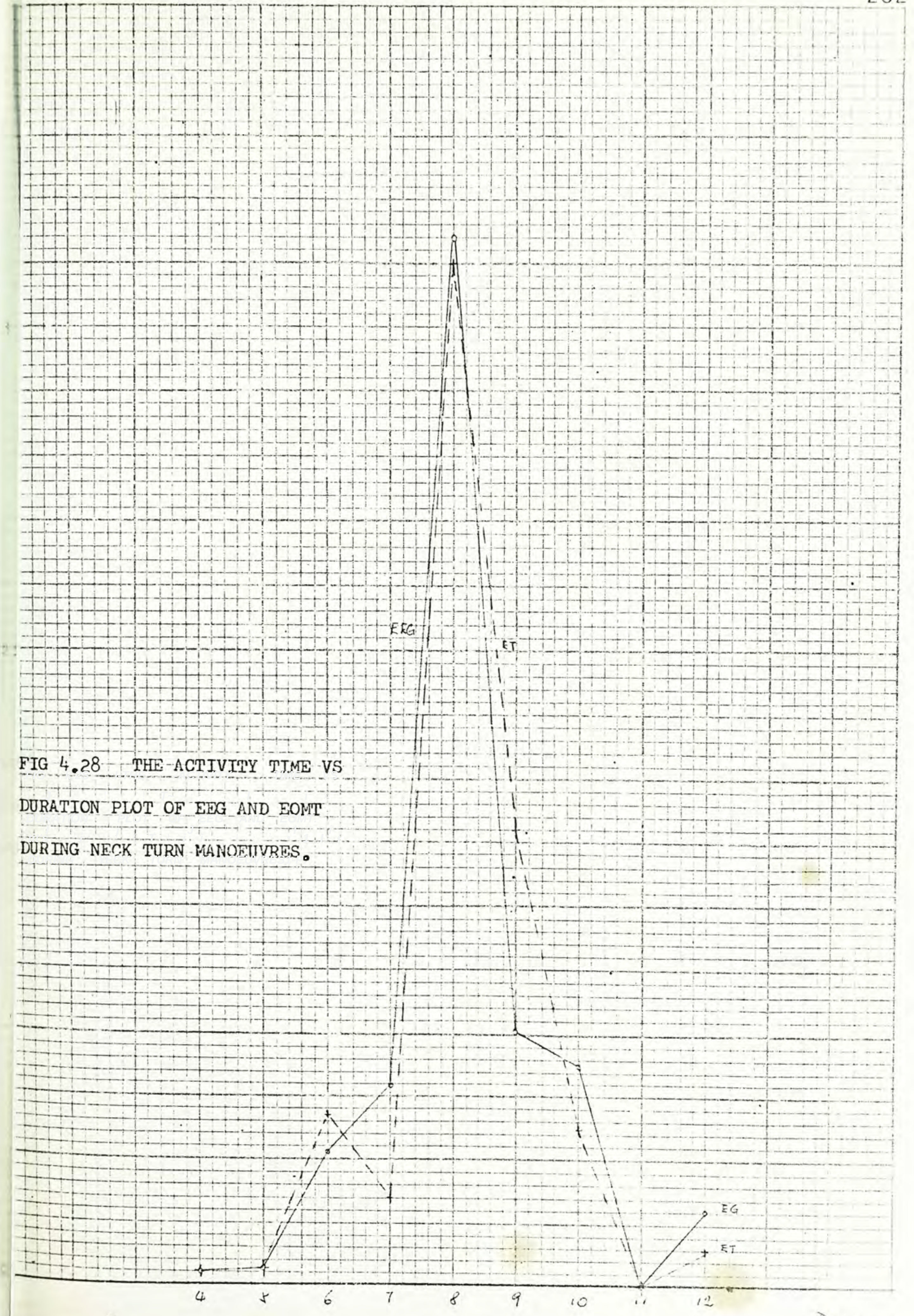


FIG 4.28 THE ACTIVITY TIME VS DURATION PLOT OF EEG AND EOMT DURING NECK TURN MANOEUVRES.

CHAPTER FIVE

CORNEORETINAL POTENTIAL AS THE SOURCE

5.1 THE POSSIBLE SOURCES

The intimate linkage between alpha rhythm and EOMT is strongly in support of the eye-tremor hypothesis. Supposing the hypothesis is true, what are the possible mechanisms of the generation of the 10Hz cortical potentials? Bearing in mind that the alpha rhythm is largest at the occiput and gradually declined to the minimum from the occipital to the frontal regions and the close relationships between the rhythm and oculomotor functions, potentials in the OMN, eye muscles or the eye may suggest themselves as a possible source of the cortical potential. Lippold and Novotny (1970) suggested three main possibilities :

(i) Eye tremor occurs and the potentials picked up over the scalp are mass potentials or envelopes of action potential spikes occurring in the motoneurone pool within the OMN. A further possibility in connection with this idea is that pathways from the oculomotor nucleus might indirectly influence the visual cortical neurones, so that although eye tremor does occur, both it and the potentials of alpha rhythm found in the occipital cortical cells are in a sense secondary phenomena.

(ii) Tremor occurs in the feedback loop controlling muscle length and tension in the external eye muscles. Due to the geometry of the skull and orbit, it could be that the action potential groups in the eye muscles, concomitant with this tremor, are smoothed and appear as alpha waves at the occiput.

(iii) The tremor of the six extra-ocular muscles may in some way modulate the corneoretinal potential, which again, because of skull geometry, is recorded at the occiput.

All the three possibilities have a feedback loop involving the six extra-ocular muscles. Thus, by altering the loop properties experimentally, the true mechanism of the generation of alpha waves can be revealed.

5.2 EXPERIMENTAL STUDIES

The simultaneous recordings of the motor potentials in the OMN, occipital cortex potential, eye movement and EOG in 3 alert cats (Lippold 1973) showed that the first proposal is not likely. Stimulating the OMN of the alert cats also suggested that eye movements appeared to be generating the electrocortical potentials (Lippold 1973). Nevertheless, the cortical waves in alert cats do not resemble human alpha in many respects (not vary with light and dark and frequency not constant). The possibility that the oculomotor nucleus generates alpha waves in man has not been supported or disproved so far and further experimentations in human patients may be helpful.

If the possible potential source producing the alpha waves is the electrical activity in the eye muscles which implies a simple electrical transmission in a volume conductor and pick-up from the scalp, the action potentials and the alpha waves would necessarily be in phase and correspond exactly in their shape, amplitude and frequency. However, no recordings made of action potentials from these muscles have ever been found to resemble the alpha rhythm identically. In light of these, we proceed to investigate the third possibility : alpha waves are the modulated CRP (by EOMT).

1. The Corneo-retinal Potential (CRP)

The corneoretinal potential, thought to be intimately bound up with the metabolism of visual purple (Arden and Kelsey 1962b), is a large standing potential between the cornea (positive) and the fundus of the eye (negative). A microelectrode when thrust through the various layers of the retina, shows that there are several charged membranes, the one across which the major part of the potential is developed being the pigment epithelium (Tomita et al 1959). The potential change thus recorded is about 70 mV whereas the standing potential appearing between the front and back of the eye is about 30 mV. The CRP can be measured by recording the electro-oculographic (EOG) potential when the eye is voluntarily moved from side to side with a constant magnitude (Arden et al 1962). A lateral movement of the eye shifts the field due to the CRP (eye acting as a dipole). The CRP of the human eye also changes with different levels of ambient illumination (Arden and Kelsey 1962 a).

2. Published Works

The changes produced by light in the human CRP were first studied by Arden and Kelsey (1962 a) by recording the EOG with 20° eye rotations. Lippold (1970 b), employing the same technique, found that the magnitude of the CRP can be varied by a factor of 3 by altering the ambient illumination. Dark trough appears after about 12 min in darkness and light rise is brought about after about 8 min re-illumination, Arden et al (1962 a) interpret these results to mean that two separate processes cause the dark trough and the light rise. Contrariwise, Lippold (1971) suggested one unique process only. Aside from these changes, EOG records were found to display certain 10Hz oscillations during EC condition (see Arden et al 1962a ; Byford 1964; Harlan et al

1958) though the authors were unaware of that. Lippold finally in 1973 demonstrated that the electro-oculographic potentials are correlated with the occipital alpha waves and this supports that the waves are actually modulations of the CRP by EOMT. Furthermore, CRP magnitude and the amplitude of alpha waves are well correlated in dark and bright environments (Lippold 1970d).

3. EXPERIMENTAL METHOD

As the previous works favour the CRP as the alpha potential source and not the OMN motor potentials and the EOM action potentials, we performed experiments on the investigation of the CRP following all the described procedures in the hope that further results can be obtained. The method of EOG recording and that of changing the CRP by light and dark environments were described by Arden et al (1962 a). The experiments were carried out in a large quiet laboratory with the ambient illumination controllable. The subjects were unaware of the effect of the light and dark conditions on the recordings. The CRP was measured by recording across the eyeball from the skin of the nose near inner canthus and the temple (near outer canthus) when the eye is voluntarily rotated fully from side to side. In this way (swaying fully from side to side), the troubles with the targets or optical markers were eliminated without loss of accuracy. Usually, these targets or markers are illuminated bulbs and have two pit-falls; experiments with EC are difficult since the bulbs cannot be seen and after-images may be generated if they can be seen. During the experiment, the subjects (EO) were instructed to swing their eyes fully from side to side at about once a second for fifteen times during which the EOG recordings were obtained. They were then instructed to relax (EC) and their EEG was recorded immediately following eye-closure for 20 sec. The sequence was repeated at different times under light and dark conditions. The whole room (or environment) was darkened to produce the dark trough and re-illuminated to bring forth the light rise. An average of the 15 EOG recordings and of the 20 sec epoch of EEG record of a sequence were taken as representative values of that particular time. EEG was recorded with electrode locations T5-01 and T6-02.

In order to record the 10Hz electro-oculographic oscillations clearly, we found that the subject must be able to keep his eyes stationary. Thereby, distinct 10 Hz waves similar to and correlated with those of alpha would readily be observed. Both phenomena were anlysed by different approaches to reveal their relationship.

Experiments on polarization of the orbits were carried out by passing small polarising currents (0.5-1.5 mA) through the orbit with electrode just below each eyebrow and over each orbit (positive) and eletrode on the palm (reference). The current was generated by a battery (18V) and a resistance box. In order not to irritate the subject, the current was increased to the desired value (the maximum current each subject could bear is different) gradually and good skin-electrode contact was enabled by the electrode gel.

Related experiments were also carried out ~~in~~ on a blind subject to establish whether or not there are any standing potentials in the enucleated orbit, alpha waves in the occipital region and 10 Hz electro-oculographic oscillations in his EOG. This will be described in detail in Chapter seven.

4, Results and Discussions

Supposing the CRP is in reality the potential source of the alpha waves, through its interaction with the EOM tremor, the amplitude of the alpha waves should change correspondingly by altering the CRP magnitude in various ways. Besides, oscillations in the alpha range and correlated with the alpha waves should be obtained from the EOG recordings of human subjects. The CRP was altered in two ways, namely, alteration of the ambient illumination and passing a small polarising current through the orbit. The results are as follows.

a. EOG recordings : the 10Hz electro-oculographic oscillations

When the same scales were employed in the EOG and EEG recordings (0.5 or 0.2 mV/100 div), one must be struck by the resemblance of the two phenomena (Fig. 5.1). They appear to be related in frequency, amplitude and phase. However, these are often ignored by other investigators as they recorded EOG with the usual scale of 10 or 5 mV/div (10-20 times larger) which means that the small 10 Hz electro-oculographic oscillations would not be observed. In order to study how closely related they are, 20 sec epochs of EOG and EEG records were analysed in various ways. Both the interval (Fig. 5.2) and the amplitude (Fig. 5.3) distribution plots show similar profiles and dominant peaks. This indicates that the two phenomena have similar frequency and amplitude distribution as well as content. Their phase differences are illustrated in the phase histogram (Fig. 5.4). Over 70 % of the observations have phase differences less than 10 msec. Unanimously, they are, to certain extent, related in phase. The frequency and phasic relations are further demonstrated in the duration-wave number plot (Fig 5.5) whereas the amplitude and phasic relations are further supported in the amplitude-wave number plot (Fig 5.6). Both plots are characteristics of related phenomena with similar time variations. Finally, their frequency variations with time are shown to be nicely correlated in the accumulative-average-duration plots (Fig 5.7). On the whole, 10 Hz electro-oculographic oscillations are shown to be existing and that they are well correlated to the alpha waves. Should they be independent phenomena, no such results could be obtained. Moreover, the magnitudes of the EOG oscillations are comparable with the alpha amplitudes though the former is always smaller. These are supporting the CRP as the source of the alpha rhythm.

b. Experimental Variations of EEG and EOG

The alpha waves and the 10 Hz EOG oscillations (8-13 Hz also) were shown to be related in normal cases. Supposing they are really related, various tests should impose similar changes upon them. The first test was the EO and EC changes. The result is positive. Both were much reduced with opened eyes (visual fixation) and increased about 110% in amplitude on eye-closure. Another oculomotor variable affecting alpha waves is the act of forcing the eye to extreme positions. EOG oscillations were found to be enhanced similarly as the alpha waves by about 50% together with a slight increase in frequency (5%). They were also disturbed in a similar way by blinking with closed lids. There is a short period of about 0.5 sec of suppressed waves (about 30% of normal amplitude) after the eye blink in both records.

Muscle manoeuvres enhanced both phenomena. The act of turning the head to the right side or tilting the head to the left side increased the magnitude of both phenomena (right side) by about 116% whilst rotating the head to the left side or tilting it to the right side increased by about 45%. These are average values taken from over thirty trials.

In addition, the phenomena appeared to be better correlated under head turn conditions (Fig 5.8). Similar results were observed for clenching and skin pinching. Amplitude increases of about 64% (clenching force 30Kg) and 14% (pinching) were observed for alpha waves and EOG oscillations without considerable changes in their frequency spectra.

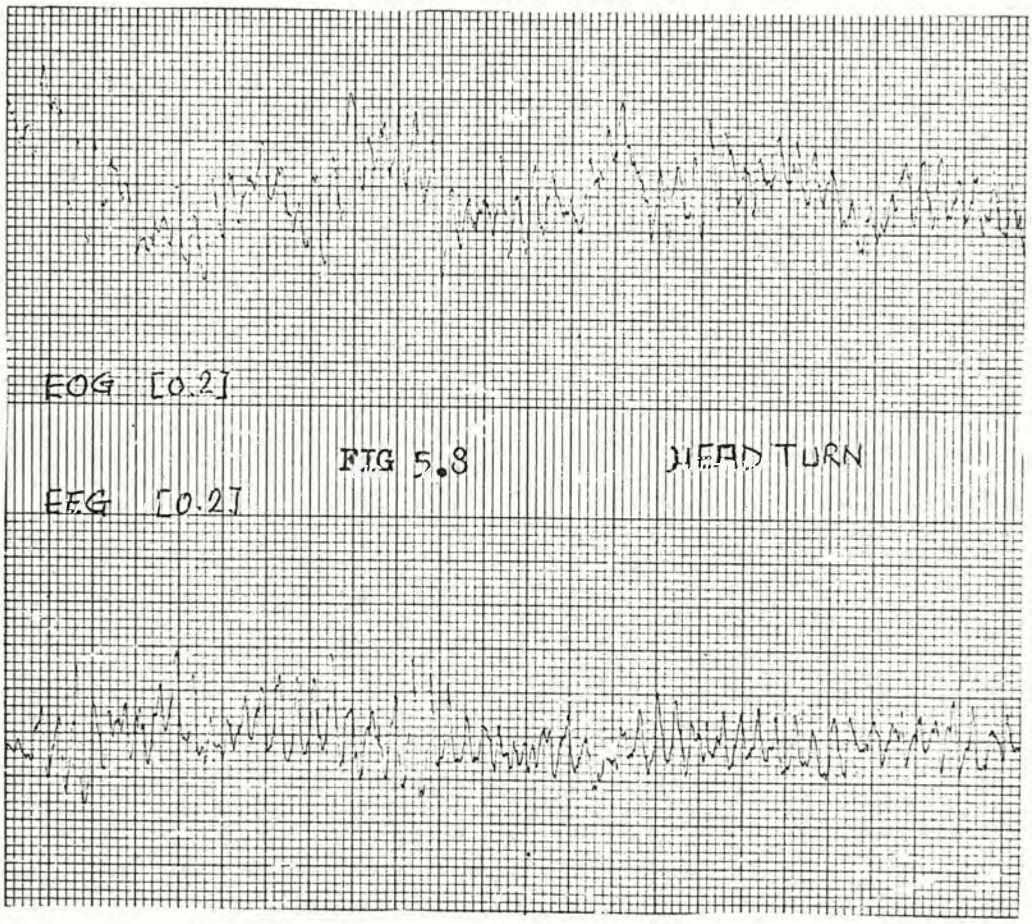


Fig 5.8 The effect of neck turn on EEG and EOG recordings
scale = 0.2 mV/div, 5 large squares = 1 sec.

Mental tasks reduced the magnitude of both phenomena. Average amplitude decreases of about 28 % (mental arithmetic, procedure described in section 4.5.2) were observed for alpha waves and EOG oscillations without considerable changes in their frequency spectra (during the experiments, the subjects must be able to maintain their eyes in stationary positions).

. Thus, it can be concluded that the various tests imposed similar changes upon the two phenomena.

C. Change of Ambient Illumination

The final step taken to show that the CRP is the potential source of alpha waves was to demonstrate the correlation between the amplitude of the waves and the magnitude of the CRP as the latter is varied experimentally. Two methods were employed for the variation of the CRP, namely, by altering the ambient illumination and by passing polarising currents through the eye. Both methods again illustrate that a rather good correlation exists and that once again, as in the ocular cooling and warming experiments, the events occurring in one eye alone determine the characteristics of the alpha waves on the same side of the hemisphere.

In the first method, the dark trough could readily be obtained after about 5 min in complete darkness and the light rise was brought forth after about 6 min of re-illumination (Fig 5.9). The dark trough, clearly observed in the graph, had an amplitude decrease of about 0.24mV (37.50%) in the CRP and 6.2μV (41.33%) in the alpha waves. On the other hand, the light rise, also distinctly observed, had an amplitude increase of about 0.25 mV (62.50%) in the CRP and 6.25μV (69.44%) in the alpha activity. The correlation between the magnitudes of the CRP and occipital alpha activity is also promised by the striking similarity in the respective profiles in the graph. Unanimously, these results illustrate that the CRP and the amplitude of the alpha waves co-vary. The explanation for this could be either that both are generated by some other potentials or that the one controls the other. The former one is not likely as no other potentials have been reported to respond to the level of illumination with exactly the same time course as does the CRP and have effects upon the EEG and EOG localised to the same side of the head only. In addition, it is not likely for the alpha waves to generate the CRP directly. Thus, the only reasonable conclusion to be drawn from these results is that the primary source of the alpha waves is the standing potential across the eyes. Supporting evidence is also obtained from the experiment onthe polarisation of the orbits. Passage of small polarising currents (0.5-1.5 mA) through the eye enhanced both the EEG and EOG recordings at the same side of the head as the polarised eye. This is supposed to be an augmentation of the CRP of the polarised eye. Finally, experiments on a blind subject will be dealt with in detail in section 7.1. The results obtained are also supporting the proposal that the alpha waves (in normal and blind subjects) are in reality the modulations of the CRP by the EOM tremor.

5.3 CONCLUSION

This chapter provides experimental evidences in support of the proposal that alpha waves are the modulations of the CRP by the EOM tremor. 8-13 Hz electro-oculographic oscillations were found in EOG records using the same scale as EEG recordings. These oscillations were found to be related to the alpha waves in amplitude, frequency and phase (though the correlation is not as strong as that of EOM tremor and alpha activity). Their similarities are further supported by the results of various tests. Oculomotor functions, muscle manoeuvres and mental tasks were found to impose similar changes upon the two phenomena. Finally, when the CRP was varied by altering the ambient illumination and by passing polarisation currents through the eye, the amplitude of the alpha waves were found to have related changes. A good correlation between the magnitude of the CRP and the alpha amplitude was also obtained. Thus, it is quite safe to conclude here that the CRP acts as the potential source of the alpha waves. Consequently, the eye-tremor hypothesis is completed in describing the mechanism of generation of the occipital alpha activity as well as the potential source. Further supports will be obtained from the specialised studies in Chapters six and seven.

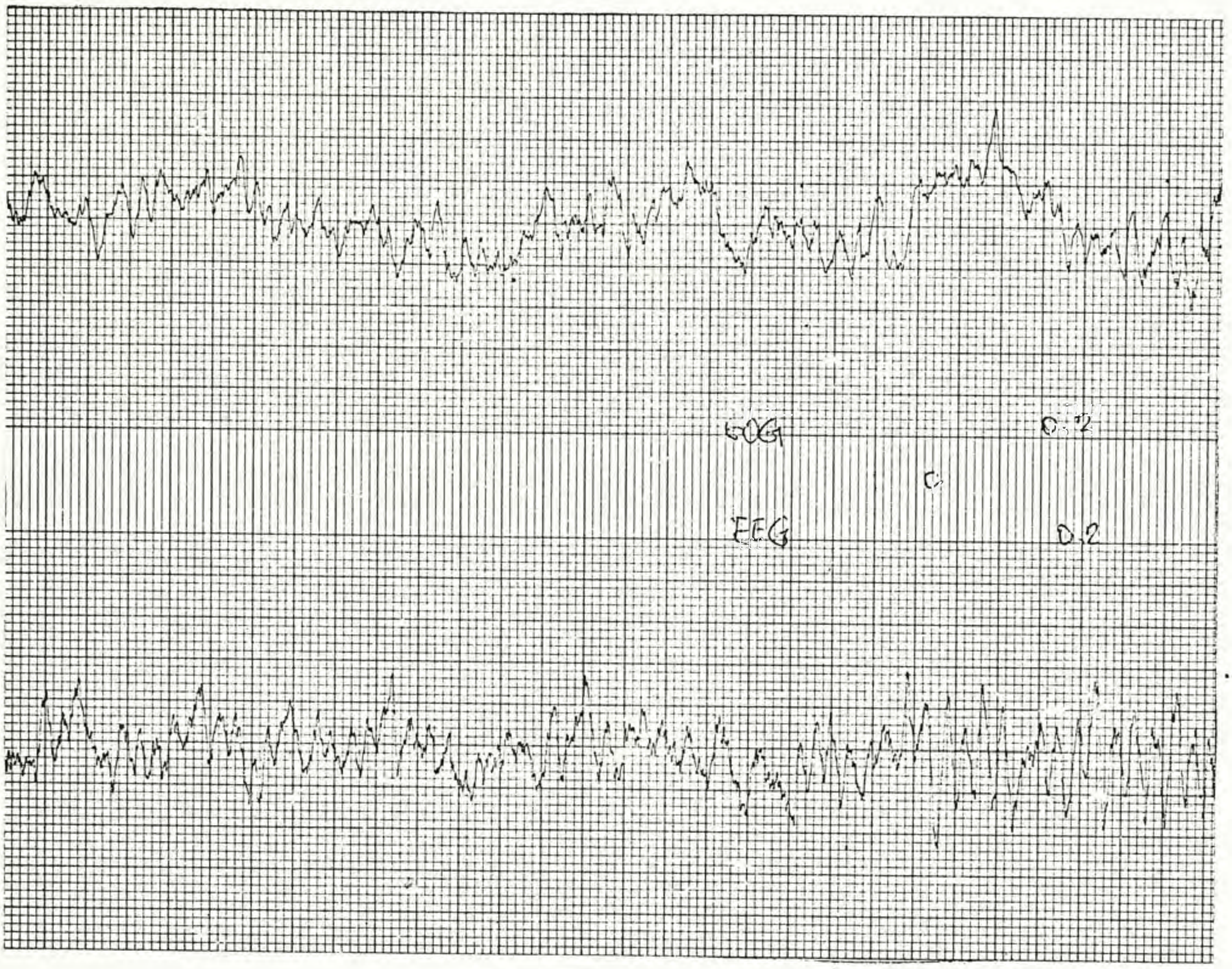


FIG 5.1 SIMULTANEOUS RECORDINGS OF EOG AND EEG (BOTH FROM THE RIGHT SIDE) OF A NORMAL SUBJECT. SCALE = 0.2mV/100 div 5 LARGE SQUARES = 1 SEC.

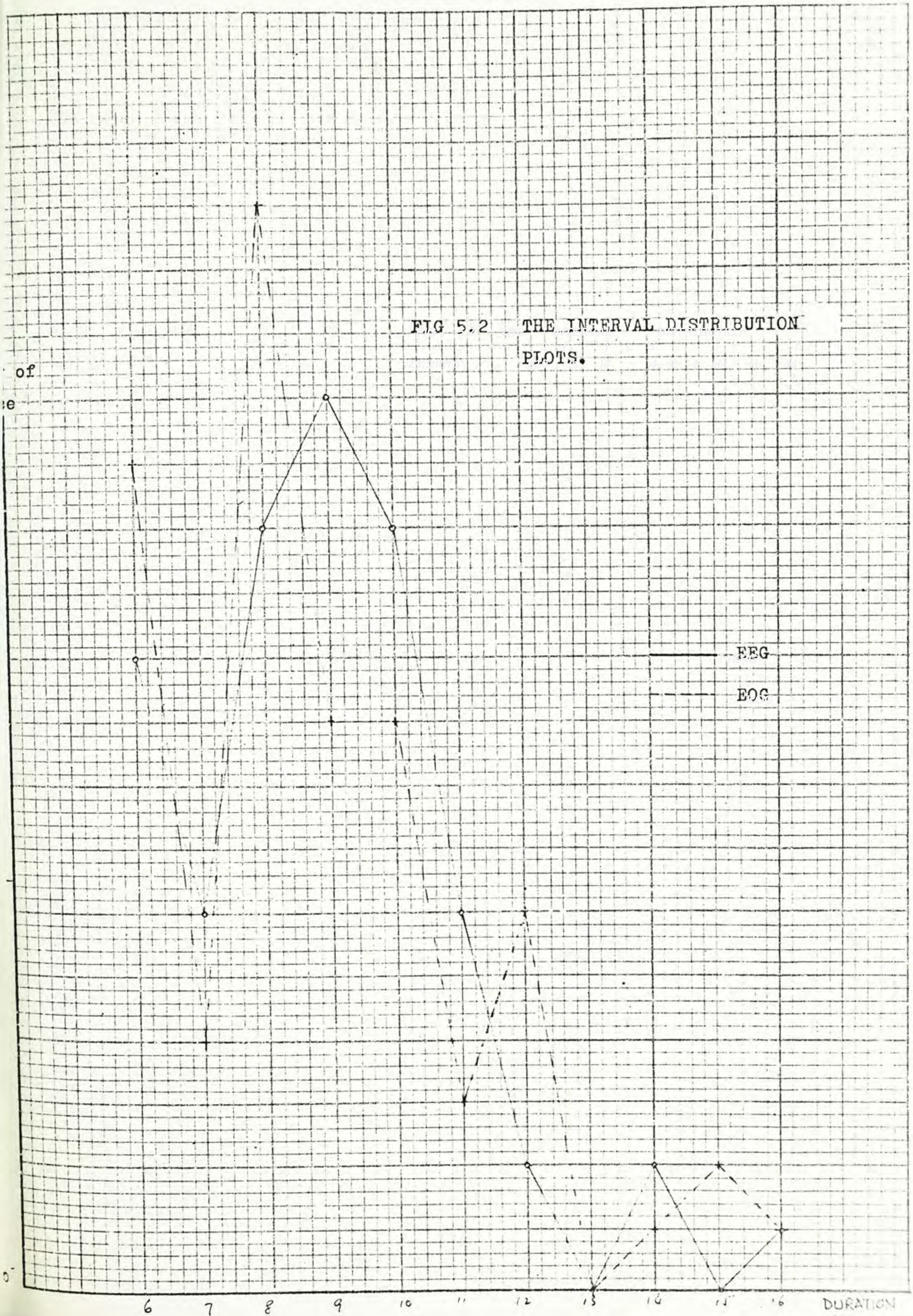
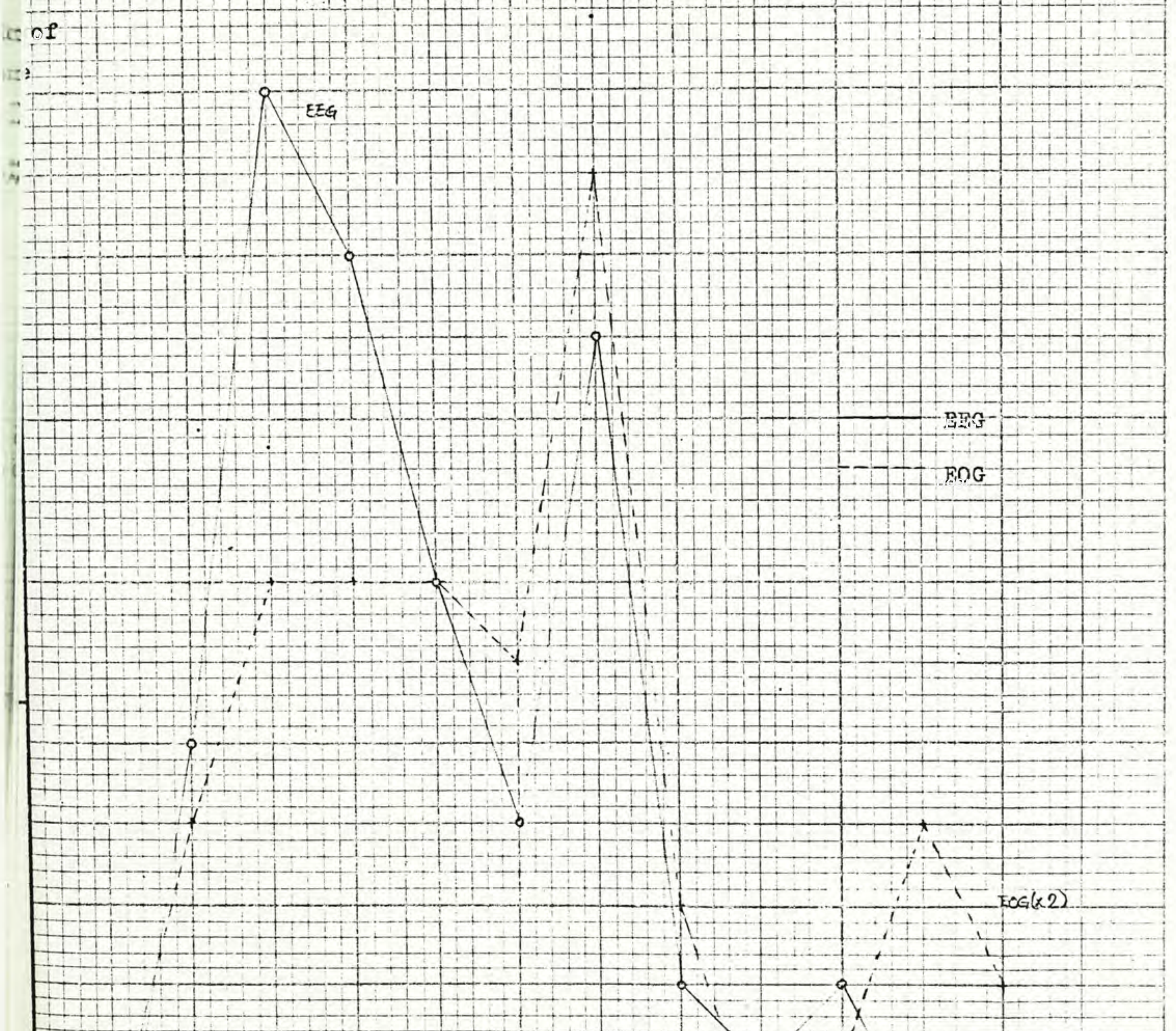


FIG 5.2 THE INTERVAL DISTRIBUTION PLOTS.

FIG 5.3 THE AMPLITUDE DISTRIBUTION PLOTS



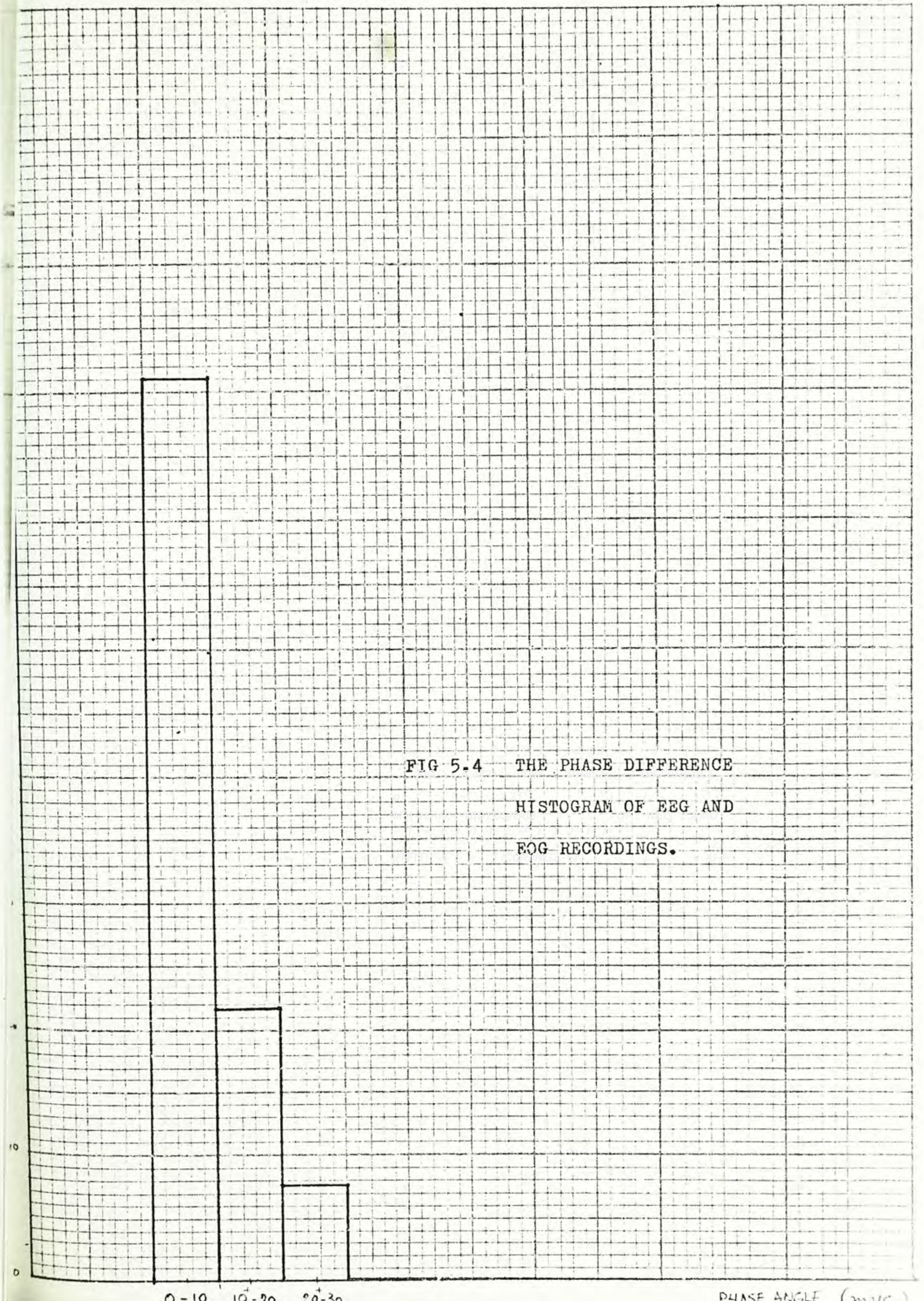


FIG 5.4 THE PHASE DIFFERENCE HISTOGRAM OF EEG AND EOG RECORDINGS.

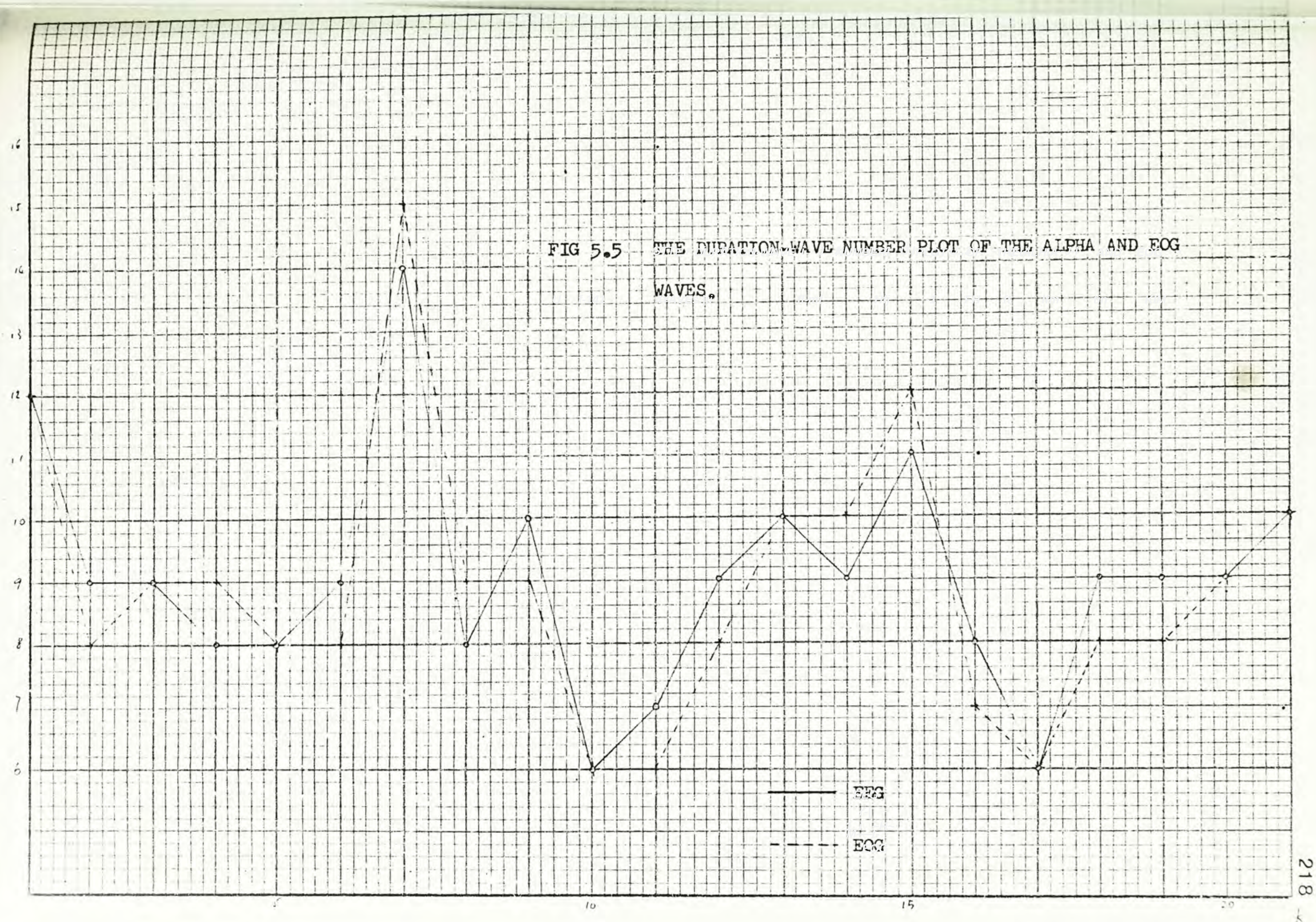


FIG 5.5 THE DURATION-WAVE NUMBER PLOT OF THE ALPHA AND EOG WAVES.

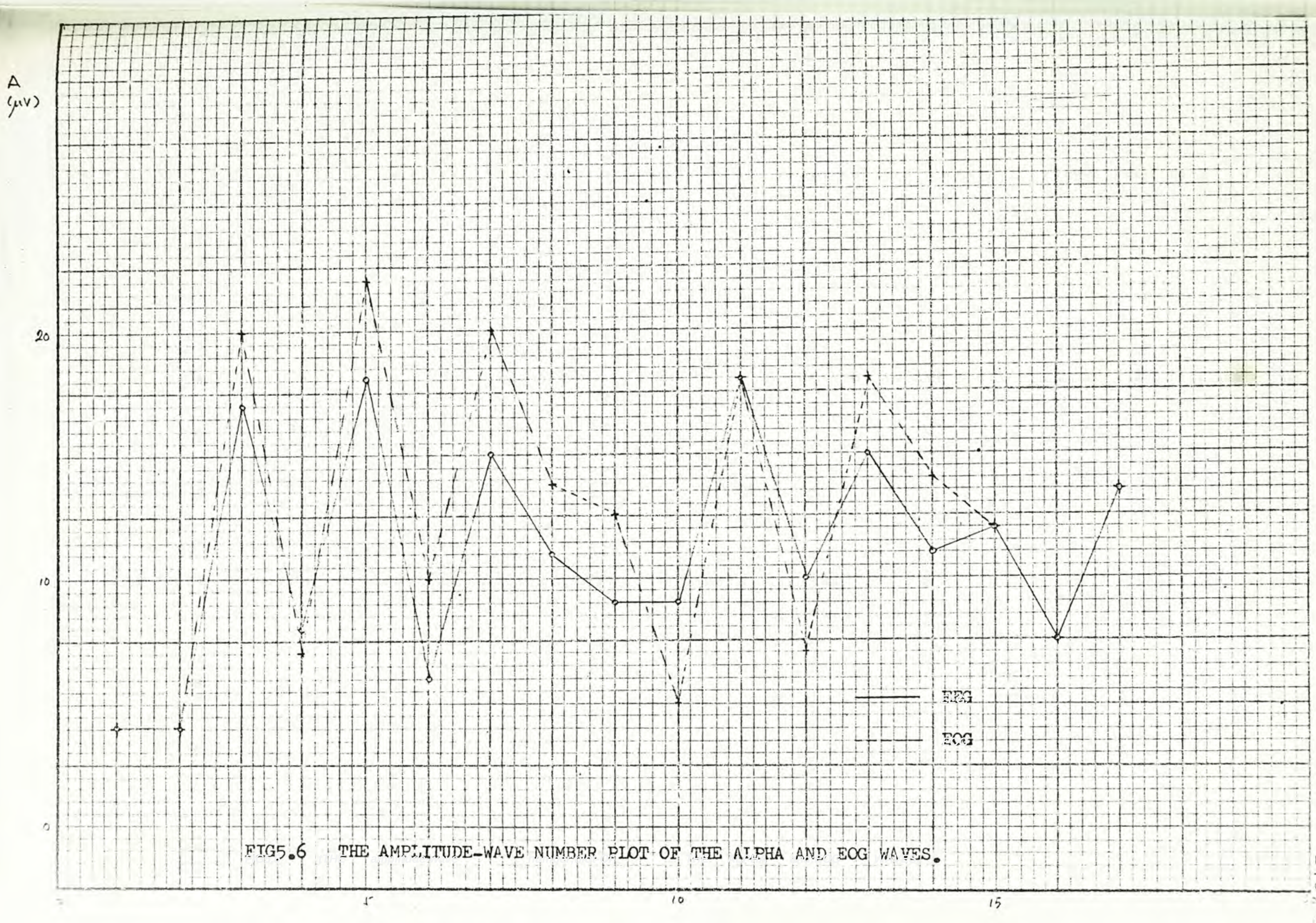


FIG5.6 THE AMPLITUDE-WAVE NUMBER PLOT OF THE ALPHA AND EOG WAVES.

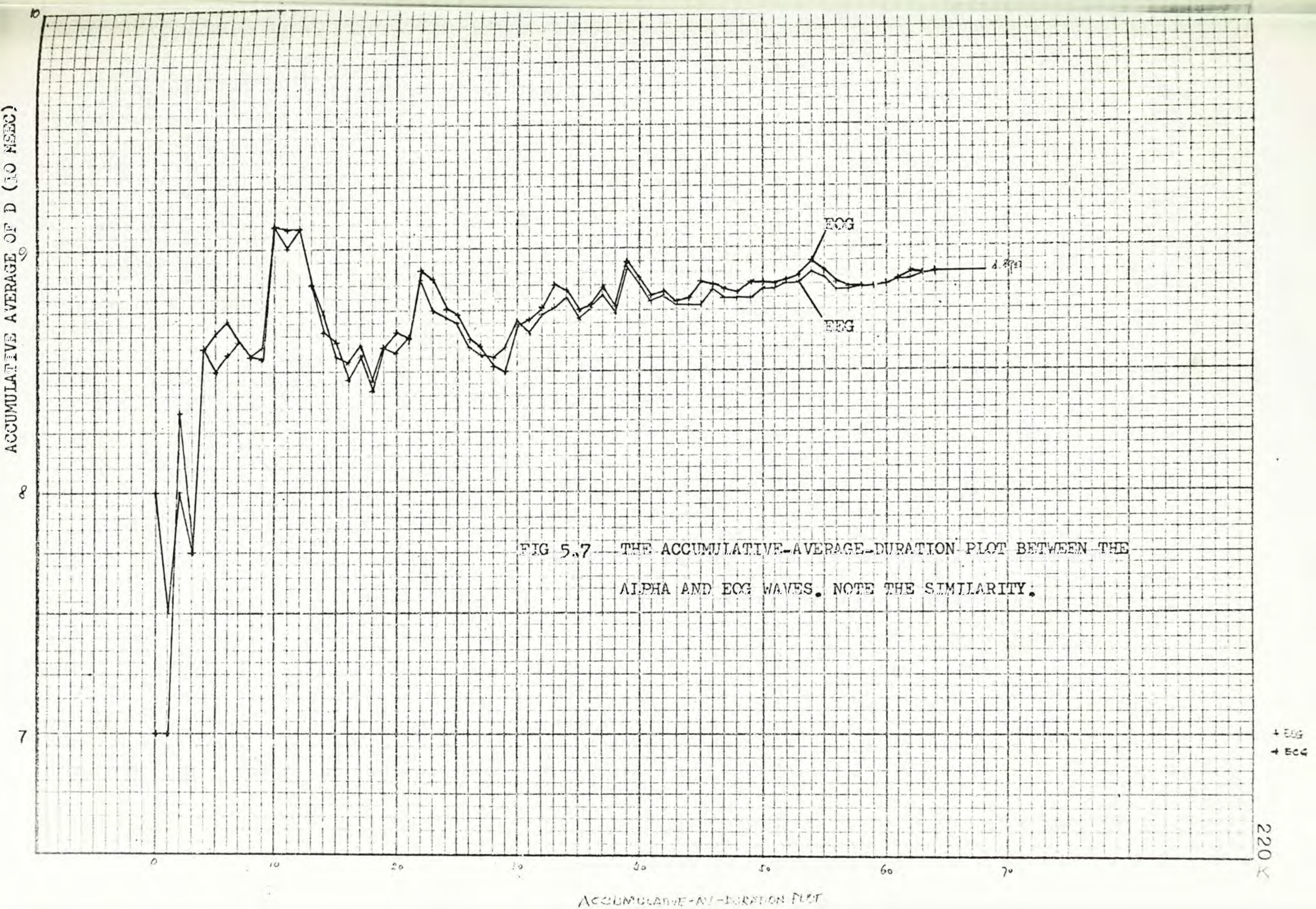


FIG 5.7 THE ACCUMULATIVE-AVERAGE-DURATION PLOT BETWEEN THE ALPHA AND EOG WAVES. NOTE THE SIMILARITY.

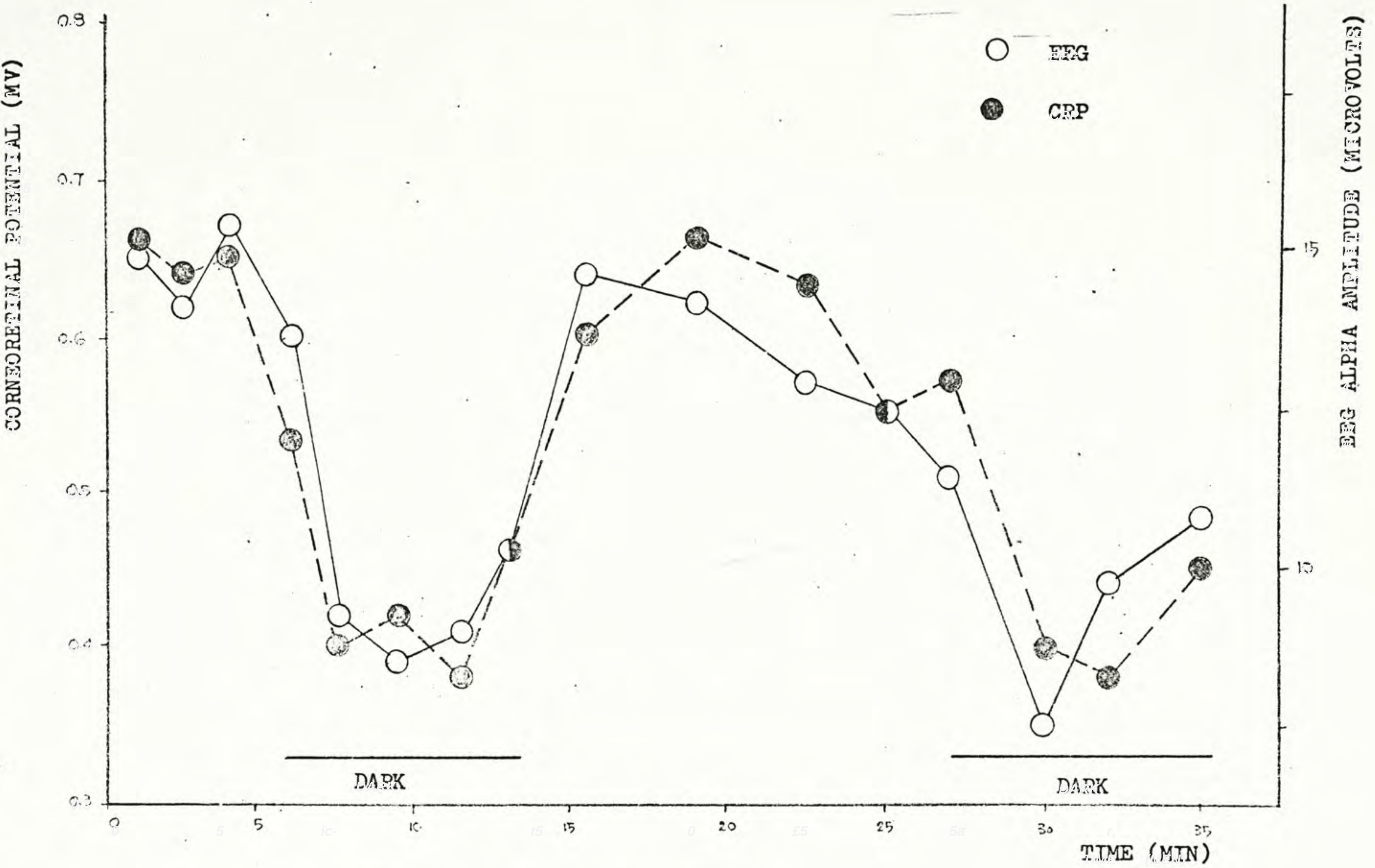


FIG 5.9 THE CRP AND THE AMPLITUDE OF ALPHA WAVES DURING LIGHT AND DARK CONDITIONS.

BARS SHOW PERIODS OF COMPLETE DARKNESS. THE REST ARE LIGHT PERIODS.

CHAPTER SIX

DIURNAL VARIATIONS OF EEG, EOMT AND FT

6.1 HISTORICAL INTRODUCTION

The eye-tremor hypothesis describing the mechanism of generation of the occipital alpha activity as well as the potential source has been supported in various ways in the previous chapters. It will be interesting to know whether or not the alpha waves and EOM tremor have any circadian rhythm and are related in their diurnal variations. This is certainly helpful in understanding more about the two phenomena. The eye-tremor hypothesis predicts that they are diurnally related. Unfortunately, we can cite no literature in support as no investigators have studied the problem before. Actually, only a few investigators have independently worked on the diurnal variations of EEG or FT hitherto (but not EOMT). Lindsley et al (1962, 1964) studied the diurnal activity, behaviour and EEG responses in visually deprived monkeys. However, they only investigated the diurnal bodily activity (movements in a dark environment) of those monkeys. Gale et al (1972) actually studied the diurnal EEG changed by recording EEG at four specific times of the day: 0700, 1100, 1500, and 2000 hours. They found that: (1) there were no general effects for the time of day nor any indication of an interaction between time of day and personality (extroversion -introversion and neuroticism); (2) the subjects maintained rank order for alpha abundance, within the group over the 4 visits ($P < 0.01$); (3) alpha abundance was greater on the first visit than on the last visit ($p < 0.05$). They concluded from their results the within-subject stability of the EEG and that the time of day has no effect on the EEG. Nevertheless, their results are not of any great value as they only worked at four times of a day (three of which are climax periods in our studies!) and the subjects feeding times are not given. Tyrer and Bond (1974) was the first to study the diurnal variation in finger tremor. They found a significant diurnal variation in the amount of finger tremor within the physiological range (6-14Hz) but not at other frequencies. Most tremor was recorded at 11.00 h and the least at 14.00h. They also showed a similar trend in self-ratings but this was not significant. When their subjects were treated with the adrenergic beta-receptor blocking drug, propranolol ("Inderal"), the diurnal variation was found to be much reduced but not entired abolished. They thus concluded that the diurnal variation of finger tremor is primarily due to changes in circulating catecholamines. However, they only recorded tremor within 7 hours ranging from 10.00 to 17.00 h. and the night time is not included. To our best knowledge, these four papers are all the literature we can find related to our problem. Of these, only Tyrer et al showed a significant diurnal variation in finger tremor. Luckily, we are not depressed by this and patiently carried on with our experiment on the diurnal recordings of EEG, EOMT and FT of the subject at every hour of the day between 9.30 h and 23.00 h for a whole week. Our patience is rewarded by gratifying results. We found significant diurnal variations in the three phenomena recorded and the strong correlations between alpha waves and EOM tremor maintained throughout the whole day. These results again supported the eye-tremor hypothesis.

6.2 EXPERIMENTAL METHODS

Experiments were carried out in a large, quiet room with the subject seated and relaxed in a comfortable chair. The same environment, set-up and procedure were maintained throughout the diurnal recordings to reduce the experimental deviations to a minimum. Recordings of EEG, EOMT and FT of the subject were taken every hour from 9.30 h to 23.00 h diurnally for one whole weak. During that period of time the subject was instructed to have constant feeding times and regular sleeps such that the daily cycle was maintained constant to his best effort, and no alcohol was allowed. The results of the seven days were then averaged and analysed by the various approaches discussed in section 4.3. EEG recordings with electrode locations T5-O1 and T6-O2 were performed with the procedure described in section 2.5. Finger tremor was recorded by the new technique employing the dynamic mike and the 'hanging' posture described in section 3.5. EOM tremor was recorded by the new technique comprising the dynamic mike and its mounting in a diving mask described in section 4.2. The new recording techniques of finger tremor and EOM tremor have made it possible to take recordings at frequent intervals (every hour !) during the day with the minimum of inconvenience and discomfort to the subject and with reliable results (this may be the reason why so few investigators tried the diurnal studies). The temperature and humidity of the laboratory were maintained roughly constant throughout the whole period of experimentation (24.5 ± 0.5°C, 86 ± 2% R.H.). During each hourly recording, EEG vs FT (double channel recordings), EEG vs EOMT and EOMT vs FT were each recorded for one minute consecutively in the sequence, totalling 3 min. 20 sec epoch of each minute's recording was analysed by various approaches. Finally, aside from diurnal variations, weekly, monthly and yearly variations were also noted but they were found to be insignificant.

6.3 RESULTS AND DISCUSSIONS

1. Diurnal amplitude and frequency variations

A fascinating result is illustrated in the diurnal amplitude plots of EEG and EOMT (Fig. 6.1). The amplitudes of the alpha waves and eye-tremor were found to be correlated with the food-taking times. The food-taking times were 9.00 h (breakfast), 14.00 h (lunch) and 19.00 h (dinner) respectively and were found to correspond roughly to the troughs of the amplitude profiles of the alpha waves and EOM tremor. Three peaks occurred in between the food-taking times at 10.30 h, 16.30 h and 20.30 h in the order of increasing magnitude with the largest peak at 20.30 h. Insomuch that the two profiles of EEG and EOMT magnitudes in the graph are strikingly similar, the strong correlation between the alpha waves and eye-tremor is confirmed. However, no such correlation exists between finger tremor and alpha waves or eye-tremor. The diurnal amplitude plot of finger tremor also displays a significant diurnal variation of the tremor and that its magnitude is also related to the food-taking times but has different profiles and peaks(Fig. 6.2). The peaks occurring at 12.30 h, 15.30 h, 17.30 h and 21.30 h are different from those of alpha waves and EOM tremor. Moreover, there are two peaks between lunch and dinner whereas there is only one peak between two consecutive food-taking times for alpha waves and EOMT. Several points can be noted from these results : (1) alpha waves and eye-tremor are strongly related diurnally but not finger tremor, (2) all the three phenomena show a significant diurnal variation related to the fool-taking times with minimum amplitudes (troughs) at those times and maximum (peaks) in-between, (3) the diurnal studies of the three phenomena can be divided into three periods: after breakfast and before lunch, after lunch and before dinner as well as after dinner and before sleep, (4) various studies (frequency spectra, activity times, amplitude distributions, etc.) of the characteristics of the three phenomena within each of these periods are proposed, and (5) the significant diurnal variation only exists in the amplitude of the three phenomena and not in their frequency (Fig. 6.3). The diurnal frequency plots of the three phenomena show that their frequency variations in a day are not very significant (< 0.5Hz for EEG and EOMT, < 0.75Hz for FT) and are not related to the food-taking times. Furthermore, the EEG and EOMT are again shown to be strongly correlated whereas the FT is distinctly different from both.

2. correlative studies

In order to confirm the diurnal correlations of alpha waves and eye-tremor, the crosscorrelograms of them were plotted at thirteen times of day: 9.30, 10.30, 11.30, 12.30, 13.30, 14.30, 15.30, 16.30, 17.30, 19.00, 20.30, 21.30 and 23.00 h respectively (see Appendix II). The consistency of the correlation throughout the whole day as expected by the eye-tremor hypothesis is found to be true. This can readily be observed in the respective crosscorrelograms shown in Appendix II. The values of r of the alpha activity and EOM tremor at delays of 0, +10 and -10 msec were plotted against the time of the day in Fig. 6.4. It can be seen that the values of r (d = 0) are greater than 0.5 for most of the time with a maximum of 0.83 at 10.30 h. In fact, an average of 0.533 is obtained. Minimum correlation occurs at

9.30 h. Deviations from the average correlation mainly reside to the period before lunch and correlation is fairly constant after lunch. Another significant result observed is that the alpha waves and EOM tremor were in phase (no phase shift) for most of the time as the value of r (d = 0) is always greater than those of r (d = +10) and r (d = -10). The average values of r(d = 0), r(d = +10) and r(d = -10) for the whole day are 0.533, 0.492, and 0.361 respectively. This contradicts with Lippold's proposal that there should be a phase difference of 50 msec between the alpha waves and EOM tremor. we found that the in-phase relationship is the more probable one, and also a more attractive one.

The value of r (d = 0) of the alpha waves and finger tremor (Fig. 6.5) as well as the eye-tremor and finger tremor (Fig. 6.6) were also plotted against time of the day. Both graphs show an insignificant correlation indicating that the respective phenomena are not related. The average values of r for Fig. 6.5 and Fig. 6.6 are -0.06 and -0.004 respectively.

The values of the average amplitudes of the alpha and tremor waves of a particular duration are tabulated in Fig. 6.7. The distributions are slightly skewed to the side of larger durations indicating that both the alpha and tremor waves of the alpha range (8 - 13 Hz) contribute most to the magnitudes of the respective phenomena. The alpha and physiological tremor waves are alike in this case.

Finally, the variances of EEG, EOMT and FT are plotted against time (Fig. 6.8). EEG and EOMT profiles nearly coincide with one another whilst the FT profile deviates from them. There are 3 distinct peaks for EEG and EOMT at 9.30, 14.30 and 20.30 h respectively, corresponding roughly to the food-taking times and with the troughs in-between. This is interesting as it is exactly the reverse of the case of the diurnal amplitude plot. In other words, a high amplitude roughly corresponds to a low variance and a low amplitude to a high variance. Anyhow, a significant diurnal variation and a good correlation between EEG and EOMT are again demonstrated. The FT profile shows 5 peaks at approximately regular intervals at 10.30, 12.30, 15.30, 17.30 and 20.30 h respectively and also displays a significant diurnal variation.

On the whole, the various correlative studies show that: (1) EEG and EOMT are strongly correlated throughout the day and not FT, (2) an in-phase relationship between EEG and EOMT is found, (3) maximum correlation occurs at 10.30 h and minimum at 9.30 h, and the average is 0.533, and (4) a roughly inverse relationship is found for the amplitude and variance of the phenomena.

3. Activity time studies

The following studies are divided into three periods: (1) after breakfast and before lunch, (2) after lunch and before dinner and (3) after dinner and before sleep. In the activity time plots of the alpha waves and eye-tremor, each period is characterised by a particular pattern formed by the hourly curves. The activity time plot of period 1 (before lunch) shows a dominant peak at a duration of 100 msec (Fig. 6.9) and similarly for period 3 (after dinner) (Fig. 6.11). The graph of period 2 (before dinner) on the other hand, is double-peaked at durations 80 and 100 msec (Fig. 6.10). The activity time of the alpha rhythm (8-13Hz) is largest for period 3, medium for period 1 and least for period 2. Their respective characteristics can be clearly seen in the graphs. Unambiguously, the significant diurnal variation is again demonstrated and is further shown to be divided into three periods, each having its own characteristic. Moreover, the hourly curves within each period correspond to one another well but not corresponding so well to those in other periods. It follows that a coherence existed for activity times of the alpha waves or eye-tremor within each of the three periods.

Contrariwise, these are not the same for finger tremor. The activity time plots for periods 1, 2 and 3 are shown in Fig. 6.12, Fig. 6.13 and Fig. 6.14 respectively. Their patterns are alike and they all peak at a duration of 80 msec. The hourly curves of the activity time of the tremor are correlated within all periods. The activity time of the alpha range (8-13 Hz) of the tremor is greatest for period 3, medium for period 2 and least for period 1. In other words, the 8-13 Hz range becomes more significant as time goes by from morning to night.

4. Amplitude distribution studies

For the alpha waves (and similarly for eye-tremor), the amplitude distribution plots of periods 1, 2 and 3 are illustrated in Fig. 6.15, Fig. 6.16 and Fig. 6.17 respectively. Fig. 6.15 shows a general peak at 15-20 μV (the most active amplitude range) and the pattern becomes less regular for period 2 and most irregular for period 3. The hourly curves within each period appear to have no significant relation. From the graphs, it can be seen that the amplitude distributions of alpha waves (and also eye-tremor) do not show any significant diurnal variations although the alpha amplitude does show. However, the plot of period 3 appears to have a broaden and relatively a more even distribution (Fig. 6.17). This indicates a shift of the distribution to larger amplitudes at night.

As for the finger tremor, the amplitude distributions are even much more irregular. There are hardly any diurnal relations. The amplitude distribution plots of periods 1 (Fig. 6.18), 2 (Fig. 6.19) and 3 (Fig. 6.20) are similar in only one aspect -- the hourly curves within each are equally unrelated. Nevertheless, there is also a tendency for the amplitude distribution to shift to larger amplitudes at night. Anywise, the amplitude distributions of all the three phenomena, EEG, EOMT andFT, show no significiant diurnal variations.

5. Frequency spectrum studies

The frequency spectra of the three phenomena remain roughly constant throughout the day. Again, no significant diurnal variation is demonstrated. The frequency spectra of the alpha waves of periods 1, 2 and 3 are illustrated in Fig. 6.21, Fig. 6.22, and Fig. 6.23 respectively. A dominant peak at 10 Hz is observed except that Fig. 6.23 shows an extra peak at 11Hz. The delta and theta rhythms in period 2 seem to be more significant than other periods. The beta and gamma rhythms are relatively very stable.

6.4 CONCLUSION

The results found in this chapter have not been noted before and yet they are significant. They are briefly summarised as follows:

1. New recording techniques were employed to provide reliable recordings at thirteen times of day ranging from 9.30 h to 23.00 h.
2. EEG, EOMT and FT all show a significant diurnal variation in their average amplitudes related to the food-taking times, with minimum amplitudes (troughs) during the food-taking times and maximum (peaks) in-between. However, their amplitude distributions show no significant diurnal variation. Amplitude peaks occur at 10.30, 16.30 and 20.30 h for both alpha waves and eye-tremor and at 12.30, 15.30, 17.30 and 21.30 h for finger tremor.
3. The peak frequencies and the frequency spectra of the three phenomena are quite stable throughout the day and show no significant diurnal variation.

4. All the studies confirm that EEG and EOMT are strongly correlated throughout the day but not FT. An in-phase relationship between EEG and EOMT is confirmed. Maximum correlation (r = 0.83) occurs at 10.30 h. The eye-tremor hypothesis is supported.
5. The variances of EEG, EOMT and FT also show a significant diurnal variation, but with peaks at the food-taking times and troughs in-between.
6. The diurnal studies were found to be best divided into three periods according to the food-taking times. The activity time of the alpha rhythm and EOMT (8-13 Hz range) in decreasing order is period 3, period 1 and period 2 whilst that of the 8-13 Hz range of finger tremor is period 3, period 2, and period 1.

The mechanisms underlying the diurnal variations are complex. Tyrer in a personal communication with the author (1977) pointed out that, "As tremor is high when catecholamine excretion is high and tremor is low when catecholamine excretion is low, it is reasonable to assume that the two are related although this conclusion cannot be definite without measuring both simultaneously." Euler <u>et al</u> (1955) reported that peak adrenaline and noradrenaline excretion occur at 08.00 - 11.00 h and there is reduced excretion at 11.00 - 14.00 h. This coincides fairly well with our results on EEG, EOMT and FT of period 1 (Fig. 6.1, Fig. 6.2). Thereafter, no diurnal measurements of plasma catecholamines have been reported as accurate measurements are difficult (Carruthers et al 1970). Marsden et al (1969) reported that some of the fluctuations of tremor amplitude that occurs in the normal subject may be due to variations in catecholamine secretion, for adrenaline infusion has also been found to increase tremor considerably. Tyrer and Bond (1974) reported that after pre-treatment with the adrenergic beta-receptor blocking drug, propranolol ("Inderal"), the diurnal variation of tremor is much reduced. They concluded that this is difficult to explain by other mechanisms other than that changes in circulating catecholamines are primarily responsible for the diurnal variation of tremor. However, their results are not definite as they only recorded tremor within seven hours (10 - 17 h) which is not representative for the whole day and they have not recorded tremor and catecholamine secretion simultaneously.

As for the alpha waves, Lindsley and Rubenstein (1937) found a very significant positive relationship (r = +0.903) between the frequency of the waves and metabolic rate (total calories per hour) in 13 adult subjects. When the metabolic rate was elevated by 1.6mg of thyroxin, they found an increase in the alpha frequency also. Lindsley and Wicke (1974) also reported that in hypothyroid conditions or in other metabolically depressed states, the alpha frequency is markedly reduced. However, these are only inter-individual changes and the within-subject alpha frequency is found to be very stable.

We found that the diurnal variations of EEG, EOMT and FT are significantly related to the food-taking times. The amplitudes of the three phenomena are least at the food-taking times and largest in-between. This suggests that a lack of calories may cause a decrease in the loop gain of the muscle stretch-reflex servo-loop. When calories are regained from the food in-take, the loop gain increased again and this sets up a cycle between two food-taking times. This may be a possible explanation for the diurnal variation of physiological tremor and that of alpha waves is a result of the diurnal variation of EOM tremor. Unanimously, the mechanisms underlying the diurnal variations are much more complex and many factors may be involved. Further studies into the subject are proposed.

Conclusively, this chapter demonstrates the close diurnal relations between alpha waves and eye muscle tremor and thus supports the eye-tremor hypothesis. In addition, the significant diurnal variations in EEG, EOMT and FT are demonstrated.

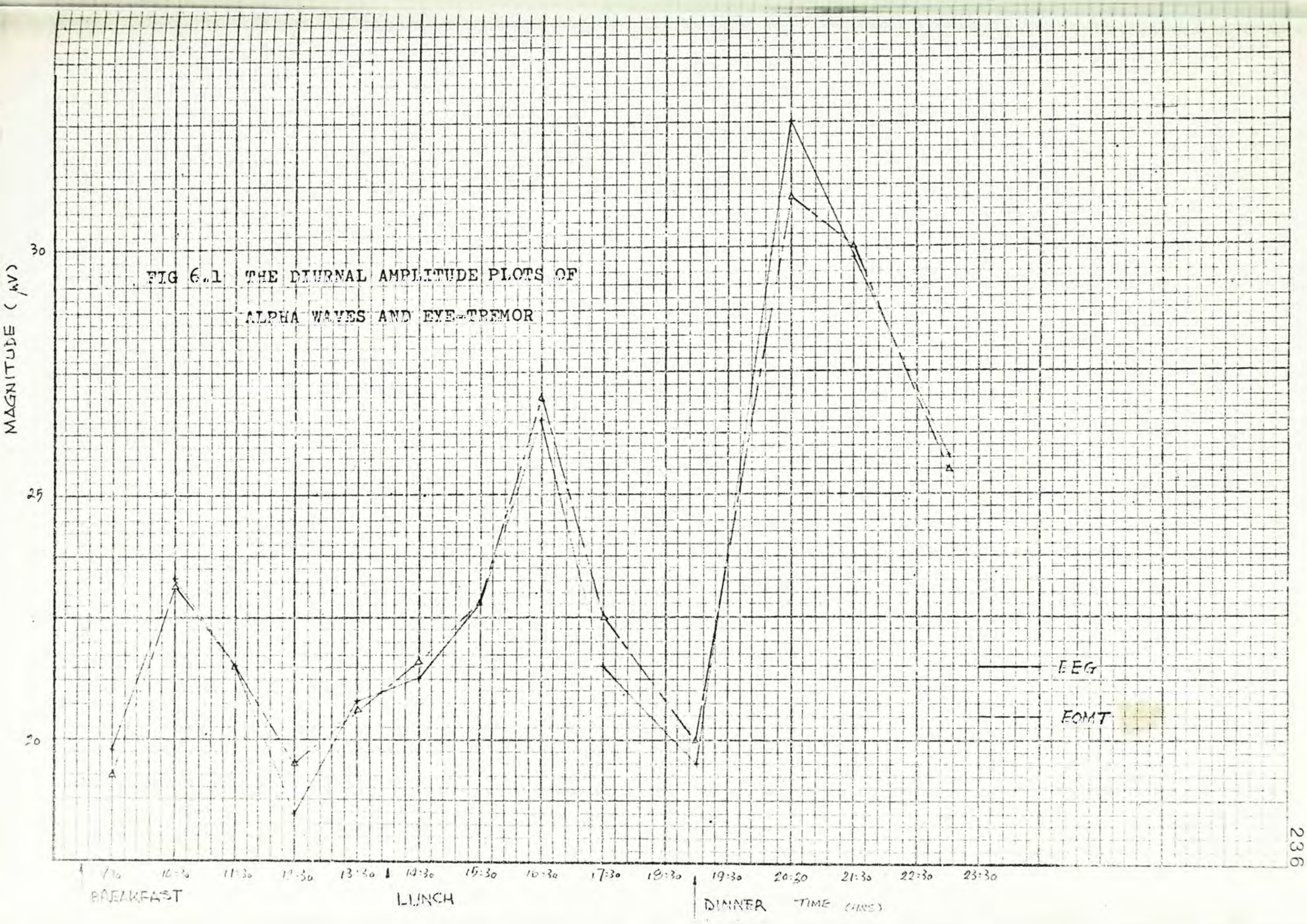


FIG 6.1 THE DIURNAL AMPLITUDE PLOTS OF ALPHA WAVES AND EYE-TREMOR

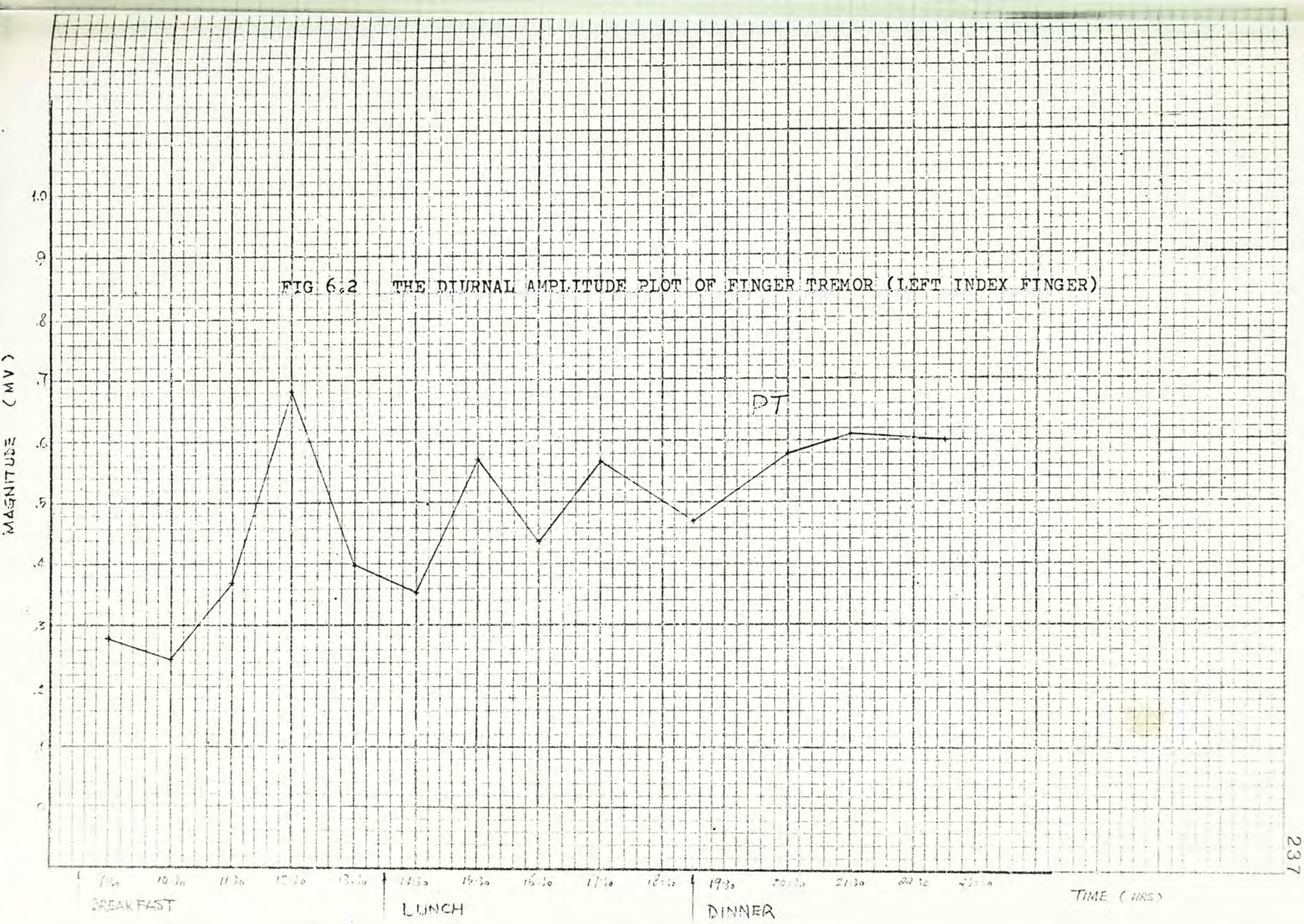


FIG 6.2 THE DIURNAL AMPLITUDE PLOT OF FINGER TREMOR (LEFT INDEX FINGER)

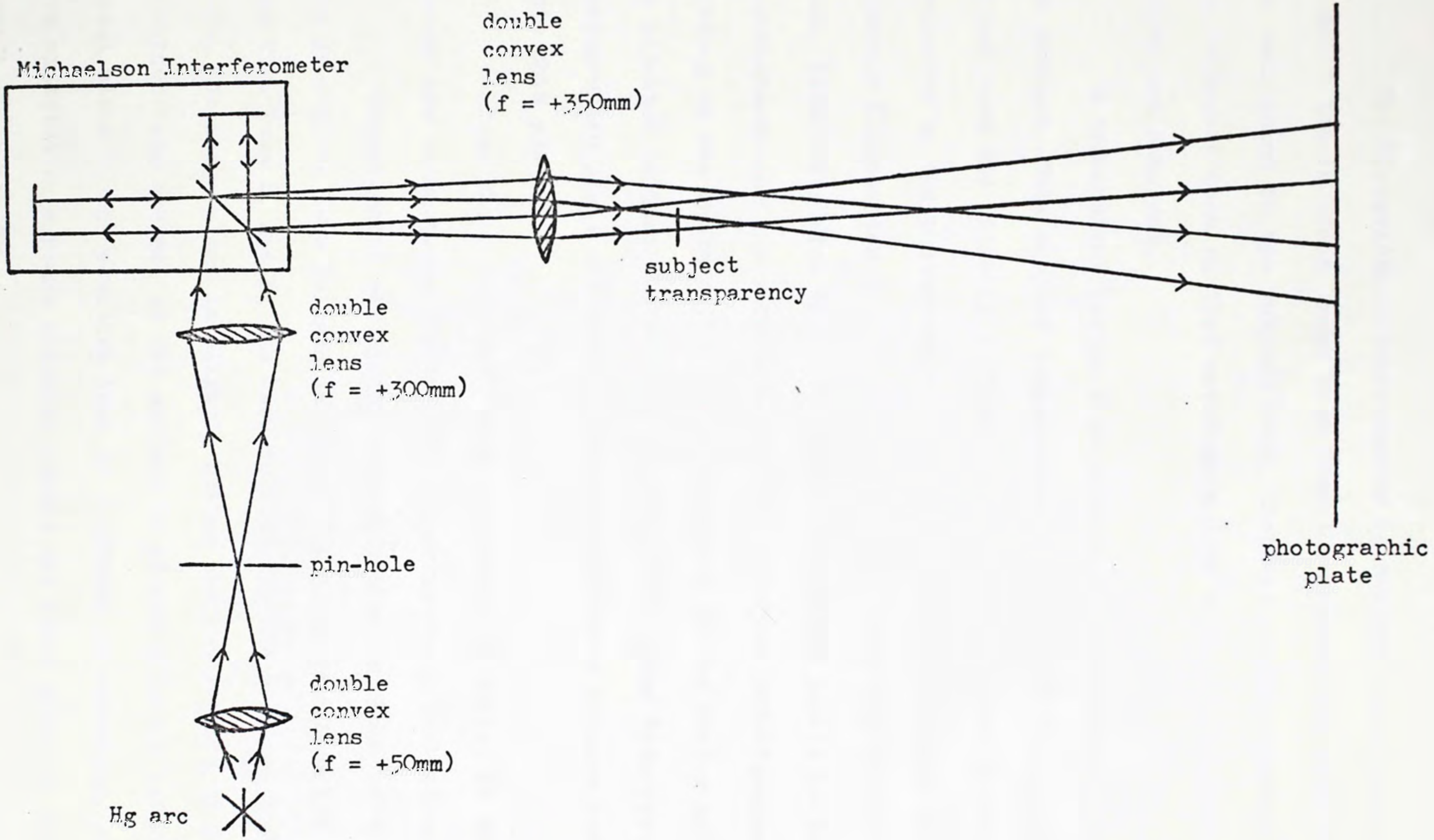


Fig. IV.1 Experimental set up for recording incoherent holograms

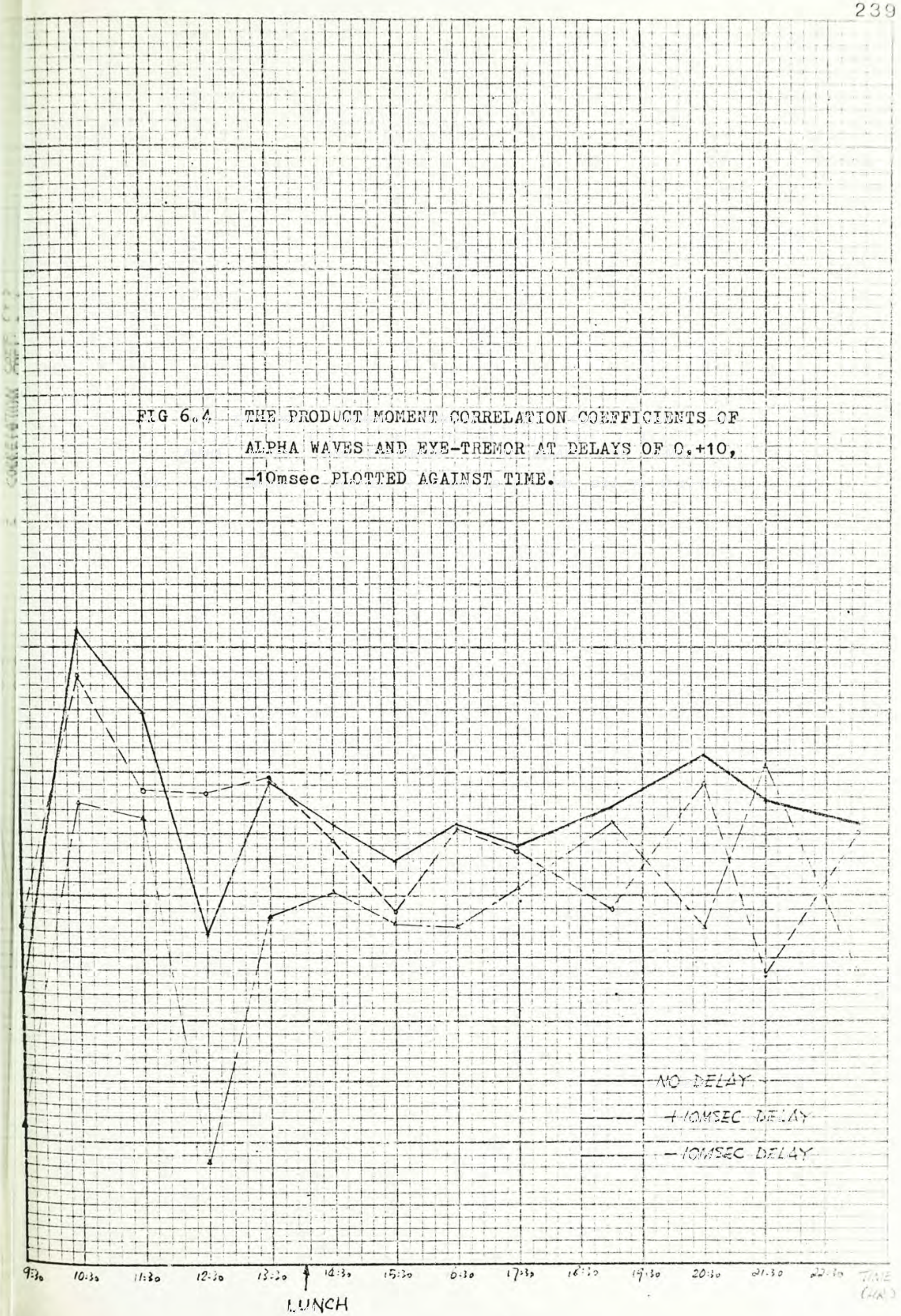


FIG 6.4 THE PRODUCT MOMENT CORRELATION COEFFICIENTS OF ALPHA WAVES AND EYE-TREMOR AT DELAYS OF 0, +10, -10msec PLOTTED AGAINST TIME.

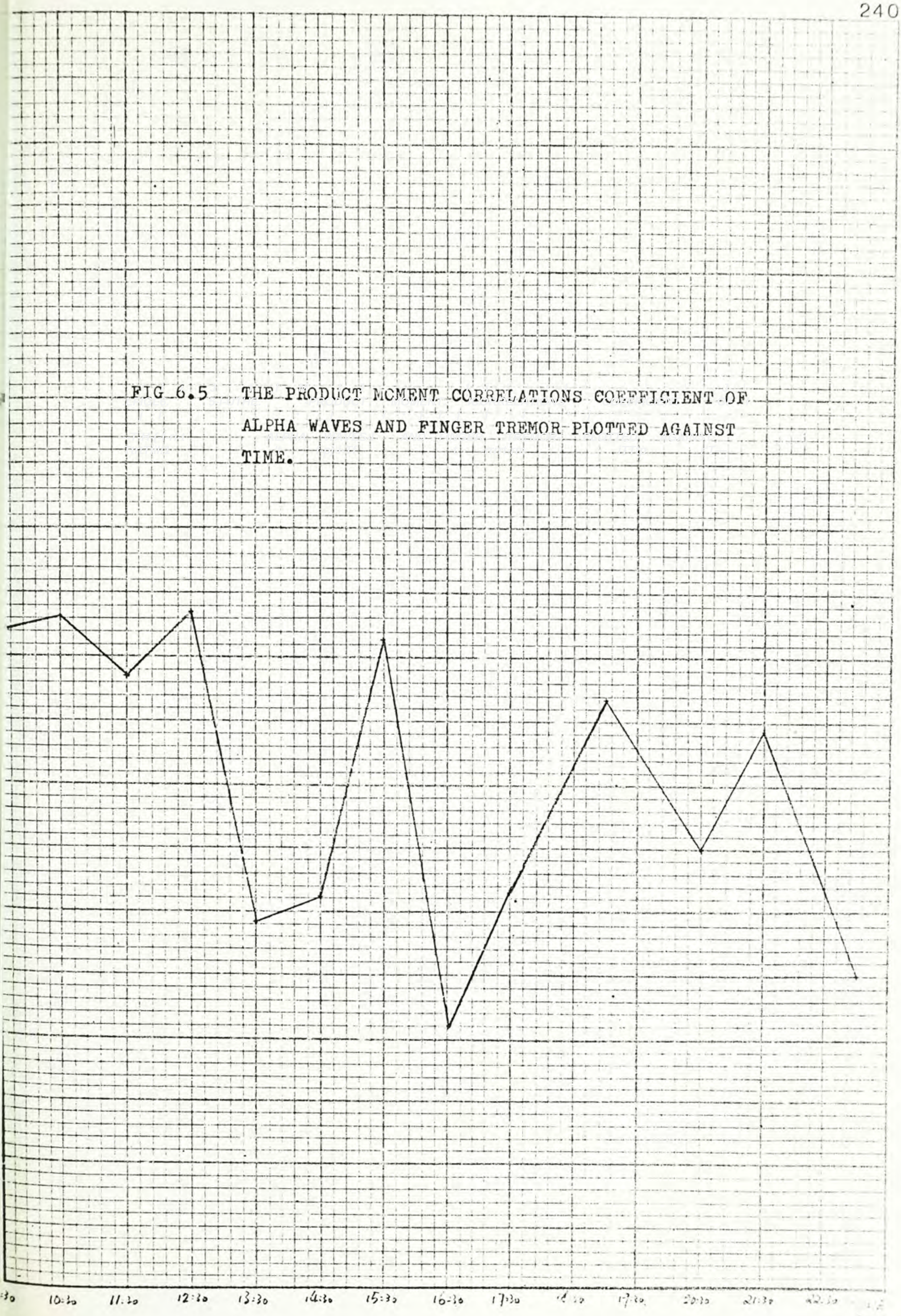


FIG 6.5 THE PRODUCT MOMENT CORRELATIONS COEFFICIENT OF ALPHA WAVES AND FINGER TREMOR PLOTTED AGAINST TIME.

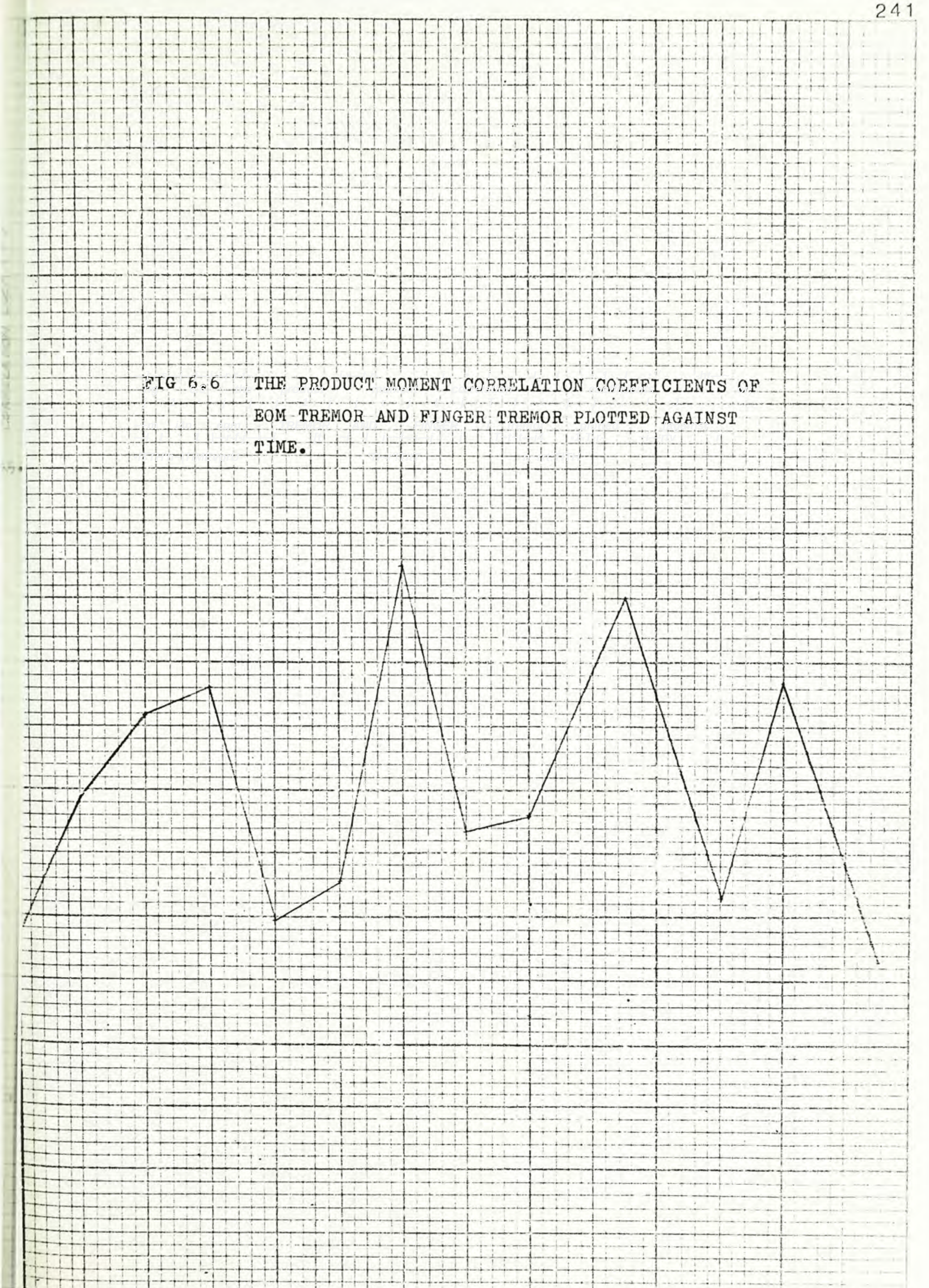


FIG 6.6 THE PRODUCT MOMENT CORRELATION COEFFICIENTS OF EOM TREMOR AND FINGER TREMOR PLOTTED AGAINST TIME.

FIG 6.7 THE AVERAGE AMPLITUDES OF ALPHA WAVES AND TREMOR OF A PARTICULAR DURATION.

EEG

D 10MSEC	TIME(H) 9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	19:00	20:30	21:30	23:00
4	0.1	0.1					0.5		0.1			0.1	
5	0.3	0.3	0.2	0.1	0.2	0.2	0.2		0.1			0.2	
6	0.35	0.5	0.3	0.5	0.6	0.6	0.3	0.4	0.4	0.2	0.5	0.7	0.1
7	0.5	0.5	0.5	0.65	0.5	0.95	0.7	0.4	0.75	0.3	0.7	0.9	0.1
8	1.77	0.758	0.62	0.6	0.71	0.62	0.79	0.96	0.87	0.67	0.94	1.32	0.82
9	2.61	1.094	0.95	0.77	1.033	0.86	0.83	1.11	1.08	0.73	1.03	1.28	0.92
10	1.59	1.02	0.94	0.875	0.943	1.1	1.06	1.16	1.0	0.84	1.4	1.27	1.23
11	2.345	0.99	0.98	0.75	0.975	1.025	0.97	1.23	0.9	1.26	1.6	1.12	1.25
12	2.97	1.017	1.28	1.12	2.9	0.65	1.1	1	1.1	0.5	0.7	1.55	0.6
13		0.5	1.0	0.1	1	0.8	1.6		0.7	0.5			0.6
14				0.7	1.1					0.7			

(a) alpha waves

PT

D 10MSEC	TIME(H) 9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30	19:00	20:30	21:30	23:00
4		0.1		0.1									
5		0.1		0.1						0.3			
6	0.27	0.16	0.3	0.6	0.4	0.2	0.2	0.35	0.5	0.2	0.6	0.45	0.25
7	0.3	0.325	0.375	1.2	0.54	0.5	0.83	0.8	0.60	0.43	0.43	1.2	0.5
8	0.82	0.35	0.662	1.07	0.643	1.73	1	0.74	1.12	0.86	1.22	1.70	1.17
9	0.99	0.675	0.92	2.425	0.88	0.83	1.26	1.08	1.20	1.36	1.17	1.44	1.55
10	0.78	0.574	0.92	1.5	1.28	0.89	1.28	1.6	1.07	1.4	1.38	1.45	1.6
11	0.63	0.58	0.92	1.4	1.35	0.75	1.3	1.15	1.8	0.67	1.85	2	1.3
12	0.55	0.38	0.55	1.27	0.65	0.55	1.6	0.6	0.90	0.93	0.8	1.07	0.6
13	0.6	0.8	0.45	0.8		0.6	1.1	0.95			0.8		0.8
14		0.625	0.8	1		0.7							

(b) finger tremor

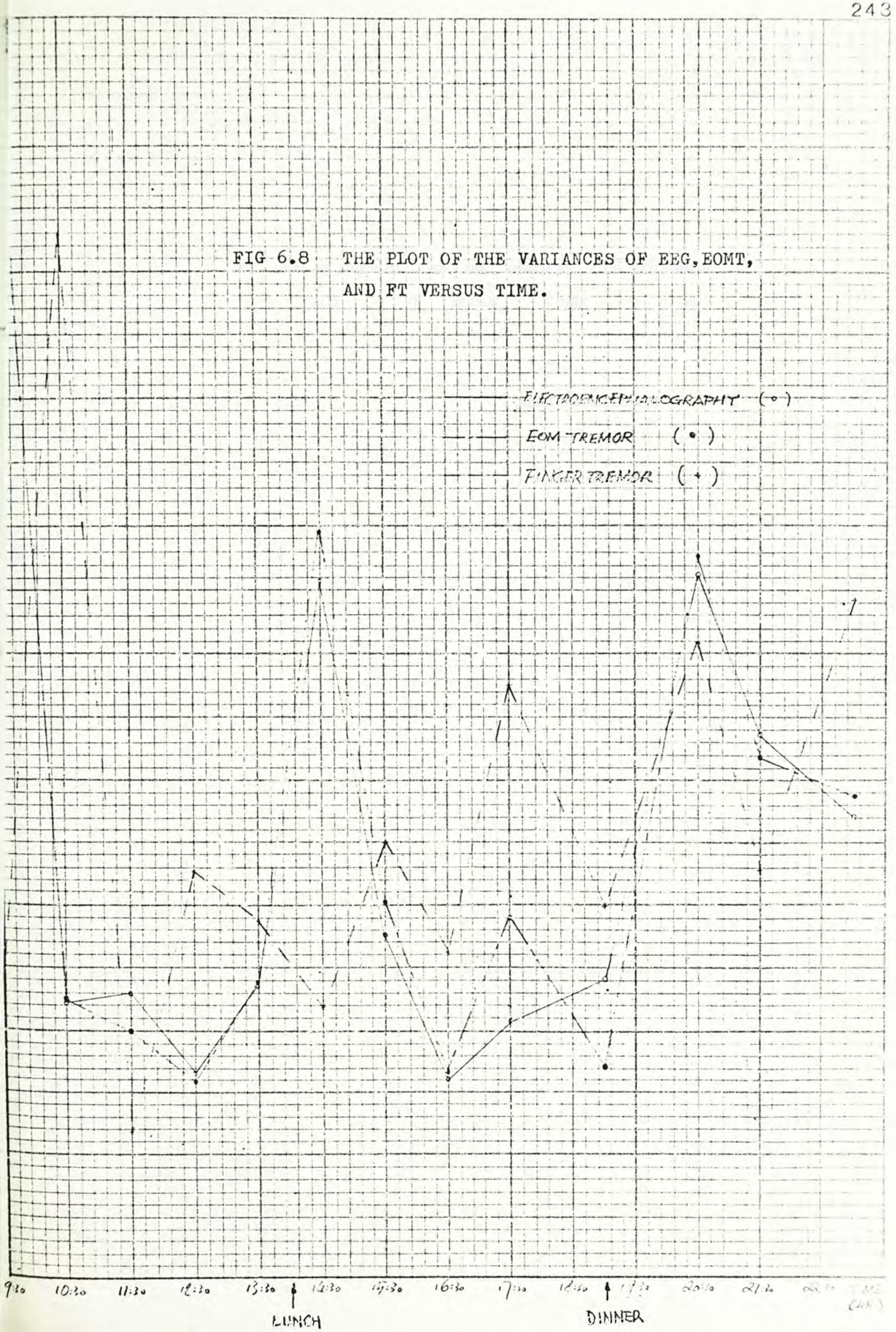


FIG 6.8 THE PLOT OF THE VARIANCES OF EEG, EOMT, AND FT VERSUS TIME.

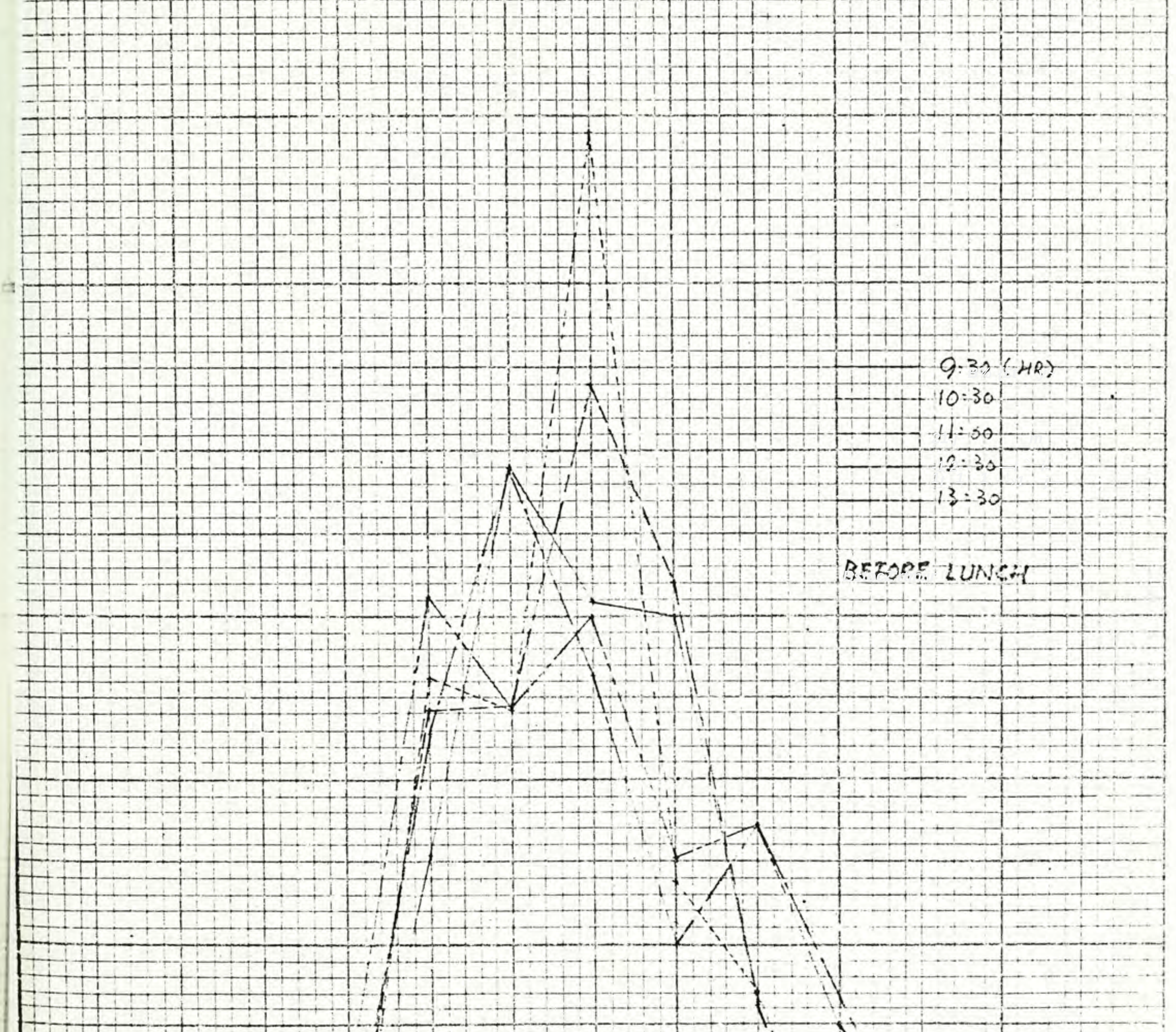
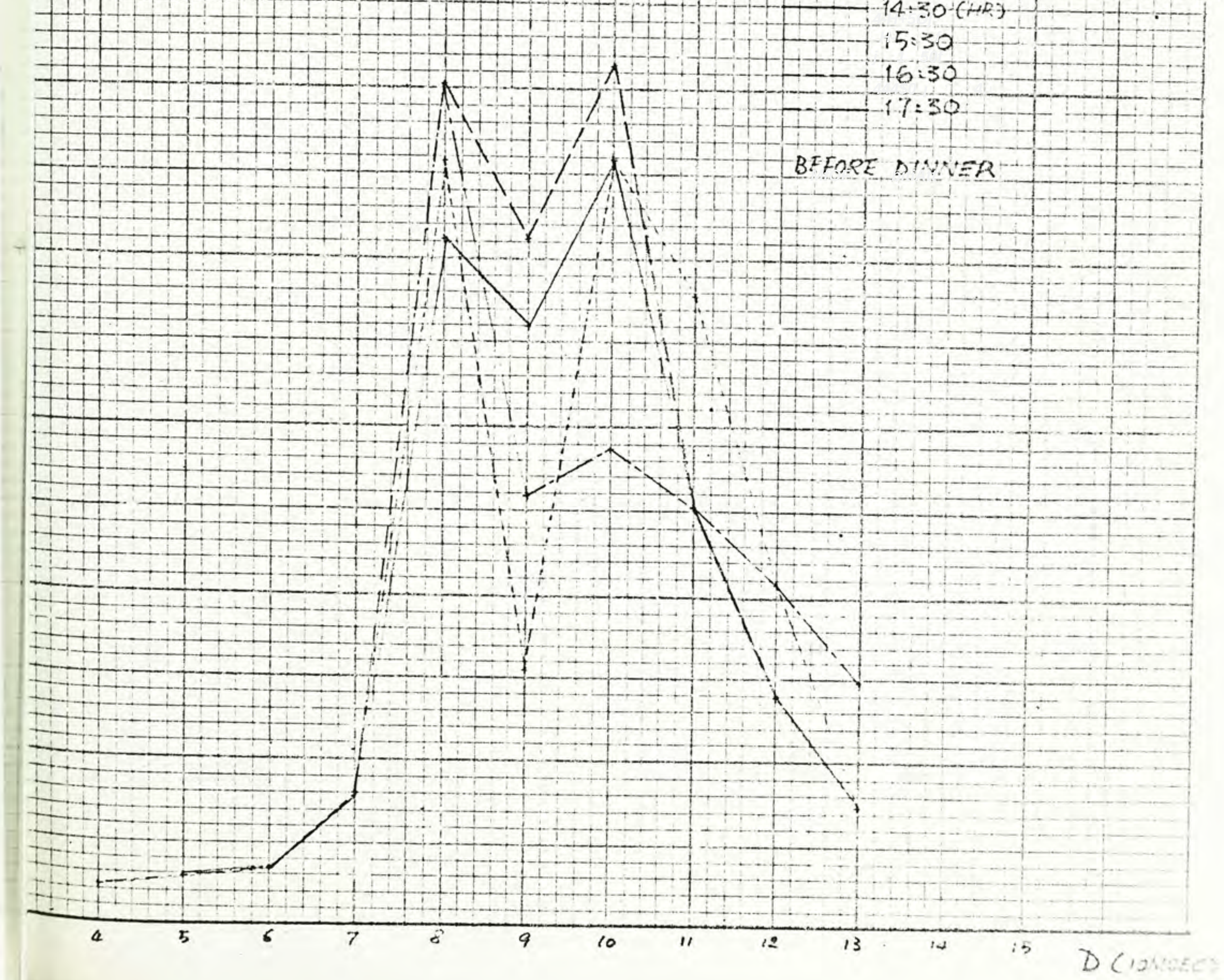


FIG 6.9 THE ACTIVITY TIME PLOT OF THE ALPHA WAVES IN PERIOD ONE OF A 20 SEC EPOCH.

FIG 6.10 THE ACTIVITY TIME PLOT OF THE ALPHA WAVES OF A 20 SEC EPOCH IN PERIOD TWO.



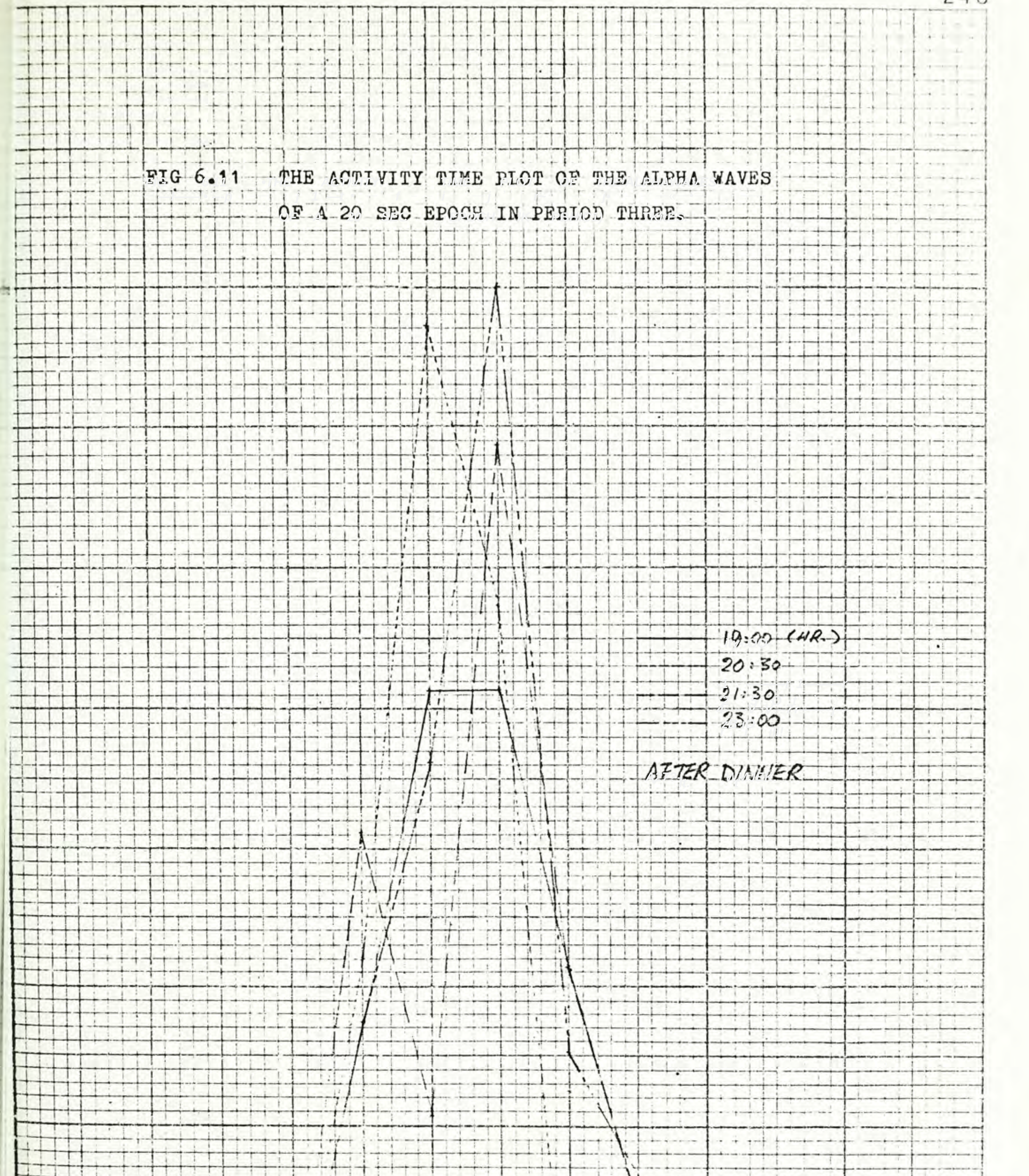
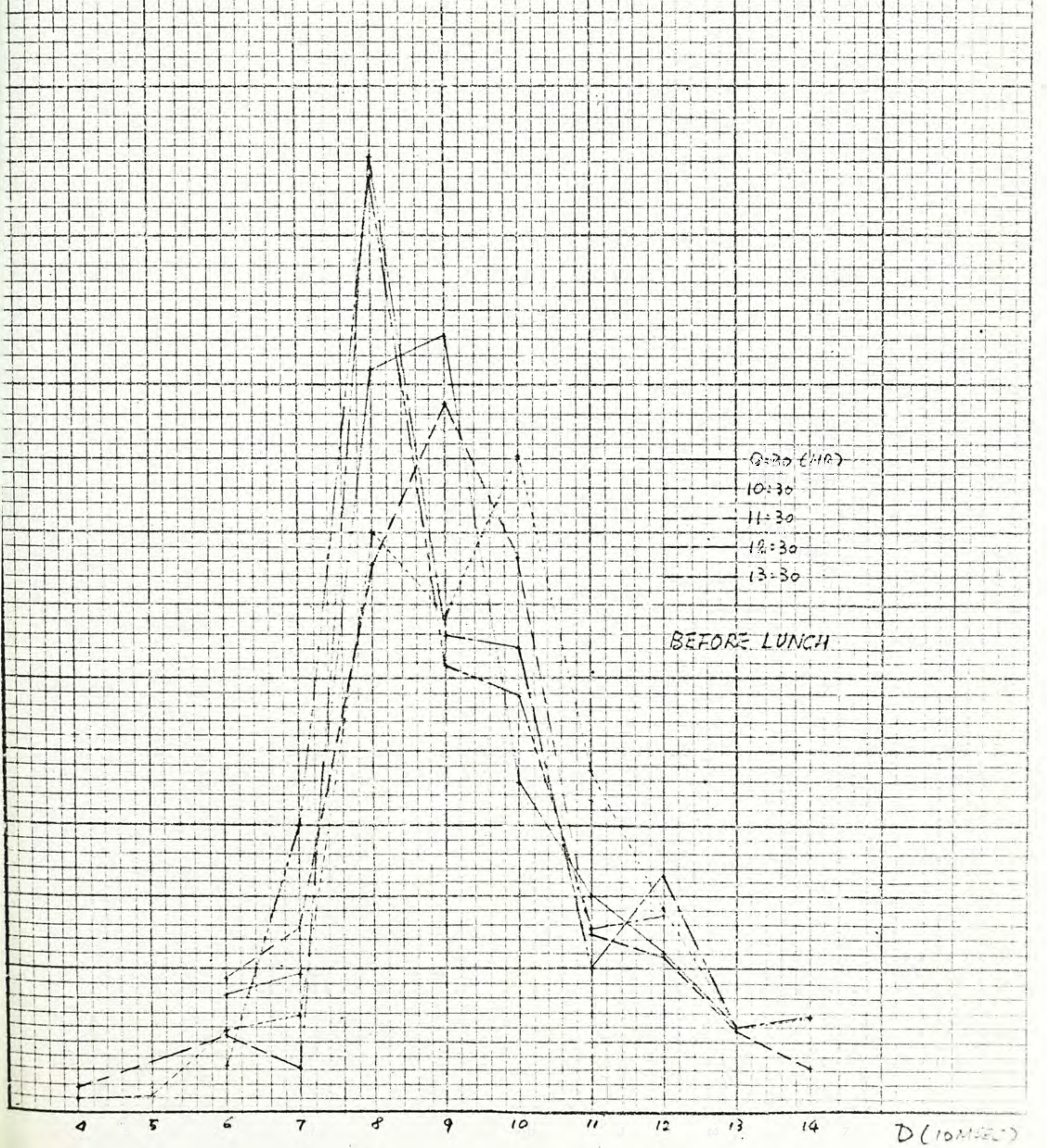


FIG 6.11 THE ACTIVITY TIME PLOT OF THE ALPHA WAVES OF A 20 SEC EPOCH IN PERIOD THREE.

FIG 6.12 THE ACTIVITY TIME PLOT OF THE FINGER TREMOR OF A 20 SEC EPOCH IN PERIOD ONE.



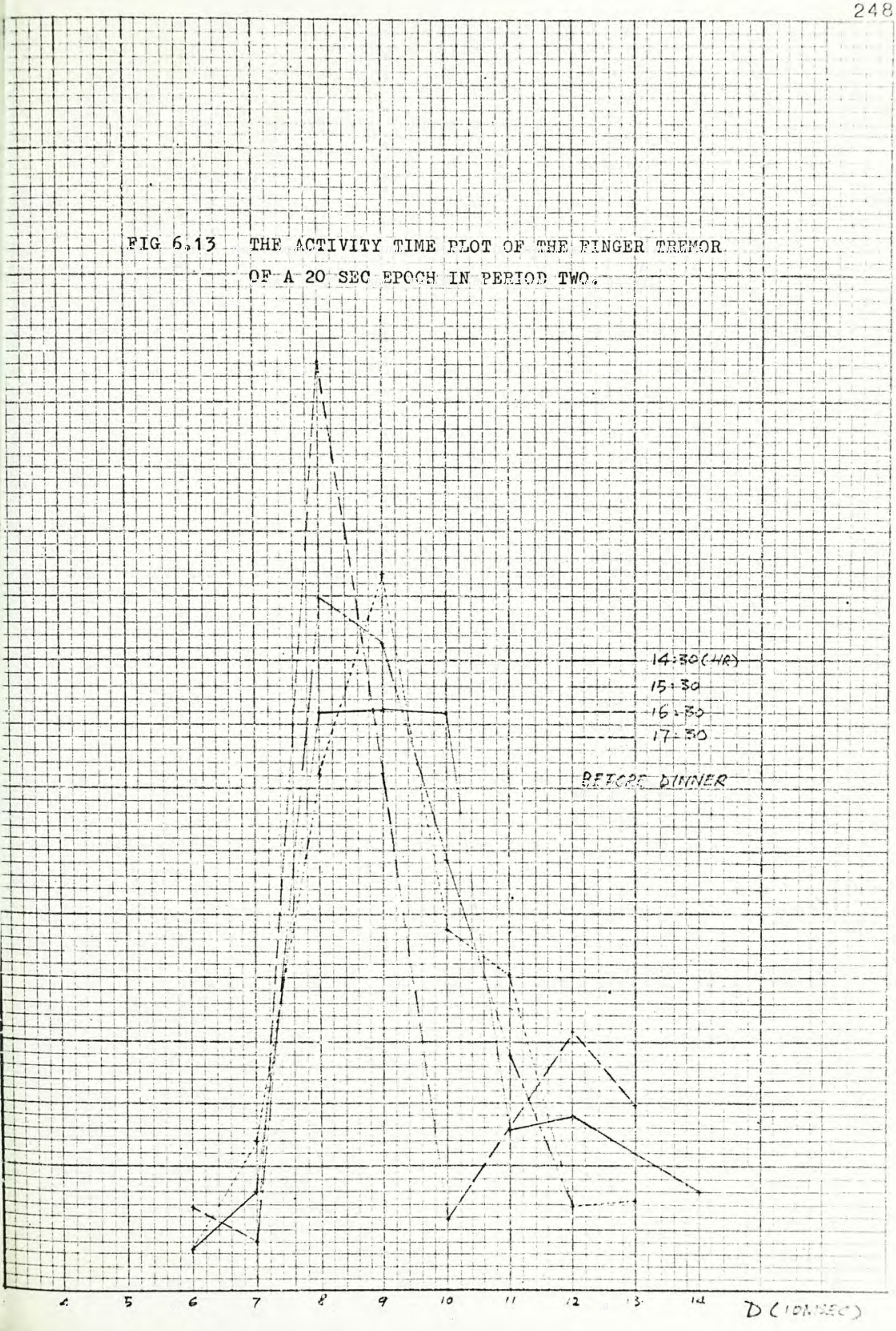


FIG 6.13 THE ACTIVITY TIME PLOT OF THE FINGER TREMOR OF A 20 SEC EPOCH IN PERIOD TWO.

FIG 6.14 THE ACTIVITY TIME PLOT OF THE FINGER TREMOR OF A 20SEC EPOCH IN PERIOD THREE.

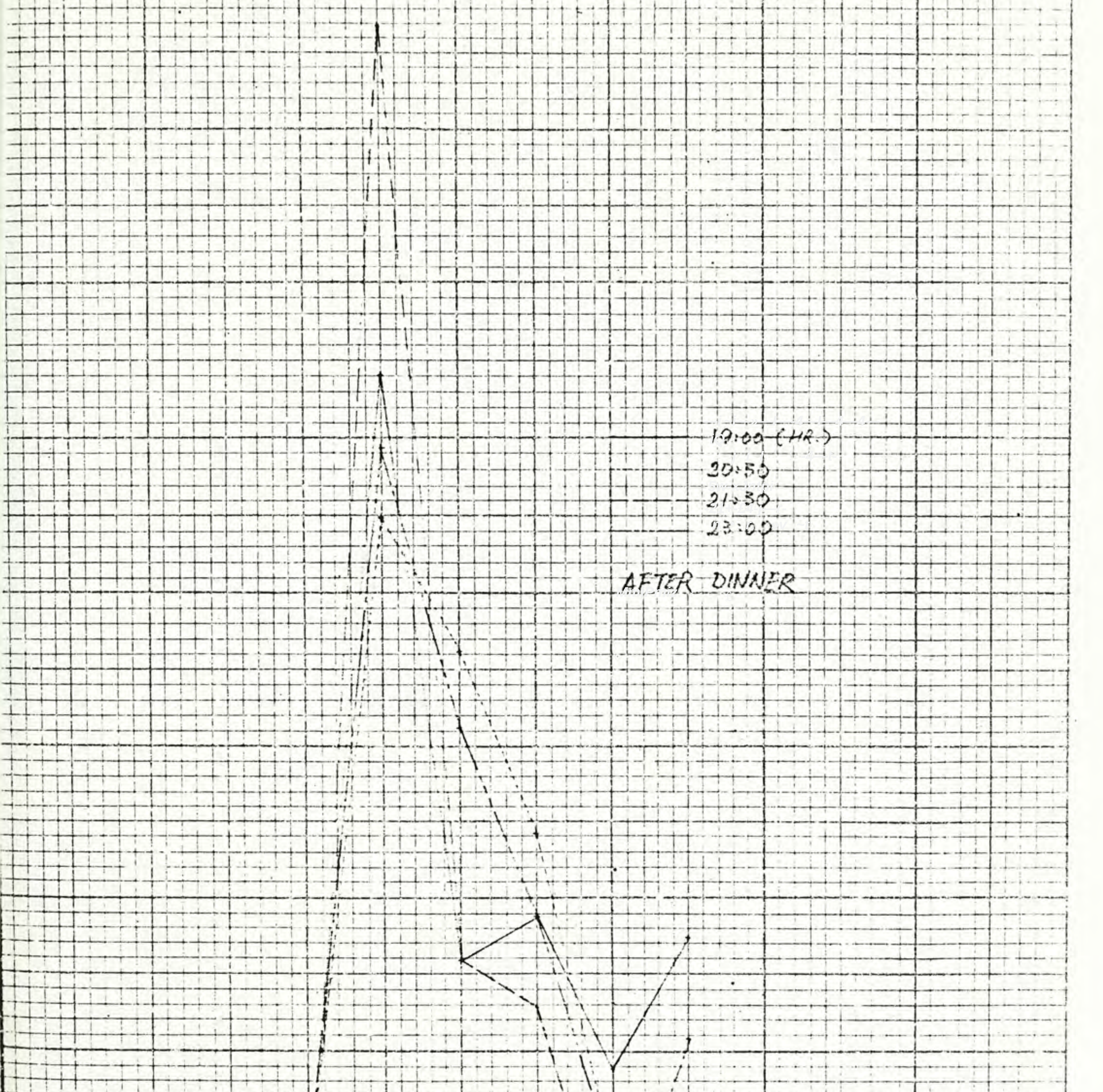


FIG 6.15 THE AMPLITUDE DISTRIBUTION PLOT OF THE ALPHA WAVES OF A 20 SEC EPOCH IN PERIOD ONE.

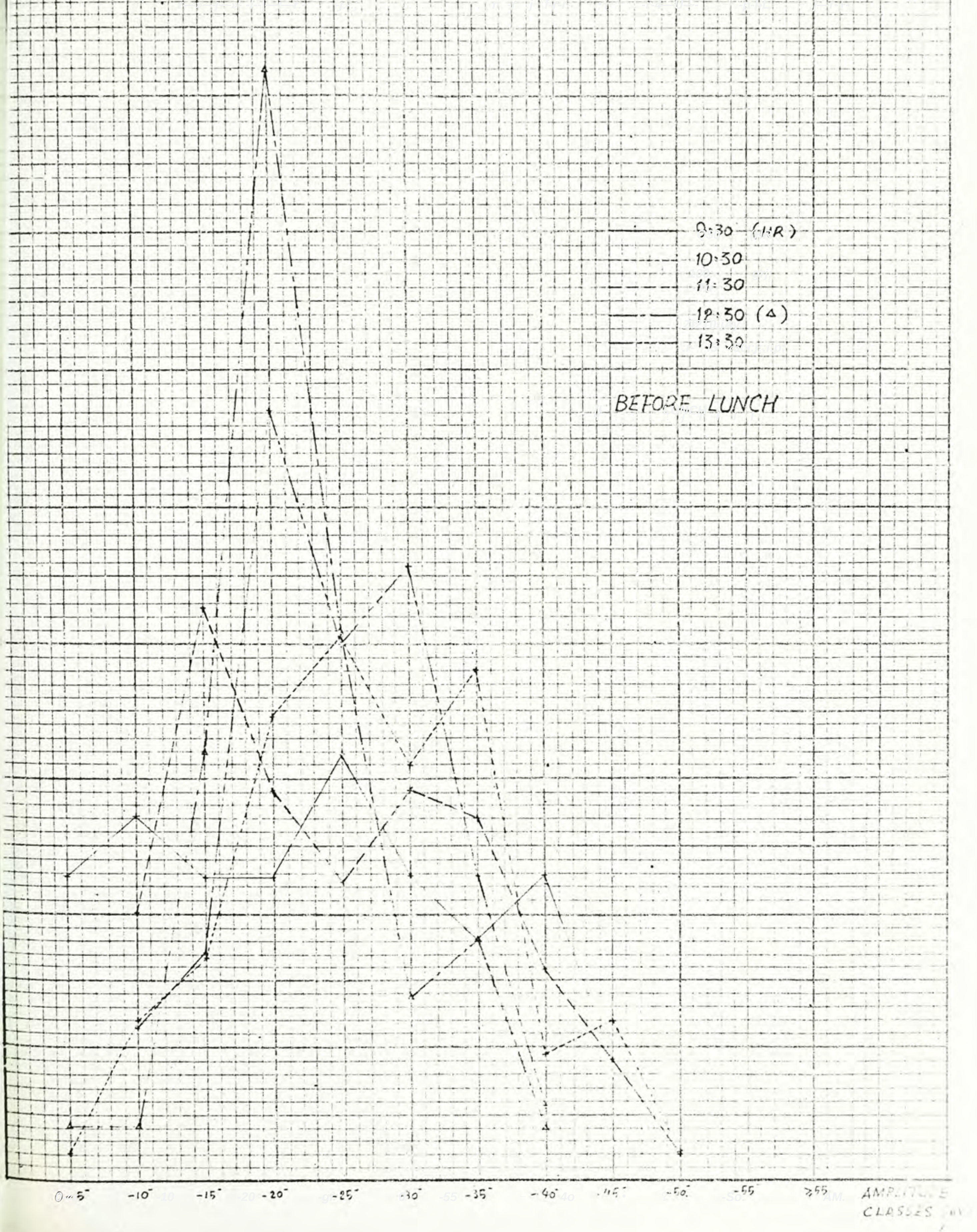


FIG 6.16 THE AMPLITUDE DISTRIBUTION PLOT OF THE ALPHA WAVES OF A 20 SEC EPOCH IN PERIOD TWO.

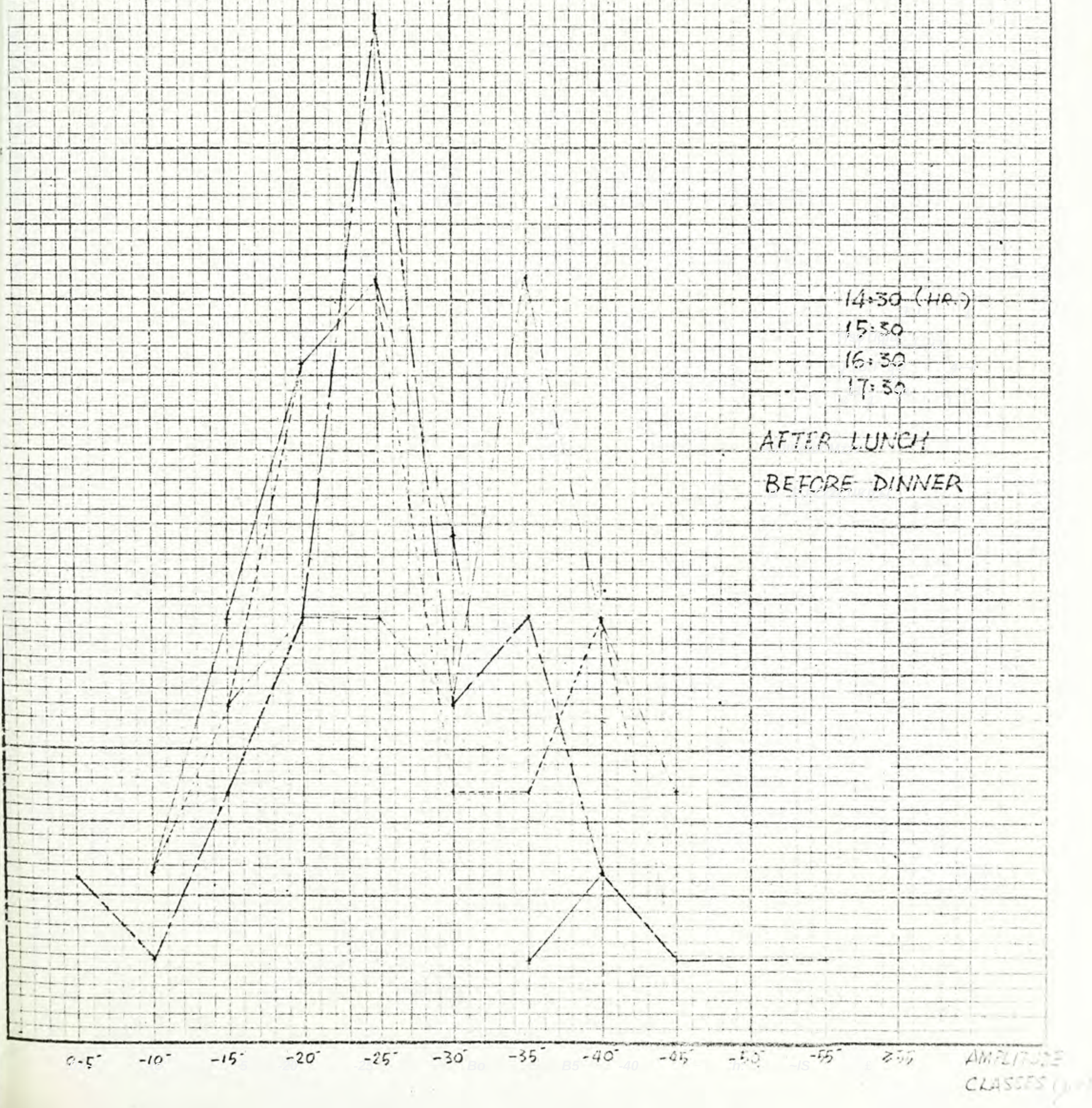


FIG 6.17 THE AMPLITUDE DISTRIBUTION PLOT OF THE ALPHA WAVES OF A 20 SEC EPOCH IN PERIOD THREE.

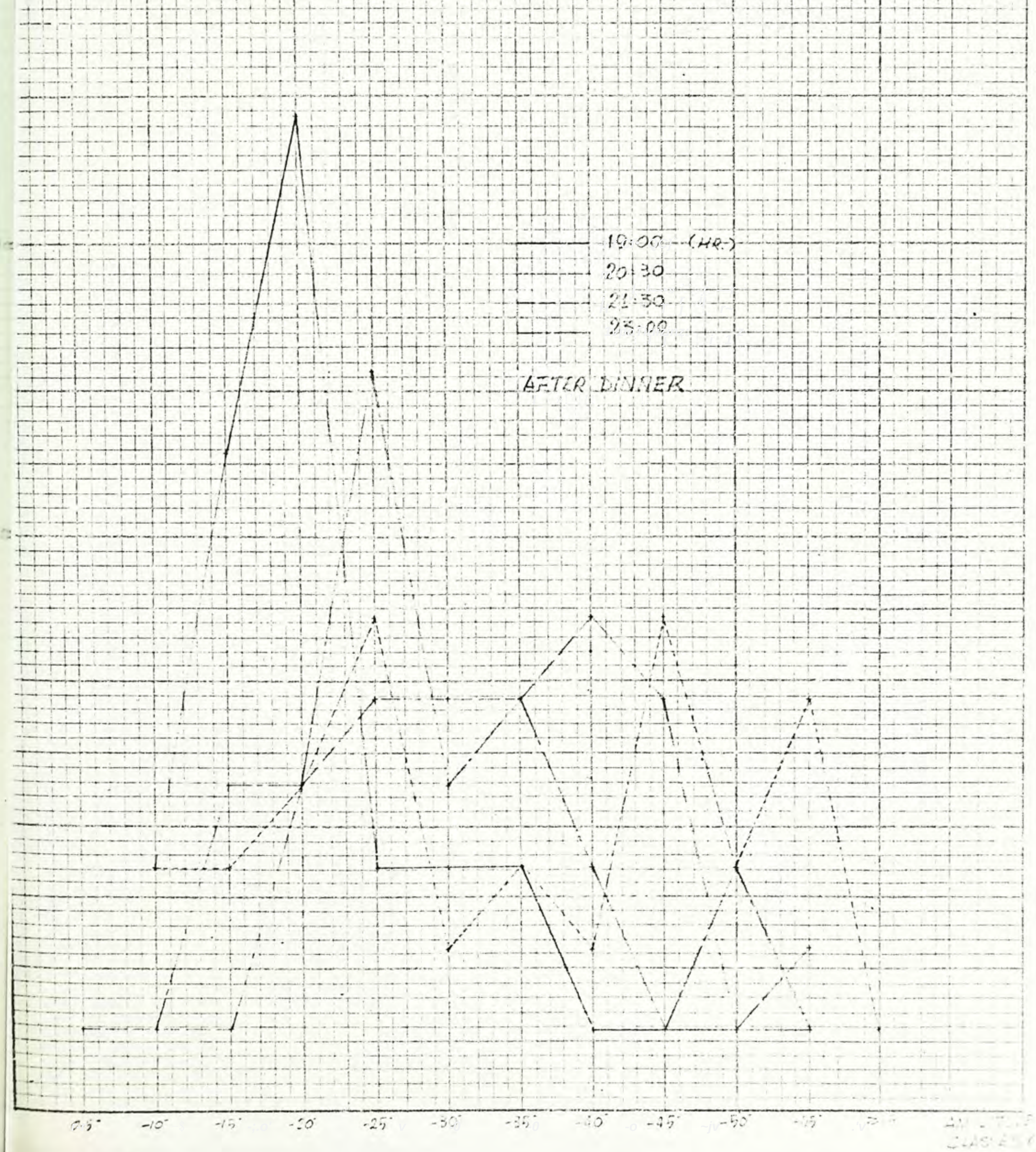


FIG 6.18 THE AMPLITUDE DISTRIBUTION PLOT OF THE FINGER TREMOR OF A 20 SEC EPOCH IN PERIOD ONE.

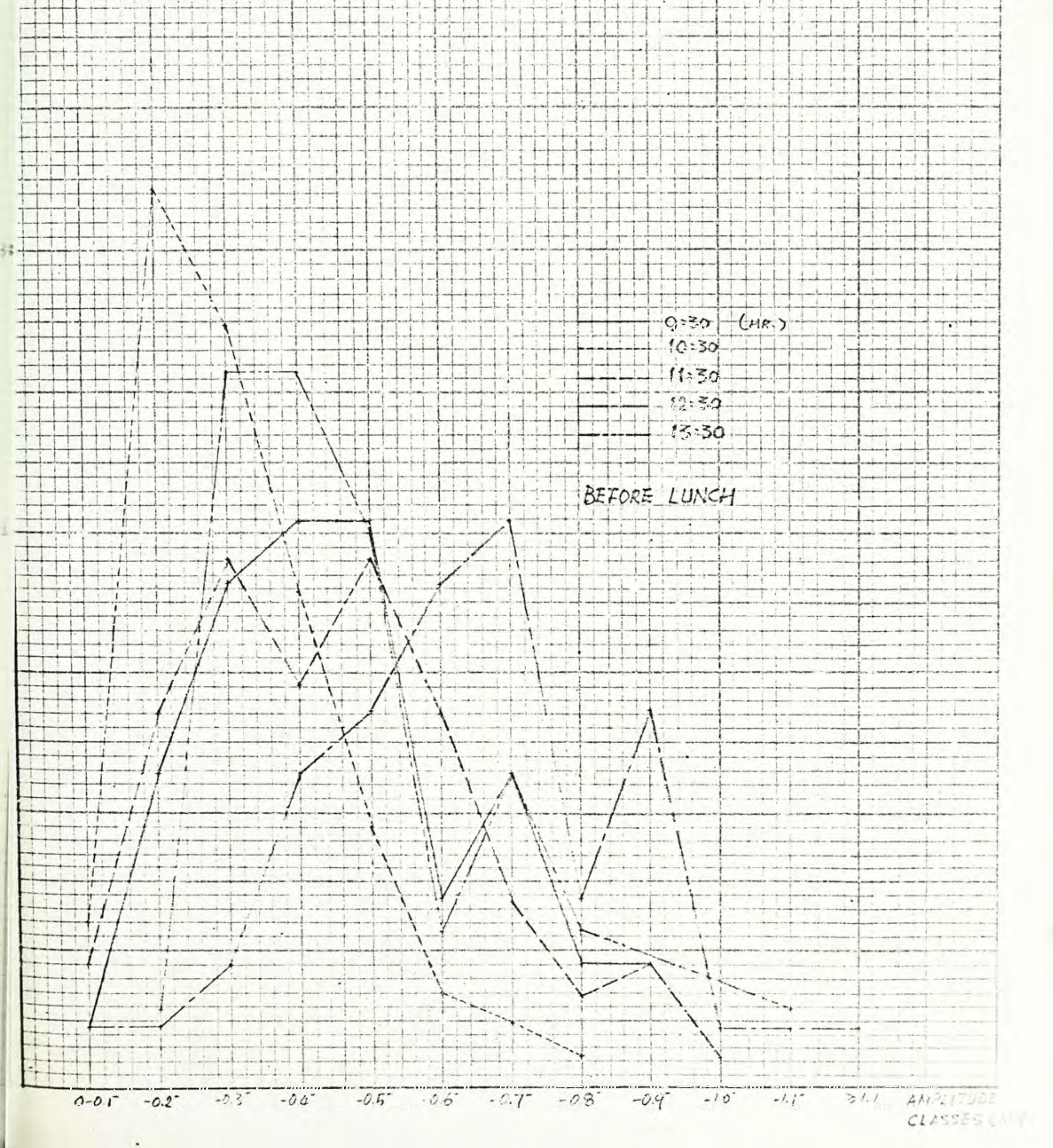


FIG 6.19 THE AMPLITUDE DISTRIBUTION PLOT OF THE FINGER TREMOR OF A 20 SEC EPOCH IN PERIOD TWO.

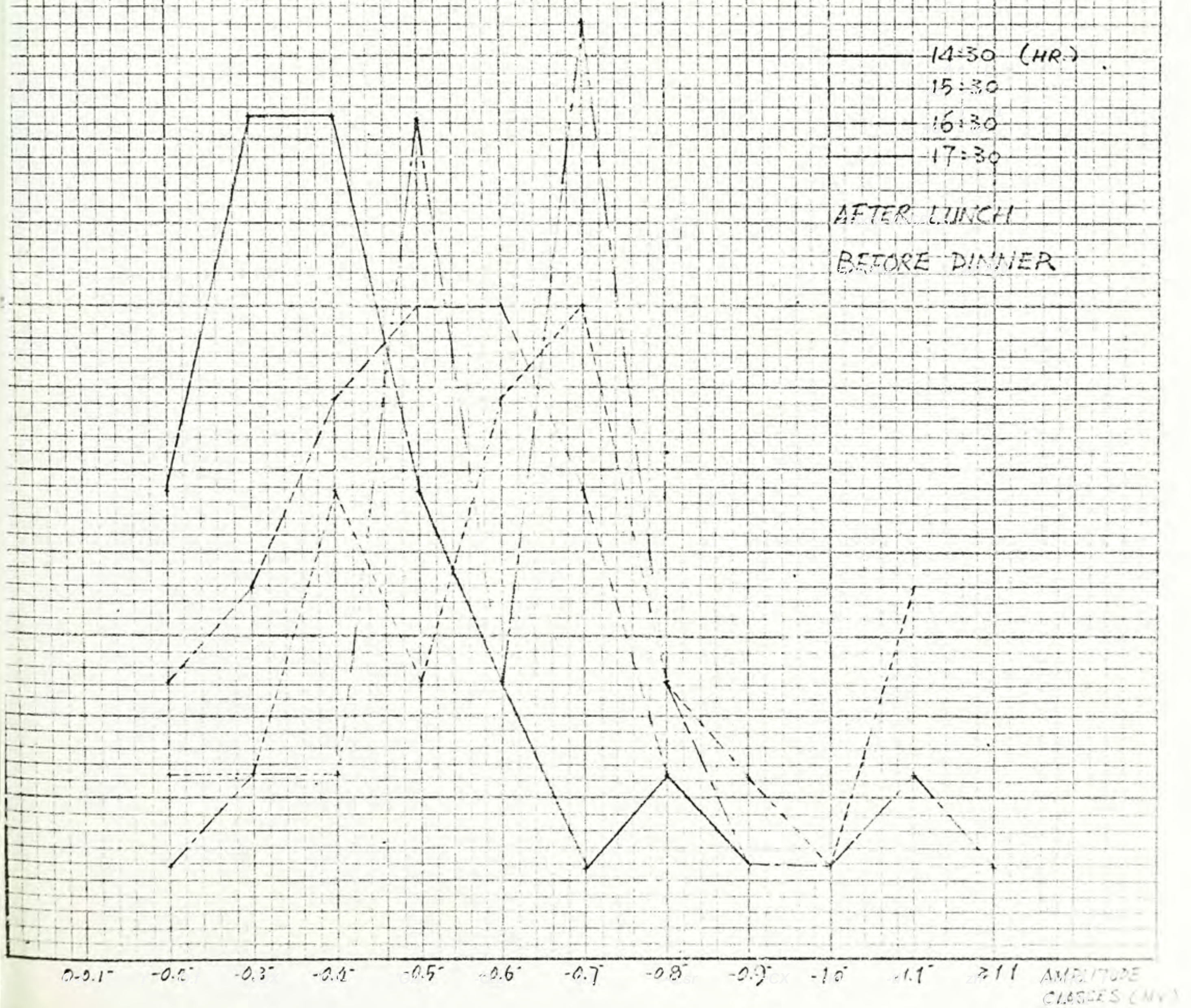
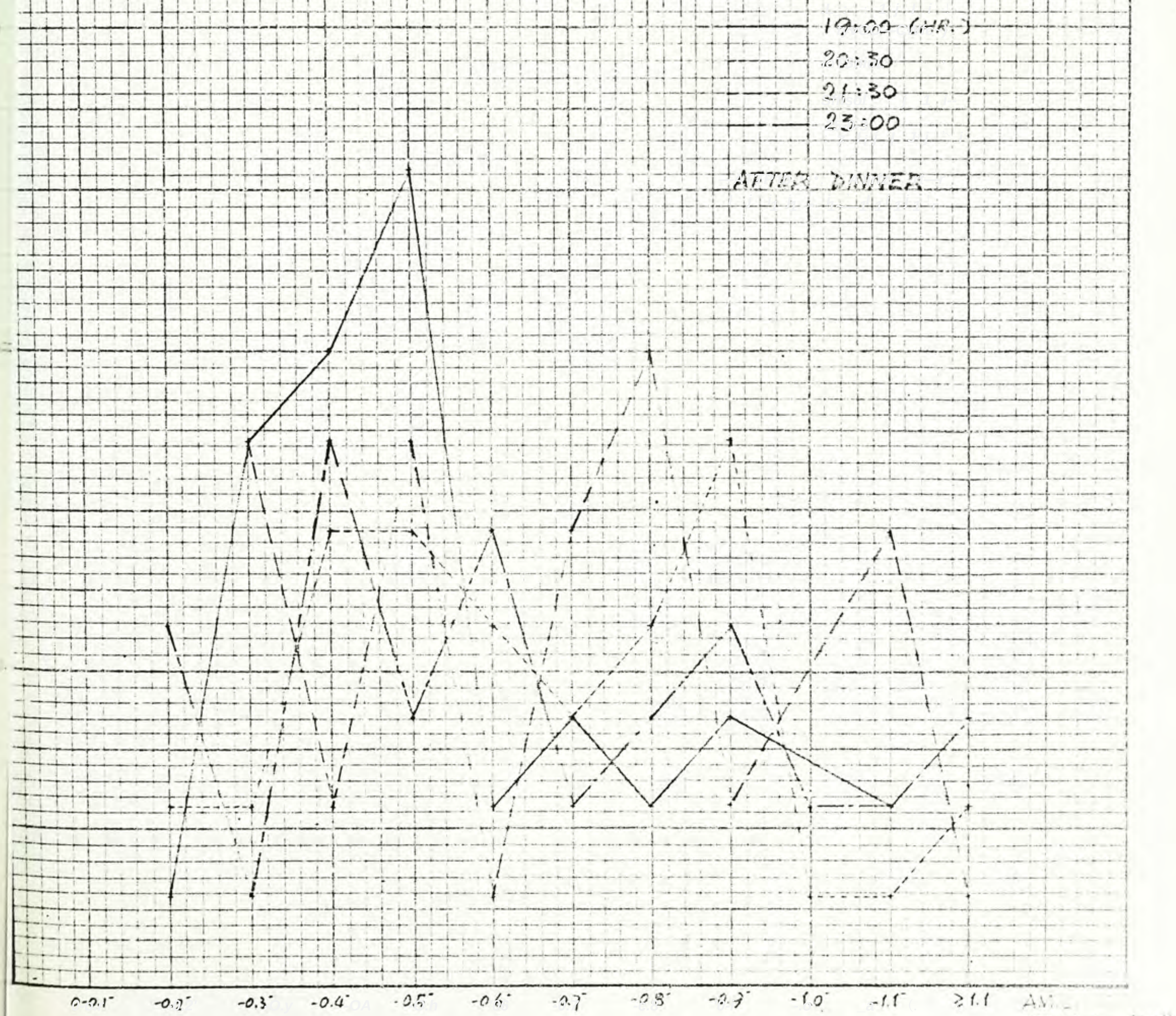


FIG 6.20 THE AMPLITUDE DISTRIBUTION PLOT OF THE FINGER TREMOR OF A 20 SEC EPOCH IN PERIOD THREE.



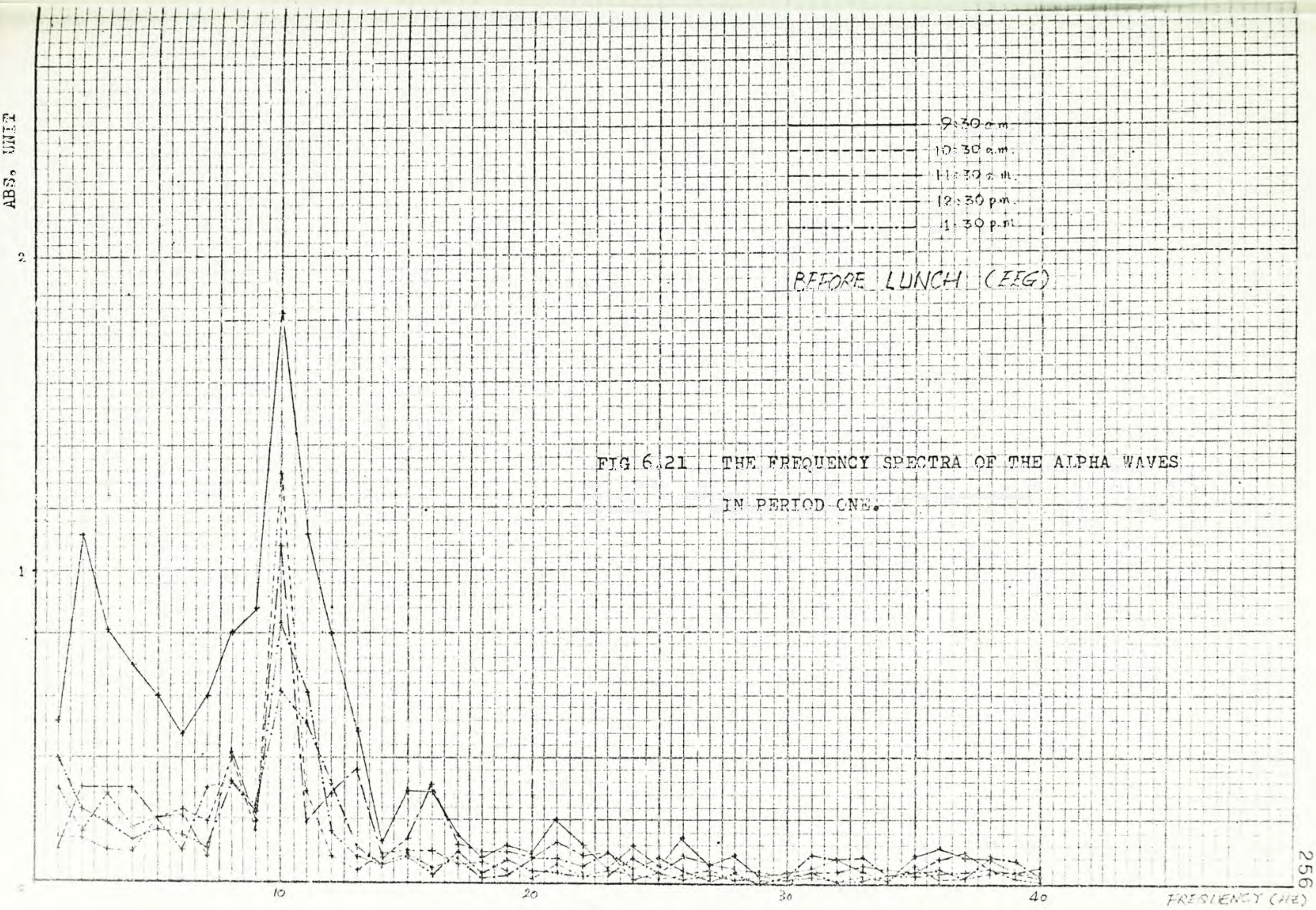


FIG 6.21 THE FREQUENCY SPECTRA OF THE ALPHA WAVES IN PERIOD ONE.

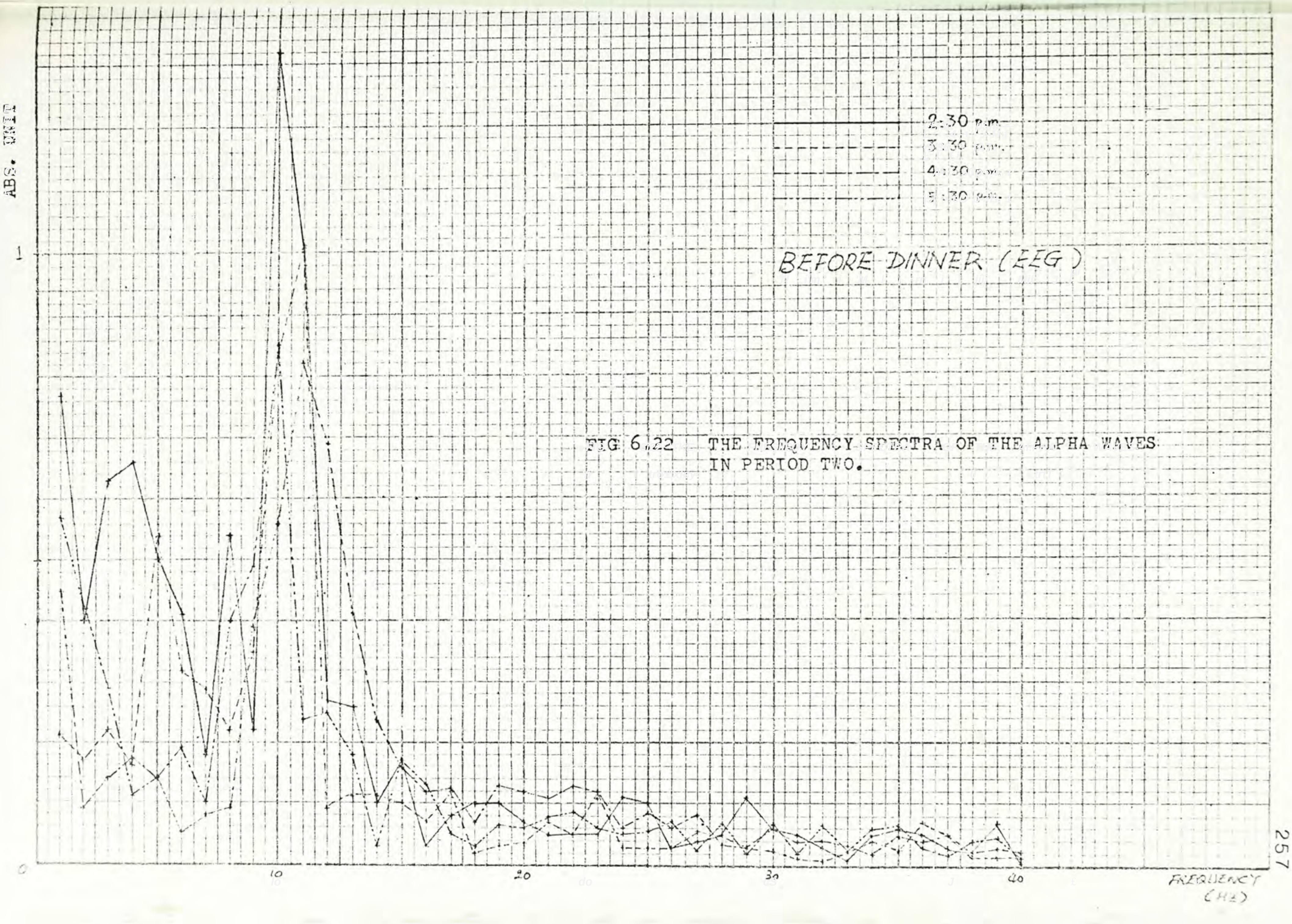


FIG 6.22 THE FREQUENCY SPECTRA OF THE ALPHA WAVES IN PERIOD TWO.

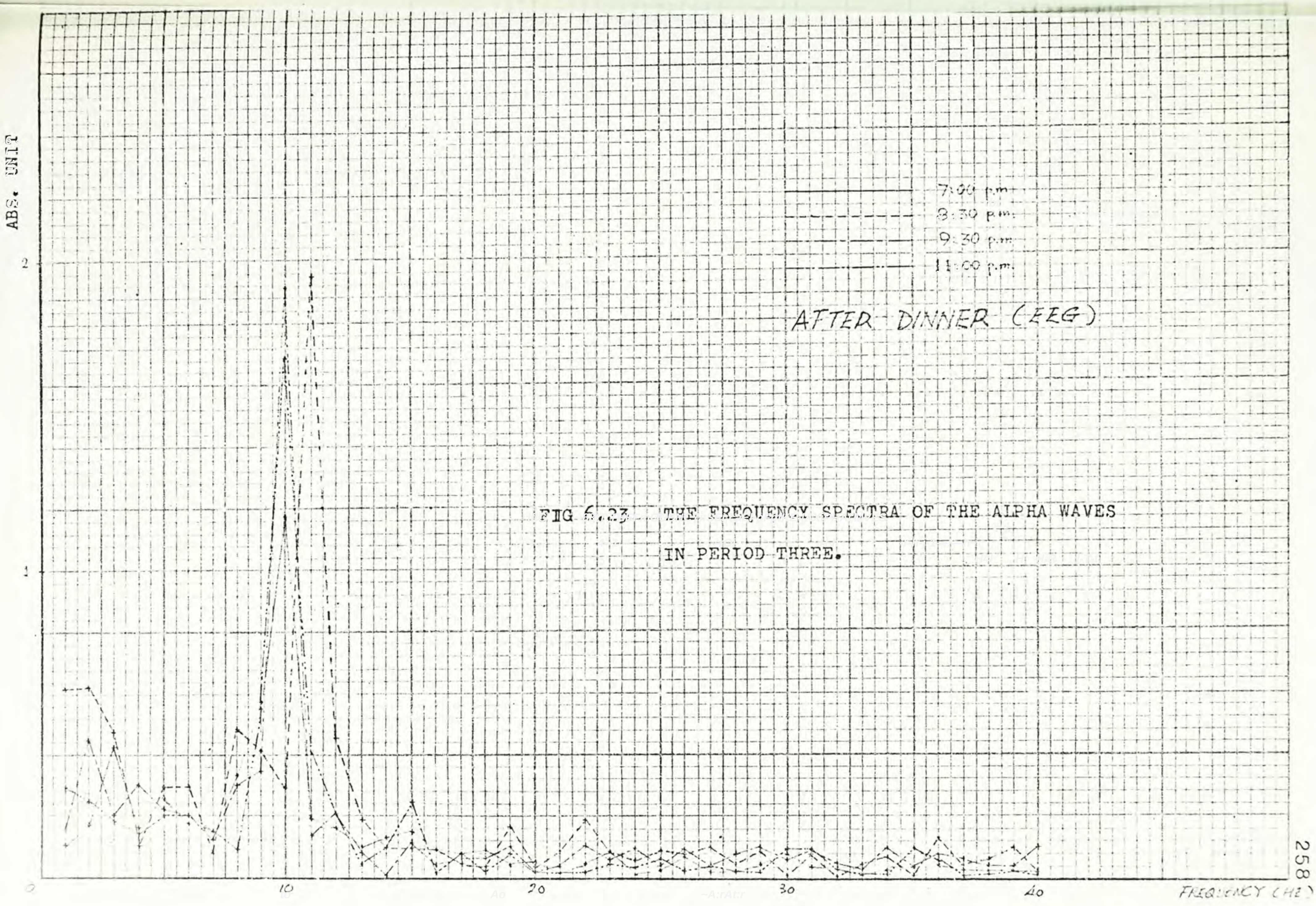


FIG 6.23 THE FREQUENCY SPECTRA OF THE ALPHA WAVES IN PERIOD THREE.

CHAPTER SEVEN

CASE STUDIES

7.1 ELECTROPHYSISLOGICAL STUDIES IN CORTICAL BLINDNESS : REPORT OF A CASE

1. Introduction

The eye-tremor hypothesis that the alpha waves are electrical concomitant of EOM tremor appears to be well supported by the various tests and experiments so far in this work. However, one possible objection to it is the indisputable fact that it is possible to record alpha wave in blind subjects. It is important that the eye-tremor hypothesis should be able to account for the case of cortical blindness. The knowledge about its cerebral electrophysiological correlates is yet scanty (Bergman 1957; Kooi et al 1966). Several reports on the electrophysiological findings in blind subjects showed contradicting results and proposed different interpretations (Abbott and Dymond 1970; Chapman et al 1971; Shaw et al 1970; Lippold and Shaw 1971; Kooi and Sharbrough 1966). Chapman et al (1970) reported the presence of normal alpha and kappa waves in a bilaterally enucleated subject as well as the absence of marked left-right differences in 2 one-eyed subjects and concluded that alpha and kappa activity are not directly dependent on the CRP, extra-ocular tremor, eye positions, accomodation and eyelid flutter. The result was also supported from recordings of an eyeless patient by Shaw, Foley and Blowers (1970). These results are the principal objections raised to Lippold's findings. However, when Lippold and Shaw (1971) re-examined the eyeless patient described by Shaw et al (1970), they found that there are present, across the empty orbits, standing potentials which behave in a manner similar to the normal CRP. Potential changes of 50 to 75 µV in amplitude occur concomitant with the commands : "Please look to the left, look right, look left,...". They were found to resemble CRP recordings in normal subjects. Lippold and Shaw (1971) then examined the interior of the orbit and showed the lining membrane to be in a state of continual fluttering movement which was clearly affected by external stimuli such as sounds or tapping on the face. Supporting evidences are also gained from the absence or very small amplitude of alpha waves in children suffering from Retrolental fibroplasia (Cohen et al 1961; Jeavons 1964). Retrolental fibroplasia is a total or partial blindness due to diseased retinal blood vessels in premature infants probably leading to a partial or total abolition of the CRP. It follows from chapter 5 (CRP as the source of the alpha waves) that an absence or very small amplitude of alpha waves should be obtained.

In enucleated subjects, the extra-ocular muscles and a large part of the fundus of the eye may remain, including Bruch's membrane, which is responsible for generating the CRP. This is a probable explanation for the existence of the alpha rhythm in blind subjects as the EOMT and the source, CRP, are present. This is also consistent with the fact that some blind subjects show little or no alpha waves. In all the 12 blind subjects studied by Bergman (1957), no alpha activity was found. The globe in their orbit may have been entirely removed or that all their eye muscles and the bruch's membrane are completely de-functioned. This chapter is directed towards a deeper study into the problem of the existence of alpha waves in the blind. EEG, EOG, EOMT and FT were recorded under different experimental conditions in a case of cortical blindness secondary to measles.

2. Case report

(a) The subject

The subject is a 36 year old male, blinded since 3 year old due to the complications of measles. He is neurologically normal, has real eyes and lost complete sense of perception of light or movement over ten years ago. He found difficulties in moving his eyes but his EOM is intact without nystagmus. The pupils are indistinct and fixed and do not respond to any stimuli. Other modalities of sensation are intact.

(b) Method

The subject was made familiar with the enironment and the whole procedure was explained to him in detail before actual recordings. The experiment was carried out with the same set-ups with the subject seated comfortably in a padded chair. Resting EEGs were recorded under EO and EC conditions, utilising conventional electrode placements and montages (T5-O1 and T6-O2 of the standard 10-20 system). The recording technique has been described in section 2.5.1. Visual evoked responses by stroboscopic flashes were tested under the EO condition to stabilize level of alertness and avoid inter-individual variability introduced by differences in lid thickness and vascularity (Kooi _et al_ 1966). The procedure is described in section 5.2.3, simultaneously with occipital EEG under different tests. The recordings of EOMT and FT were same as described in section 4.2 and 3.5 respectively. Polarising currents are passed into the subject's orbit as described in section 5.2.3 to test the variation in his alpha amplitude. The respective recording techniques have enabled the various tests to be carried out in the blind subject.

(c) Results and Discussions

(i) EEG studies

This case study establishes that a normal resting EEG and the presence of the occipital alpha rhythm are not incompatible with complete cortical blindness. In addition, the low incidence and small amplitude of the alpha waves indicating a substantial alpha deficit are characteristics of the blind subject. Bilateral occipital recordings of the subject's EEG are shown in Fig. 7.1. The crosscorrelogram of the right and left occipital alpha is characterised by its irregularity, low-frequency and low correlation ($r=0.253$) (Fig. 7.2). The average amplitude of the alpha waves was found to be about 10μV. It is interesting to note that the alpha amplitude of the blind subject is extremely small throughout and is only about 0.2-0.3 that of normal. The frequency spectrum of the EEG shows a dominant peak at 8Hz and the occipital alpha activity ranges from 7 to 10Hz (Fig. 7.3). Sub-maximal peaks occur at 6 (theta rhythm), 11 and 17 (beta rhythm!)Hz respectively. Notwith-standing that the alpha rhythm is much less significant than the normal, the theta and beta rhythms appear to be much more significant. The delta and gamma rhythms are the same as normal. It is observed from a lengthy record (about 2 min) that the alpha incidence is less than 50% and the remainder of the record is non-rhythmic, mixed-frequency activity of amplitude less than 10μV. Overall, the regularity, stability, synchrony and intensity are low.

(ii) Correlative studies

The EOM tremor and finger tremor (left index) were recorded as in normal subjects. The frequency spectrum of the EOMT is very similar to that of EEG in the subject (Fig. 7.3) but not that of finger tremor (Fig. 7.4). They eye-tremor profile shows a dominant peak at 8Hz ranging from 7 to 10Hz, and a sub-maximal peak at 6Hz (theta range), exactly the same as that of the alpha waves. Unambiguously, the most important factor for the generation of alpha waves the eye-tremor, is found to be present. Moreover, they are found to be correlated fairly well. The value of r for the left occipital alpha and left-eye-tremor in the blind subject is 0.582 (Fig 7.5) and that for the alpha waves and eye-tremor of the right hemisphere is 0.335 (Fig 7.6). Nevertheless, the two profiles are not as regular as the normal ones, but they are compatible with each other. the correlation is localised to one side of the hemisphere only. Autocorrelograms of the alpha waves and EOM tremor are also compatible with each other (Fig 7.7 and Fig 7.8 respectively). They both have a peculiar profile as compared to the normal ones but they are similar in appearance. The correlation between the alpha waves and EOM tremor is thus demonstrated in the blind subject. Aside from this , 7-10 Hz oscillations are found in the EOG recordings and are also correlated with the alpha waves as in normal subjects (Fig 7.9). They are found to have similar magnitudes and fairly related in phase, amplitude and frequency. Thus , the source of the alpha waves in the blind subject - the CRP - is also found to be present. All in all, these results suggest that alpha waves may be recorded from blind subjects if their EOM and CRP are present and intact . Therefore, the appearance of the alpha rhythm in blind patients should not necessarily be an objection to the eye-tremor hypothesis. Contrariwise, the EEG recordings in the blind subject are found to be supporting the hypothesis.

The finger tremor, on the other hand, shows no correlations with the EEG and EOMT but has similar peak frequency. The crosscorrelogram of the EEG and FT in the blind subject shows a poor correlation (r=0.008) (Fig 7.10). It is characterised by its irregularity. The frequency spectrum of FT shows a dominant peak at 1 Hz and two sub-maximal peaks at 8 and 10 Hz respectively (Fig 7.4). It is characterised by a dominance of the delta rhythm.

It merits to mention here that although FT and EOMT are both physiological tremors and have similar magnitudes in normal subjects, average FT amplitude (about 1.5 mV) in the blind subject (same as normal) is about 5 times large than that of EOMT (about 0.5 mV). This may be due to a gradual degeneration of the extrinsic ocular muscles for a long history of blindness which is in turn due to the lack of use of the muscles. The tension engendered in them by the accomodation-convergence disparity is released and thus tremor is reduced. Consequently, the EEG amplitude of the subject should be about one-fifth that of normal as the EOMT magnitude of normal subjects is 5 times larger than the blind. The small amplitude and low incidence of alpha waves in blind patients are thus explained.

(iii) Experimental tests

All the prodedures involved in these tests have already been described in section 2.6.

EO and EC conditions had no effects on EEG, EOMT, FT and EOG recordings of the blind subject. They were also not appreciably altered during periods of visual stimulation by stroboscopic flashes; No visual evoked responses occurred. Eye blinks and forcing the eye to extreme positions had no effects either.

Mental tasks (mental arithmetic and thinking) diminished alpha activity, EOM tremor and EOG waves.

Hyperventilation and muscular manoeuvres (clenching and skin-pinching) enhanced alpha waves, eye-tremor and EOG oscillations in a similar manner as the normal subjects. Action spikes were also readily observed in the 3 phenomena. The activation of the sternocleidomastoideus enhanced EEG, EOMT and EOG of the same side of the hemisphere only, similar to recordings in normal cases.

These results show that alpha waves, eye-tremor and EOG waves roughly co-vary under different experimental conditions, especially the alpha waves and eye-tremor. The alpha waves and EOM tremor showed a fairly good correlation throughout all these tests. It follows that not only in normal subjects, but also in blind patients, the extra-ocular muscle tremor is responsible for generating the alpha waves recorded over the occipital regions and the CRP is the potential source for the waves. Supporting evidences for the potential source are also gained from the following experiments. Passing a small polarising current into the orbit of the blind subject for about half an hour enhanced both the amplitude of the alpha and EOG waves in similar proportions. On the other hand, pressing the eyeball of the subject diminished the amplitude of both phenomena. As explained in chapter 5, the CRP is also demonstrated to be the potential source of alpha waves in the case of cortical blindness. All in all, the eye-tremor hypothesis that the alpha rhythm is the modulations of the CRP by the EOM tremor is again supported.

3. Conclusion

The existence of the alpha rhythm in blind subjects appears to conflict strongly with the eye-tremor hypothesis to some authors. We demonstrated in this case study that this existence is not incompatible with cortical blindness. The rhythm is in reality generated by the same source and mechanism as in normal subjects. Should eye-tremor and CRP be present, the rhythm would exist. This proved to be the case. EOMT and EOG waves were found to be with the alpha waves. It is interesting to note that the magnitude of the three phenomena are only about one-fifth that of normal whereas the FT amplitude remains the same . The frequencies of all the four phenomena are similar and lower than normal. Experimental tests showed that the alpha waves and eye-tremor are correlated and the CRP is probably the source of the alpha activity. Thus the appearance of the occipital alpha rhythm in the blind should not necessarily be conflicting the hypothesis. On the contrary, the EEG recordings appear to be supporting the hypothesis.

7.2 EEG,EOG,EOMT AND FT STUDIES IN A DIZYGOTIC PAIR

1. Introduction

Genetic factors are significant determinants of the EEG background activities (Dumermuth 1968) and of changes induced in this by experimental stimulation (Young et al 1972). Genetical investigations are a new approach and have potential value in elucidating some unanswered problems posed by EEG studies, not the least of which is the relationship between EOM tremor and alpha waves. As the alpha waves are genetically influenced, EOM tremor would have to be similarly influenced if it is the cause of the alpha rhythm. Tyrer and Kasriel (1975) were the first to investigate the genetic factors are important in determining tremor near the peak frequency of 9-10 Hz but do not affect tremor at other frequencies. They also reported that genetical influences affect the frequency profile of tremor rather than amount of tremor. No genetical study on eye-tremor has been reported so far. This section deals with the EEG, EOG,EOMT and FT recordings in a dizygotic pair with the intention to know a bit more about the above problem.** Nevertheless, the exact role of heredity still remains unknown (Clarke and Harding 1969).

**We have not been able to find even a single monozygotic pair and thus the results in this section may not be very significant. Further work is proposed.

2. Method

The fraternal (DZ) twins (Aand B) are both males, age 18 years and neurologically normal. EEG,EOG, EOMT and FT were recorded utilizing previously described techniques and simultaneously from the two twins and one genetically unrelated subject (C, age 23 years).

3. Result and Discussion

The EEG, EOG, EOMT and FT recordings in subjects A, B (DZ twins) and C (genetically unrelated) responded similarly to the set of experimental tests utilized throughout our work. EO blocked the alpha waves, EOM tremor and EOG waves but had no effect on FT. Visual stimulation by stroboscopic flashes produced the 'ringing' effect on the EEG of the three subjects. Forcing the eye to extremities enhanced the magnitudes of their EEG whereas pressing the eye diminished them. The alpha activity, EOM tremor and EOG waves were emasculated by mental tasks and enhanced by hyperventilation, muscular manoeuvres and the activation of the sternocleidomastoideus. In each instance, the DZ(A-B) twin correlations are higher than those in the unrelated subject pairs formed by A-C or B-C. Certain genetic factors may be involved.

a. Frequency spectrum study

All the three subjects showed a stable alpha peak of high intensity and with the same peak frequency at 10 Hz (Fig 7.11 for A and B; Fig 2.5 for C). The twin pair (A-B) shows a sub-maximal peak at 1 Hz (delta range) but it is at 8 Hz (alpha-theta boundary) for the subject C. The delta and beta rhythms in the DZ twins are similar and appear to be much more significant than the unrelated subject. The gamma and theta rhythms are the same for subjects A, B and C. Overall, the frequency profiles of the twin pair are strikingly similar with the respective rhythms compatible with each other but the profile of the unrelated subject, though showing a similar peak, is distinctly different from the twin profiles. It follows that genetical influences may affect the frequency profile of the EEG. Studies on EOMT and FT come to the same conclusion. The frequency profiles of the phenomena are alike in the twin pair and show pronounced individuality in the unrelated subject pairs (A-C and B-C).

b. Amplitude studies

The amplitude distribution histograms and the average amplitudes of the EEG, EOMT and FT in the 3 subjects show pronounced individuality, expressed by the different peaks and profiles in the histograms and by the different intensities of the phenomena. Genetical influences on the amplitude of the phenomena (EEG, EOMT and FT) are found to be not substantial.

c. Correlative studies

In Fig. 7.12, the intra-pair correlation coefficients are listed for the three subjects for the EOM tremor and al-pha waves.

Phenomena	DZ pair A - B	Unrelated pair A - C
EOMT	+0.684	+0.271
EEG	+0.711	+0.304
Individual	+0.741 (B)	+0.550 (C)
EEG/EOMT correlation coefficients	+0.745 (A)	+0.745 (A)

Fig 7.12 Comparison of the product moment correlation coefficients within the DZ and unrelated pair for EEG and EOMT

Individual correlation coefficients of the alpha waves and eye-tremor (average value) are also given. The crosscorrelograms of EEG and EOMT in subjects A, B and C are shown in Fig 7.13, Fig 7.14 and Fig 4.16 respectively. The intra-DZ pair (A-B) correlation functions for each of the EEG and EOMT are shown in Fig 7.15 and Fig 7.16 respectively. It can be seen that significant correlations are obtained in terms of EEG and EOMT in the DZ twin pair whilst those in the unrelated pair do not reach significance. The crosscorrelograms show good correlations between the alpha activities of A and B and between the EOMT of them. In both cases, the decrease of r towards larger delay times is small, indicating a good phasic, frequency and amplitude relationship. This is expected to be due to genetic factors. Moreover, the twins show good support for the eye-tremor hypothesis as their occipital alpha activities and extra-ocular tremor correlate to a significant level ($r > 0.74$). The crosscorrelative functions are also well-defined. Supporting evidences are gained from the autocorrelograms of the EEG and EOMT of the twin pair. All the four graphs show very similar pattern, expressed by the frequency as well as the amplitude contents. This indicates a good within-subject correlation between the two phenomena in the two twins and a good intro-pair correlation between their EEGs and between their EOMTs.

4. Conclusion

Genetic factors are possibly affecting the frequency profiles of the EEG, EOMT and FT as shown in a DZ twin pair. The alpha, beta and delta rhythms are influenced in such a way that they are more significant than unrelated subjects. Magnitudes of the phenomena are unaffected. Good correlations between the alpha activities and between the EOMT of the twins are obtained. Furthermore, the twins show good EEG-EOMT correlations. The eye-tremor hypothesis is again supported and the role of genetic factors is touched upon in this section.

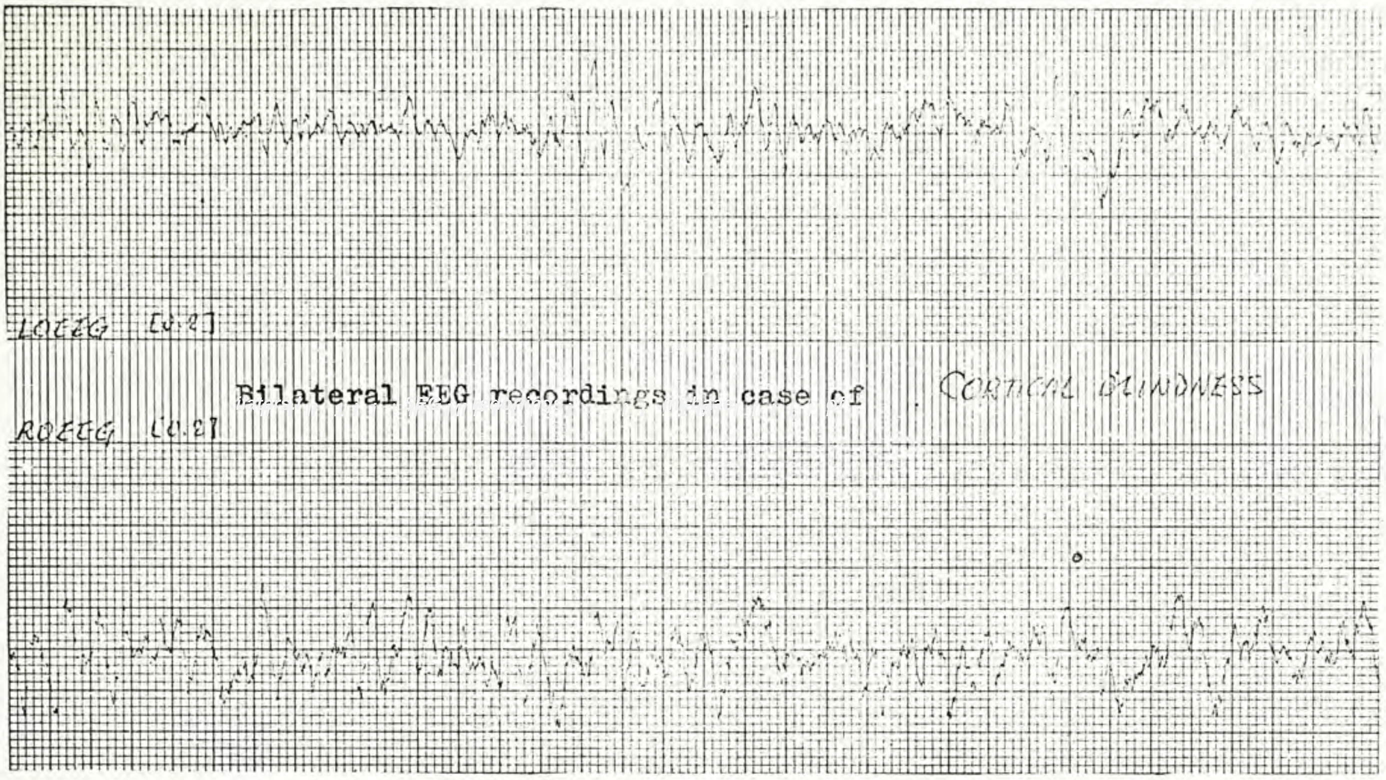


FIG 7.1 THE BILATERAL EEG RECORDINGS IN A BLIND SUBJECT.

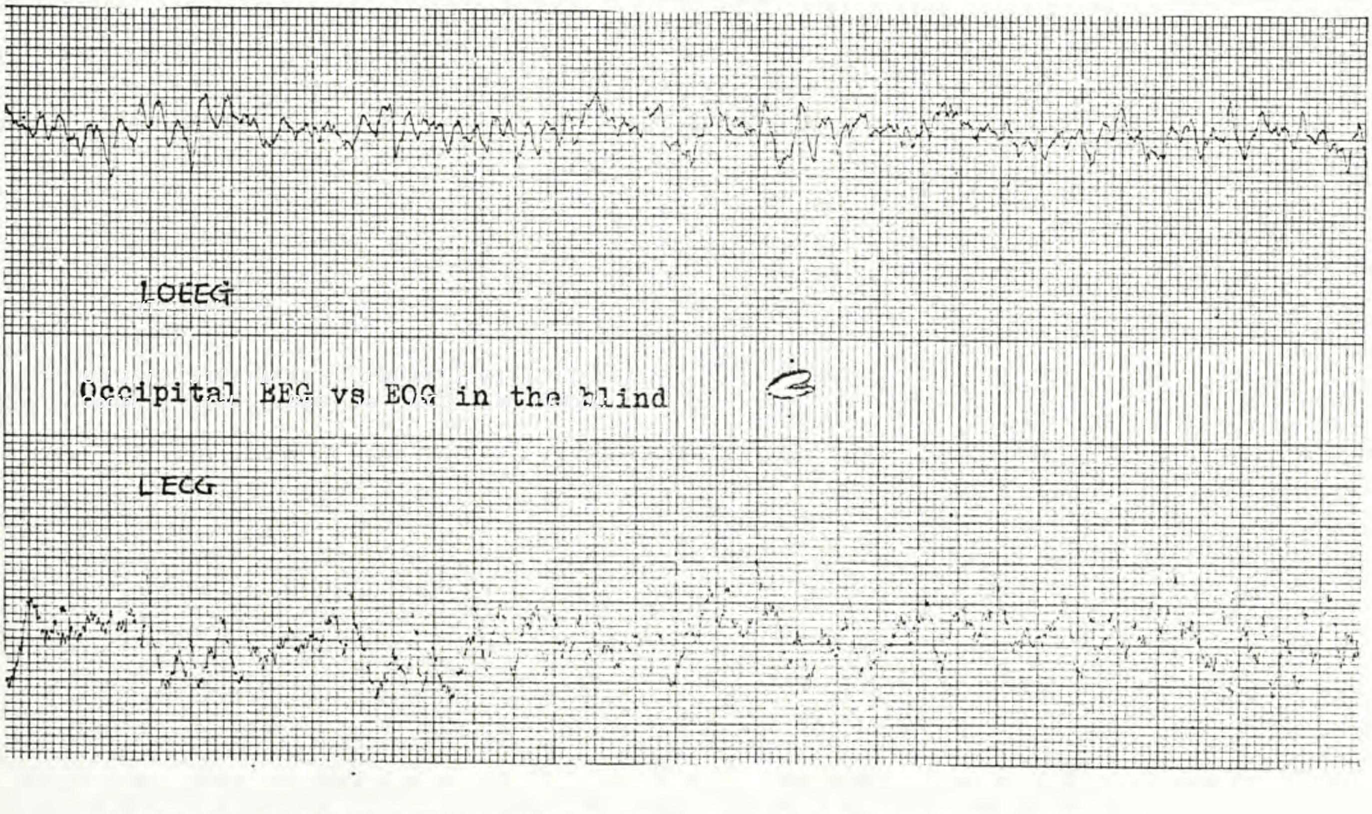


FIG 7.9 THE RECORDINGS OF EEG AND EOG IN A BLIND SUBJECT.

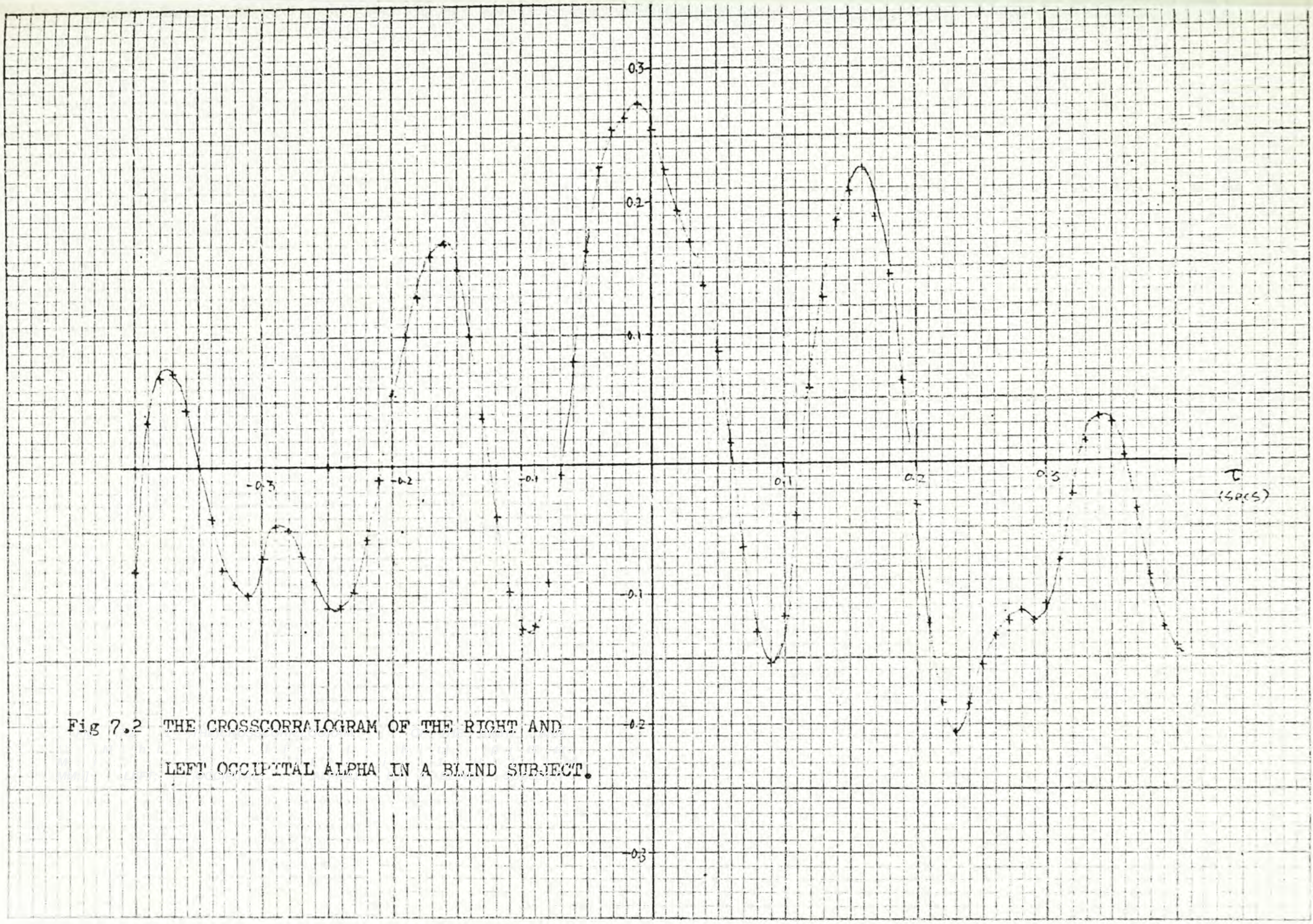


Fig 7.2 THE CROSSCORRALOGRAM OF THE RIGHT AND LEFT OCCIPITAL ALPHA IN A BLIND SUBJECT.

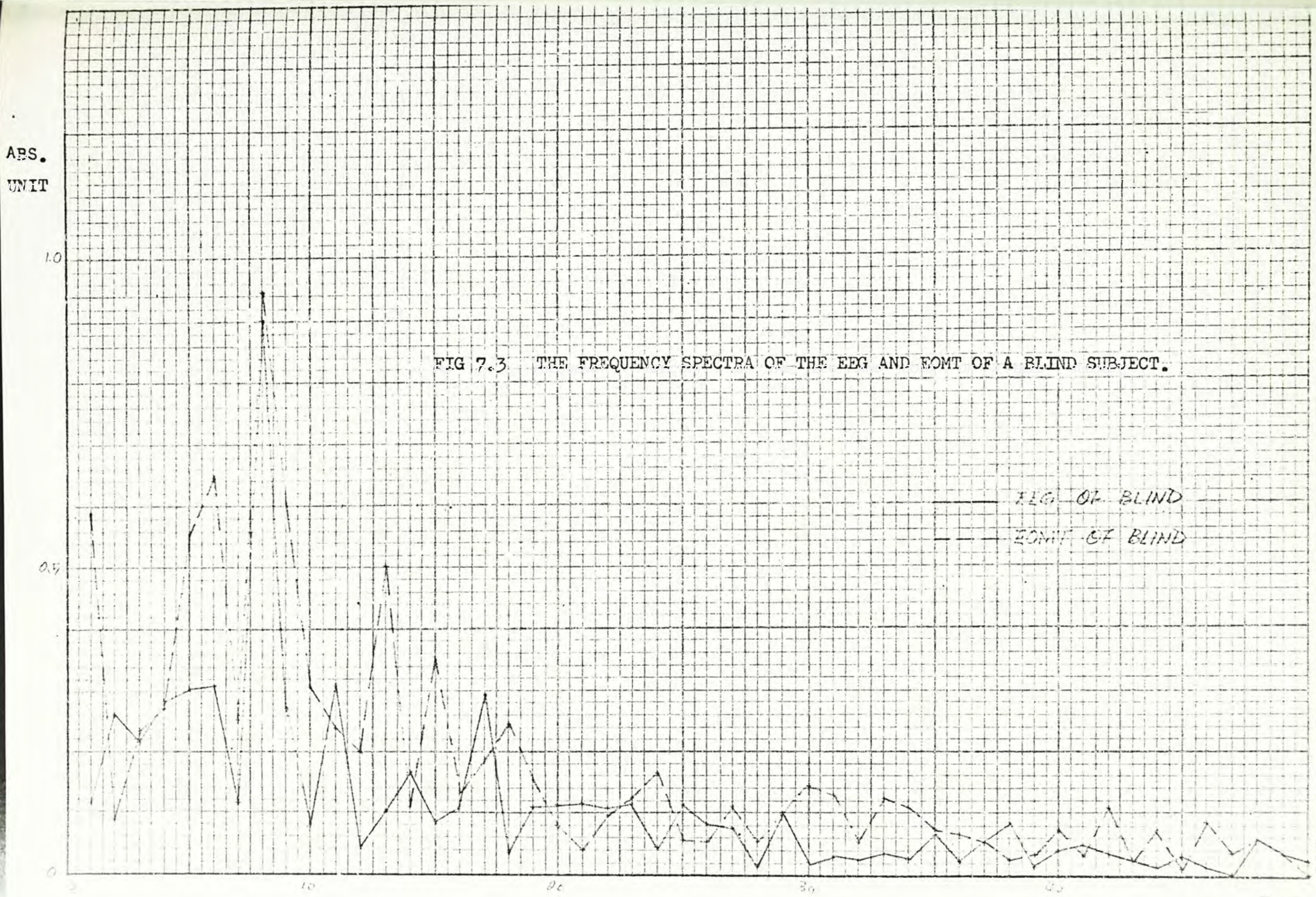


FIG 7.3 THE FREQUENCY SPECTRA OF THE EEG AND EOMT OF A BLIND SUBJECT.

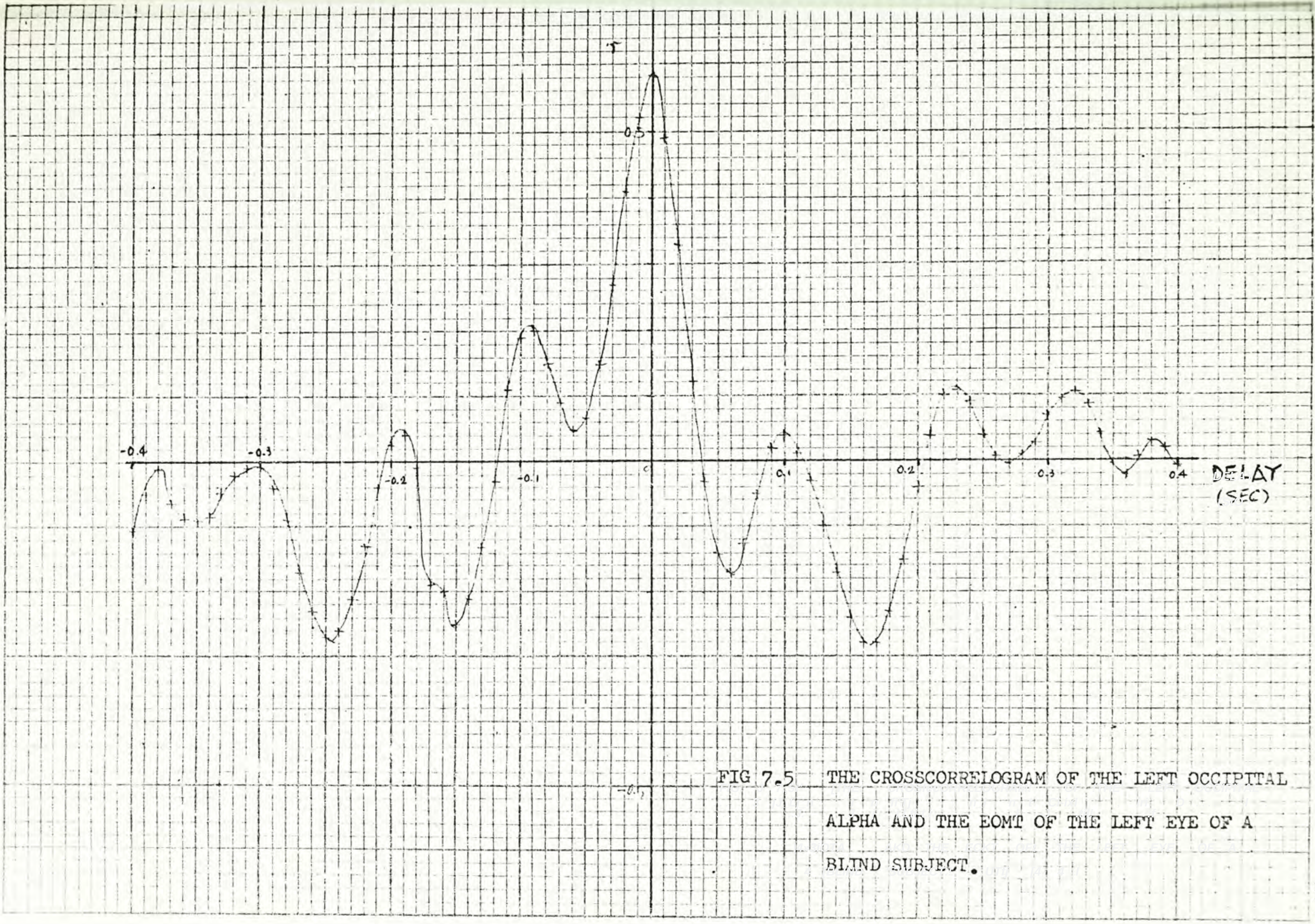


FIG 7.5 THE CROSSCORRELOGRAM OF THE LEFT OCCIPITAL ALPHA AND THE EOMT OF THE LEFT EYE OF A BLIND SUBJECT.

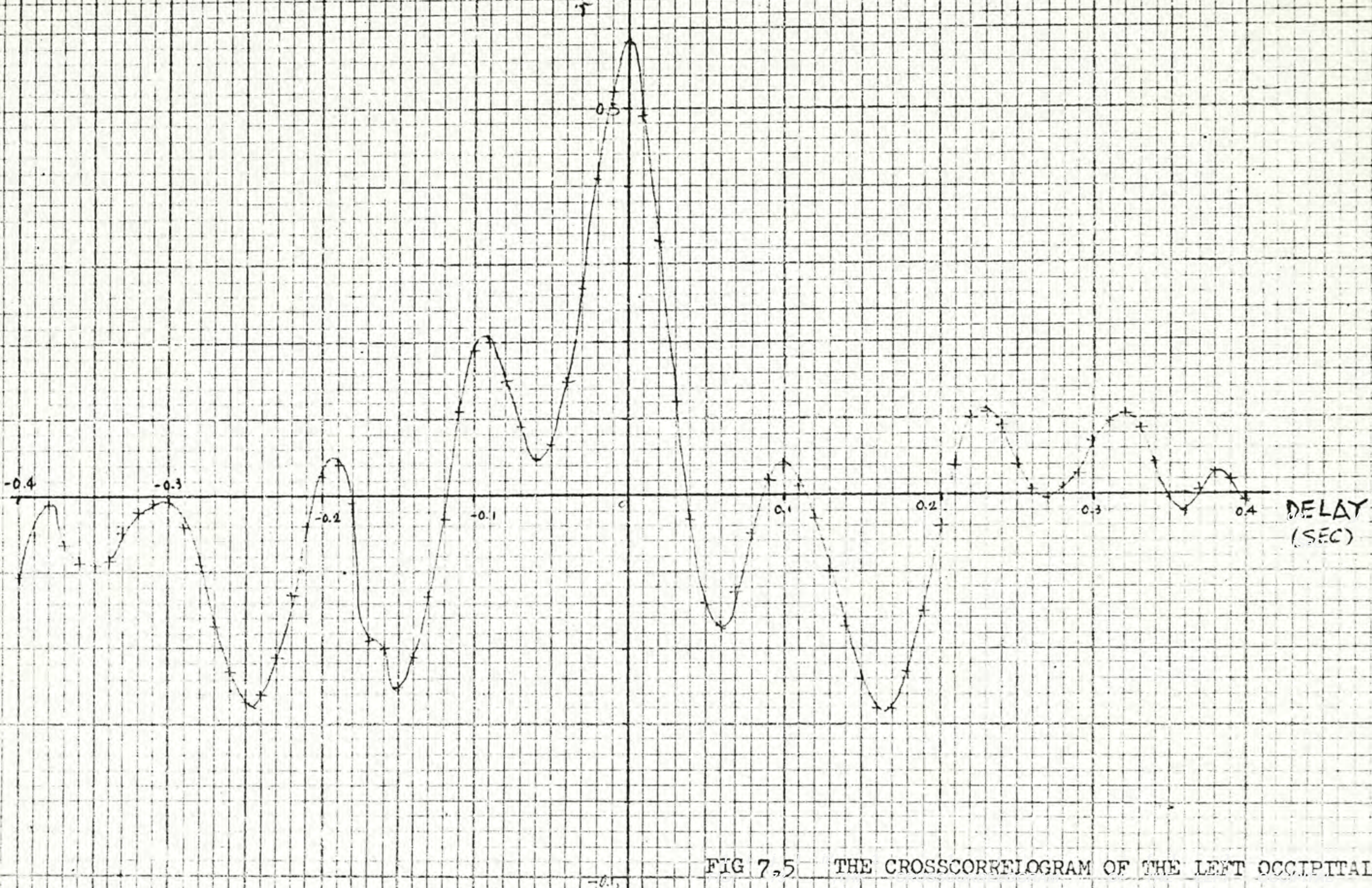


FIG 7.5 THE CROSSCORRELOGRAM OF THE LEFT OCCIPITAL ALPHA AND THE EOMT OF THE LEFT EYE OF A BLIND SUBJECT.

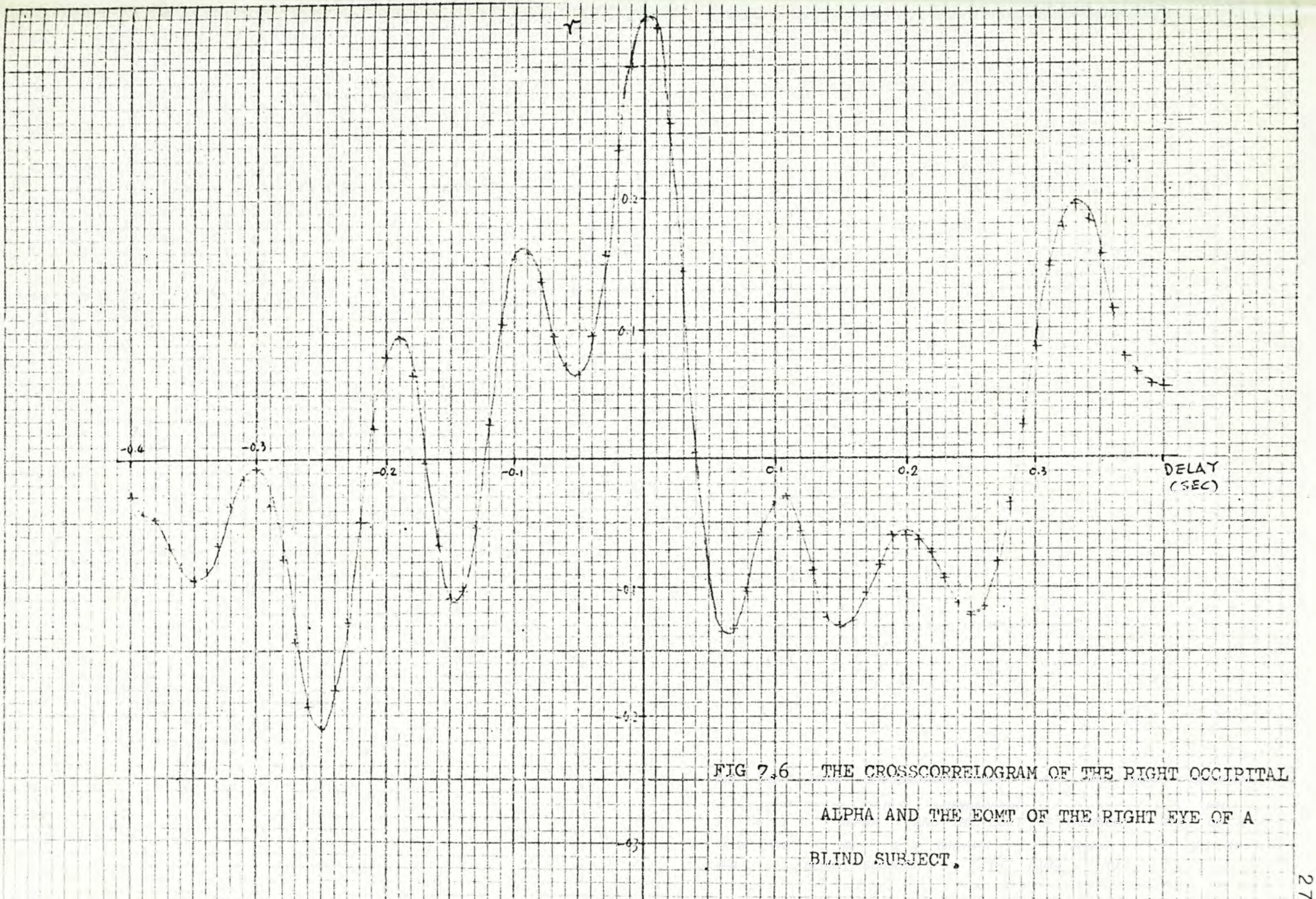


FIG 7.6 THE CROSSCORRELOGRAM OF THE RIGHT OCCIPITAL ALPHA AND THE EOMT OF THE RIGHT EYE OF A BLIND SUBJECT.

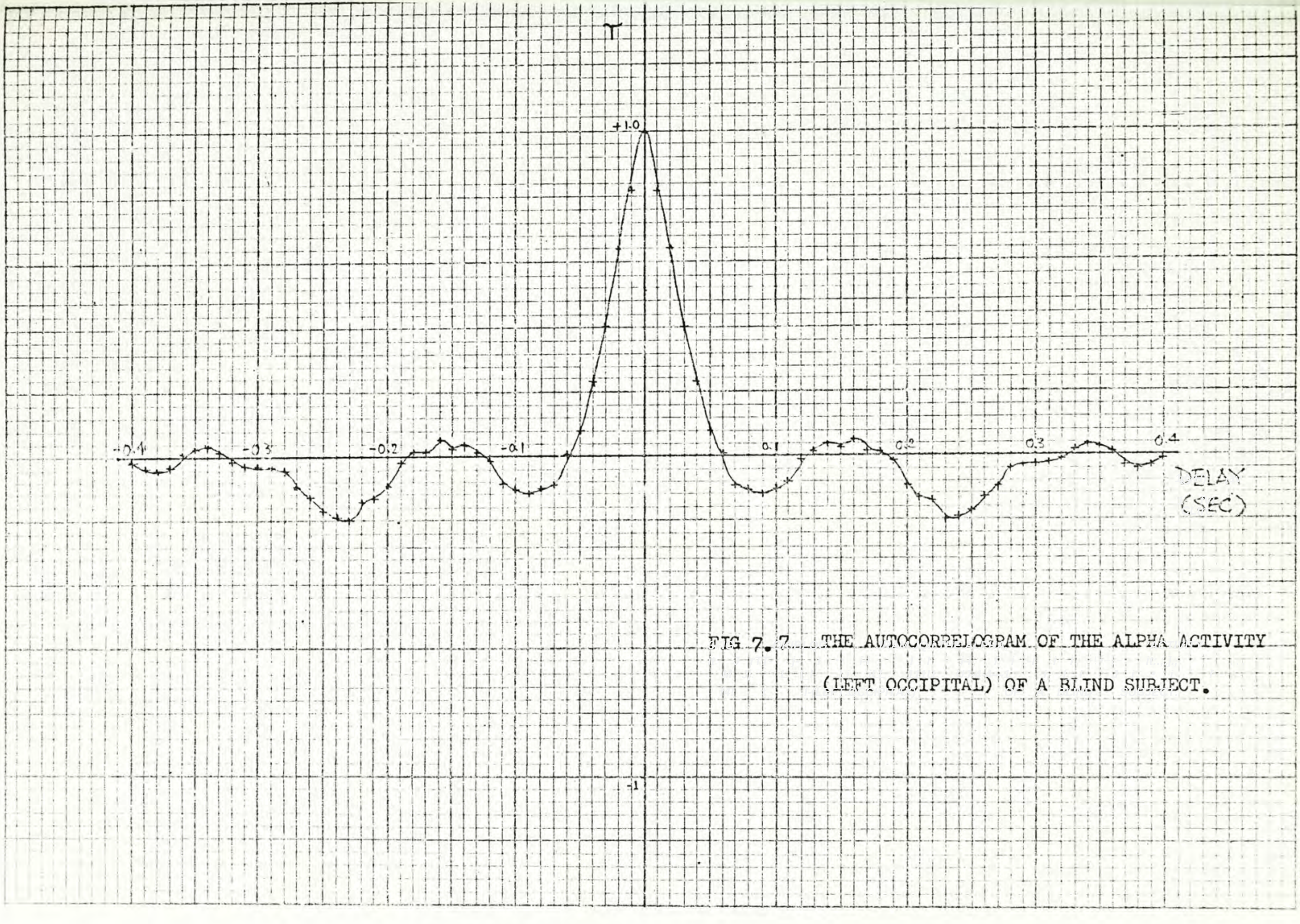


FIG 7. 7 THE AUTOCORRELOGRAM OF THE ALPHA ACTIVITY (LEFT OCCIPITAL) OF A BLIND SUBJECT.

APPENDIX B

ESTIMATED LOCAL CONSUMPTION OF COSMETICS AND GROSS DOMESTIC PRODUCT PER CAPITA,

1965 - 1974

Year Value	1965	1966	1967	1968	1969
(1) Imports -- Re-exports	16,997.8	20,084.8	23,397.1	23,216.8	31,611.3
(2) 10% of Exports	190	170.9	188.5	211.3	303.1
(3) = (1) + (2) Estimated Local Consumption	17,187.8	20,255.7	23,585.6	23,428.1	31,914.4
Gross Domestic Product per Capita (HK $)	2,897	3,061	3,242	3,293	3,702

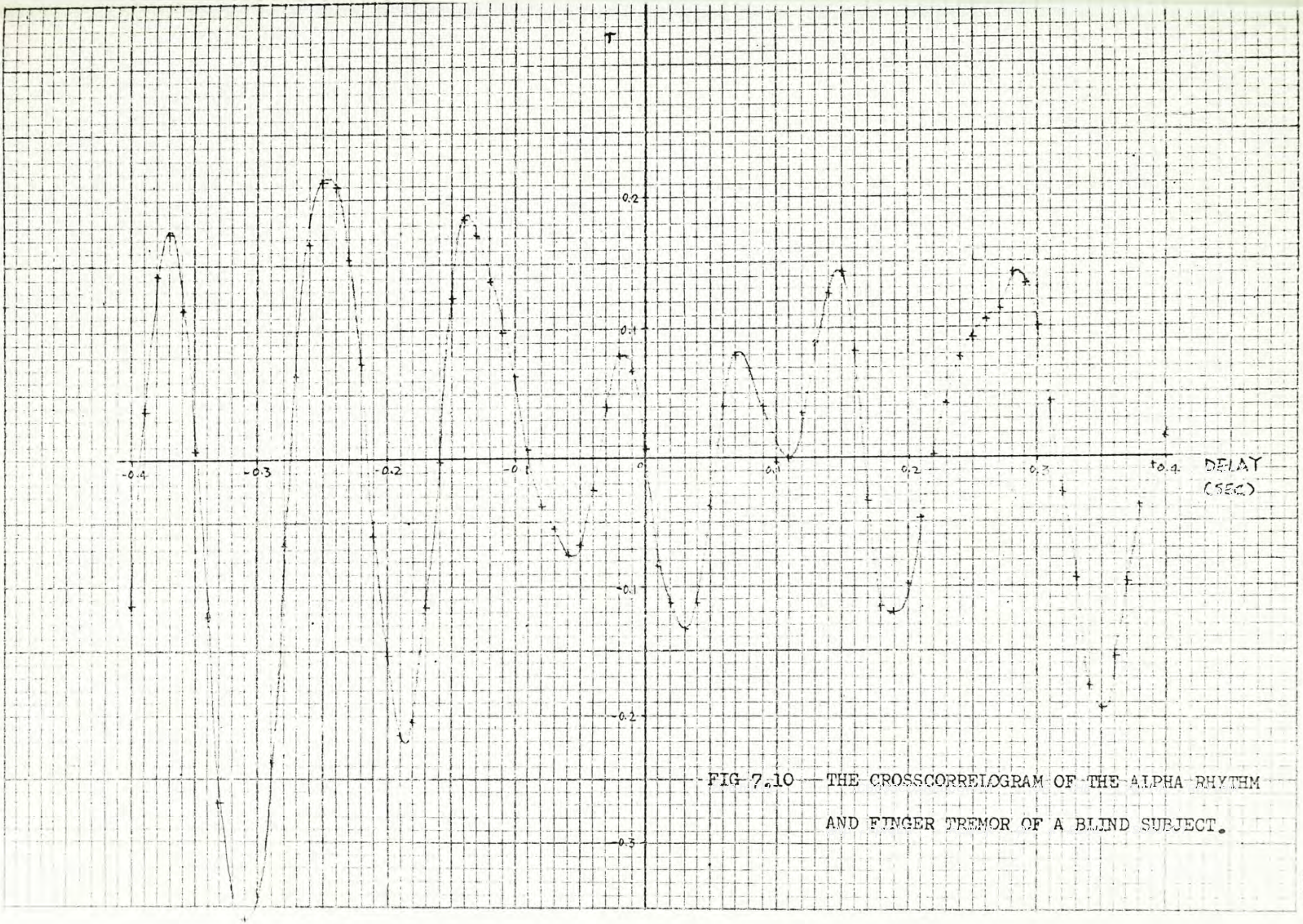


FIG 7.10 THE CROSSCORRELOGRAM OF THE ALPHA RHYTHM AND FINGER TREMOR OF A BLIND SUBJECT.

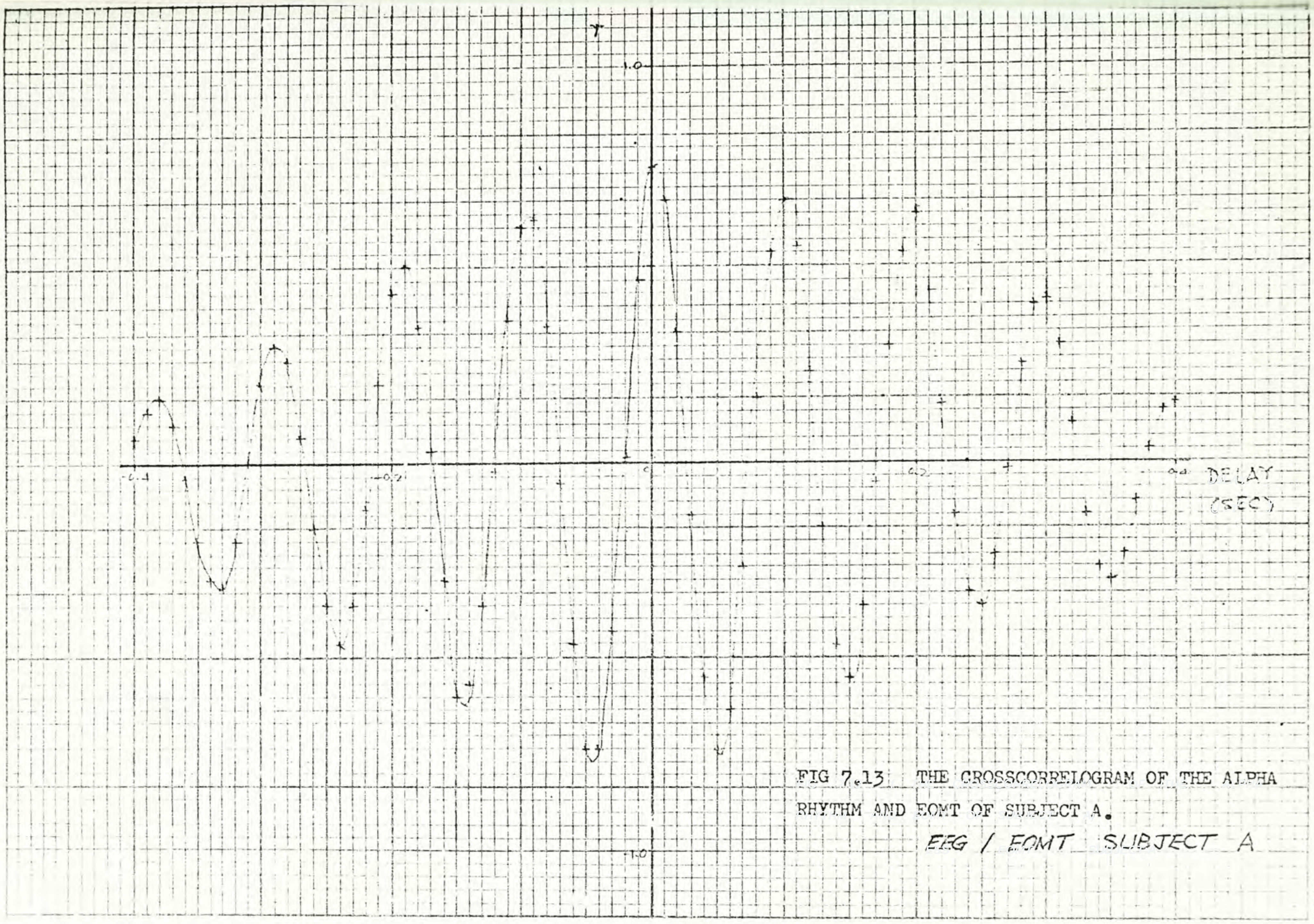


FIG 7.13 THE CROSSCORRELOGRAM OF THE ALPHA RHYTHM AND EOMT OF SUBJECT A.

EEG / EOMT SUBJECT A

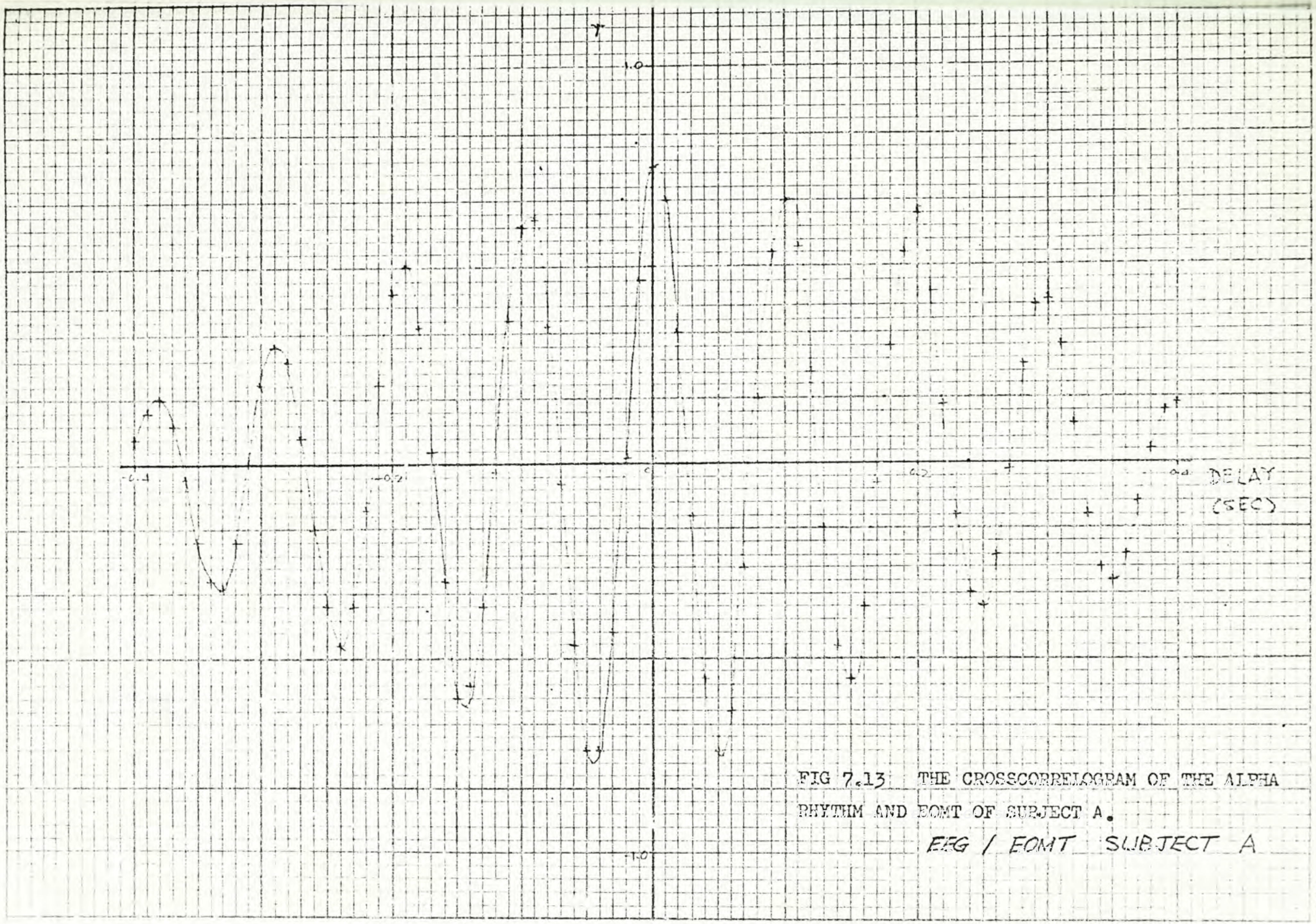


FIG 7.13 THE CROSSCORRELOGRAM OF THE ALPHA RHYTHM AND EOMT OF SUBJECT A.

EEG / EOMT SUBJECT A

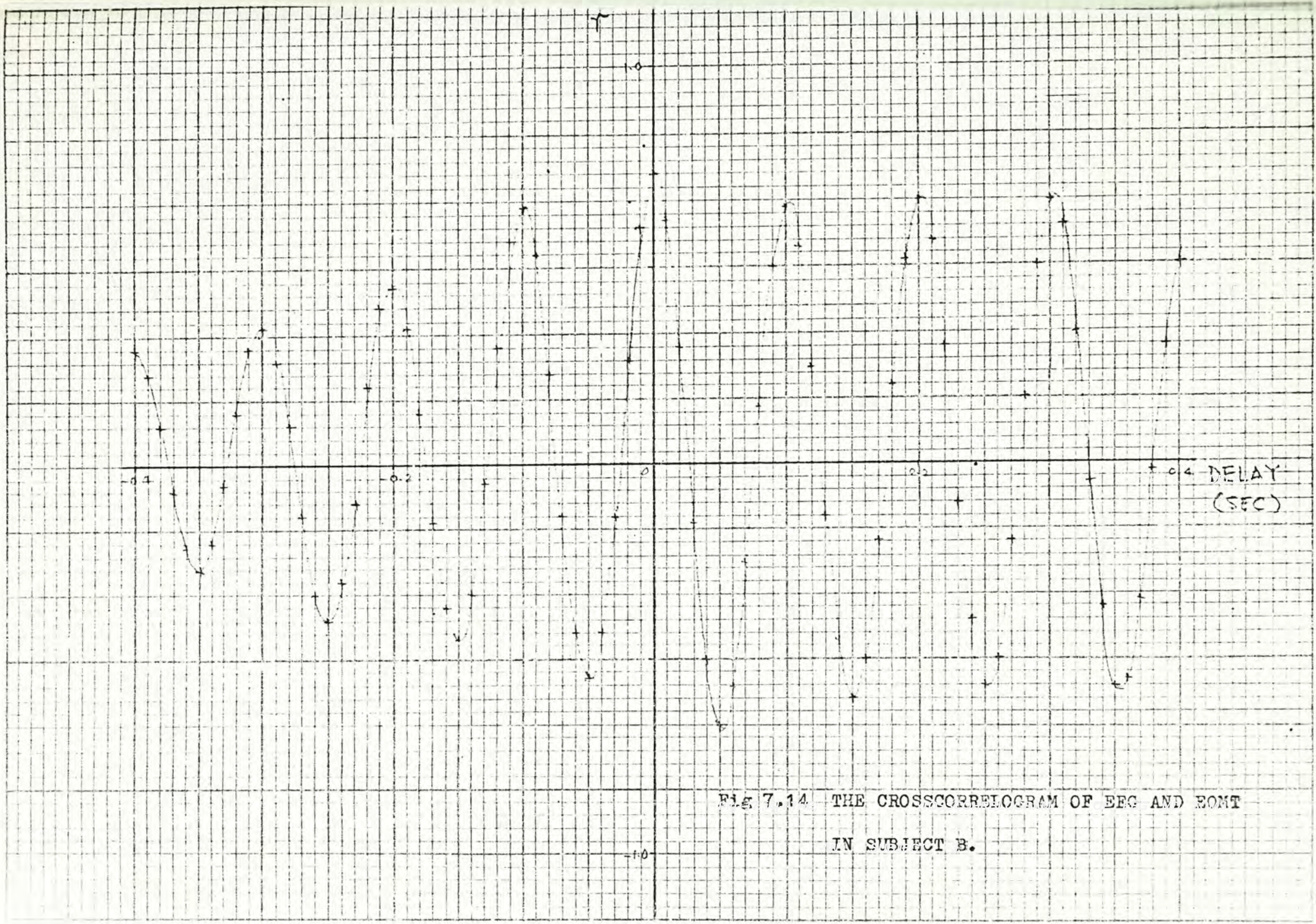


Fig 7.14 THE CROSSCORRELOGRAM OF EEG AND EOMT

IN SUBJECT B.

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          LINGNAN  INSTITUTE  OF  BUSINESS  ADMINISTRATION  -  SYSTEM  DEVELOPMENT  COMPANY


                                 ********  TASK   REPORT  ********


TASK  NUMBER  :  2                                                      TASK  BEGAN  :   14 JANUARY

TASK  NATURE  :  SURVEY REGIONS                                         TASK  COMPLETED  :  0

MONTH  OF  MARCH   1984                                                 %  COMPLETED  :    63 %

                                                          ***** THIS     MONTH *****   ***** TO      DATE *****

                                                           ESTIMATED       ACTUAL       ESTIMATED      ACTUAL

LABOUR :

     EMP.NO.    NAME                  GRADE  HOURS

       31.   NEWTON PETER R.           6    184.8     $      0.00   $  8736.42   $      0.00   $  21513.43
        3    GO KIM JO                 5    167.2     $      0.00   $  7119.41   $      0.00   $  18627.55
       26    XA HU                     5     96.8     $      0.00   $  4121.76   $      0.00   $  15629.91
       34    KWOO SAN YAN              4    184.8     $      0.00   $  6562.38   $      0.00   $  16159.86
       12    NG PANG KEE               4    184.8     $      0.00   $  6562.38   $      0.00   $  16159.86

     TOTAL                                  818.4     $      0.00   $ 33102.35   $      0.00   $  88090.61


COMPUTER  :                         0.0  CPU HOURS    $      0.00   $     0.00   $      0.00   $      0.00


MATERIALS  AND  SUBCONTRACTS  :


                                                      $      0.00   $     0.00   $      0.00   $      0.00

     TOTAL                                            $      0.00   $     0.00   $      0.00   $      0.00


TRAVEL  AND  MISCELLANEOUS  ITEMS  :

     SINGPR,TAIP,SEOU                                 $      0.00   $ 27896.00   $      0.00   $  44328.00

     TOTAL                                            $      0.00   $ 27896.00   $      0.00   $  44328.00


TASK  TOTAL                                           $      0.00   $ 60998.35   $      0.00   $ 132418.61
```

Fig. 4.9 TASK REPORT SAMPLE

TABLE 5.2

OVERALL RESULTS OF THE TRIAL GAME*

Cost items	Team One	Team Two	Team Three	Team Four	Team Five
Total project labor cost	HK$767,739	HK$698,255	HK$727,640	HK$770,705	HK$775,710
Total project computer time cost	HK$ 69,618	HK$ 69,769	HK$ 50,149	HK$ 36,922	HK$ 57,417
Total Project overtime premium	HK$ 18,416	HK$ 15,090	HK$ 7,685	0	HK$ 6,795
Total project unapplied time	HK$ 3,247	HK$ 9,838	HK$ 7,746	HK$ 5,423	HK$ 11,402
Total project L.I.B.	HK$ 19,538	HK$ 21,507	HK$ 22,138	HK$ 14,338	HK$ 22,798
Date of project completion	10th Dec., 1984	8th Dec., 1984	21st Dec., 1984	2nd Jan., 1985	1st Jan. 1985
Total project cost	HK$980,078	HK$915,980	HK$916,879	HK$865,256	HK$957,039

* See Appendix VII.

CHAPTER EIGHT

GENERAL CONCLUSIONS

It is some nine years since Lippold first proposed the hypothesis that alpha waves are electrical concomitant of tremor in the extra-ocular muscles. We think it is appropriate to name it as the eye-tremor hypothesis according to its mechanism of generation. This striking hypothesis on the origin of the alpha rhythm is certain to engender much discussion but since Lippold's original proposal, neither clear-cut refutation nor clear-cut verification has been reported. This work has encompassed a general experimental study of the EEG, EOMT, EOG and FT in normal, blind and twin subjects utilizing new techniques,along with comparative and correlative studies as well as a set of tests, leading to a support of the eye-tremor hypothesis. Extension of the work to diurnal and feedback training studies has provided interesting results. During the course of this work, several important observations have been made. They are briefly summarised as follows:

1. New techniques were employed in the recordings of FT and EOMT. The dynamic mike and the 'hanging' posture (we think it is appropriate to name it as such according to its nature) was utilized in FT recordings whereas EOMT was recorded by the dynamic mike and its mountings in a diving mask. The excellence and reliability of these techniques were fully appreciated.

2. Though very similar in appearance, EEG and FT were found to be two unrelated phenomena.

3. A very close relationship in frequency, amplitude and phase was found for the alpha waves and eye-tremor. Various tests imposed similar changes on them. Manoeuvres performed on the eye (warming or cooling, pressing, prodding and polarizing) caused related changes in the alpha activity recorded over the occipital scalp. When the EOM servo-loop was disturbed or modified in various ways, the occipital alpha waves showed concomitant and corresponding changes, as expected by the eye-tremor hypothesis. In each instance, the two phenomena showed a good correlation which support that the alpha activity is electrical concomitant of the EOMT.

4. 8-13 Hz electro-oculographic oscillations (we name it as EOG waves) were found in EOG recordings. They are related fairly well to the 8-13Hz alpha rhythm, both having similar appearance and similar changes imposed by various tests.

When the CRP was varied by altering ambient illumination or by passing small polarising currents through the eye, the alpha amplitude was found to have similar variations, indicating a good correlation between the magnitudes of the CRP and the alpha waves. The CRP is thus suggested to be the source of the alpha potentials.

5. The servo-loop hypothesis, stating that physiological tremor (including finger and EOM tremor) originates in the stretch-reflex-arc, is verified experimentally by modifying or changing (by external inputs) the properties of the loop. Experimental results show that the loop delay is responsible for the tremor frequency whereas the system's sensitivity or the loop gain determines the trèmor amplitude.

6. Alpha feedback training was found to be effective for EOMT similarly. The subject could enhance his own alpha and EOMT via audio feedback by the intention of allowing no visual fixation and could suppress by the intention to fixate visually.

7. The activation of a sternocleidomastoid was found to enhance alpha, EOG wave and EOMT of one side of the hemisphere only. Head rotation and tilting yielded exactly opposite results.

8. A significant diurnal variation was found for EEG, EOMT

and FT in their average amplitudes relating to the food-taking times with troughs during the times and peaks in-between. The reverse was obtained for their variances. No such variation occurred in their amplitude distributions and frequency spectra. EEG and EOMT showed a good correlation throughout the day.

9. Alpha rhythm was recorded in a blind subject and was found to be generated by the same mechanism -- modulation of the CRP by EOMT -- as in normal subjects. EEG, EOMT and EOG obtained from the subject were found to be correlated to certain extent. Their magnitudes are only about one-fifth that of normal. The results show that the existence of the alpha rhythm in the blind should not necessarily be conflicting the eye-tremor hypothesis.

10. The frequency profiles of the EEG, EOMT and FT may be influenced by genetic factors as demonstrated in a DZ twin pair and an unrelated pair.

Further works on the followings are proposed. According to the eye-tremor hypothesis, Retrolental fibroplasia should show an abolition or a large suppression of EEG, EOG and EOMT in the blind children; Parkinsonism should lower the frequency of EEG, EOG wave, EOMT and FT; Palatal myoclonus in extra-ocular muscles should result in reflections of myoclonus in EEG, EOMT and EOG recordings ; Nystagmus rectatorius should enhance to some extent the patients' EEG, EOG and EOMT. In addition, fasting or altering the subject's food-taking times for a long period of time may reveal more on the diurnal studies. Experimental investigations on more blind subjects and monozygotic twins are certainly desired.

Overall, the work, though very involved, shows gratifying results on the origin of the alpha rhythm of the human EEG. Whether or not one agrees with the eye-tremor hypothesis, it is difficult to explain these results on the basis of the more generally accepted hypothesis that alpha waves arise from the synchronous beating of occipital cortical neurones. Out of the so many hypotheses on the alpha origin, our experimental results support the eye-tremor hypothesis that the alpha waves are in reality the modulations of the CRP by the extra-ocular tremor.

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APPENDIX I

THE PROGRAMS TO GENERATE THE NORMALISED CROSSCORRELATION AND AUTOCORRELATION FUNCTIONS AND THE FREQUENCY SPECTRA OF THE ALPHA WAVES, EXTRA-OCULAR TREMOR, FINGER TREMOR AND ELECTRO-OCULOGRAPHIC WAVES UNDER DIFFERENT EXPERIMENTAL CONDITIONS. EXAMPLES ON A DIURNAL STUDY ARE GIVEN. THE RESULTS ARE THEN PLOTTED AS THE CROSSCORRELOGRAM, AUTOCORRELOGRAM AND FREQUENCY SPECTRUM.

```
      DIMENSION CXY(1000),CCXY(1000),X(1000),Y(1000),YY(100
C
C
C     DIURNAL STUDIES
C     10.30 AM.
C     11.30 AM.
C     CROSSCORRELATION
C     ELECTROENCEPHALOGRAPHY
C     EYE TREMOR
C     PHYSIOLOGIC TREMOR
C
C
      INTEGER B
      READ (5,39) NS
      DO 99 JJ=1,NS
      READ (5,41) N
      DO 25 KK=1,N
   25 X(KK)=0
      READ (5,40,END=100) (X(I),I=1,N)
      READ (5,40,END=100) (Y(I),I=1,N)
      CALL SUMS(X,N,SIGXS)
      CALL SUMS(Y,N,SIGYS)
      CALL AMP (X,N,AMPX,AVX)
      CALL AMP (Y,N,AMPY,AVY)
      N1=N-1
      DO 10 J=1,N
      CXY(J)=0.0
      DO 20 K=J,N
   20 CXY(J)=CXY(J)+X(K)*Y(K-J+1)-AVX*AVY
   10 CXY(J)=CXY(J)/(N*SQRT(SIGXS*SIGYS))
      DO 60 L=1,N
      CCXY(L)=0.0
      DO 70 M=L,N
   70 CCXY(L)=CCXY(L)+Y(M)*X(M-L+1)-AVX*AVY
   60 CCXY(L)=CCXY(L)/(N*SQRT(SIGXS*SIGYS))
      WRITE (6,42)
      WRITE (6,43)
      WRITE (6,45) (I,CXY(I),I=1,100)
      WRITE (6,44)
      WRITE (6,45) (I,CCXY(I),I=1,100)
      WRITE (6,46) SIGXS
      WRITE (6,47) SIGYS
      WRITE (6,48) AVX
      WRITE (6,49) AVY
      WRITE (6,52) AMPX
      WRITE (6,53) AMPY
      WRITE (6,54)
      WRITE (6,50) (X(I),I=1,N)
      WRITE (6,51)
      WRITE (6,50) (Y(I),I=1,N)
   39 FORMAT (I3)
   40 FORMAT (10F5.2)
   41 FORMAT (I3)
   42 FORMAT (//////////10X,'CORRELATION ANALYSIS'/////)
   43 FORMAT (10X,'X(T)Y(T-DELAY)     Y LEADING X'////)
   44 FORMAT (////10X,'Y(T)X(T-DELAY)     Y LAGGING X'////)
   45 FORMAT (10X,'R (',I6,'     ) =',F15.5)
   46 FORMAT (////10X,'VARIANCE OF X  =',F15.5)
```

```
    47 FORMAT (10X,'VARIANCE OF Y  =',F15.5)
    48 FORMAT (////10X,'AVERAGE OF X  =',F15.5)
    49 FORMAT (10X,'AVERAGE OF Y  =',F15.5////)
    50 FORMAT (10F10.3)
    51 FORMAT (////10X,'Y(I)  ='/)
    52 FORMAT (10X,'AV AMPLITUDE OF X  =',F15.5)
    53 FORMAT (10X,'AV AMPLITUDE OF Y  =',F15.5////)
    54 FORMAT (10X,'X(I)  ='/)
    99 CONTINUE
   100 STOP
       END

OS FORTRAN IV 360N-FO-479 3-8          AMP                  DATE   05/05/7

       SUBROUTINE AMP (X,N,W,S)
       DIMENSION X(1000)
       U=0.0
       R=0.0
       DO 61 I=1,N
    61 R=R+X(I)
       S=R/N
       DO 62 J=1,N
    62 U=U+(ABS(X(I)-S))
       W=U/N
       RETURN
       END
OS FORTRAN IV 360N-FO-479 3-8          SUMS                 DATE   05/05/7

       SUBROUTINE SUMS(X,N,A)
       DIMENSION X(1000)
       P=0.0
       Q=0.0
       DO 30 I=1,N
       P=P+X(I)
    30 Q=Q+X(I)**2
       A=(Q-P**2/N)/N
       RETURN
       END
```

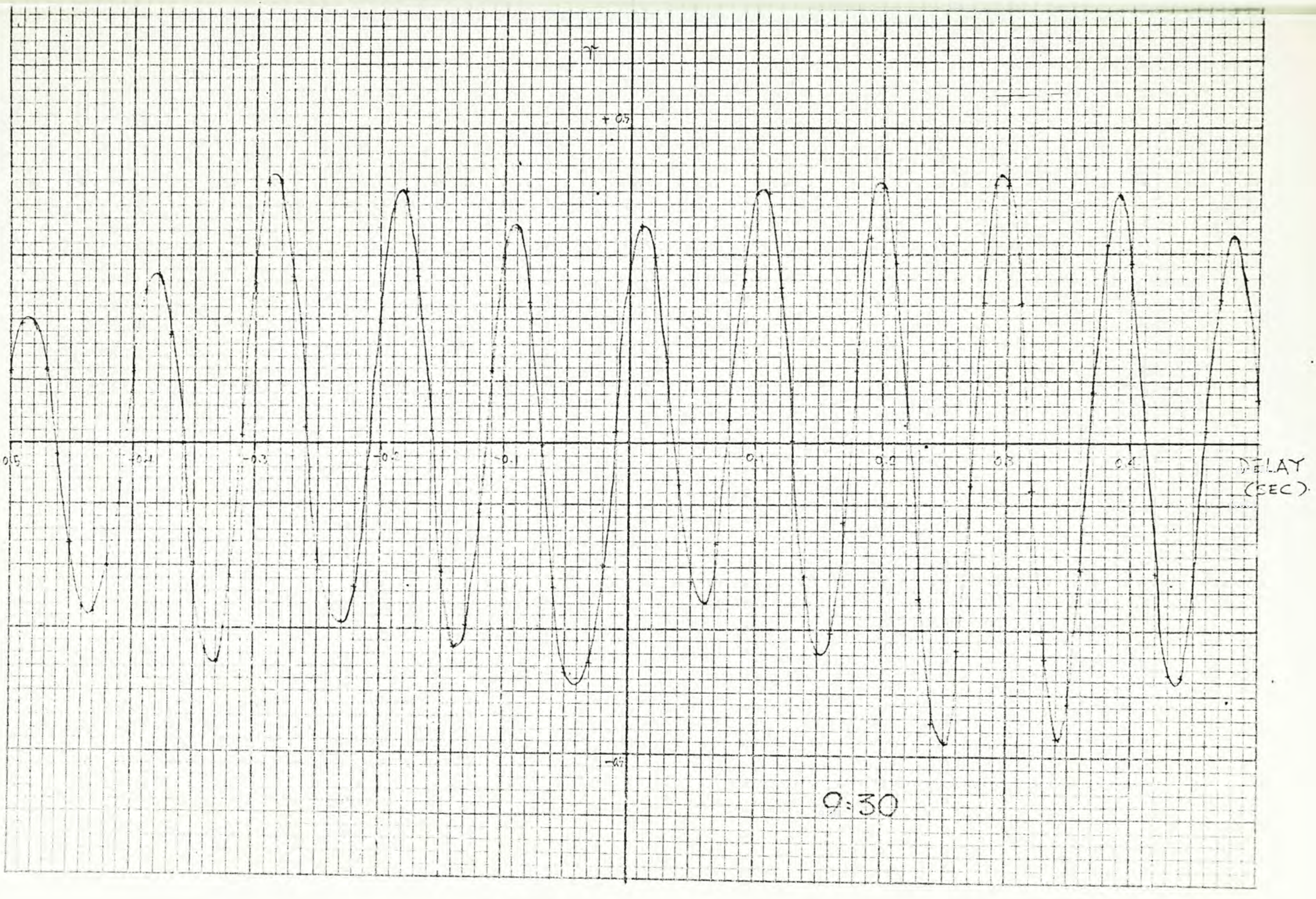
(A) AN EXAMPLE OF THE NORMALISED CORRELATION PROGRAM.

```
      DIMENSION X(1000),F(200),S(200),SS(200)
C
C
C     DIURNAL STUDIES
C     11.30 AM.
C     FREQUENCY SPECTRA OF
C     ELECTROENCEPHALOGRAPHY
C     EYE TREMOR
C     PHYSIOLOGICAL TREMOR
C
C
      INTEGER UF,B,Z
      READ (5,10) NS
      READ (5,20) UF,N,D
      DO 99 Z=1,NS
      DO 25 II=1,N
   25 X(II)=0
      READ (5,30,END=100) (X(I),I=1,N)
      NN=(N+1)/2
      DO 50 B=1,UF
      S(B)=0.0
      SS(B)=0.0
      F(B)=0.0
      DO 40 J=1,N
   40 S(B)=S(B)+X(J)*COS(2*3.1415926*D*B*(J-NN))
      DO 60 K=1,N
   60 SS(B)=SS(B)+X(K)*SIN(2*3.1415926*D*B*(K-NN))
   50 F(B)=D*SQRT(S(B)**2+SS(B)**2)
      WRITE (6,96)
      WRITE (6,89)
      WRITE (6,90) (B,F(B),B=1,UF)
      WRITE (6,96)
      WRITE (6,91) UF,N,D
      WRITE (6,96)
      WRITE (6,95) (X(I),I=1,N).
   10 FORMAT (I1)
   20 FORMAT (I3,I3,F5.2)
   30 FORMAT (10F5.2)
   89 FORMAT (/////'              FREQUENCY SPECTRUM ANALYSIS'
   90 FORMAT (10X,'F (',I6,'      ) =  ',F20.10)
   91 FORMAT (2X,I10,I10,F10.3)
   95 FORMAT (10F10.3)
   96 FORMAT (///)
   99 CONTINUE
  100 STOP
      END
```

(B) AN EXAMPLE OF THE FREQUENCY SPECTRUM PROGRAM.

APPENDIX II

The crosscorrelograms of alpha waves and EOM tremor in a diurnal study at thirteen times of day : 9.30, 10.30, 11.30, 12.30, 13.30, 14.30, 15.30, 16.30, 17.30, 19.30, 20.30, 21.30 and 23.00 h respectively. The vertical axis is the product moment correlation coefficient, normalised to a maximum value of ± 1. The horizontal axis is the delay, 2 large square = 0.1 sec, positive on the right side and negative on the left. Note the consistency of the correlation throughout the whole day.


γ̃
+ 0.5
-0.5
-0.5
-0.4
-0.3
-0.2
-0.1
0.1
0.2
0.3
0.4
DELAY
(SEC).
9:30

	GRADE 7 Hours @ 31$\underline{55}$	$	GRADE 6 Hours @ 25$\underline{23}$	$	GRADE 5 Hours @ 22$\underline{73}$	$	GRADE 4 Hours @ 18$\underline{95}$	$	GRADE 3 Hours @ 15$\underline{12}$	$	TOTAL HOURS	TOTAL $
TASK 1	172	5428	172	4340	-	-	-	-	-	-	344	9768
TASK 2	-	-	516	13019	1032	23457	1032	19556	-	-	2580	56032
TASK 3	516	16285	516	13019	1548	35186	-	-	-	-	2580	64490
TASK 4	172	5428	344	8679	860	19548	344	6519	-	-	1720	40174
TASK 5	-	-	516	13019	1032	23457	1032	19556	1032	15604	3612	71636
TASK 6	516	16285	688	17358	1548	35186	-	-	516	7802	3268	76631
TASK 7	-	-	774	19528	1032	23457	516	9778	-	-	2322	52763
TASK 8	-	-	258	6509	516	11729	-	-	-	-	774	18238
TASK 9	-	-	86	2170	-	-	-	-	-	-	86	2170

TOTAL $ 391902

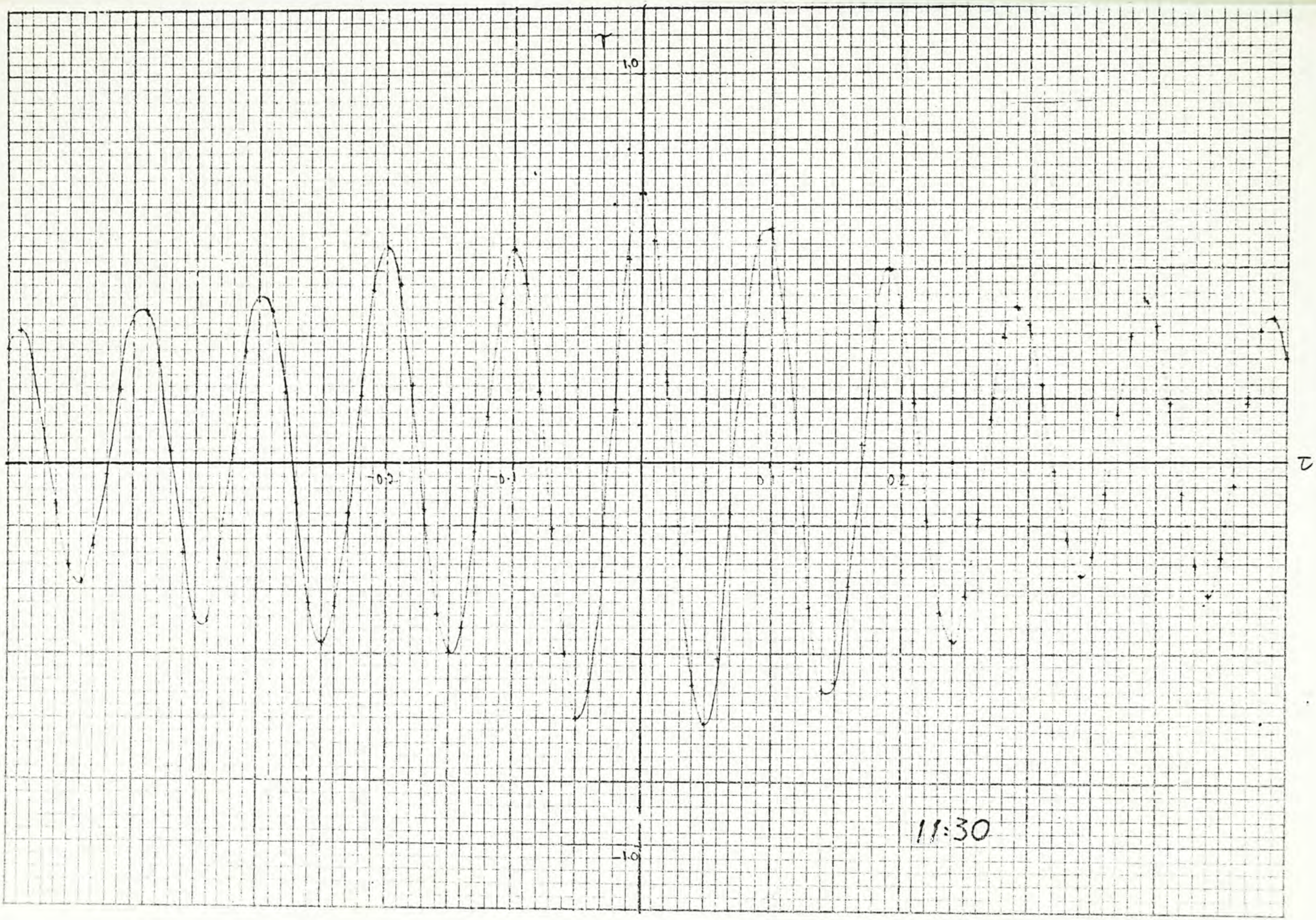
LABOR DIRECT COST

DEPARTMENTAL OVERHEAD @ 84% = $ 329198

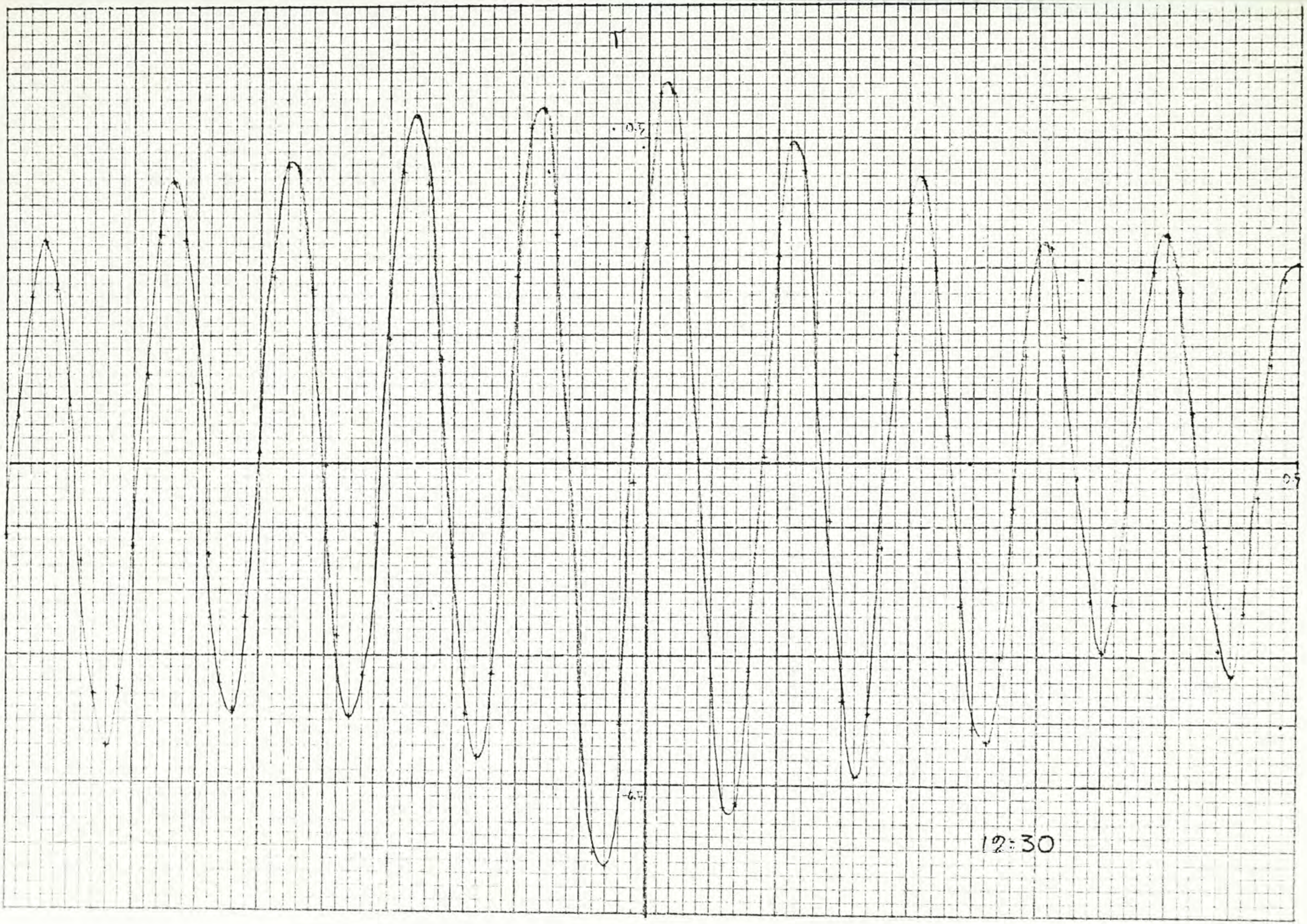
TOTAL LABOR BUDGET = $ 721100

Figure I.4: Detailed Breakdown of Labor Budget by Task

Note: Charges made at average of salary grade.



11:30


Γ
0.5
0.5
-0.5
12:30

APPENDIX III

```
                                   *** THE CHINESE UNIVERSITY OF HONG KONG ***

                                    LINGNAN INSTITUTE OF BUSINESS ADMINISTRATION

                                   MASTER THESIS - DIRECT SELLING SURVEY   BY HO YU-CHOI

                       TABLE 5.1.1 AGE VS ATTRACTIVENESS OF AMWAY SELLING SYSTEM £BEFORE JOINING-INF

                       *************************************************
                             ATTRACTIVENESS OF AMWAY SELL SYS.'BEF.IN=
                             ADDN+L 30%  FREETO OWN   100% OTHER  NO
                          BASEINCOMEDISCOT SELL BUSIN.GUARTEREASONANSWER
                       *************************************************
DISTRIBUTORS' AGE GROUP     59    27    10    10     4     3     4     1
                         100.0 100.0 100.0 100.0 100.0 100.0 100.0 100.0
                         100.0  45.8  16.9  16.9   6.8   5.1   6.8   1.7
                       *************************************************

  UNDER 20                   0     0     0     0     0     0     0     0
             COL. %        0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
             ROW  %      100.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0

  20 - UNDER 30             38    17     7     5     3     3     3     0
             COL. %       64.4  63.0  70.0  50.0  75.0 100.0  75.0   0.0
             ROW  %      100.0  44.7  18.4  13.2   7.9   7.9   7.9   0.0

  30 - UNDER 40             13     7     0     4     1     0     1     0
             COL. %       22.0  25.9   0.0  40.0  25.0   0.0  25.0   0.0
             ROW  %      100.0  53.8   0.0  30.8   7.7   0.0   7.7   0.0

  40 - UNDER 50              6     3     3     0     0     0     0     0
             COL. %       10.2  11.1  30.0   0.0   0.0   0.0   0.0   0.0
             ROW  %      100.0  50.0  50.0   0.0   0.0   0.0   0.0   0.0

  OVER 50                    2     0     0     1     0     0     0     1
             COL. %        3.4   0.0   0.0  10.0   0.0   0.0   0.0 100.0
             ROW  %      100.0   0.0   0.0  50.0   0.0   0.0   0.0  50.0

  NO ANSWER                  0     0     0     0     0     0     0     0
             COL. %        0.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
             ROW  %      100.0   0.0   0.0   0.0   0.0   0.0   0.0   0.0
                       *************************************************
```

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                   TABLE 5.1.2 AGE VS ATTRACTIVENESS OF AMWAY SELLING SYSTEM £AFTER JOINING-IN£

                   ****************************************************
                           ATTRACTION OF ASS 'AFTER JOINING-IN=
                           ADDN+L 30%  FREETO OWN    100% OTHER    NO
                       BASEINCOMEDISCOTSELL  BUSIN.GUARTEREASONANSWER
                   ****************************************************
DISTRIBUTORS' AGE GROUP   59     13     12     11      8      6      3      6
                       100.0  100.0  100.0  100.0  100.0  100.0  100.0  100.0
                       100.0   22.0   20.3   18.6   13.6   10.2    5.1   10.2
                   ****************************************************

                           0      0      0      0      0      0      0      0
   UNDER 20
            COL. %       0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
            ROW  %     100.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0

                          38     10      6      6      6      5      2      3
   20 - UNDER 30
            COL. %      64.4   76.9   50.0   54.5   75.0   83.3   66.7   50.0
            ROW  %     100.0   26.3   15.8   15.8   15.8   13.2    5.3    7.9

                          13      3      2      2      2      1      1      2
   30 - UNDER 40
            COL. %      22.0   23.1   16.7   18.2   25.0   16.7   33.3   33.3
            ROW  %     100.0   23.1   15.4   15.4   15.4    7.7    7.7   15.4

                           6      0      4      2      0      0      0      0
   40 - UNDER 50
            COL. %      10.2    0.0   33.3   18.2    0.0    0.0    0.0    0.0
            ROW  %     100.0    0.0   66.7   33.3    0.0    0.0    0.0    0.0

                           2      0      0      1      0      0      0      1
   OVER 50
            COL. %       3.4    0.0    0.0    9.1    0.0    0.0    0.0   16.7
            ROW  %     100.0    0.0    0.0   50.0    0.0    0.0    0.0   50.0

                           0      0      0      0      0      0      0      0
   NO ANSWER
            COL. %       0.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
            ROW  %     100.0    0.0    0.0    0.0    0.0    0.0    0.0    0.0
                   ****************************************************
```

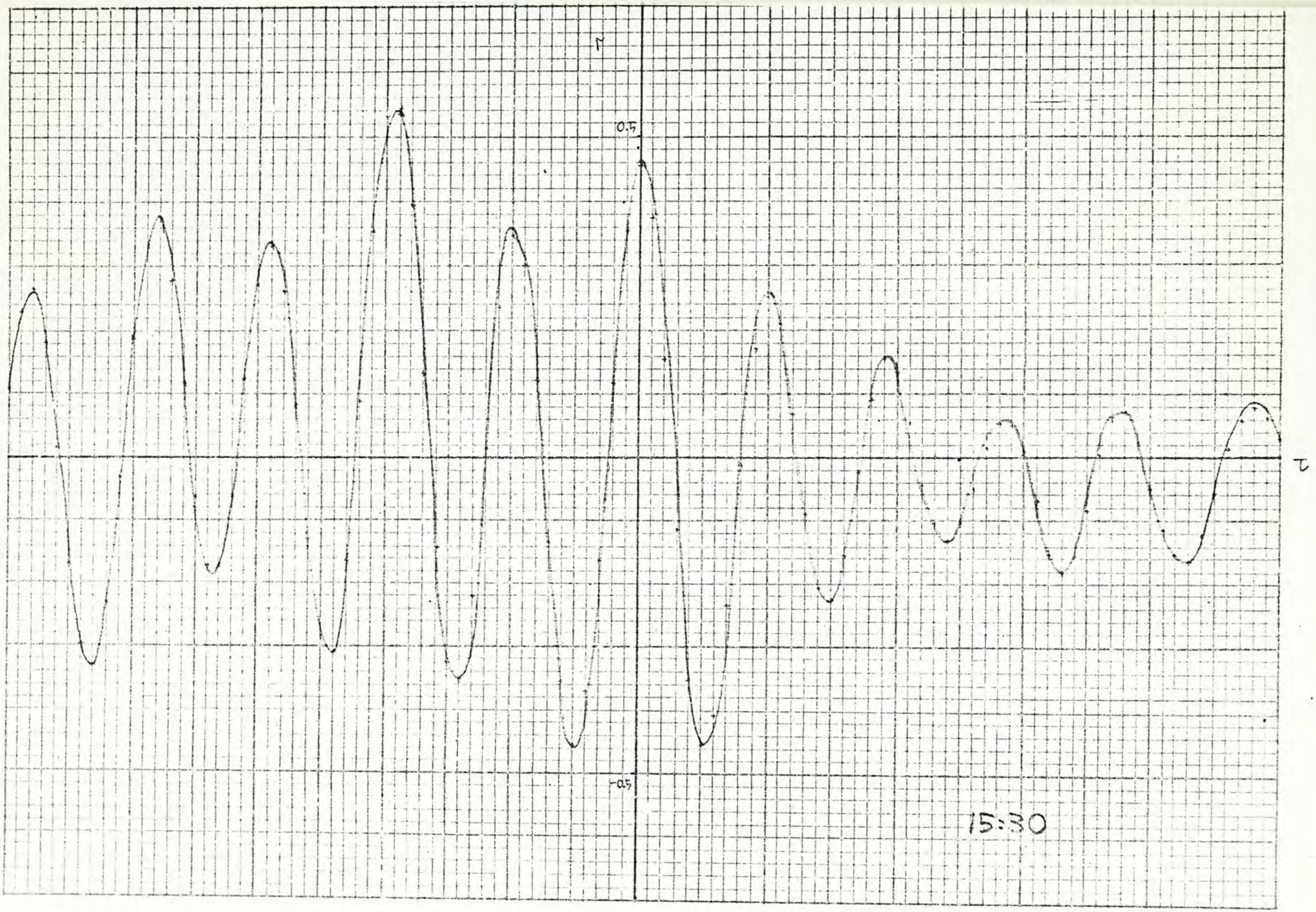

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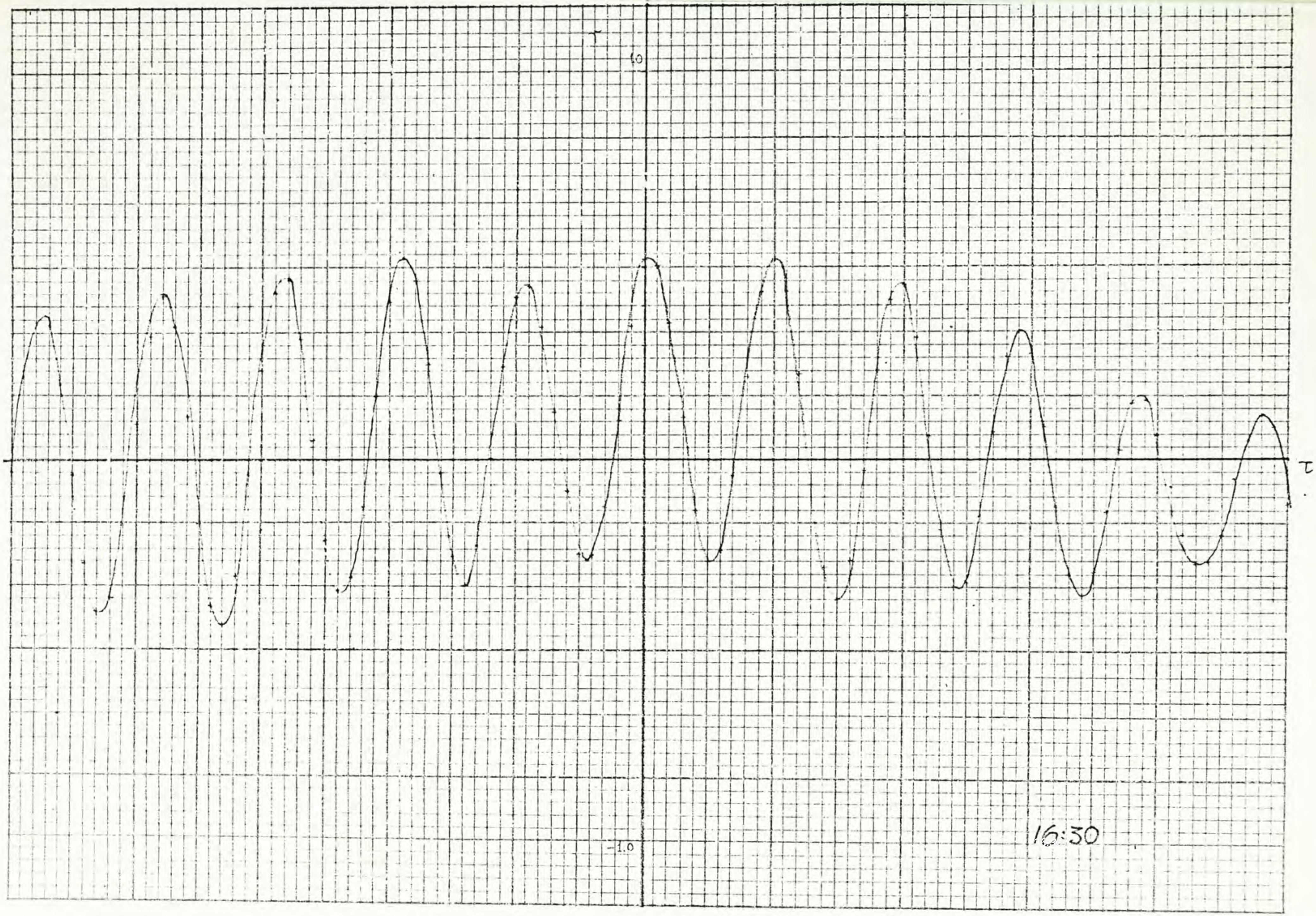
Γ
1.0
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16:30

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                              TABLE 5.1.5 AGE GROUP VS RESIDENCE OF CUSTOMERS

                              *************************
                                    CUSTOMER RESIDENCE
                                     YES    NO    NO
                                 BASE             ANSWER
                              *************************
DISTRIBUTORS' AGE GROUP          59     20    39      0
                               100.0 100.0 100.0 100.0
                               100.0  33.9  66.1    0.0
                              *************************

  UNDER 20                        0      0     0      0
                  COL. %        0.0    0.0   0.0    0.0
                  ROW  %      100.0    0.0   0.0    0.0

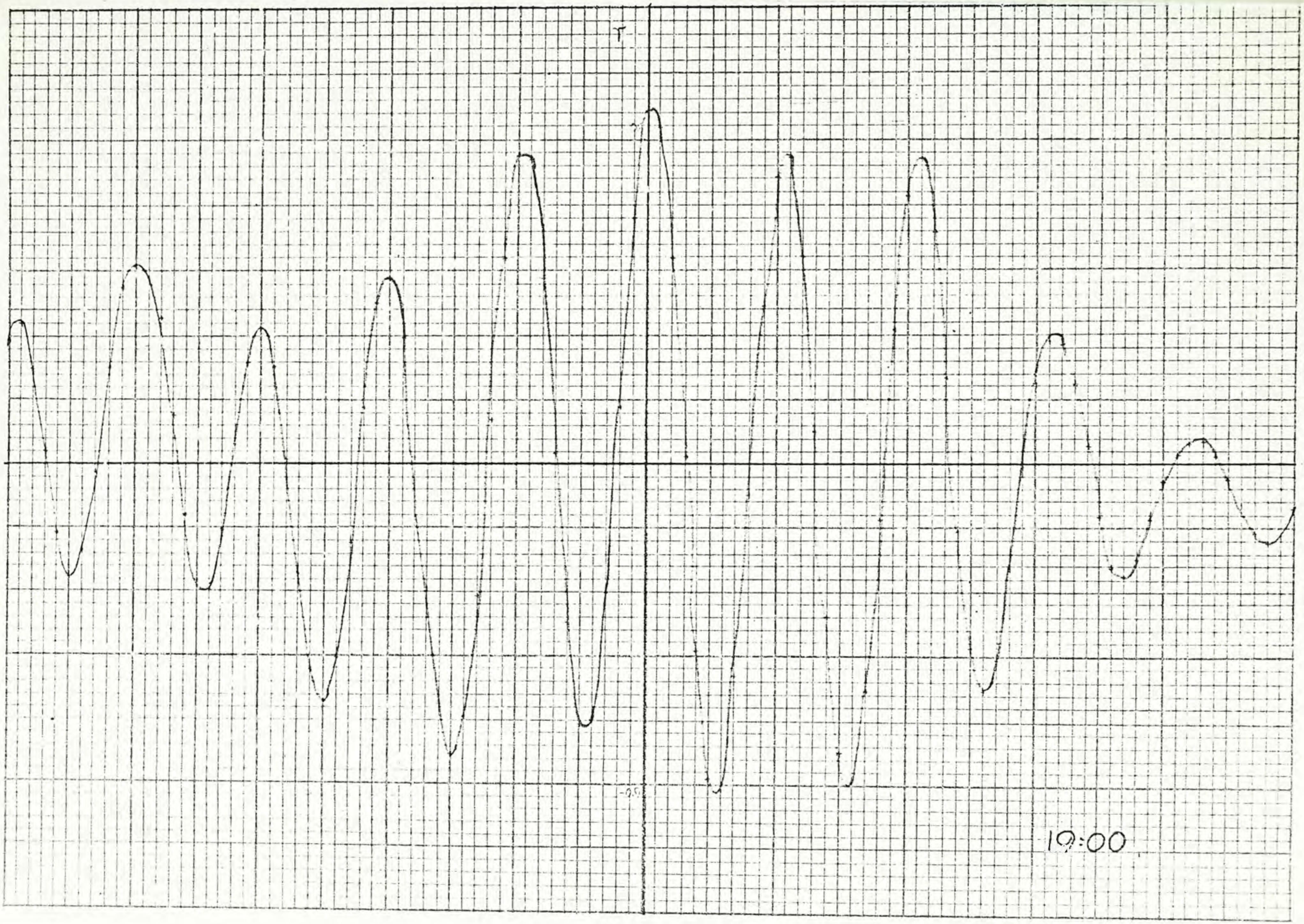
  20 - UNDER 30                  38     13    25      0
                  COL. %       64.4   65.0  64.1    0.0
                  ROW  %      100.0   34.2  65.8    0.0

  30 - UNDER 40                  13      5     8      0
                  COL. %       22.0   25.0  20.5    0.0
                  ROW  %      100.0   38.5  61.5    0.0

  40 - UNDER 50                   6      2     4      0
                  COL. %       10.2   10.0  10.3    0.0
                  ROW  %      100.0   33.3  66.7    0.0

  OVER 50                         2      0     2      0
                  COL. %        3.4    0.0   5.1    0.0
                  ROW  %      100.0    0.0 100.0    0.0

  NO ANSWER                       0      0     0      0
                  COL. %        0.0    0.0   0.0    0.0
                  ROW  %      100.0    0.0   0.0    0.0
                              *************************
```



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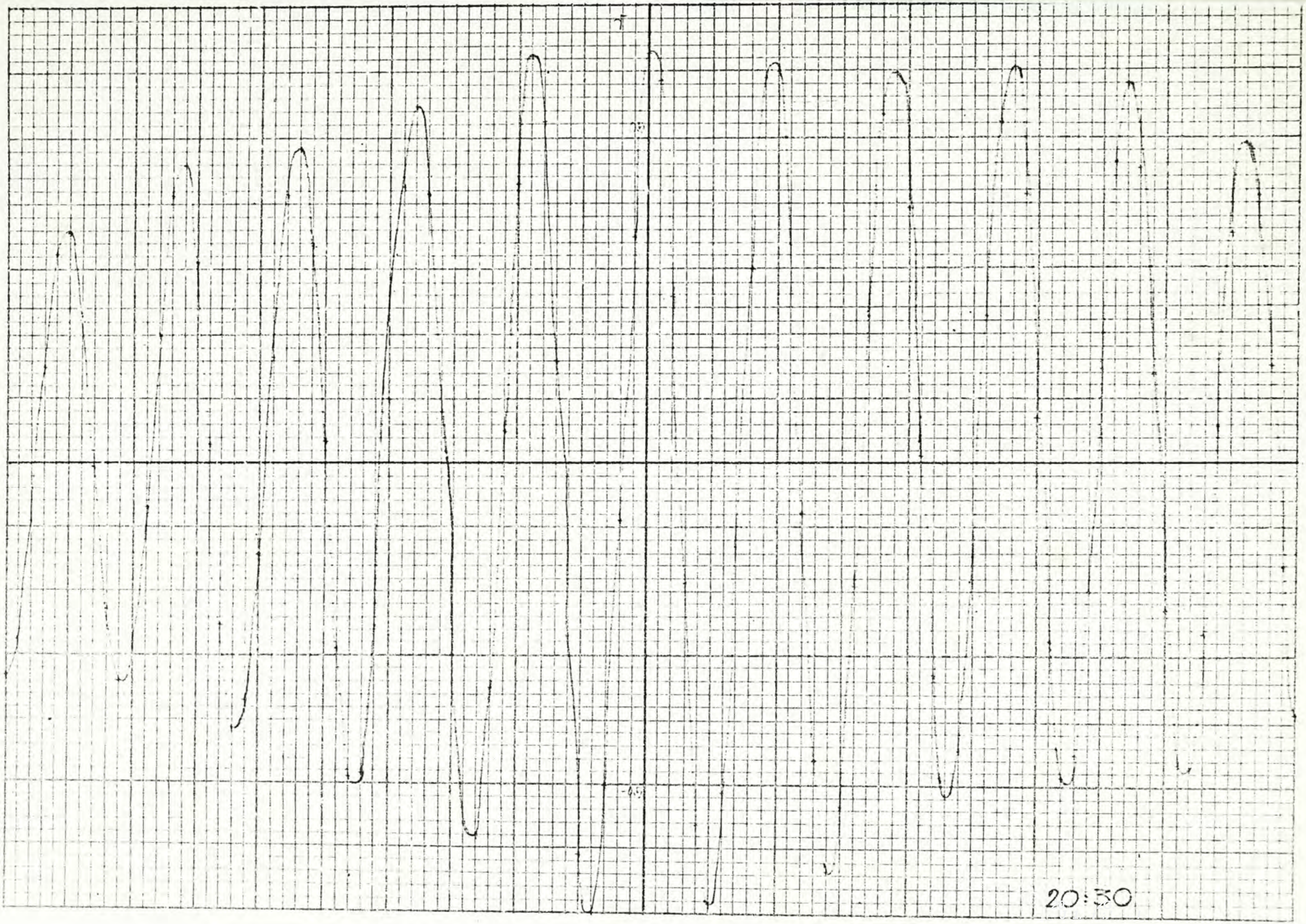
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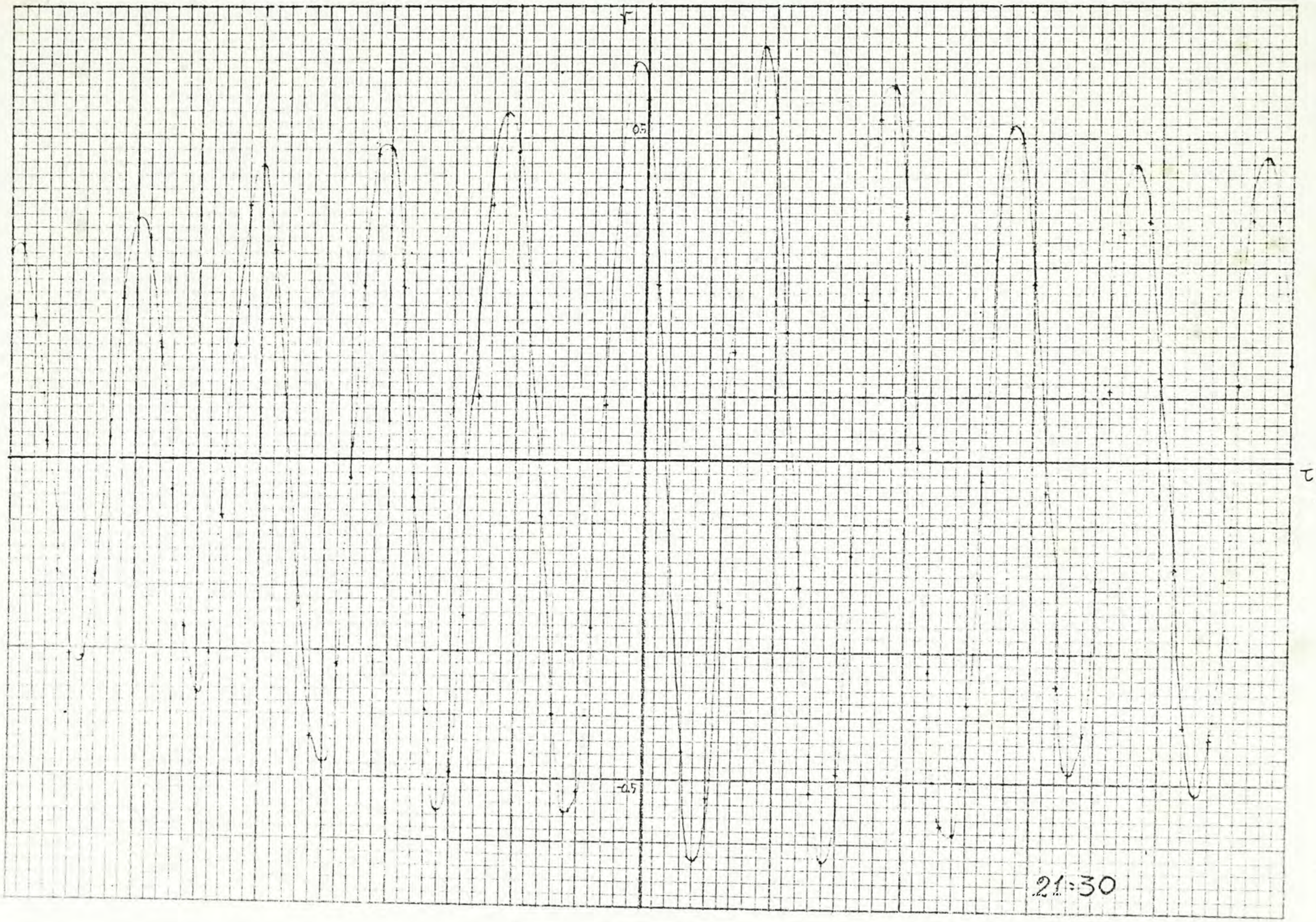
-0,5
τ
20:50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0.5
-0.5
τ
21:30

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                          TABLE 5.1.7 AGE GROUP VS TIME LAG TO REMIND CUSTOMERS TO STOCK

                          *******************************************************
                                TIME LAG TO REMIND CUSTOMERS TO STOCK
                                 ONE    TWO  THREE  FOUR  FIVE  OVER  NO
                            BASEMONTH MONTHS MON.  MON.  MON. 5 MON.ANSWER
                          *******************************************************
DISTRIBUTORS' AGE GROUP       59     17      9     4     1     0     2    26
                           100.0  100.0  100.0 100.0 100.0 100.0 100.0 100.0
                           100.0   28.8   15.3   6.8   1.7   0.0   3.4  44.1
                          *******************************************************

  UNDER 20                     0      0      0     0     0     0     0     0
                COL. %       0.0    0.0    0.0   0.0   0.0   0.0   0.0   0.0
                ROW  %     100.0    0.0    0.0   0.0   0.0   0.0   0.0   0.0

  20 - UNDER 30               38     11      6     3     1     0     1    16
                COL. %      64.4   64.7   66.7  75.0 100.0   0.0  50.0  61.5
                ROW  %     100.0   28.9   15.8   7.9   2.6   0.0   2.6  42.1

  30 - UNDER 40               13      5      2     0     0     0     0     6
                COL. %      22.0   29.4   22.2   0.0   0.0   0.0   0.0  23.1
                ROW  %     100.0   38.5   15.4   0.0   0.0   0.0   0.0  46.2

  40 - UNDER 50                6      1      1     1     0     0     1     2
                COL. %      10.2    5.9   11.1  25.0   0.0   0.0  50.0   7.7
                ROW  %     100.0   16.7   16.7  16.7   0.0   0.0  16.7  33.3

  OVER 50                      2      0      0     0     0     0     0     2
                COL. %       3.4    0.0    0.0   0.0   0.0   0.0   0.0   7.7
                ROW  %     100.0    0.0    0.0   0.0   0.0   0.0   0.0 100.0

  NO ANSWER                    0      0      0     0     0     0     0     0
                COL. %       0.0    0.0    0.0   0.0   0.0   0.0   0.0   0.0
                ROW  %     100.0    0.0    0.0   0.0   0.0   0.0   0.0   0.0
                          *******************************************************
```