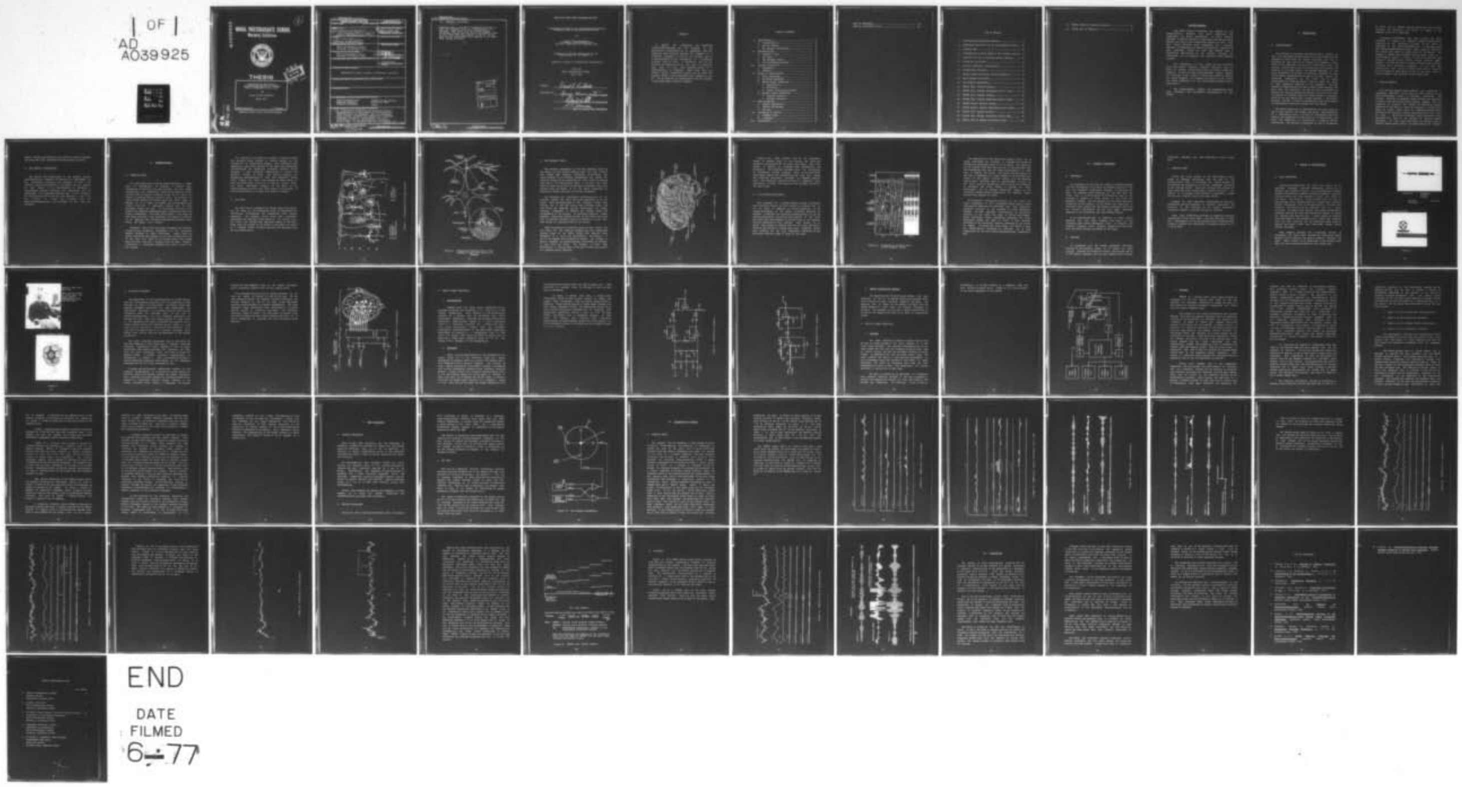
AD-A039 925 NAVAL POSTGRADUATE SCHOOL MONTEREY CALIF F/G 6/5
DISSECTION AND ANALYSIS OF ELECTROENCEPHALOGRAMS OF SUBJECTS DO--ETC(U)
MAR 77 D F LASHBROOK

UNCLASSIFIED NL

1 OF 1
AD
A039925



END
DATE
FILMED
6-77

NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

DISSECTION AND ANALYSIS OF ELECTROENCEPHALOGRAMS OF SUBJECTS DOING A SIMULATED PILOT'S TASK

by

Daniel Floyd Lashbrook

March 1977

Thesis Advisor: G. Marmont

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)

(6) Dissection and Analysis of Electroencephalograms of Subjects Doing a Simulated Pilot's Task.

5. TYPE OF REPORT & PERIOD COVERED

(9) Master's Thesis; March 1977

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

(10) Daniel Floyd/Lashbrock

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS

Naval Postgraduate School
Monterey, California 93940

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS

Naval Postgraduate School
Monterey, California 93940

12. REPORT DATE

(11) Mar[redacted]77

13. NUMBER OF PAGES

~~68~~ (12) 68p.

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)

Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Electroencephalogram
Response Signature
Preferred Frequency
Dissection and Analysis
Analysis of EEGs
Tegule

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A method for dissecting and analyzing electroencephalograms for the presence of any distinctive characteristics is presented. Data are presented which strongly indicate the presence of a preferred frequency, in the 70 - 95 Hz range, that is a characteristic of the performance of a simulated pilot's task. A conclusive test for the presence of

(cont on p 1473B)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE
(Page 1) S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

251450

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

(20. ABSTRACT Continued)

wideband noise in the EEG is presented with data to show that wideband noise is a characteristic of myograms. EEGs taken from two closely spaced electrodes located over the motor and premotor areas of the cortex show that tegules in the 70 - 95 Hz band are not simultaneous with tegules of any other band, except by chance.

1473B

DD Form 1473, 1 Jan 73

S/N 0102-014-6601

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

DISSECTION AND ANALYSIS OF ELECTROENCEPHALOGRAMS OF SUBJECTS DOING A SIMULATED PILOT'S TASK

by

Daniel Floyd Lashbrook
Lieutenant, United States Navy
B.S.M.E., University of Oklahoma, 1970

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AERONAUTICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL

March 1977

Author: Daniel F. Lashbrook

Approved by: George Marmont, Thesis Advisor

Richard W. Bell, Chairman, Department of Aeronautics

Dean of Science and Engineering

ABSTRACT

A method for dissecting and analyzing electroencephalograms for the presence of any distinctive characteristics is presented. Data are presented which strongly indicate the presence of a preferred frequency, in the 70 - 95 Hz range, that is a characteristic of the performance of a simulated aircraft pilot's task. A conclusive test for the presence of wideband noise in the EEG is presented with data to show that wideband noise is a characteristic of myograms. EEGs taken from two closely spaced electrodes located over the motor and premotor areas of the cortex show that tegules in the 70 - 95 Hz band are not simultaneous with the tegules of any other band, except by chance.

TABLE OF CONTENTS

I. INTRODUCTION.. 10

A. BIOENGINEERING...................................... 10

B. THE EEG PROJECT..................................... 11

C. THE AUTHORS CONTRIBUTION............................ 12

II. NEUROPHYSIOLOGY.. 13

A. PYRAMIDAL CELLS..................................... 13

B. THE BRAIN... 14

C. THE CEREBRAL CORTEX................................. 17

D. THE ELECTROENCEPHALOGRAM............................ 19

III. ANALYTIC PHILOSOPHY.................................... 22

A. HYPOTHESIS.. 22

B. STRATEGY.. 22

IV. METHOD OF INVESTIGATION................................ 23

A. SCALP ELECTRODES.................................... 24

B. ELECTRODE PLACEMENT................................. 24

C. ANALOG SIGNAL PROCESSING............................ 27

1. Amplification.................................... 30

2. Filtering.. 30

3. Analog Conditioning Element...................... 30

D. DIGITAL SIGNAL PROCESSING........................... 34

1. Computer Hardware................................ 34

2. Software Programs................................ 34

V. DATA COLLECTION.. 37

A. SUBJECT PREPARATION................................. 43

B. TESTING ENVIRONMENT................................. 43

C. THE TASK.. 43

VI. DISCUSSION OF RESULTS.................................. 44

A. COMPUTER PLOTS...................................... 46

B. A MYOGRAM... 46

VII. CONCLUSIONS.. 60

LIST OF REFERENCES.. 63
INITIAL DISTRIBUTION LIST.................................... 66

LIST OF FIGURES

1. Interconnections Between Neurons.................... 15

2. Simplified Pyramidal Cell of the Cerebral Cortex.... 16

3. Brodmann Map.. 18

4. Organization of Nerve Cells in the Cerebral Cortex.. 20

5. Exploded View of an Electrode Holder Assembly....... 25

6. Helmet and Electrodes................................. 26

7. Unipolar Reference Configuration.................... 29

8. Preamplifier Schematic................................ 32

9. Fourth Order Butterworth Filter Schematic........... 33

10. Block Diagram of System.............................. 36

11. The Tasking Subassembly.............................. 45

12. TEGPLT Pair, Relaxed Subject......................... 48

13. TEGPLT Pair, Subject Performing Pilot's Task........ 49

14. TWODET Plot, Relaxed Subject......................... 50

15. TWODET Plot, Subject Performing Pilot's Task........ 51

16. TEGPLT Series, Relaxed Subject...................... 53

17. TEGPLT Series, Subject Performing Pilot's Task...... 54

18. HISCAN Plot, Relaxed Subject......................... 56

19. HISCAN Plot, Subject Performing Pilots Task......... 57

20. REPLAY Plot of Subject Performing Tasks............. 59

21. TEGPLT Series of Isolated Myogram.................. 61

22. TWODET Plot of Myograms............................ 62

ACKNOWLEDGEMENTS

The author wishes to recognize the members of the bioengineering research team whose assistance and cooperation are deeply appreciated. LT Billy Cornett provided invaluable support in developing new methods which enabled the team to more effectively analyze the data. LCDR Jean Fricke provided sound leadership and a creative approach in developing new testing procedures to enhance the data gathering stages and LCDR Jack McCrory made a significant contribution to the project through his development of an expanded and detailed neural modeling program.

The information in this thesis has been collected from three general sources, reference material, most of which is listed, instructors notes, and direct laboratory research. In each of these areas Professor George Marmont has provided a great amount of advice and wisdom in guiding his thesis students. His personal attention to each detail and total dedication to the EEG research project are an inspiration .

The encouragement, support and understanding of my wife, Georgiana, has contributed significantly to this thesis.

I. INTRODUCTION

A. BIOENGINEERING

The function of the brain has always been a mystery to man. For over three hundred years now active study has been underway to learn about the brains structure and how it functions as the seat of our thoughts and behavior. These efforts have revealed a great deal of information about the overall nervous system and the correlation of structure and function of its major parts. Our present knowledge of the brain represents the product of uncounted thousands of hours of systematic investigation by some of the most gifted and dedicated researchers in the field and is indeed considerable in scope and depth. Even so, there are still so many questions remaining to be answered. The same applies to psychologists who have studied human behavior for more than two centuries now and are able to identify and catalog the various behavioral patterns, and have even taken the liberty to classify them as to being normal or abnormal. Still no one can explain why a person follows a particular behavior pattern or even to sucessfully treat those having an unacceptable behavioral pattern for that matter.

The great difficulty in understanding the human brain is due to many factors, the primary ones being inaccessibility to a functioning brain , no tools or instruments exist for testing and observing the brain while it is functioning, and last, the difficulty in maintaining a constant testing environment. The problem is analogous to that of attempting to learn how an IBM-360 computer works with only a basic knowledge of electronics and having no access to the computer while it is operating.

A number of experiments have been carried out which attempted tc connect the effects of mental activity with variations in the electrical activity of the brain as displayed in the electroencephalogram. It has been shown that electroencephalogram traces, when properly analyzed, can reveal much about the mental state of the subject. For example, a visual light stimulus repeated many times by a synchronizing pulse is known to evoke a distinctive wave pattern in the EEG called a visual evoked response (VER). However, the VER can only be clearly revealed upon waveform averaging many triggered responses. It has also been demonstrated that a state of mental alertness is signalled by the absence of alpha waves (10 Hz) in the EEG, where a relaxed subject will generate strong alpha waves.

B. THE EEG PROJECT

For the past several years research work dedicated to increasing knowledge of the brain has been underway at the Naval Postgraduate School at Monterey, California. The program, directed by Professor George Marmont and supported in part by the Naval Electronics Systems Command, has the objective to identify and catalog the electrical signals generated by the brain in terms of frequency , intensity and place of origin along with the associated mental task. Motivation for gaining a greater understanding of the brain are many . Aside from satisfying simple curiousity, such knowledge will open up new methods of treating mental disorders. It will also help reduce the learning time to perform complex motor skills, aid comprenhesion of abstract ideas, increase and maintain high states of mental alertness and countless other processes involving mental activity.

C. THE AUTHOR'S CONTRIBUTION

The author has contributed to the project through participating as a subject, and serving as a team member in the collection, recording and analysis of data. The author's primary contribution to the effort and the subject of this thesis is an investigation to establish a relationship between preferred EEG frequencies and the performance of a simulated piloting task. In the course of his investigation the author was also obliged to deal with the effects of stress and myograms upon the electroencephalogram and his findings in this area are included.

II. NEUROPHYSIOLOGY

A. PYRAMIDAL CELLS

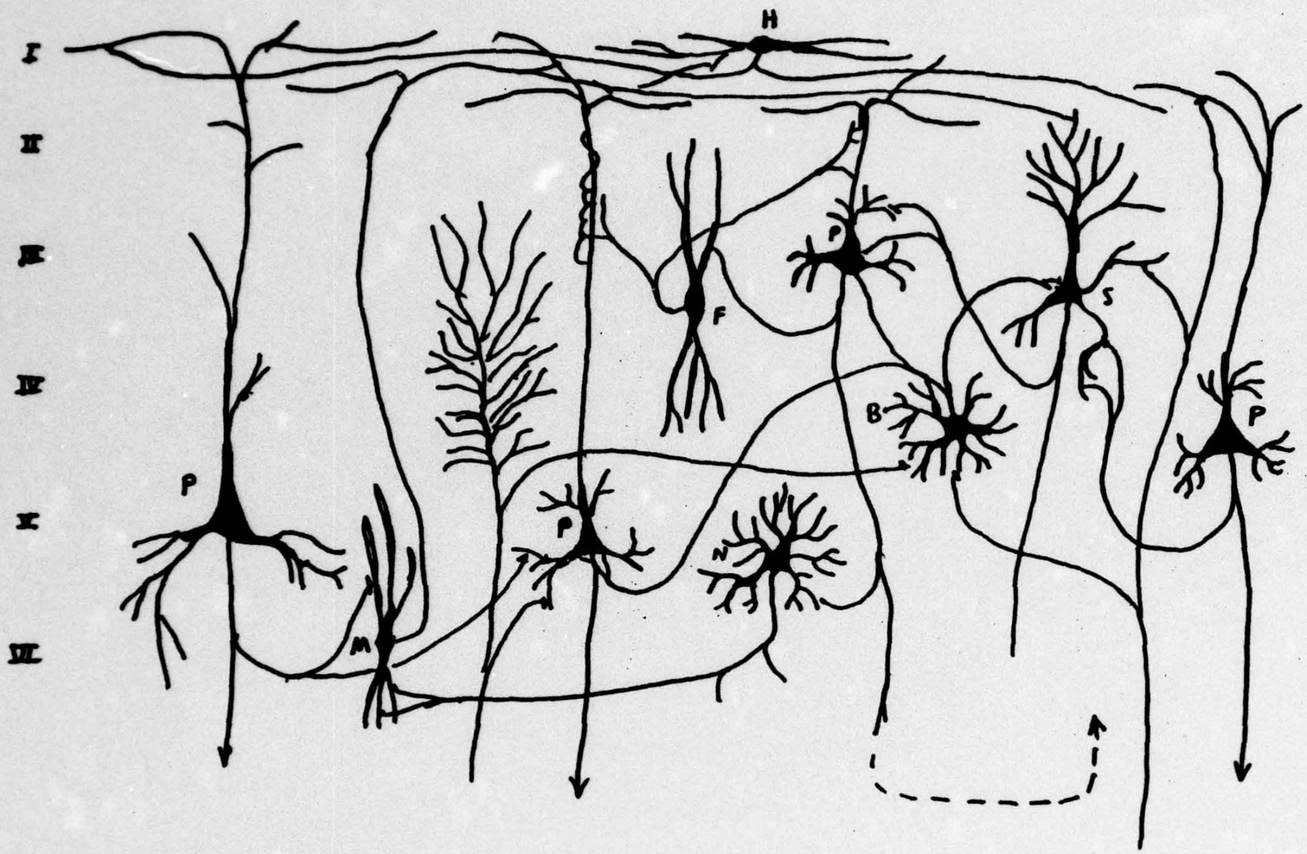
All nerve cells share certain characteristics in common such as excitability to stimulus, a receptor area, integration cf inputs at the axon hillock, one way signal transmission and transmitter areas called synaptic knobs. Neurons exist in several different forms, all of which are adapted to perform certain specific tasks. For example, the nerve fibers forming the sciatic nerve are often found to measure up to a meter in length, and are therefore best suited to the task of conducting signals over the long distances along the leg. In the brain, the need is for orderly and numerous interconnections, rather than long haul signal transmission. The nerve cells found in the brain are very short and have a well developed tree system of neurites as is required for intimate communications between brain cells. See figure 1 for a sketch.

Pyramidal nerve cells are found throughout the cerebral cortex and are primarily responsible for the electrical signals detected by scalp electrodes. These cells are easily identified the presence of two sets of dendrites and by the cone like shape of the nucleus which, when viewed from the side, look like a pyramid, thus the name. Figure 2 illustrates a simplified pyramidal cell with a close up of the synapse.

The neurons in the brain are arranged in precise layers and patterns which provide an orderly medium for the propagation of intelligible signals. The individual cells populating a particular section of the brain are extensively interconnected via chemically activated linkages called synapses to form countless combinations of serial and parallel network of cells. The various sections are elaborately interconnected to form more extensive areas, which connect via cable like bundles of nerve fibers, to form the major areas, and so on, to form the entire brain. The basic functional process of the brain is the electrochemical activity that takes place at the synapse to allow information to be passed from neuron to neuron.

B. THE BRAIN

The brain may be considered as having three major parts. One of these is the cerebellum, which is responsible for controlling, coordinating and remembering motor control sequences. The cerebral cortex where much information processing and reasoning takes places is the second part. The third and perhaps most important section is the brain stem, which is located in the center of the brain and serves as a message traffic director and sets the operating pace for the entire brain.



P- Pyramidal
M- Martinotti
F- Fusiform
N- Neurogliaform

B- Basket
H- Horizontal
S- Stellate

Figure 1. Interconnections Between Neurons.

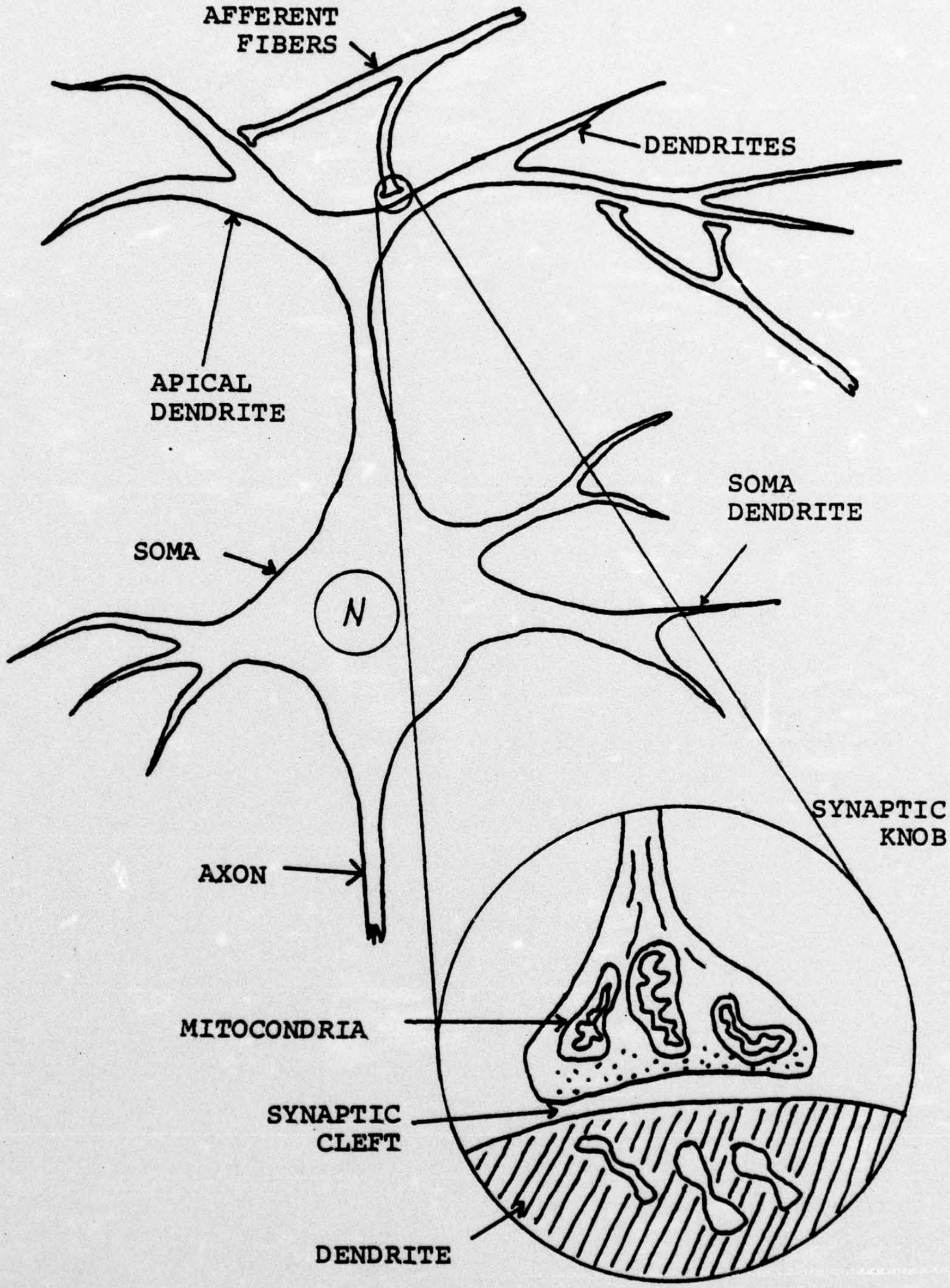


Figure 2. Simplified Pyramidal Cell of the Cerebral Cortex with Close up of Synapse.

C. THE CEREBRAL CORTEX

The cerebral hemispheres are the most prominent parts of the brain, and when placed together form the grey colored oval shaped mass commonly recognized as the brain. The outer surfaces of the cerebral hemispheres are called the cerebral cortex and are comprised of a thin layer of neurons only about 3 to 4 millimeters thick. It is this very thin layer of nerve cells that are believed to generate the ionic currents that are picked up by the scalp electrodes as electrical signals and make up the EEG recordings.

The anatomical and functional characteristics of the cerebral cortex are still the least understood of all the brain. Early investigations of the cerebral cortex were carried out by men like Golgi, Cajal, Weigert, Nissl, and many others who employed optical microscopes and tissue staining techniques to observe the various types and arrangements of the neurons. By carefully examining tissue specimen taken from different areas of the cortex they were able to identify different types and patterns of cells that were unique to a specific area of the cortex.

These structurally distinctive areas of the cortex are the basis for the familiar Brodmann map which associates certain areas of the motor cortex with specific body movements on a one to one relationship. See figure 3. A one to one mapping from stimulus to cortex, and cortex to muscle response is physiologically attractive and entirely in line with the facts. For example, we know that stimulating a certain area of the motor cortex will result in a specific motor response.

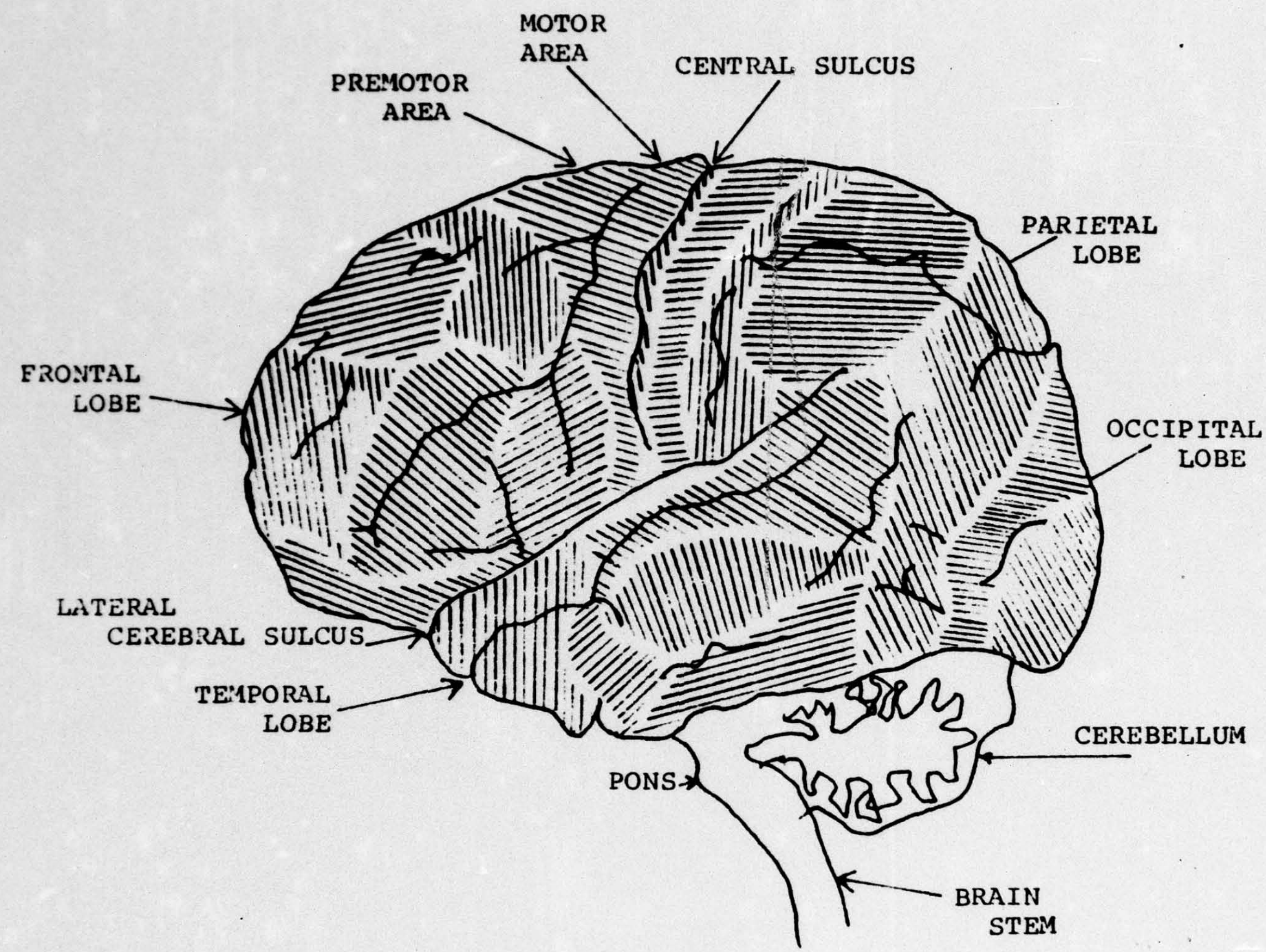


Figure 3. Brodmann Map.

Figure 4 is a cross section view of the successive layers of neurons found in the cortex, and shows the different orientations of the cells found there. Note that layers of neurons are arranged both horizontally and vertically. The horizontal networks allow the interchange of information between adjacent cells in the same layer which might explain how neurons from one area will assume the functions previously performed by a damaged adjacent area. The vertically oriented networks of dendrites carry information between the cortex and the thalamus located in the brain stem.

D. THE ELECTROENCEPHALOGRAM

The discharge of a single synapse creates a miniscule ionic potential across the axon hillock of a neuron that is far too small to generate an action potential. In the normal functioning of the brain, literally millions of synaptic discharges are occurring simultaneously in all the neurons populating a functional unit section of the brain with each cell contributing to the sum total of the synaptic activity generated in that section. Most likely, it is these large groups of neurons with all the ionic potentials building and falling in unison about near threshold levels that accounts for the slow undulating character of the electrical activity known to exist in the brain.

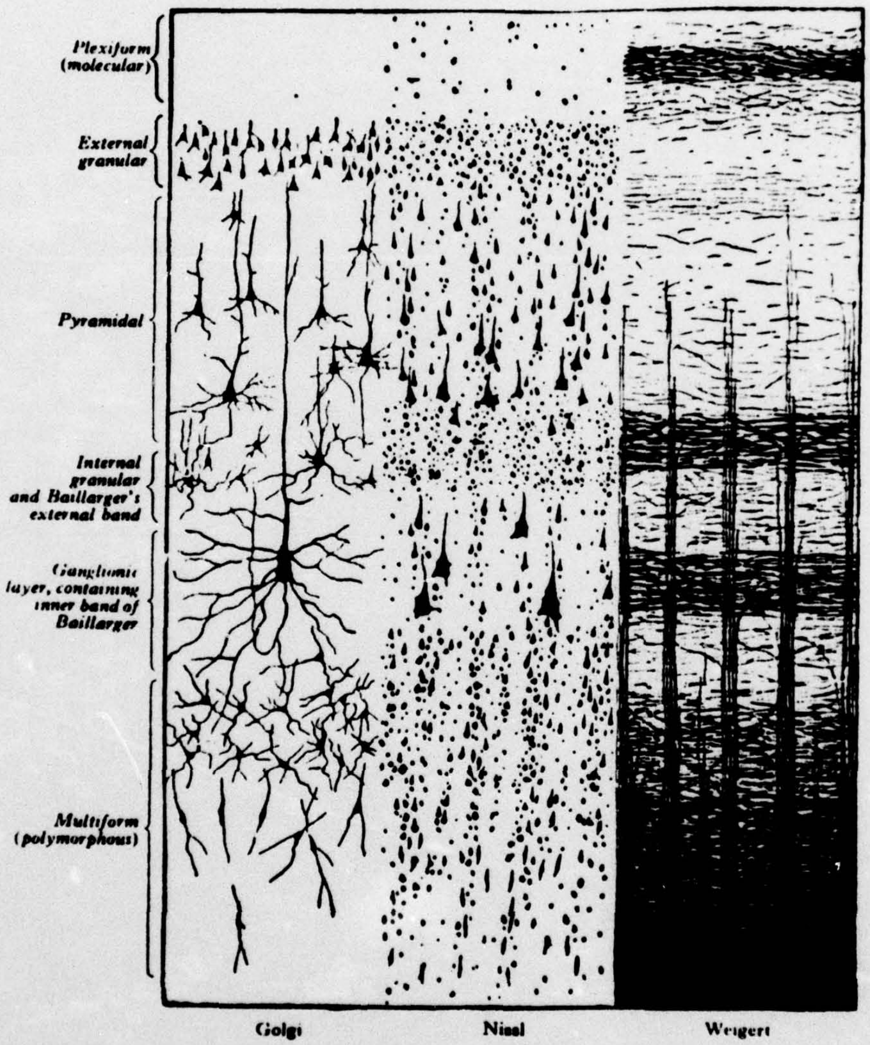


Figure 4. Organization of Nerve Cells in the Cerebral Cortex.

The undulations in the electrical signals picked up by scalp electrodes are believed to indicate the amount of information processing going on in the brain. The intensity of the signals range from near zero up to 100 microvolts and the frequencies vary from one every few seconds up to more than a hundred per second. The signal pattern present at any time is dependent to a great degree on the intensity and nature of the mental activity going on in the cerebral cortex alone. Although there is simultaneous activity in the brain stem and cerebellum, such activity is attenuated to extremely low levels before it reaches the scalp electrodes; and is thereby effectively masked by the relatively strong signals coming from the cerebral cortex located just beneath the skull.

The presence of electrical activity in the brain was first discovered in 1875 by Richard Canton using a crude galvanometer connected to electrodes that were surgically implanted directly on the cerebrum of small laboratory animals. The next important investigation of electrical activity in the brain was done in 1929 by Hans Berger. Using electronic signal amplifying equipment and scalp electrodes Berger was able to obtain a more accurate recording of the electrical activity generated by the brains of humans. He coined the terms "alpha, and "beta" to name the characteristic waveforms he observed. He is also responsible for the term "electroencephalogram", abbreviated EEG.

III. ANALYTIC PHILOSOPHY

A. HYPOTHESIS

The usefulness of EEG data as a means of gaining insight into the functioning of the brain is directly related to the care and technical expertness employed in analyzing the data. For example, visual analysis of raw EEG data can reveal only a limited amount of information; such as, the presence or absence of alpha waves, if the brain has sustained damage, and the presence of any active epileptic tendencies in the subject. In all cases the condition is detectable only because the EEG signals associated with them are visually distinctive and of such large magnitude compared to the background that they become obvious.

It is hypothesized that in addition to these easily detected and well known signals, the brain is also generating more subtle information that, if detected and properly analyzed, might possibly supply the clues which will materially advance knowledge of the brain.

B. STRATEGY

In accordance with the stated hypothesis the basic strategy of the research effort is to detect the small signals, minimize the effects of noise, make maximum use of of the digital computer, use the most sophisticated analysis techniques available and, most important, to keep an open mind.

C. STARTING POINT

During the early phases of the EEG project a large amount of wideband exploratory work was done by the Bioengineering Team to determine the normal spectrum of intensities and frequencies of the EEG responses generated by the cerebral cortex. This work verified the existance of alpha waves and their relationship to mental activity. The effects of a flashing light stimulus in producing a unique VER was also verified during this same period.

Perhaps the most important contribution of the early experiments was the discovery of evidence indicating the presence of EEG responses in the higher frequencies previously thought to contain nothing of interest.

Since time limitations preclude an adequately detailed examination of the entire band, a decision was made to limit this investigation to the the specific band considered most likely to contain the information of interest, namely the 70 to 95 Hz band.

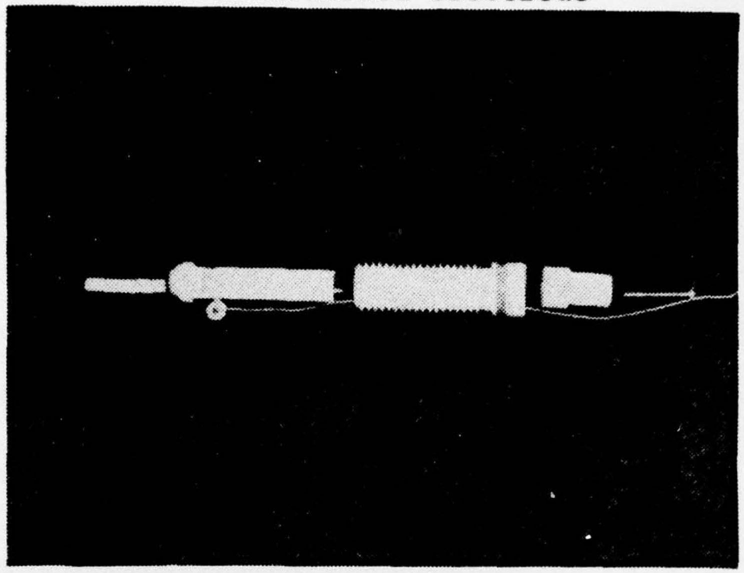
IV. METHOD OF INVESTIGATION

A. SCALP ELECTRODES

Electrical signals from the brain are picked up by specially designed electrode assemblies mounted in a modified rock climber's helmet. The electrodes are standard Beckman silver/silver chloride electrodes mounted in plastic cylinders which have been threaded to screw into holes in the helmet. See figure 6. Actual contact with the scalp is made through a salt bridge formed by a sponge like material called "Suca-Blok" that is saturated with a .15 molar NaCl solution. See figure 5 for an exploded view of a scalp electrode. To ensure good contact, the scalp is prepared by carefully bathing the area with dehydrated alcohol to remove all natural oils from the skin. A small amount of standard electrode paste is then applied to the scalp and massaged into the skin followed by the electrode holder which is screwed into place to hold the "Suca-Blok" sponge firmly against the scalp.

When properly mounted, the electrodes should be contacting the scalp only through the "Suca-Blok" sponge material with no part of the plastic assembly touching the head. There should be no sensations to the subject other than the light pressures exerted by the helmet pads.

Disassembled electrode



Suca Blok

Threaded plastic holder

Beckman electrode

Leadwire

Assembled electrode

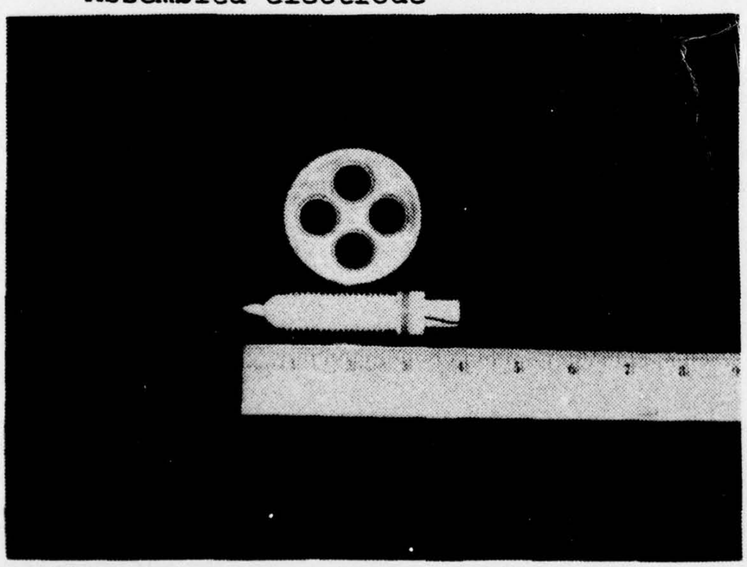
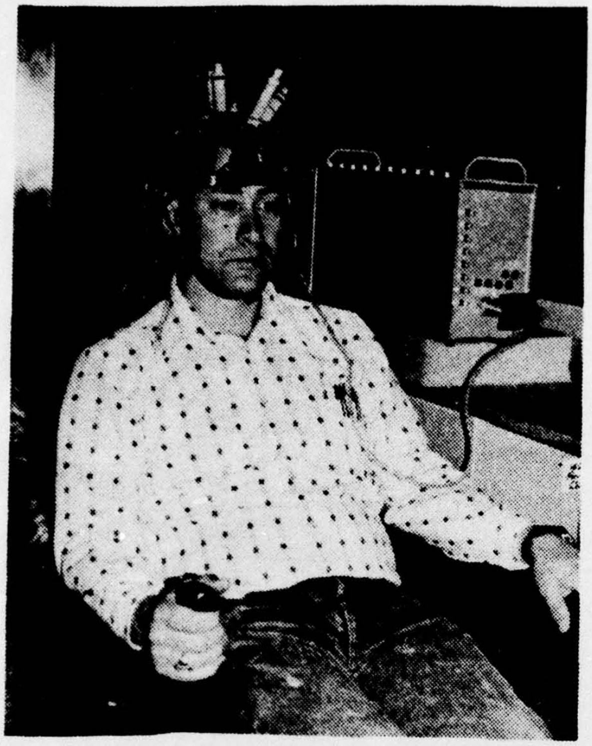


Figure 5.



Subject ready for a data run.

Note control stick at right hand and eight channel preamplifier over left shoulder.

Rock climber's helmet

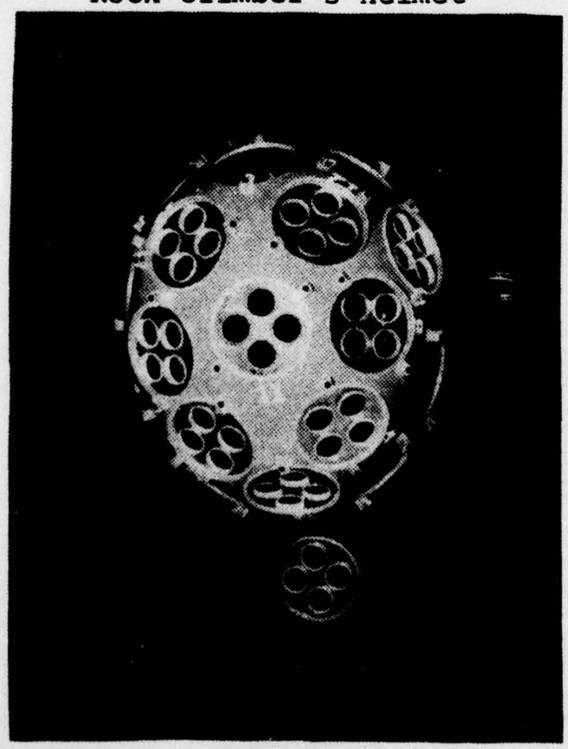


Figure 6.

B. ELECTRODE PLACEMENT

The measurement of the characteristics of an EEG signal, like any other physical quantity, must be referenced to some standard in order to be meaningful. Therefore, unless some commonly understood convention has been established, any intelligent discussion of a measured quantity must include information about the reference used. In the case of electroencephalograms, the only measured quantities are voltage and time. Here, the voltage present at some point on the surface of the scalp is detected and compared with a second voltage called the reference voltage found at some other point on the scalp , selected as the reference. As of this time the author knows of no standard reference point having been agreed upon for the measurment of EEG voltage potentials.

The basic electrode arrangement used in collecting the EEG data presented in this thesis was a unipolar electrode reference configuration which employed a total of eleven electrodes: nine scalp electrodes for detecting the EEG, plus two skin electrodes, which were used to ground the mastoid bones. A typical unipolar configuration is illustrated in figure 7. This configuration features a single designated electrode which serves as the reference electrode for all the other electrodes in use.

A unique and particularly exploitable feature of the unipolar configuration is an ability to detect mainly the activity coming from directly beneath the signal electrode. This advantage is gained because the reference electrode is placed in a relatively inactive region compared to the signal electrode which serves to emphasize the signals coming from the immediate area of the signal electrode, while attenuating signals from the more remote areas.

The reference electrode may be located anywhere on the head but cannot be located in a EEG active area. For the data presented herein, the unipolar reference electrode was located directly on top of the head in the relatively inactive region between the cerebral hemispheres. The eight remaining scalp electrodes were positioned in a circular pattern around the reference electrode. The electrode positions shown in figure 7 are the result of several trial and error attempts and were chosen because they seem to be least susceptible to myograms and other biological noise sources.

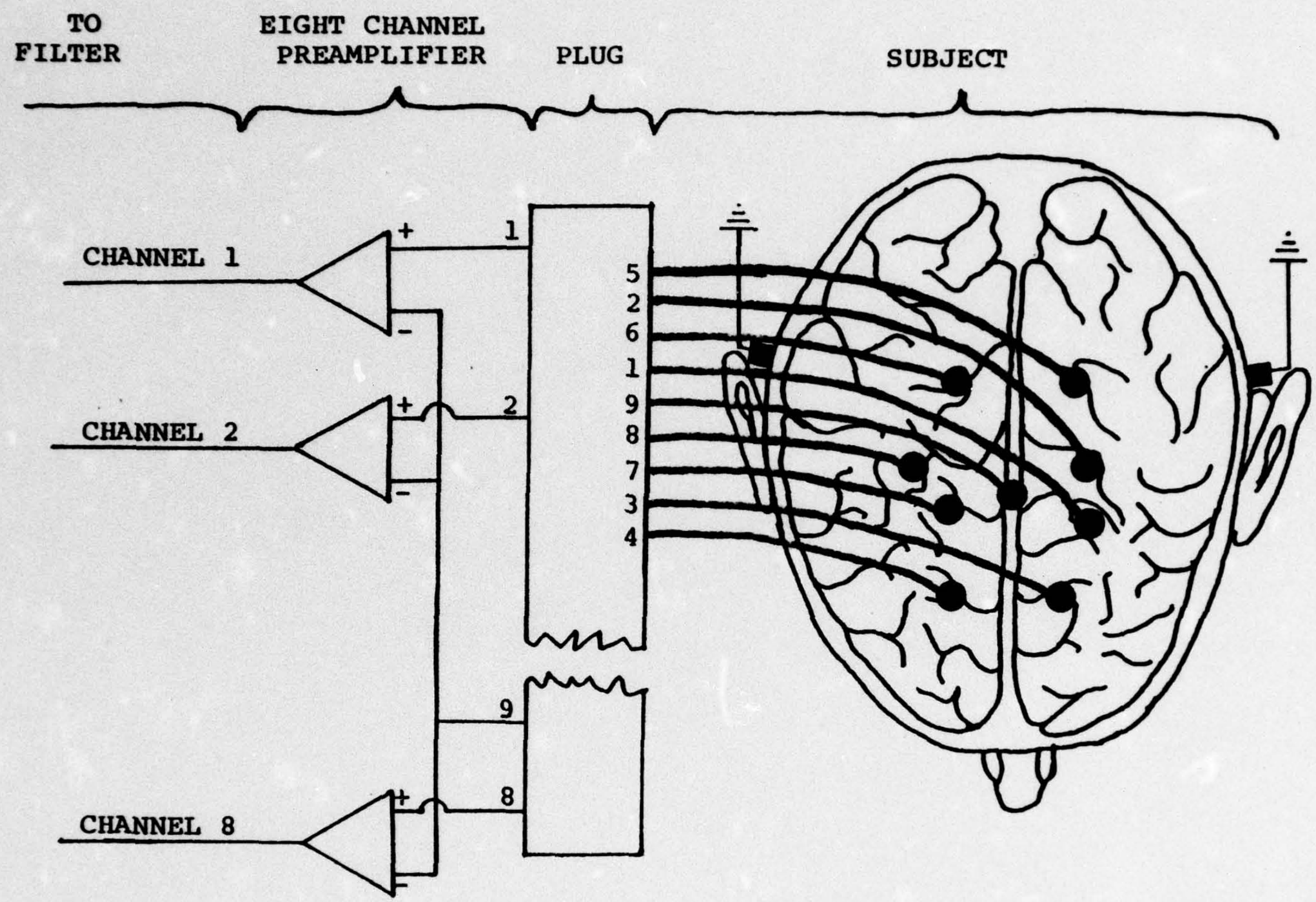


Figure 7. Unipolar reference configuration.

C. ANALOG SIGNAL PROCESSING

1. Amplification

Signals from the eight scalp electrodes and one reference electrode are conducted to the inputs of an eight channel preamplifier. Each channel of the preamplifier consists of a matched pair of Burr-Brown type 3521k operational amplifiers, connected as parallel differential amplifiers. These provide inputs to a third Burr-Brown operational amplifier connected for a common mode input. This unique arrangement, coupled with the excellent performance characteristics of the Burr-Brown operational amplifiers, has resulted in a preamplifier that is very quiet and stable while still providing an overall gain of 3850 with a common mode rejection ratio of 70 db. See figure 8 for a schematic of the preamplifier.

2. Filtering

After initial amplification in the preamplifier the signal levels are in the millivolt range and actual processing is possible which will convert the signals into a form compatible with a digital computer. The process by which analog information (continously varying) is converted into digital information (discrete bits) involves a sampling scheme. Analog signals thus converted become digital data. In all such schemes whereby an analog signal is sampled at some fixed rate, say N samples per second, there is always a risk that the signal might oscillate at a frequency F where $F > N/2$. When this is the case, the higher frequencies will be interpreted as being lower than they actually are . This situation is commonly known as aliasing or fold over and must be prevented.

In order to prevent fold over, a fourth order Butterworth filter is used in each channel to remove the higher order frequencies from the analog signals prior to sampling. These filters feature a linear phase response and very sharp frequency cutoff. The Butterworth filter is an active device utilizing a cascaded pair of Fairchild A740 operational amplifiers having a gain of 2.57 for each filter. See figure 9 for a schematic drawing. At this point the overall gain achieved from electronic amplification is approximately 10,000 which will boost a 50 to 100 microvolt signal at the electrode up to usable levels of .5 to 1.0 volts.

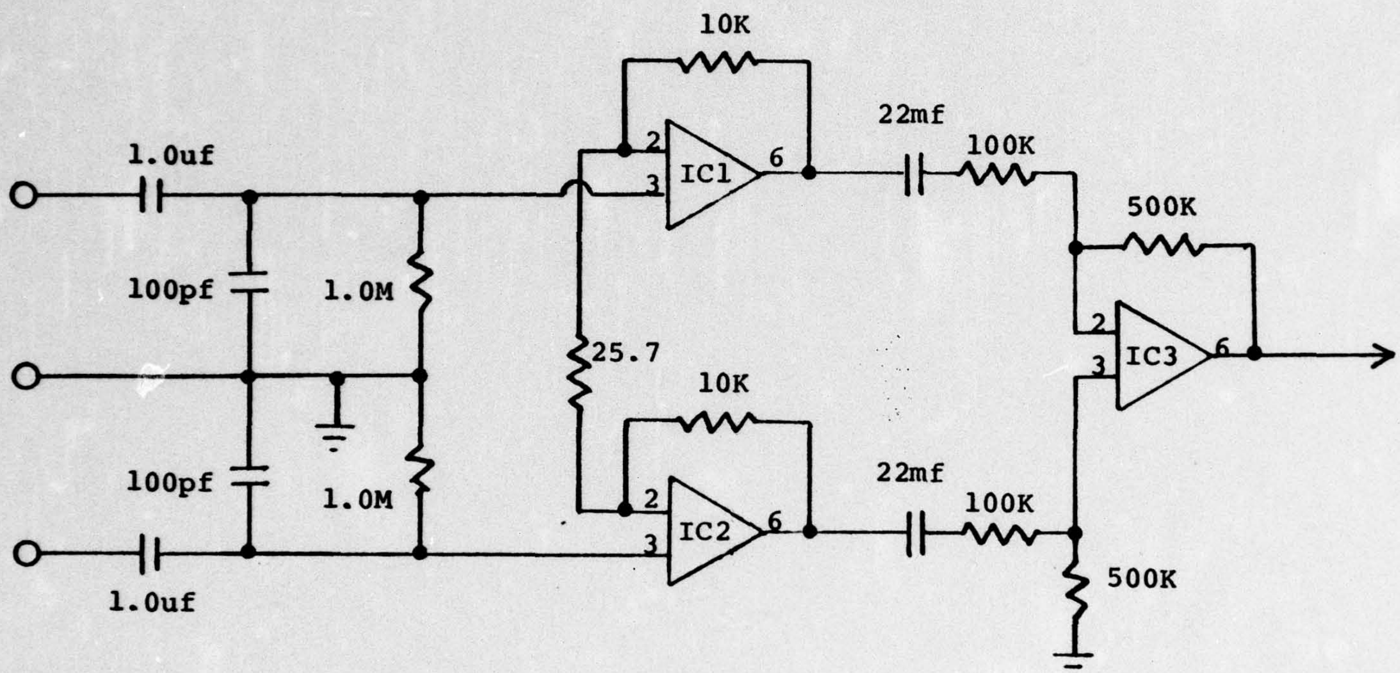


Figure 8. Preamplifier schematic.

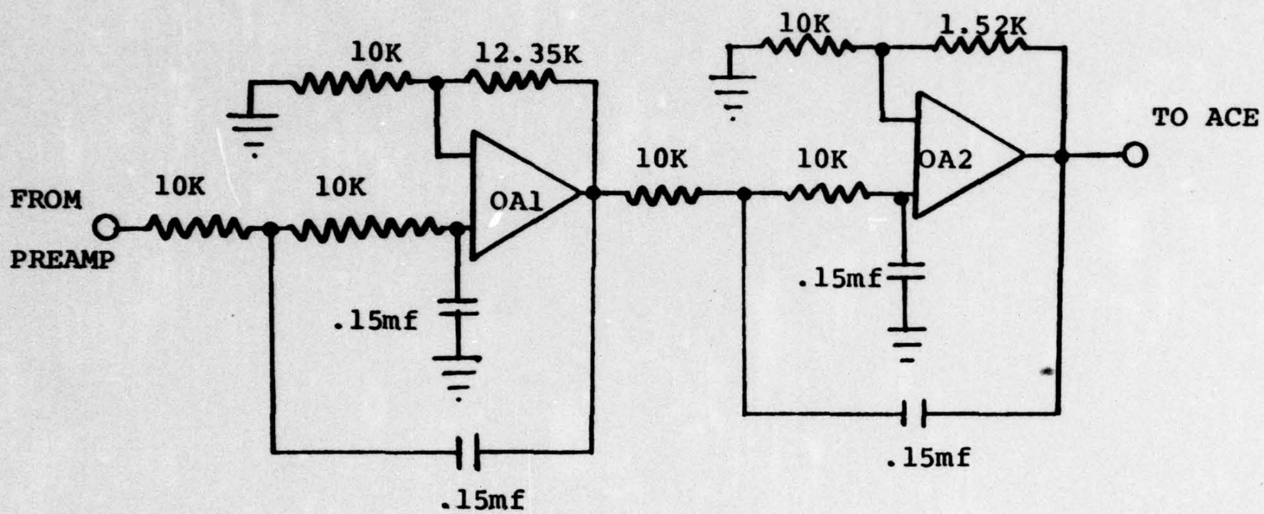


Figure 9. Butterworth filter schematic.

3. Analcg Conditioning Element

The amplified and filtered analog signal from each electrode is fed to an Analog Conditioning Element (ACE) which consists of eight parallel sampling switches. The sampling rate is based on the Nyquist criterion that one should sample at a rate twice the highest frequency of interest. For example, if you wish to sample frequencies up to 256 Hz the sampling rate must be at least 512 samples per second.

D. DIGITAL SIGNAL PROCESSING

1. Hardware

The eight channels of digital outputs from the ACE are fed in steady streams to the input buffers of a PDP 11/40 data processor. The operating characteristics of the input buffer are such that the incoming stream of bits must be halted during the time the processor register is being loaded. To compensate for this and avoid losing data, two input buffers are used in a time shareing arrangement. In this arrangement while the contents of one buffer is being processed, the other is receiving data from the ACE, consequently no data is lost. Most importantly the entire operation is carried out in real time.

The data is reduced by the processor in accordance with whatever software routine it has been programed to perform and presents the results on a real time digital CRO display for inspection. In addition, it may be used as biofeedback. It is also recorded on a magnetic disk for more detailed analysis later. Figure 10 is a block diagram of the major components of the system.

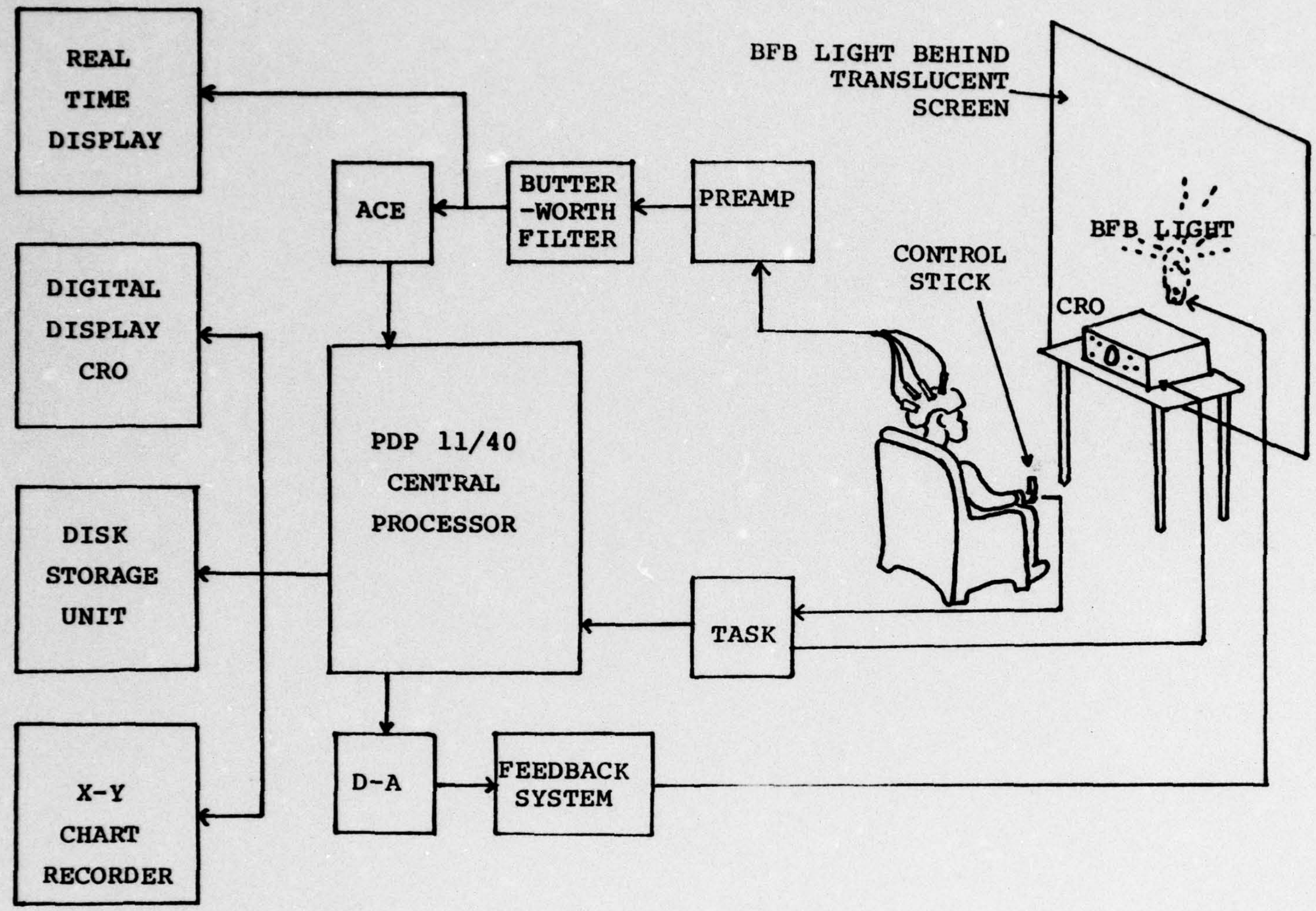


Figure 10. Block diagram of system.

2. Software

TWODET is a program which inputs eight channels of wideband (0 to 256 Hz) digital data from the ACE and performs the necessary operations to reduce the data into two channels of callable bandwidth frequencies and stores this data onto a magnetic disk.

The validity of the results provided by this program demands that only the signals orginating from the immediate vicinity of the electrodes of interest are accepted for analysis. In order to insure that signals from other sources do not enter into the problem, a cleanup routine is employed to reduce the intensity of undesirable components from the input signals. The cleanup routine utilizes six electrodes which are deployed in a circle around the two electrodes of interest. These additional electrodes sample the ambient electrical activity in the general area. The signal outputs from all eight electrodes are then algebraically summed and divided by eight to determine the overall wide area ambient signal. This wide area signal is subtracted from each of the two channels of interest which removes most of the undesired signal components. This serves to accentuate those signals that orginated from the immediate area of the two electrodes of interest.

Having thus removed most of the undesirable components, one may proceed with some measure of certainty that any commonalty between the two channels of interests most probably indicates they orginated from the same source, which must be located in the immediate vicinity of the electrodes of interest. After cleanup, the next step is a digital filtering routine to limit the data to a small band of frequencies. (The exact bandwidth and endpoints are variable and must be specified in the program callout.) This procedure involves taking the discrete fourier transform (DFT) of a block of digital data representing a quarter second of signal history. The magnitude of the fourier coefficients obtained are representative of the intensity of the corresponding discrete frequencies making up the orginal wide band data block. Digital filtering is accomplished by simply taking a copy of the DFT and making zero those fourier coefficients that correspond to frequencies outside the band you are interested in. (Certain additional processing is done to minimize "end effects".) Taking the inverse fourier transform (IFT) of the remaining coefficients will reproduce only the frequencies whose coefficients were not zeroed, namely the band of frequencies to be passed. The frequencies inside the band are invariably found to rise and fall in intensity and when displayed against time appear as amplitude modulated sine waves. Each waxing and waning sinusoidal oscillation is called a "tegule". See figure 17 (page 54) for an example.

At this point all signals at frequencies other than those in the selected band have been removed from the two channels of interest. One may now compare the respective sequences of tegules to see if they share a common orgin and frequency. This comparision is made by multiplying the signals from the two channels together and recording their product onto a third channel. Multiplications that yield a positive product imply that the multipicands are of the same frequency and in phase while those yielding a negative product implies the multipicands are either out of phase and/or have different frequencies. See figure 15 (page 51) for a sample TWODET plot.

The positive correlation product is integrated in quarter second intervals and the resulting sum is used as a cumulative indicator of the correlation between the two channels and may also be used to control a source of biofeedback presented to the subject in the form of a variable intensity background light. The quarter second intervals of time are then pieced together in groups of four and presented on the CRO display at a repetition rate of 1 per second. The CRO shows four simultaneous traces for real time viewing:

1. Trace 1 is the filtered EEG from electrode 1.

2. Trace 2 is the correlation (product).

3. Trace 3 is the filtered EEG from electrode 2.

4. Trace 4 is the performance indicator.

The performance indicator is a running plot of the radial displacement of the pip from the center of the error display CRO. See figure 11. After viewing on the CRO, all four traces are recorded on a magnetic disk for permanent storage.

The second program used is called REPLAY and is designed to analyze the data recorded from the TWODET program described above. This program reads the data in 1 second frames, integrates the correlation channel, and displays the resulting integral quantity frame by frame by placing a single dot the appropriate distance above or below the zero reference line. The position of the dot above or below the reference line is related to the sign of the correlation integral and the displacement distance of the dot corresponds to the magnitude of the correlation integral. The program then computes the numerical mean and standard deviation of the dots and superimposes everything to form a single composite plot. See figure 20 (page 59) for an example. In addition to the composite plot of the product integrals the program also provides the capability to obtain a frame by frame plot of the data stored on the magnetic disk.

Another program called REC2CH is used for recording wideband (0 to 256 Hz) EEG data onto a magnetic disk. As in TWODET, the data are cleaned up to remove any wide area undesirable components before recording takes place.

TEGPLT is a program which is used to analyze the wideband digital data recorded on a magnetic disk by the REC2CH program. TEGPLT is designed to read the wideband digital data from the disk, perform a digital filtering routine on that data, and then plot out the resulting tegules on graph paper for inspection. The digital filtering routine used in TEGPLT is identical to that used in TWODET which was previously described. The wideband data is read from the disk , processed, and plotted in one second blocks. Sequential blocks are fitted together automatically to form a continous plot of the tegule over the requested interval of time.

The callout parameters of the TEGPLT program enable the operator to select the particular period of time he wishes to look at and the particular band of frequencies he wishes to include in the tegule. By doing a series of TEGPLTs of sequential frequency bands covering the same period of time one can obtain a plot of simultaneous tegular activity. This plot is called a "TEGPLT series". See figure 16 (page 53) for an example.

A variation of TEGPLT, called TEGDET is designed to multiply together the pair of tegules recorded by the REC2CH program to produce a plot of the correlation between them. Then by using TEGPLT one can obtain a plot of the tegular activity at each electrode of the pair. By running these plots in a TEGPLT 1, TEGDET, TEGPLT 2 sequence over the same time period one can produce a composite plot like the one shown in figure 13 (page 49). This plot is called a "TEGPLT pair" and is identical to the first three traces of a TWODET plot described previously.

A spectrum detecting program is also used to analyze the wideband data obtained with the REC2CH program. This program, called HISCAN employs a digital band-pass filtering routine followed by a routine which measures the time between zero crossings, which together are capable of detecting the presence of extremely small signals and resolving the frequency to within .05 Hz. HISCAN uses the same digital filtering routine as TWODET and TEGPLT, except, it also employes a sweeping action which is necessary to get a frequency count across the entire band of interest rather than the narrower fixed bandwidth of the filter. Here the passed band is swept from 2 to 256 Hz across each data block in a discretely stepped scanning motion. Each discrete step of the digital filter results in a unique tegular pattern. A frequency analysis is done on each tegule by measuring the elapsed time between successive negative to positive crossings of the tegule to determine the value of the particular frequency present. As the measuring process is stepped through the record, the appearance of each discrete frequency is acknowledged and recorded by incrementing a counter dedicated to that discrete frequency.

At the conclusion of the sweeping, measuring and incrementing loops the dedicated counters will contain numbers that are directly related to the persistence of each discrete frequency present in the wideband waveform recorded on the disk. The output of this program is a histogram of discrete frequencies from 2 to 256 Hz along the X axis versus number of occurrences, or persistence of the frequency, plotted on the Y axis. The advantage of this arrangement is that we sense the persistence, rather than the intensity of the signal frequencies. This serves to make the visibility of weak signals equivalent to the visibility of strong signals as far as the detection of discrete frequencies is concerned. This technique vastly improves the detectability of the weaker signals in a noisy environment. See figure 19 (page 57) for an example of a HISCAN plot.

V. DATA COLLECTION

A. SUBJECT PREPARATION

Prior to each data collection run the equipment is carefully checked and calibrated to ensure that the maximum degree of continuity from run to run is achieved. In addition to making comparisions valid, it also minimizes confusion and tends to make the entire operation more smooth and efficient.

The electrodes are then carefully fitted into place against the subjects scalp at the various locations of interest and their positions recorded on a map of the helmet. Additionally, the impedance of each electrode is measured with a Grass electrode impedance meter and recorded. Electrodes having an impedance greater than 20K should be removed, checked, and refitted. Typical impedance values of 5 to 10 K ohms were achieved during this investigation.

Having thus prepared the subject and equipment all that remains is to brief the subject concerning his responsibilities and begin data collection.

B. TESTING ENVIRONMENT

During the time of actually collecting data, the subject with electrodes in place, is secluded in a darkened, electromagnetically shielded room along with the eight channel preamplifier, a control stick for correction inputs, a visual display of the error (CRO), and a light-screen biofeedback display capable of indicating to the subject information about his EEG.

The subject is seated and made comfortable with the head supported on cushions allowing complete relaxation of the neck muscles to reduce and hopefully eliminate interference from myograms. During each run all audio and visual stimuli are removed as much as possible in order to accentuate the the EEG signals generated in response to the tasking and feedback systems.

C. THE TASK

The task is a simulated aircraft controlling exercise requiring eye-hand coordination by the subject to keep a pip centered on the error CRO screen. See figure 11. The pip is randomly displaced in both direction and magnitude to simulate the random attitude errors in pitch and roll normally encountered by an actual aircraft in moderately turbulent air. When the pip is displaced, the subject must drive it back to the center by introducing the proper offsetting voltages with the control stick.

The level of difficulty presented to the subject can be varied by either changing the average rate at which the pip is randomly displaced or by simply switching the pitch and roll control outputs from the control stick. This requires that an error in pitch be corrected by a roll output from the control stick and a roll error be corrected by a pitch output from the stick.

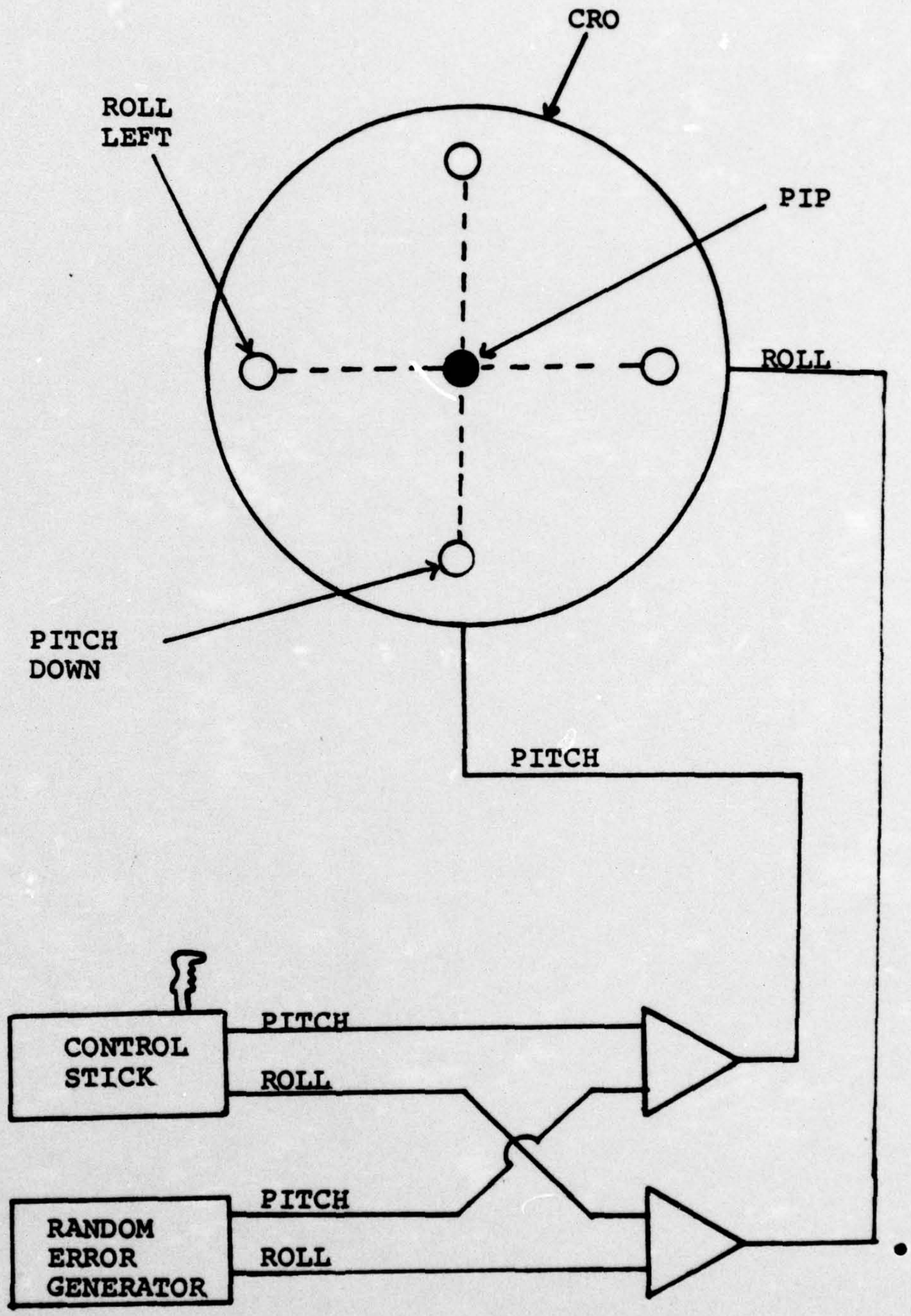


Figure 11. The tasking subassembly.

VI. DISCUSSION OF RESULTS

A. COMPUTER PLOTS

Our results show the presence of task related activity in the 70 - 95 Hz tegules. The activity is consistent in timing and form to the point that it can be identified visually from the tegular waveforms alone about 90 percent of the time by a trained observer. The term "response signature" will be used to describe this activity which exhibits the following characteristics: First, it always follows a deflection of the error pip after a short latent period of about .15 s average as reported in Ref 10. Second, the response signature is preceded and succeeded by a slight reduction in overall tegular activity. Third, the response itself is the synchronization and reinforcement of the tegules from each of the electrodes of the pair being correlated; this generates a distinctive pattern in the correlation trace. Similar response signatures are seen in TWODET plots and in TEGPLT pairs. Figure 12 shows the amount of correlation in the tegule pairs for the frequency bands of 45 - 70, 70 - 95, and 95 - 120 Hz which were taken from a time period when the subject was at rest. This is compaired to the correlation traces shown in figure 13 which were made when the subject was performing the simulated pilot's task. The tegules in each of the figures cover the same frequency bands and all other controlable parameters were constant. This comparison shows that there is less activity in the tegular bands in figure 12 when the subject was at rest than in figure 13 when the subject was actively performing the task. In figure 13 there appears to be some related activity in tegules from adjacent frequency bands. Note activity in the 45 - 70 Hz tegules which follows the 70 - 95 Hz response signature by about .2 s. The same possibility might apply to activity in the 95 - 120 Hz tegule which precedes the 70 - 95 Hz response signature by about .1 s. Due to time limitations, the possible related activity in bands other than 70 - 95 Hz were not investigated but it does afford a very interesting subject for future investigation.

The TEGPLT pairs shown in figure 13 are from a time period when the subject was performing the simulated pilot's task, using reversed stick, at a clock rate of 2.8 Hz. Note the phasing changes in the 70 - 95 Hz tegule pairs and the correlation patterns produced. This is very similar to the response signature from the TWODET plot as reported in reference 10 and shown in figure 15. Figure 14 is a TWODET plot made from the same electrode configuration as the plot in figure 15, except with the subject relaxed. This plot is found to be similar to the TEGPLT pair plot shown in figure 12.

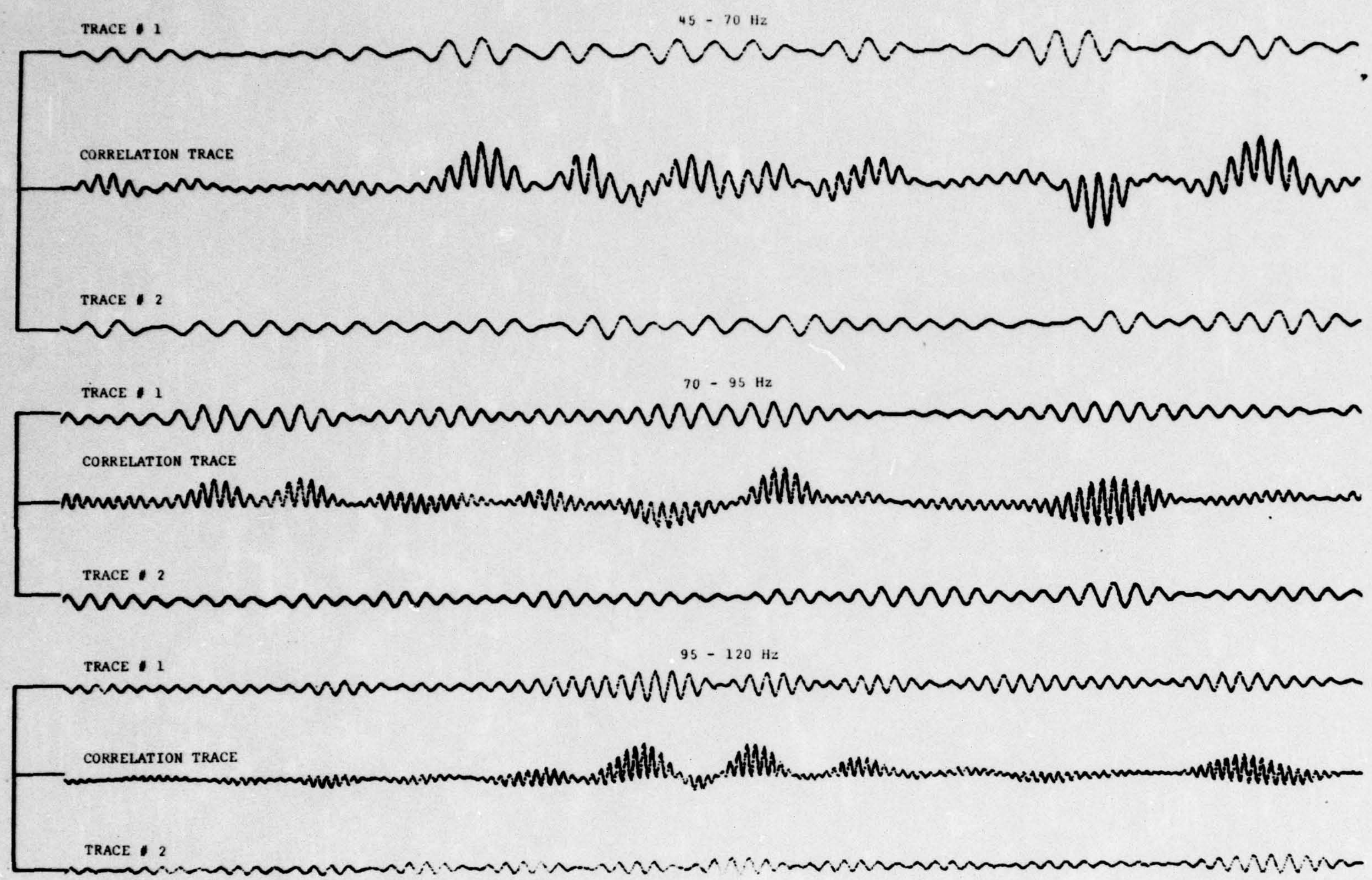


Figure 12. TEGPLT pair, relaxed subject.

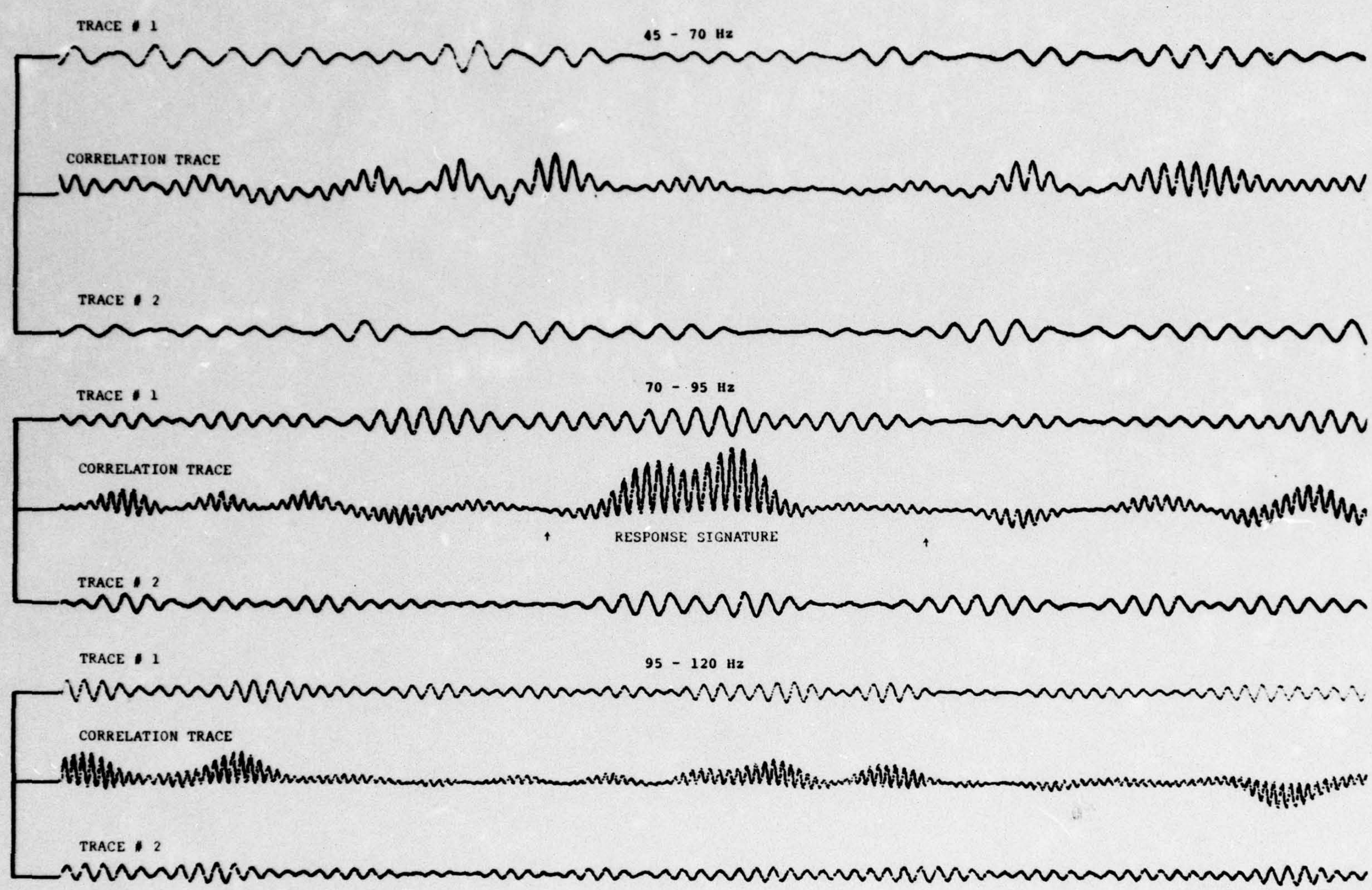


Figure 13. TEGPLT pair, subject performing pilot's task.

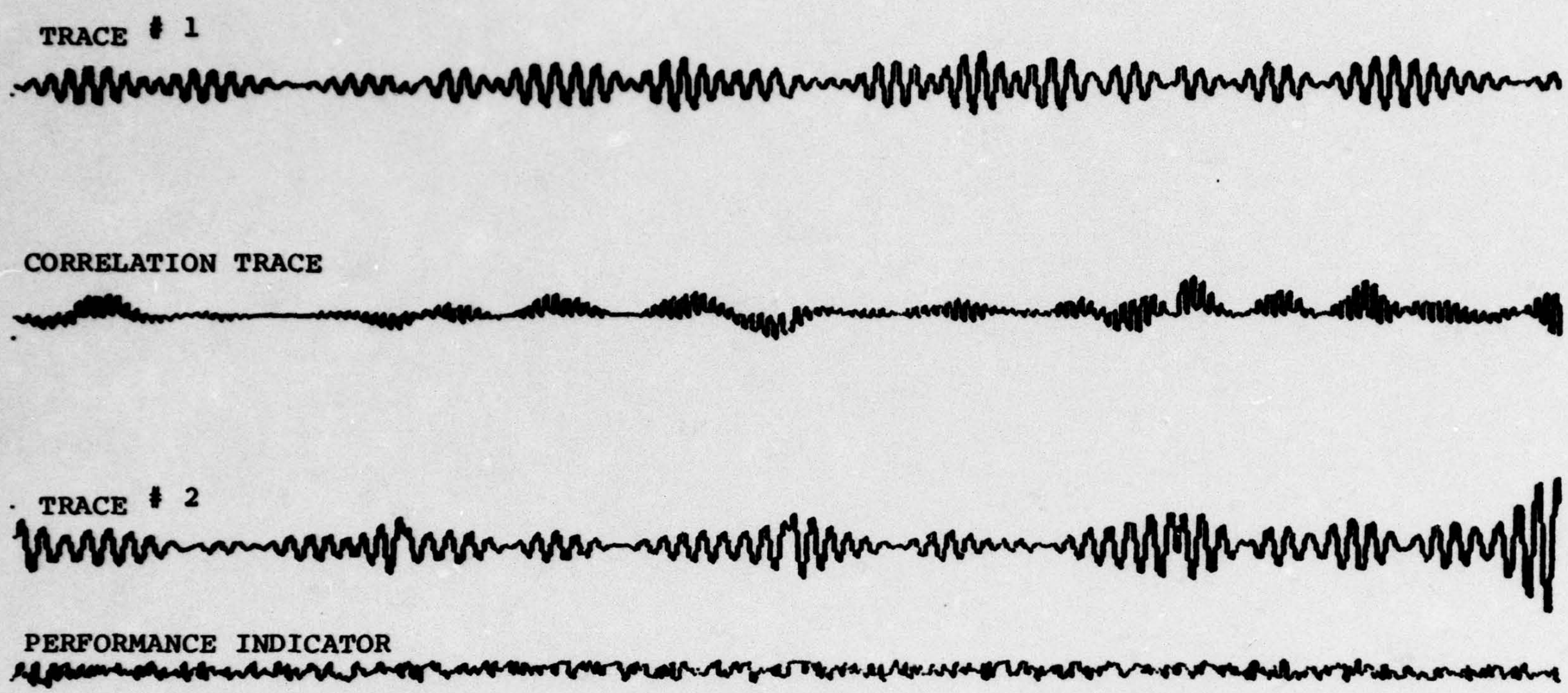


Figure 14. TWODET plot, relaxed subject

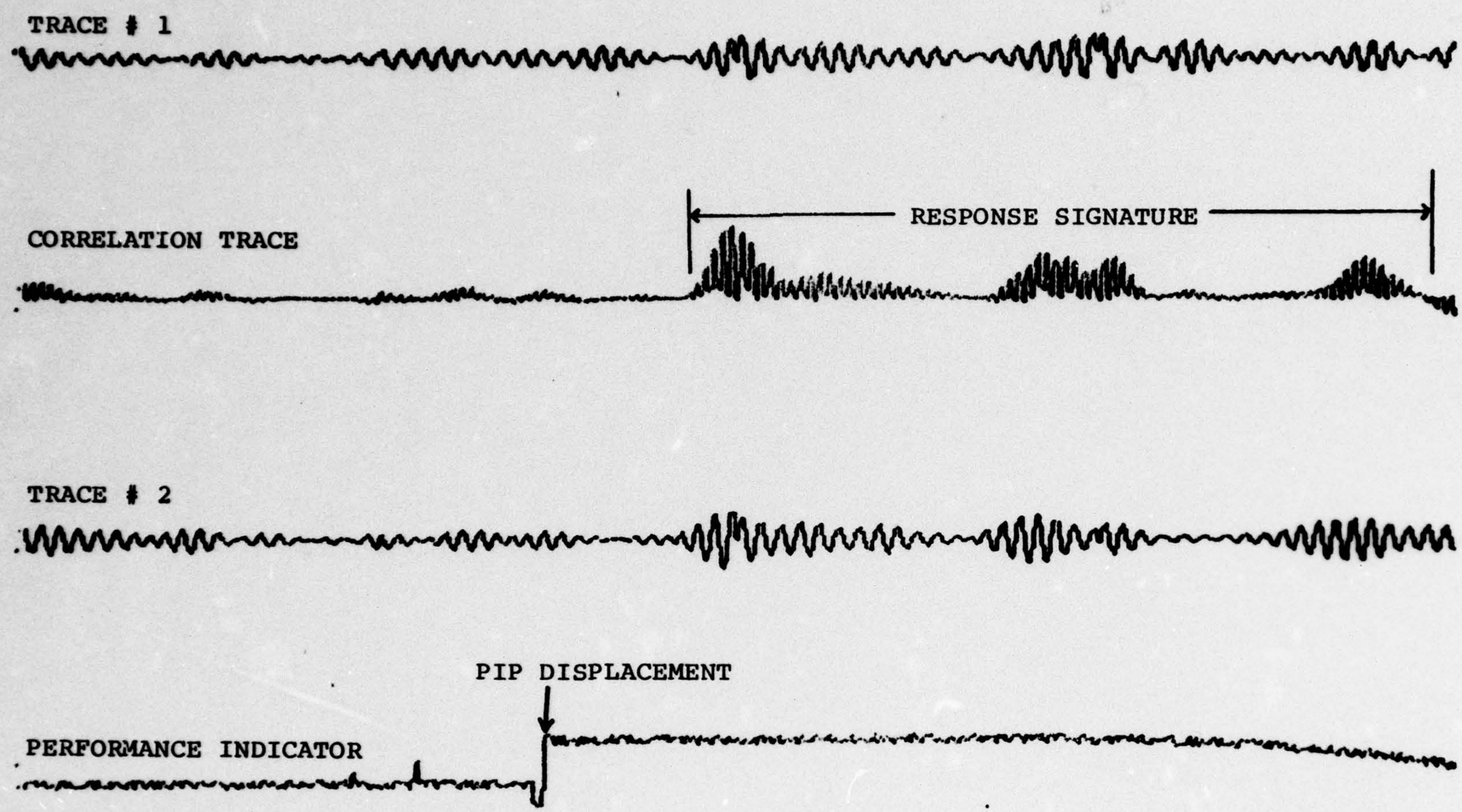


Figure 15. TWODET plot, subject performing pilot's task.

Note in figure 16 which is a TEGPLT series of a subject at rest, that the activity is pretty well constant in all the tegules in both amplitude and patterns indicating phase changes.

The TEGPLT series shown in figure 17 is from a period when the subject was actively doing the task. The activity is registered in the tegules by the variation in the pattern of phase changes and by the longer sustained tegules and slightly larger amplitudes. Comparision of figures 16 and 17 illustrate the increased tegular activity in the 70 - 95 Hz band while the subject is performing.

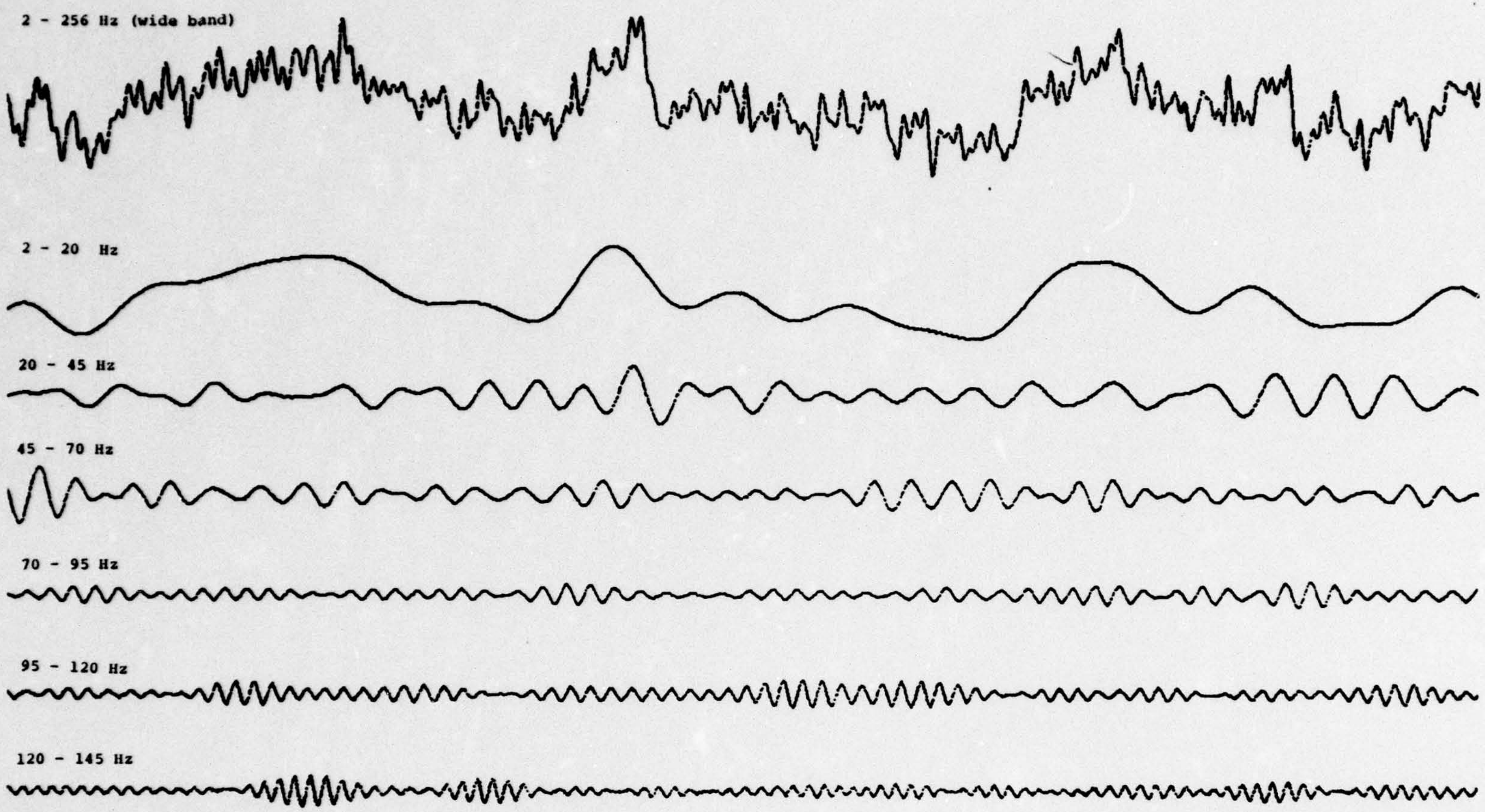


Figure 16. TEGPLT series, relaxed subject.

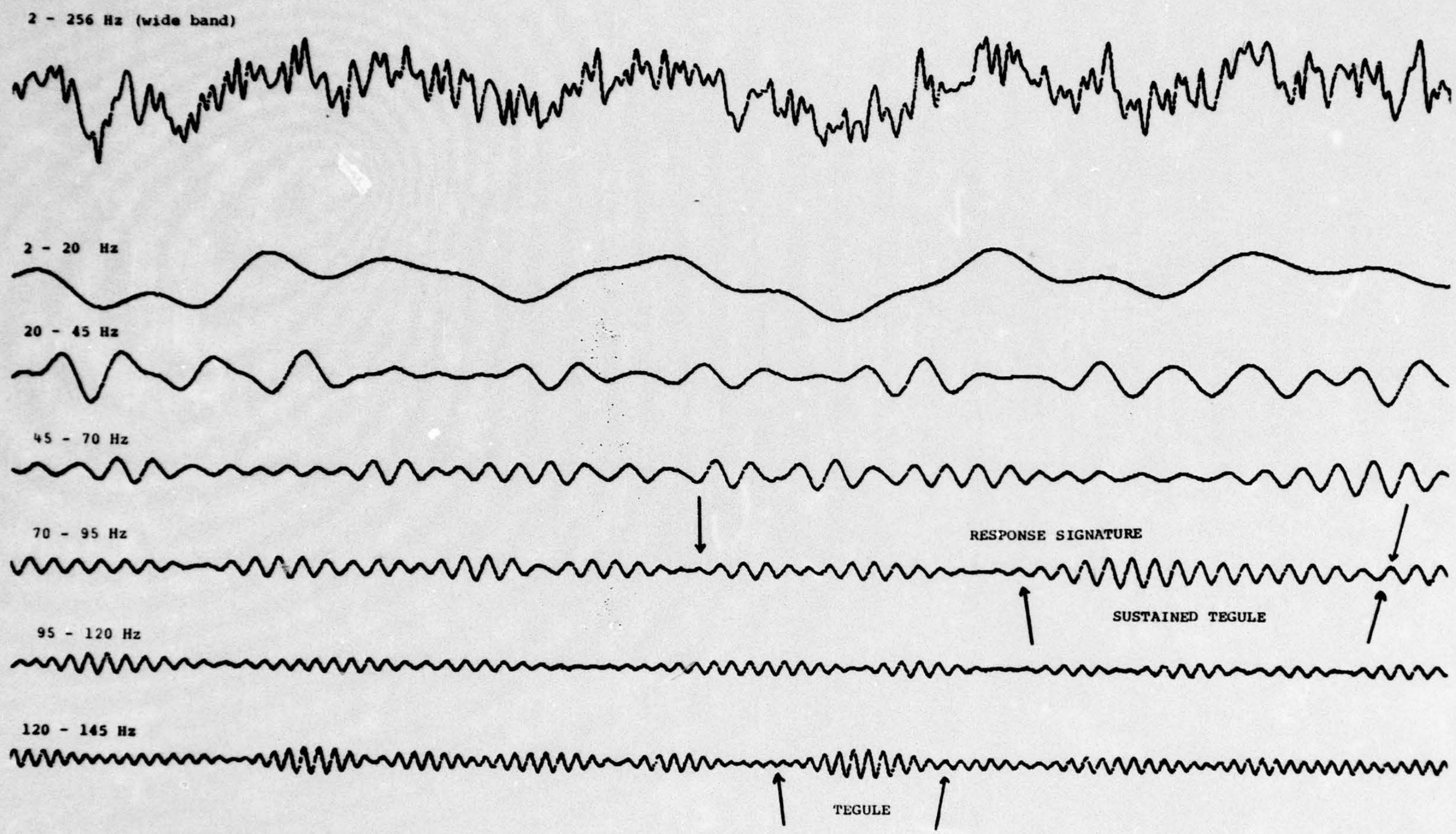


Figure 17. TEGPLT series, subject performing pilot's task.

Figures 18 and 19 are HISCAN plots of the wideband EEG data obtained from an electrode located over the motor cortex. Figure 18 is the histogram plot of data obtained when the subject was relaxed. No peaks are found in the frequency band of interest to indicate the presence of a distinct frequency. The histogram shown in figure 19 is from a period when the subject was performing the pilot's task. Here we have peaks at 75, 79, 83, 88, and 95 Hz. These results reinforce the results of TWODET and TEGPLT, and suggest the possibility of a preferred family of frequencies existing in the 70 - 95 Hz band.

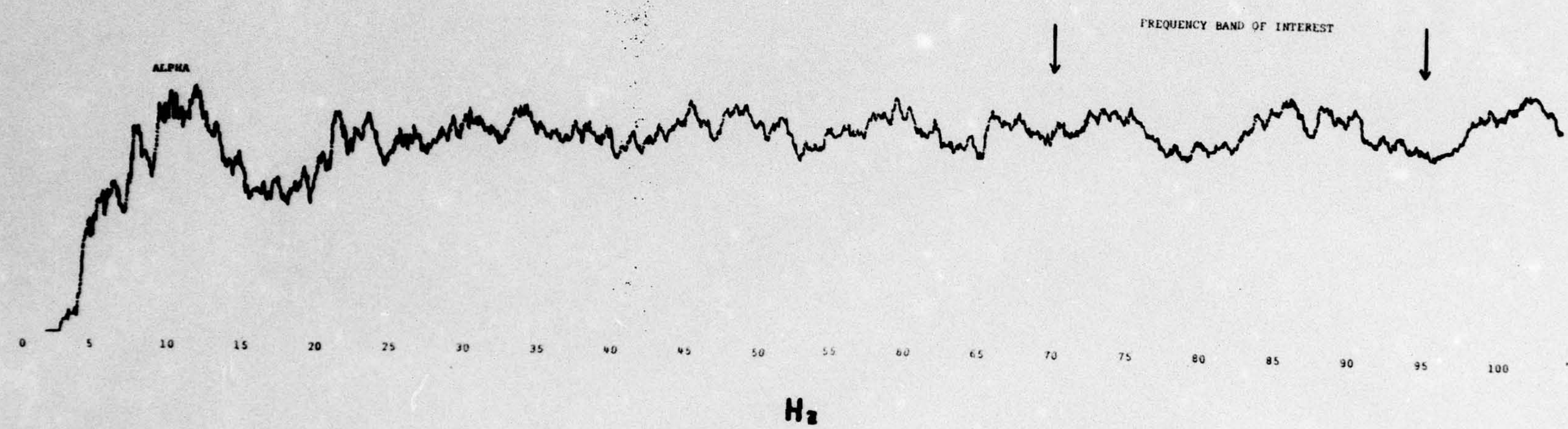


Figure 18. HISCAN plot, relaxed subject.

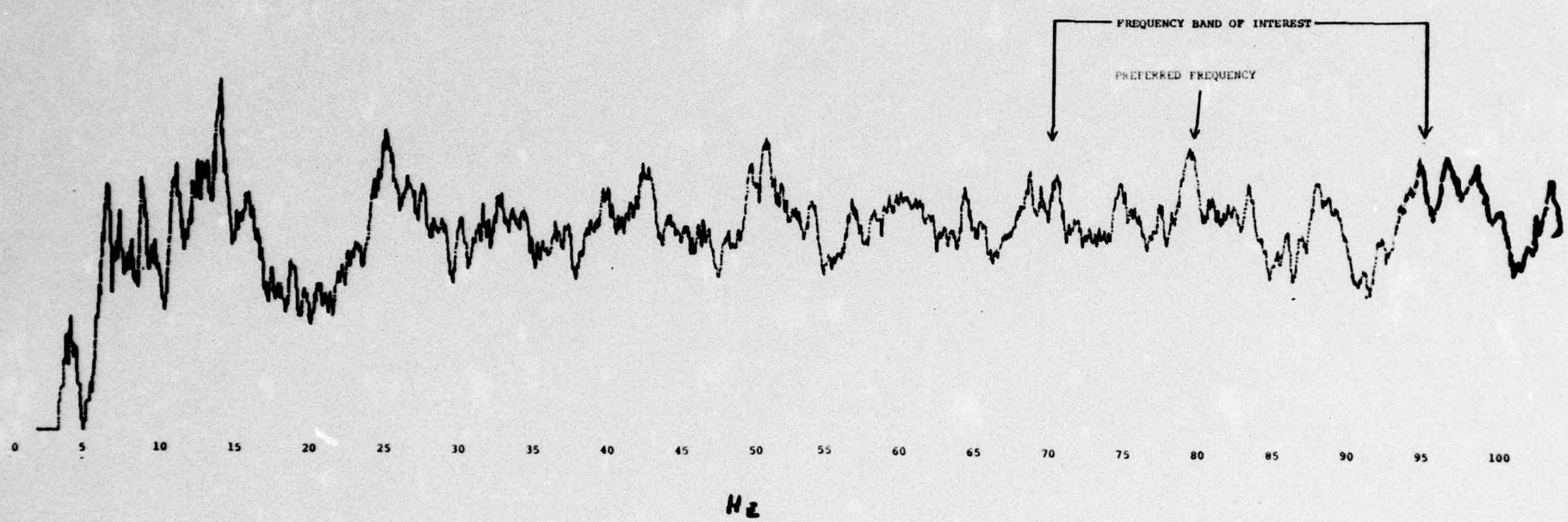
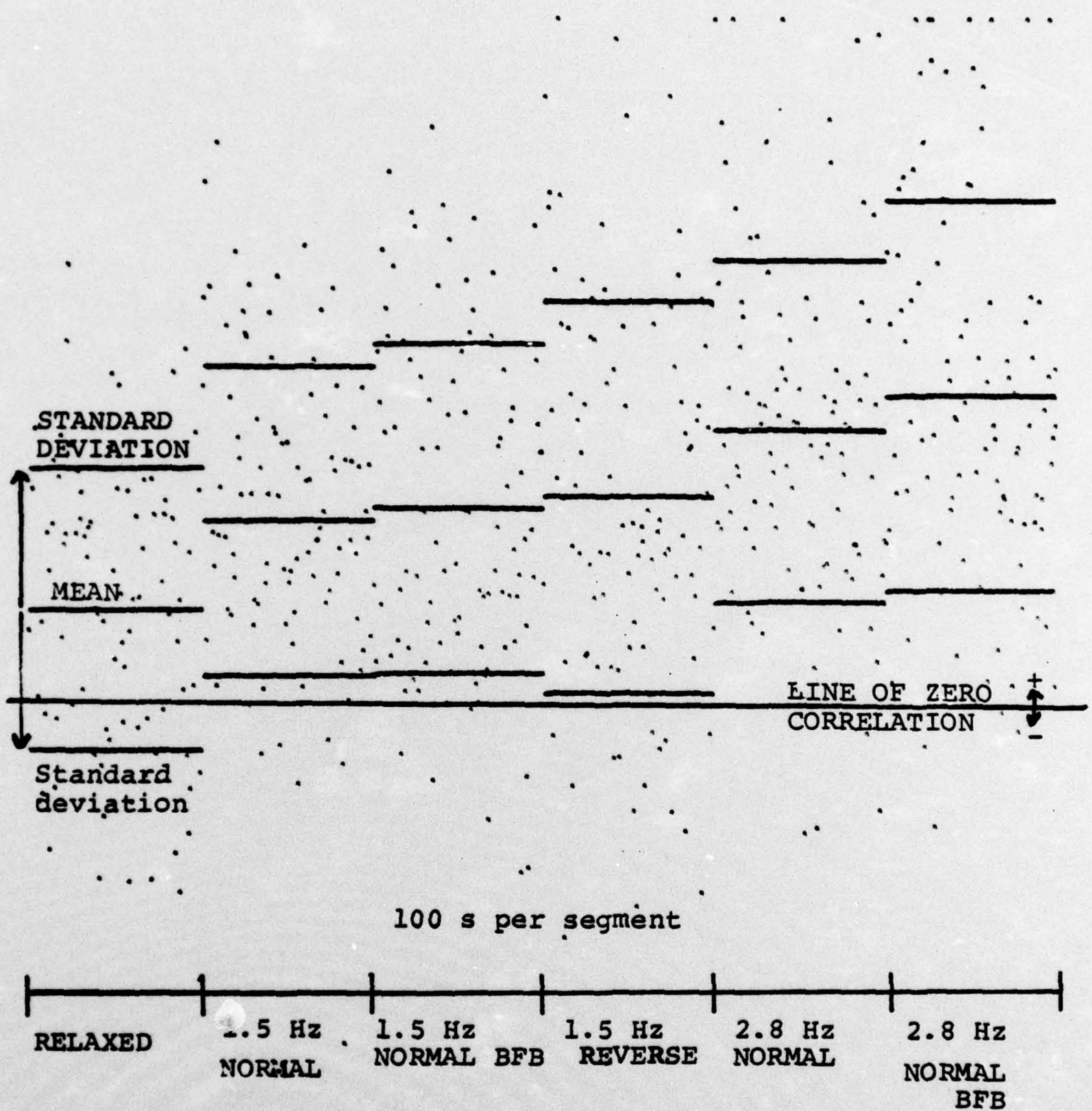


Figure 19. HISCAN plot, subject performing pilot's task.

REPLAY plots were obtained which show variations in the amounts of correlation generated by a subject who was engaged in performing the simulated pilot's task. The data were obtained for tasks having various degrees of difficulty. Figure 20 is a representative plot which illustrates the variations in correlation along with the particular conditions under which the task was being performed. This plot is based on the data reduced by TWODET and the amount of correlation indicated is related to the degree of commonalty between the two 70 - 95 Hz filtered EEGs which orginate from a specific area on the cortex. This statement is supported by the following line of reasoning. The fact that we have positive correlation at all proves that we have similar waveforms at each of the two electrodes of interest. Due to the cleanup routine as described on page 37, these waveforms cannot be identical with the waveforms from any one of the other six electrodes on the head or they would have been reduced or removed. Therefore, the positive correlation cannot be entirely due to any signals which would be propagated over the entire head. This serves to greatly reduce the effects of all normal sources of biological noise. We may conclude that the positive correlation indicated in the REPLAY plots in all probability result from a signal that is common to each of the two electrodes of interest and no others, provided a pip displacement occurred during that frame, and must therefore represent a 70 to 95 Hz tegule that is unique to the immediate area of the two electrodes of interest. Note that in frames where no pip displacement is generated there will be a lower probability of a response like signature and consequently only normal random correlation is likely. These "empty" frames of data are averaged in with the ones containing the response signatures and act to dilute the results.



NOTE: NORMAL - Control stick produces normal outputs.
REVERSE- Control stick produces reversed outputs.
BFB - Biofeedback presented to subject via the backlighted translucent screen.

Each dot represents the integral of the correlation trace from one frame of TWODET data and each frame contains one second of data.

Figure 20. REPLAY plot, active subject.

B. A MYOGRAM

Figure 21 is a TEGPLT series taken from an interval of time when the subject inadverently produced an isolated myogram while he was relaxed. The data were obtained from a scalp electrode placed over the premotor area of the cortex and were recorded via the REC2CH program onto a magnetic disk. The distinctive charateristics of a myogram is revealed as a sharp pulse seen in the wideband EEG in the top trace. Another characteristic, especially important in tegular analysis, is the wideband activity which is seen as simultaneous activity in the filtered EEG bands.

Figure 22 is a TWODET plot of the same subject generating myograms which were caused by noticeable muscle twitches from fatigue. Here we see the same strong simultaneous tegule activity as we have in the TEGPLT plot.

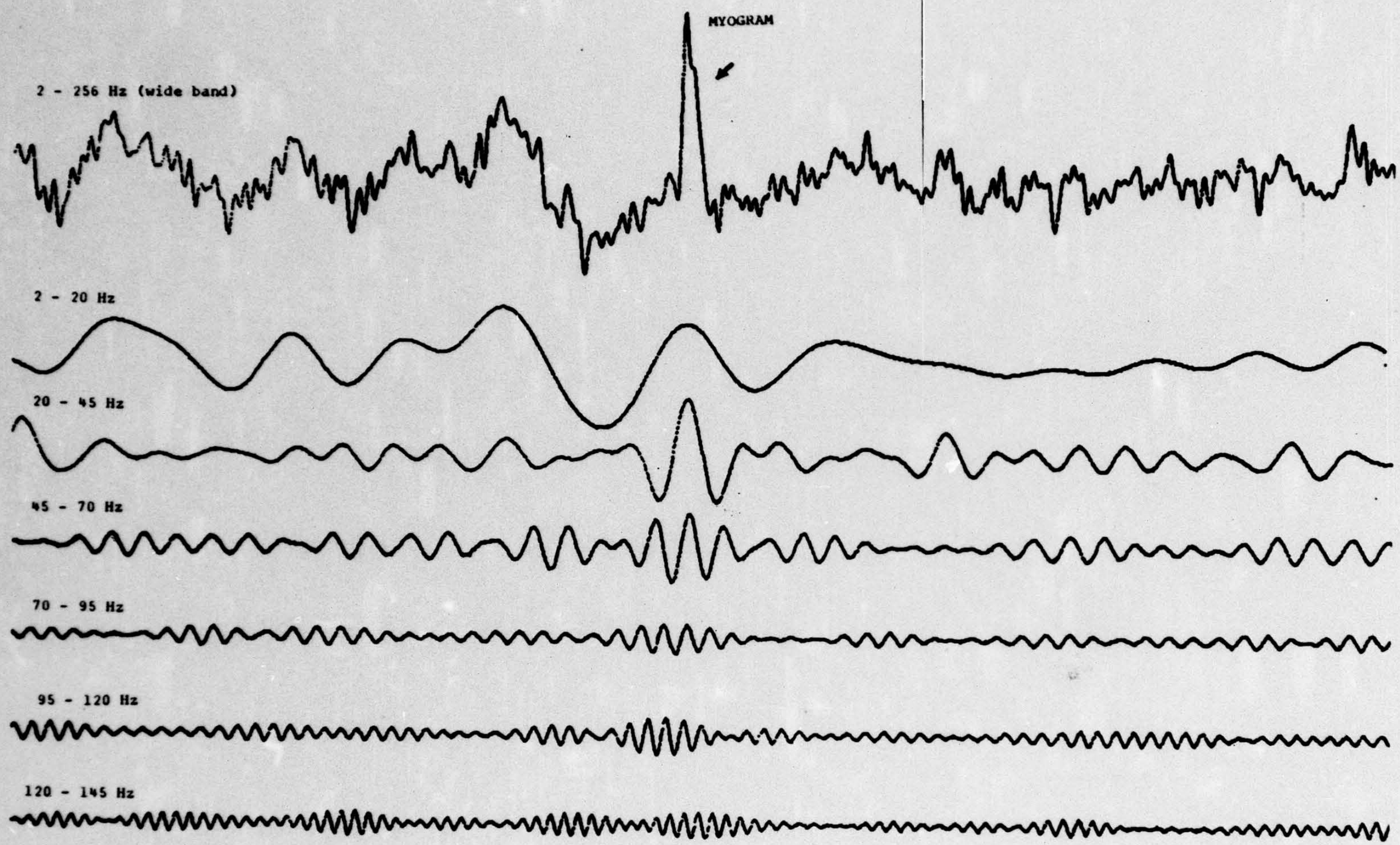


Figure 21. TEGPLT series of isolated myogram.

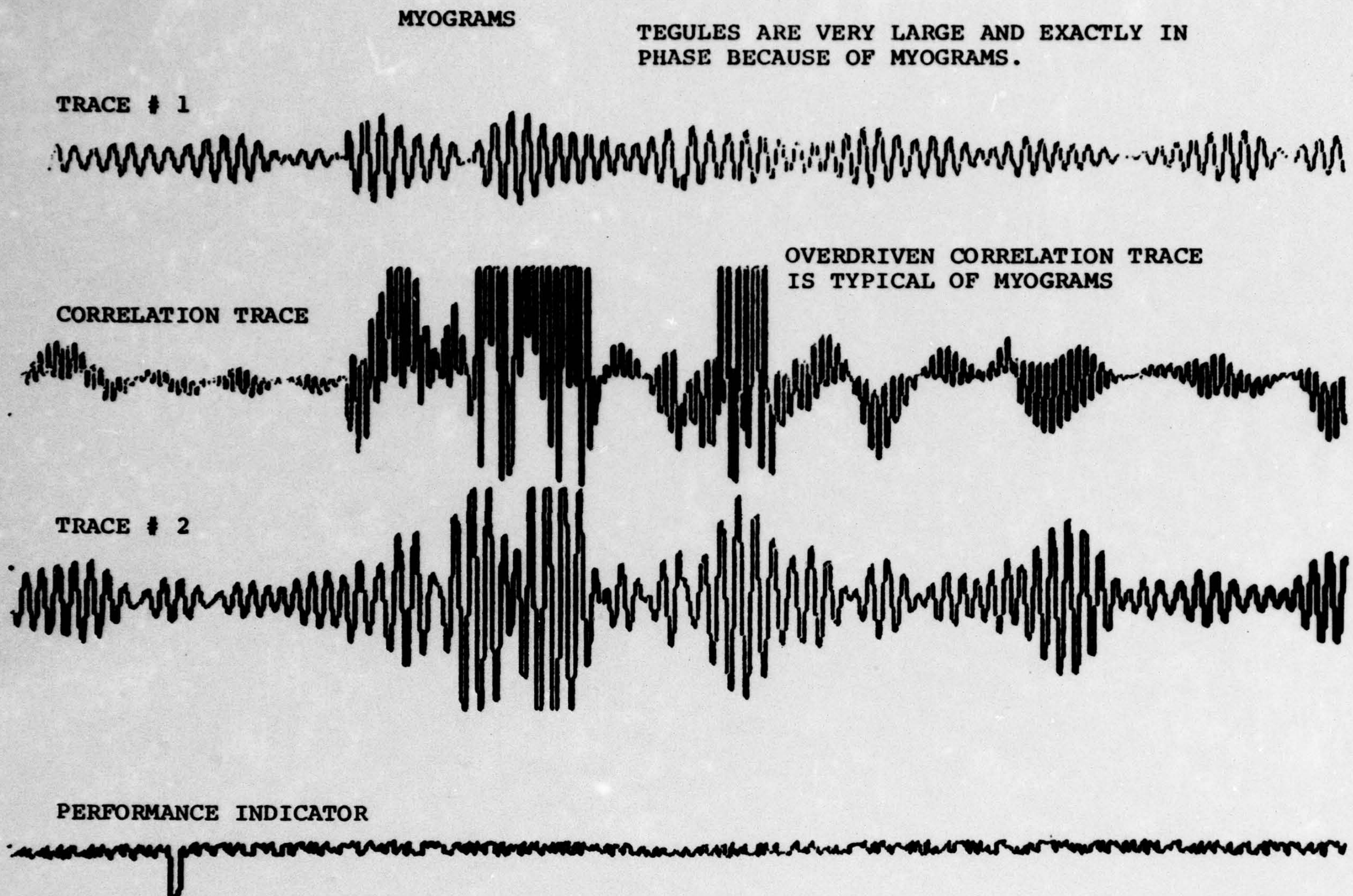


Figure 22. TWODET plot of myograms.

VII. CONCLUSIONS

The results of this investigation indicate that the dominant feature of the EEG response of a person performing a simulated piloting task is the generation of a frequency in the range of 70 to 95 Hz. While the unique frequency generated varies slightly from subject to subject, every subject tested did generate a unique frequency during the time of performing the task. It is concluded, therefore, that the generation of frequencies in the 70 to 95 Hz band is a physiological trait common to all people who are engaged in a task similar to the piloting task described in Section V of this thesis.

One of the most interesting points this investigation brings out is the behavior of tegules in adjacent frequency bands when the subject is actively performing the task. The capability to dissect out a specific band of frequencies from a wideband EEG record has enabled us to show that the signals in adjacent frequency bands do not normally act together. Furthermore, if two seperate EEG records are analyzed from an electrode pair we find that the tegules coming from the electrode pair are not normally simultaneous, even within the same frequency band.

The effect of stress on the EEG was investigated in detail in Ref 9 and found to greatly disturb the normal EEG frequency patterns associated with the performance of a task. All studies of EEGs which are concerned with discrete frequency content must take the effects of stress into account and should attempt to eliminate these effects from the problem.

Myograms, which are seen as wide band electrical signals in the EEG, are also to be avoided. The apparently random variations in voltage and frequency generated by the myogram serve to effectively mask over the actual EEG signals. It is highly recommended that a concerted effort be made to make the subject physically comfortable and relaxed for the study of EEG waveforms. Myograms are readily identifiable because of their large amplitudes and by the simultaneous tegules which occur in all frequency bands as previously illustrated.

The placement of the electrodes was found to be a very important consideration in EEG data analysis. It was found that a very small displacement of less than a centimeter is sufficient tc cause a drastic change in the appearance of the waveforms.

Each subject tested seemed to have a distinctive set of characteristics as far as his ability to generate alpha waves, and each had his own level of sensitivity to myograms and individual way of reacting to stress. Prior to attempting to obtain EEG data from a new subject an investigation of his individual characteristics will be worthwhile.

Alpha waves were generated in varing amounts by all subjects during the baseline runs, as verified by visual observations and the HISCAN plots presented in figures 18 and 19. The alpha activity completely stopped in some subjects when they began performing the task while for others the alpha waves were only slightly diminished in amplitude.

The helmet and electrode assembly performed without problem throughout the six month period the author was involved with the project. During this time, no complaints were made by any of the subjects, although some wore the assembly in excess of 5 hours without a rest. Such an assembly would be the optimum method should it ever become necessary to monitor a pilot's EEG during the time he is piloting an aircraft or other aerospace vehicle.

The technology for inflight monitoring of a pilot's EEG is certainly available to us. With the availability of an efficient and comfortable helmet-mounted electrode assembly similar to the one developed by the Bioengineering Team, it would be a simple matter to incorporate such a system into almost any of today's aircraft.

By locating the amplifier and a microprocessor in the aircraft, his EEG waveform could be monitored and processed continously throughout each flight. Such a capability would provide valuable information about his visual evoked responses, his state of alertness, and about his overall performance with respect to his state of stress, his instrument scan, and how fatigued he might be, to mention a few. This technique might prove especially valuable in evaluating the performance of student pilots during critical phases of training.

LIST OF REFERENCES

1. Guyton, A. C, M. D., Textbook of Medical Physiology, p. 716 to 720, W. B. Saunders, 1971.

2. Curtis, B. A., Jacobson, S., Marcus, E. M.,, An Introduction to the Neurosciences, p. 47 to 83, W. B. Saunders, 1972.

3. Plonsey, R., Bioelectric Phenomena, p. 1 to 87, McGraw-Hill, 1969.

4. Williams, P.L., Warwick, R., Functional Neuroanatomy of Man, p. 943 to 982, W. B. Saunders, 1975.

5. McClane, J. L., Biofeedback Related To Enhancement of Preferred Frequencies In The Electroencephalogram, Masters Thesis, Naval Postgraduate School, 1976.

6. Wicklander, E.R., An Analysis of Electroencephalograms, Masters Thesis, Naval Postgraduate School, 1975.

7. Dollar, S. E., Multidimensional Analysis of the Electroencephalogram Using Digital Signal Processing Techniques, Engineers Thesis, Naval Postgraduate School, 1973.

8. Thompson, Richard F., Patterson, Michael M., Bioelectric Recording Techniques, p. 12 to 48, Academic Press, 1973.

9. Fricke, H. J., Stress Detection Utilizing the Electroencephalogram, Masters Thesis, Naval Postgraduate School, 1977.

10. Cornett, B., Electroencephalogram Preferred Frequency Response Signature to Skilled Motor Functions, Masters Thesis, Naval Postgraduate School, 1977,

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria Virginia 22314	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Professor George Marmont, Code 52 (Thesis Advisor) Department of Electrical Engineering Naval Postgraduate School Monterey, California 93940	10
4.	Department Chairman, Code 67 Department of Aeronautics Naval Postgraduate School Monterey, California 93940	1
5.	LT Daniel F. Lashbrook, USN (Student) FAIRECONRON FOUR (VQ-4) Naval Air Station Patuxent River, Maryland 20670	1