

COMMUNO POTENTIAL.

by John Ertl

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CURRICULUM STUDIOUM

John Ertl was born September 25, 1933, in Budapest, Hungary. He received the Bachelor of Arts degree from Carleton University, Ottawa, in 1959, and the Master of Arts degree in Psychology from the University of Ottawa, Ontario, in 1961.

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TABLE OF CONTENTS

Chapter	Page
INTRODUCTION	v
I.- REVIEW OF THE LITERATURE	1
II.- EXPERIMENTAL DESIGN	5
1. Method	7
2. Analysis of Data	8
III.- RESULTS AND DISCUSSION	11
SUMMARY AND CONCLUSIONS	16
BIBLIOGRAPHY	17
Appendix	
ABSTRACT OF <u>Command Potentials</u>	18

LIST OF FIGURES

Figure	page
1.- Systems Diagram of Command Potential Experiment.....;	12
2.- Summated EMG and Voice Activity Preceding the Spoken word "tea".....	13
3.- Summated EMG and EMG Activity Preceding Left Wrist Contraction.....	14

INTRODUCTION

The idea and techniques of studying non-random changes in the electrical activity of the brain in response to external stimulation, has led to an exponential growth in the field of electroencephalography. There is compelling evidence that the statistical properties of the electrical activity of the brain are neurological correlates of consciousness and mental function. A probabilistic rather than deterministic view of the brain may account for the success of techniques based on the analysis of the statistical properties of the EEG. The deterministic approach, based on the analogy between the human brain and the digital computer, has not been fruitful and is still the subject of philosophical controversy.

"Sensory Evoked Potentials" have been extensively studied and related successfully to a large number of psychological and psychophysiological variables and represent a major advance in the scientific study of input-output relationships in terms of electrical activity of the human brain. There is no doubt that time-locked, non-random changes in the electrical activity of the brain occur in response to discrete external stimulation. It is also a well established fact that the electrical activity of the brain manifests a number of rhythmic components which

can be enhanced and driven by external stimulation and also blocked or enhanced by internal states of the brain.

In any system which exhibits such behaviour, it is highly probable that non-random changes in electrical activity would occur not only in response to external stimulation, but also prior to self initiated behaviour.

This prediction can safely be made either on logical grounds or with reference to the established causal relationships between neurons of the brain. The logical aspect is simply that an organism which exhibits purposive behaviour must at some level (single neurons, networks or as a whole) be governed by determinable laws which are not random. The transmission of information from neuron to neuron in the form of a spike interval modulation code is of course a time varying function, which implies that a particular spatio temporal pattern must precede the final behavioural output of the organism. This is true in a stimulus response situation and also for self initiated activity. The link between neuronal events and behavioural manifestations is very tenuous at present and it is perhaps more rewarding in the present state of knowledge to approach the problem at a level where there are fewer missing links or intervening variables. The statistical properties of the MEG representing the time course and the analog of information processing codes at the neuronal level has the

important property of being time-locked to external stimulation and as this study shows is also time-locked preceding voluntary acts. In view of this, investigations at this level appear to be very promising. Thus the purpose of this study is a search for non-random changes in the electrical activity of the human brain preceding voluntary acts.

CHAPTER I

REVIEW OF THE LITERATURE

The review of the literature is restricted to studies attempting to detect non-random electrical changes in the human brain prior to voluntary acts. Gilden et al¹ independently and following completion of the experimental work in this study have published data confirming the prediction that command potentials, which they prefer to call "Motor Potentials", exist. They demonstrated, in ten subjects, by summing the EEG activity prior to fist contraction and foot dorsiflexion that non-random electrical changes do occur, prior to these voluntary acts. Motor Potentials were also obtained from an implanted electrode estimated to be over the premotor cortex. The similarity of the cortical recording to the scalp recordings makes it unlikely that the Motor Potentials represent extracranial artifacts. The general waveform of the summated potentials prior to voluntary movement showed intra-subject reproducibility in the published records but the latency of components of this waveform appeared to be unstable within subjects. As averaging devices enhance

¹ L. Gilden, H.G. Vaughan Jr. and L.D. Costa, "Summated Human EEG Potentials with Voluntary Movement" EEG and Clinical Neurophysiology, Vol. 20, No. 5, May 1966, p. 433-438.

components that are time-locked to a trigger point it is necessary to demonstrate intra-subject reliability in the latency as well as the waveform of summated activity designated as non-random. Present methods of decision making with regard to identification of summated components as "non-random" are very unsatisfactory (Krttl 1965)² and depend on the subjective judgements of the investigator. In most cases the investigator acts as a second detection device and visually extracts signals he considers meaningful from the computer averaged waveform. In view of this numerous replications of the experiment with the same subject appears to be a reasonable way of overcoming this problem. Gilden *et al.*³ have done this, and strictly speaking the latency variability they show and in fact the whole waveform they designate as Motor Potentials would probably be unacceptable as a reliable non-random component and certainly not as an evoked potential by the scientific community. It is evident, therefore, that a need for independent corroboration of these findings is necessary.

² J.P. Krttl, "Detection of Evoked Potentials by Zero Crossing Analysis", *EEG and Clinical Neurophysiology*, Vol. 18, 1965, p. 630-631.

³ Gilden, Vaughan and Costa, *Op. cit.* p. 433-438.

The work of Bates⁴ is probably the first effort using a crude averaging technique (poor signal to noise ratio) to detect CPs. Bates concludes that "On no occasion has this technique revealed any potential changes in the cortex preceding the onset of voluntary movement." The technique used could not extract signals with a signal to noise ratio of less than 1:5. Modern electronic averaging devices can deal with S/N ratios less than 1:100 and it is thus not surprising that Bates was unable to detect CPs, which are difficult to detect even with present day computers.

A recent study by Donchin et al⁵ also failed to detect CPs. In this study a cue stimulus (click), light stimulus and reaction time sequence were involved and averaging of the EEG before onset of the voluntary reaction indicated no time-locked activity. Under these conditions it is probable that the evoked potentials due to the light stimulus interfered with the command potentials preceding the voluntary movement.

⁴ J.A.V. Bates, "Electrical Activity of the Cortex Accompanying Movement", Journal of Physiology, Vol. 113, 1951, p. 240-257.

⁵ E. Donchin and D.B. Lindsley, "Average Evoked Potentials and Reaction Times to Visual Stimuli", Annals and Clinical Neurophysiology, Vol. 20, No. 3, 1966, p. 217-223

The primary hypothesis of this study is based on the prediction that the human brain which responds to external stimulation by non-random changes in the electrical activity of the system, will also show non-random electrical changes before self initiated activity.

CHAPTER II

EXPERIMENTAL DESIGN

A systematic search for non-random electrical changes in the brain preceding voluntary acts was undertaken. Nothing was known about the characteristics of Command Potentials except that on theoretical grounds their existence is probable. By educated guessing certain limits and characteristics of CPs could be predicted and the available methods for the detection of CPs evaluated. The analysis indicated the following: a) To make detection possible by averaging techniques CPs must be accurately time-locked to the voluntary act¹; b) the onset of the voluntary act must be accurately (in time) determinable to serve as a trigger point for the averaging device; c) EEG must be recorded on FM tape and played backwards in time to be able to average activity preceding the voluntary act; d) it is unlikely that CPs would occur more than 1 sec before the voluntary act and thus an analysis period of one second should be sufficient; e) as the characteristics

¹ Reaction time methods in which the cue triggers the averaging device would make it possible to analyse the ~~time~~ before the reaction without tape recording, but the variability of reaction times is far too great to permit detection of time-locked signals by this method.

of the CPs are not known, e.g., signal to noise ratio, bandwidth, topography on the head, etc., analysis must proceed on the worst case assumption; f) voluntary acts with the largest cortical representation will probably be the easiest to detect; g) although there are several methods of detecting signals from noise averaging the EEG activity preceding the onset of a voluntary act was considered most efficient in view of the known behaviour of the brain in response to external stimulation (evoked potentials).

The electrical activity from different regions of the head was averaged preceding a large number of different voluntary acts, e.g., heartbeat, eyeblink, tongue movements, foot tapping, etc. Results with these voluntary acts are not reported as they were inconclusive due to a variety of technical reasons.

The experience gained from these failures led to the selection of hand clenching and speech, specifically the spoken word "tea" as suitable voluntary acts. They were suitable because it was possible to determine accurately their onset by the technique used.

Method

The EEG of one female and four male adult subjects was derived with scalp electrodes from the right motor area (C4 according to the international convention) and recorded on magnetic tape in a bandwidth 3 db down at 5 and 40 Hz. A microphone pickup of the spoken word "tea" and the electromyogram (EMG) from electrodes on the flexor musculature of the left forearm were amplified, filtered in the same bandwidth as the EEG and recorded on tape. These waveforms (Voice, EMG) triggered an oscilloscope which produced a pulse out for each sweep. This pulse was shaped, delayed by 150 milliseconds and recorded on a third channel of the FM tape recorder (Precision Instrument Model 6100). The microphone pickup of the spoken word and the EMG were also tape recorded unfiltered (DC-15KHz). A simplified systems diagram, Fig. 1, illustrates the experimental set up. Subjects spoke the word "tea" 100 times at a self paced rate of about once every two seconds and following this performed 100 quick voluntary contractions of the left fist at the same rate. With two subjects the experiment was repeated on three different occasions.

Analysis of Data

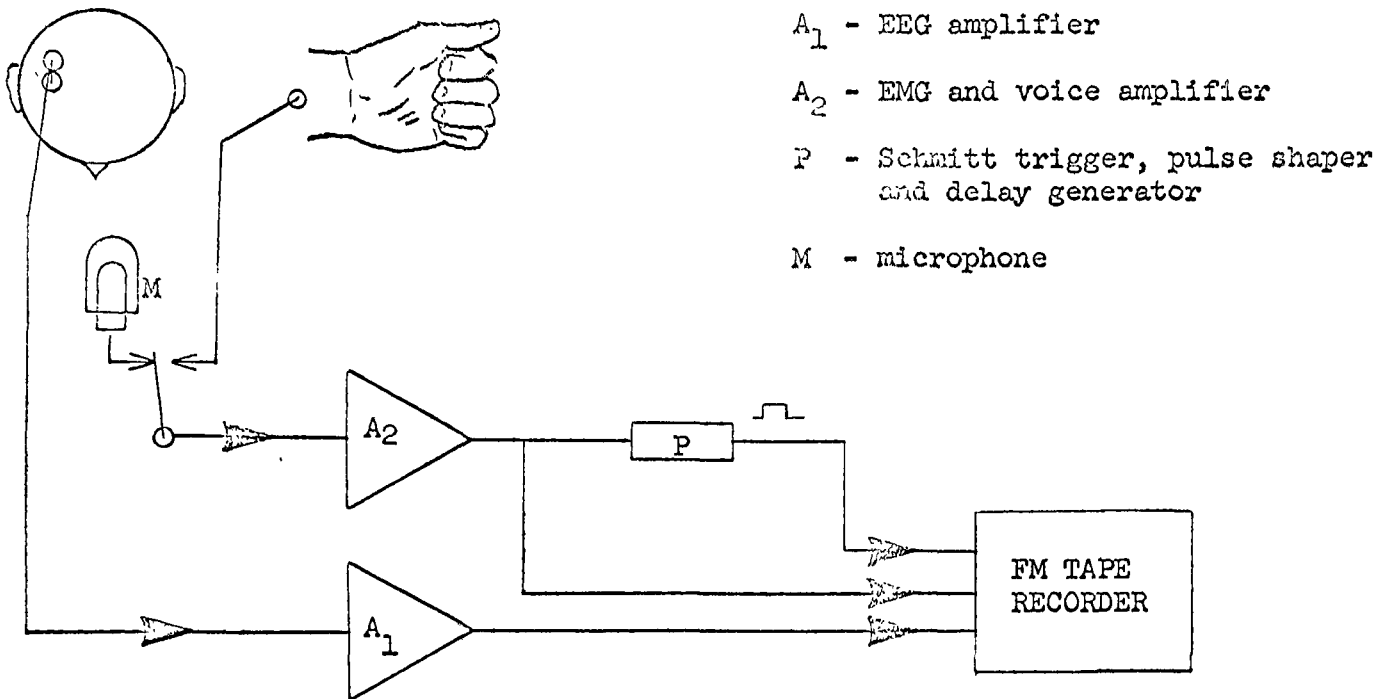
Tape recorded data was played backwards (in time) into the Nuclear Data Vanancetron digital memory oscilloscope which extracted cortical activity time-locked to the trigger pulse representing the onset of the spoken word or the LMO. The delay introduced when recording permitted on playback demonstration of summated ECG, EMG and voice activity before an: 150 milliseconds after onset of the spoken word or LMO. (Figs. 2 and 3).

The averaging device summates time-locked components linearly and non-time-locked components (noise) as a square root function of the number of sweeps and hence the signal to noise ratio is greatly improved. However, due to a number of physiological and electronic artifacts such as chance autocorrelation of the low frequency EMG, a decision problem remains involving the identification of non-random components even after computer averaging. This is especially true of the low amplitude components. To partially overcome this problem a few simple criteria were devised to improve this situation: 1) Two sets of 50 trials were averaged in each case and compared. 2) In order to be classified as reliable, reproducible Cns the latency of components so identified in the two averages must

be within twice the error of measurement (± 10 milliseconds).

3) If the general waveform appeared similar and especially if comparisons of sets of 100 trials from the same subject obtained on two or more separate occasions agreed the ± 10 milliseconds rule was relaxed to 20 milliseconds¹.

¹ It must be pointed out that such relatively rigid criteria are not used as far as it can be determined from published literature, by other investigators in this field.



DATA ANALYSIS

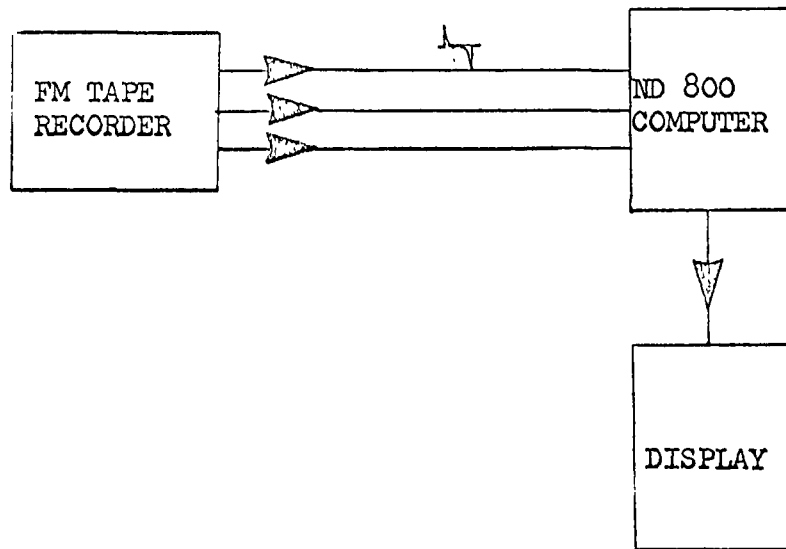


Figure 1
Systems diagram of command potential experiment.

CHAPTER III

RESULTS AND DISCUSSION

Reliable non-random changes in the *EEG* of all subjects were detected preceding speech (Fig. 2) and fist contraction (Fig. 3). The summated EEG waveform preceding onset of the spoken word comprised a positive peak 70 to 170 milliseconds and a negative component 10 to 50 milliseconds before voluntary action in all five subjects. Summated EEG activity preceding fist contraction was similar in waveform with inter-subject latency variation of the same magnitude. Cortical command potentials preceding the spoken word showed greater intra-subject latency reliability than command potentials preceding fist contraction. No reproducible time-locked cortical activity other than the two major components was detected in analysis periods up to 350 milliseconds preceding the voluntary acts. The unfiltered computer averaged microphone pickup of the spoken word and the *EEG* indicates the stability of the trigger point (Fig. 2(A); Fig. 3(A)).

The work of Gilden *et al*¹ on summated *EEG* activity preceding fist contraction is partially corroborated. Low frequency filtering at 5 Hz did not permit substantiation of the

1 Gilden, Vaughan and Costa, *ibid.* p. 433-438.

slow negative variation observed by Gilden et al¹ 1 second prior to fist contraction.

while non-random cortical activity preceding voluntary acts may serve as an efferent analog of the sensory evoked response, observations to date indicate differences in these two phenomena. Sensory evoked cortical potentials are multiphasic waveforms persisting for as long as 1 second after stimulation with a frequency spectrum in the normal EEG range. In contrast, obtained waveforms of cortical command potentials prior to voluntary acts show only two reliable components with periods up to 200 milliseconds (Fig. 2). Differences may be due to loss of information by the averaging technique with respect to individual cortical commands or a smaller signal to noise ratio and/or better synchrony (smaller latency variance) in the evoked cortical response phenomenon. Techniques more suited to the analysis of non-stationary data may reveal a number of components in the cortical command potential not observed to date.

As both evoked and cortical command potentials show analogous inter-subject variability and intra-subject stability, investigation of the psychophysiological correlates of command potentials may prove as fruitful as the extensive

¹ Gilden, Vaughan and Costa, Op. cit. p. 433-438.

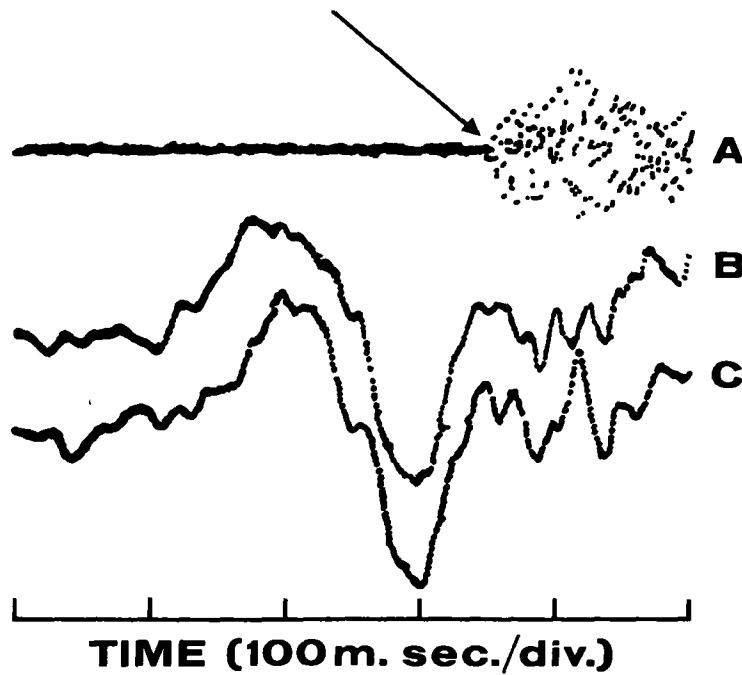


Figure 2

Summated EEG and voice activity of subject E.W. preceding and 150 milliseconds following the spoken word "tea". A: computer averaged voice activity (unfiltered); arrow indicates onset of the spoken word which serves as the trigger point for the averaging device. B: average of 50 samples of EEG activity preceding and following the word "tea". C: average of a different sample of 50 as in B indicating the reproducibility of the phenomenon.

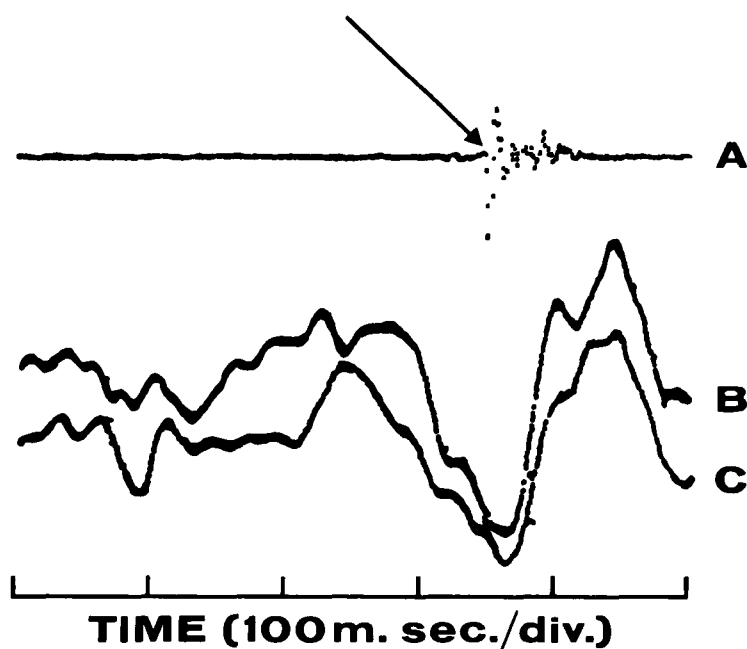


Figure 3

Summated EEG and EMG activity of subject J.C. preceding and 150 milliseconds following left fist contraction.
A: computer averaged EEG (unfiltered); arrow indicates onset of muscular contraction. B: average of 50 samples of EEG activity preceding and following fist contraction.
C: average of a different sample of 50 as in B indicating greater latency variability in command potentials preceding fist contraction.

work done on evoked potentials. Demonstration of non-random cortical activity preceding voluntary acts may lead to new insights in the study of intra-cerebral communication and control at the micro and macroscopic levels.

SUMMARY AND CONCLUSIONS

Reliable non-random changes occur in the electrical activity of the human brain prior to speech and fist contraction.

These computer averaged waveforms were named "command potentials" and show intra-subject stability and inter-subject variability.

In relation to sensory evoked potentials, components of command potentials were a) fewer in number, b) of lower frequency.

Investigation of the psychophysiological correlates of command potentials may prove as fruitful as the extensive work done on evoked potentials. Demonstration of non-random cortical activity preceding voluntary acts may lead to new insights in the study of intra-cerebral communication and control at the micro and macroscopic levels.

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Sates, J.A.V., "Electrical activity of the cortex accompanying movement", Journal of Physiology, Vol. 113, No. 2, April, 1951, p/ 240-257.

One of the first attempts using an averaging technique to detect non-random changes in the EEG preceding movement. Results were negative.

Donchin, E., and D.B. Lindsley, "Average evoked Potentials and Reaction Times to Visual Stimuli", EEG and Clinical Neurophysiology, Vol. 20, No. 3, 1966, p. 217-223.

A reaction time experiment in which EEG activity was averaged before and after the reaction. No command potentials were detected, probably because of interfering variables and inappropriate technique.

Gilden, L., H.G. Vaughan Jr. and L.D. Costa, "Summated Human EEG Potentials with Voluntary Movement", EEG and Clinical Neurophysiology, Vol. 20, No. 5, May 1966, p. 433-438.

Non-random EEG activity preceding fist contraction and foot dorsiflexion demonstrated with human subjects.

APPENDIX

ABSTRACT OF

Command Potentials

The electrical activity of the human brain changes in response to external stimulation. In any system which exhibits such behaviour it is highly probable that non-random changes in electrical activity would occur not only in response to external stimulation, but also prior to self initiated behaviour.

A systematic search was initiated to detect non-random changes in the electrical activity of the human brain preceding voluntary acts. The EEG was computer averaged preceding a spoken word and also fist contraction in five subjects. As predicted non-random changes in the electrical activity of the brain, designated "command potentials", was detected in all cases.