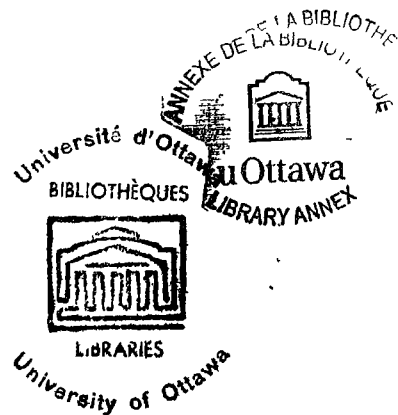


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INTRA-COLLEGE DELAY  
AND  
INTELLIGENCE

by John P. Ertl

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Psychology and Education of the  
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CURRICULUM STUDIORUM

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## INTRODUCTION

The discovery of the electrical activity of the brain offered great hopes for finding electrophysiological correlates of human behaviour. These hopes remain largely unfulfilled. There are many reasons for this. Psychologists have shown little interest in this field. This is partly due to the complex instrumentation required and the necessity for training in the physical sciences which is a prerequisite for successful research in this field. Medical men are more interested in the clinical applications and great progress has been made in this area. However the main reason for disappointing results is the enormous gap between advances in electronics and the application of this knowledge to brain research.

There is a need for psychologically oriented research in the field of electroencephalography and the possibilities for research with presently available instruments are by no means exhausted. There also appears to be a great concentration of research effort on the still unexplained alpha rhythm, at the expense of other electrical phenomena associated with the brain. The importance of time as a variable both at the neuronal level and in integrated activity cannot be denied. Yet this variable has been neglected in electroencephalography, though not in

neurophysiology when dealing with individual or relatively small networks of neurons.

It is in this background that the problem of this study evolved. It became clear early in the review of the literature that an MEG variable other than the alpha rhythm and related to time offers some promise of revealing an electrophysiological correlate of intelligence. No innovations appeared necessary in the instrumentation, but the lack of related research was discouraging. Although a tentative theory was formulated, details were not sufficiently clear to allow a properly controlled design. This study is therefore a pilot study whose major aims are first, to demonstrate the feasibility of measuring intra-cortical delay and second to test the theoretical prediction that intra-cortical delay may be related to psychometric intelligence.

In chapter one the literature is analysed from the point of view of the type of MEG variables which have been correlated with intelligence and the technical problems involved in the delay and detection of evoked cortical responses. This is followed by a statement of theoretical assumptions and the formulation of a hypothesis.

In chapter two the sample population, the instrumentation and the experimental procedures are described. The last section is concerned with the first major aim of

this study namely the demonstration of the possibility of measuring intra-cortical delay.

The first section of chapter three is a presentation and discussion of the results relating intra-cortical delay to intelligence. In section two the validity and reliability of the ISC variable is considered. In section three the theoretical background of this study is elaborated in terms of network efficiency and biological intelligence. After a summary of the findings certain suggestions for further research are made.

## CHAPTER I

### REVIEW OF THE LITERATURE

Studies of the relationship between EEG<sup>1</sup> variables and intelligence have been few. These have been unsuccessful in large samples of normal adults and moderately successful in groups of adults and children with known or suspected organicity. It is proposed here, that the failure is due not to the type of intelligence tests that were selected by previous authors, but to the nature of the EEG variables which were correlated with test intelligence.

There are no studies reported relating intra-cortical delay<sup>2</sup> to intelligence, the technique to be employed in this study. Thus the previous work in this area is relevant mainly from the point of view of the EEG variables that have been considered and the problems encountered in measuring cortical delays. The literature will therefore be reviewed under two headings:

1. EEG variables and intelligence
2. Delay and detection of evoked cortical responses.

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1 The abbreviation EEG will be used to connote the following depending on the context: Electroencephalogram, Electroencephalograph, Electroencephalography.

2 Intra-cortical delay is defined here as the time required for information to be assimilated and propagated from one area of the brain to another. It is observed as a change in the electrical output of the cortical area involved.

## 1. EEG Variables and Intelligence.

The majority of papers relate alpha index<sup>3</sup> and alpha frequency to intelligence and these are summarized in the following references. Knott et al.,<sup>4</sup> tested a group of 48 eight year old children and another group of 42 twelve year olds. Mental age was compared with both alpha frequency and alpha index in each of these groups. The only significant correlation found was one of 0.5 between mental age and alpha frequency of the eight year old children. The authors suggested, that at the twelve year level organic changes associated with adolescence may alter an otherwise significant correlation between mental age and alpha frequency.

Kreezer's<sup>5</sup> subjects were 46 non-differentiated familial type mental deficient of adult age. A marginally significant correlation of 0.32 was found between mental age and alpha frequency, while there was no significant correlation between mental age and alpha index.

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3 The alpha index is the percent time during which an EEG tracing is occupied by the alpha rhythm.

4 J.R. Knott, H. Friedman and R. Bardsley, "Some Electroencephalographic Correlates of Intelligence in Eight Year and Twelve-Year Old Children", Journal of Experimental Psychology, Vol. 30, 1942, p. 380-391.

5 George L. Kreezer and Franklin W. Smith, "The Relation of the EEG and Intelligence Level in the Non-Differentiated Familial Type of Mental Deficiency", The Journal of Psychology, Vol. 29, 1930, p. 47-51.

Shagass<sup>6</sup> in a major study of normal adults used 1100 aircrew candidates and found no significant correlation between occipital alpha frequency and a group test of mental ability (R.C.A.F. Classification Test).

A recent study by Mundy-Castle<sup>7</sup> using alpha index and alpha frequency as the EKG variables is not in agreement with previous work. In a group of 34 subjects he found significant correlations between alpha index and Verbal I.Q. (0.33), alpha frequency and Verbal I.Q. (0.42) and Practical I.Q. (0.40) and General I.Q. (0.50). The South African version of the Wechsler-Bellevue test was used. To account for this disparity he proposes the following explanation; the sample was highly selected (I.Q. range 112-135) and he argues that in a homogenous group non-intellective factors tapped by the Wechsler test will serve to reveal their underlying electrophysiological correlates, whereas in a less homogenous group such relationships would be obscured by the greater variance contributed by non-intellective factors.

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6 Charles Shagass, "An Attempt to Correlate the Occipital Alpha Frequency of the EKG with Performance on a Mental Ability Test", Journal of Experimental Psychology, Vol. 36, Feb. 1946, p. 68-92.

7 A.C. Mundy-Castle, "Electrophysiological Correlates of Intelligence", Journal of Personality, Vol. 26, No. 2, June 1958, p. 184-199.

In his book the Living Brain, Walter<sup>8</sup> reports observations which suggest the possible positive relationship between KEG frequency pattern variation and intelligence. In data from his automatic frequency analyser Walter observed a greater variation of the frequency spectrum among his more "brilliant colleagues" than among his "duller patients". He suggested the term versatility to describe the tendency toward greater pattern variability. This may be related to Walter's concept of brain rhythms as scanning mechanisms; brains with more numerous and variable scanning rhythms being more versatile.

These observations were tested experimentally by Ellingson<sup>9</sup> in the first of two studies in which the EEG variable was not the alpha index or alpha frequency. The subjects were 26 psychiatric aides and one high grade mentally deficient subject hospitalised for observation, who was considered neither mentally ill nor brain damaged. The subjects were given a short form of the Wechsler-Bellevue test. Ten artifact free 10 second epochs were recorded from various areas of the brain. The inter epoch similarity was

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<sup>8</sup> W. Grey Walter, The Living Brain, New York, Norton, 1953, xv-311 p.

<sup>9</sup> R.J. Ellingson, R.C. Wilcott, J.C. Sine, and F.J. Dudek, "EEG Frequency Pattern Variation and Intelligence" EEG and Clinical Neurophysiology, Vol. 9, No. 4, Nov. 1957, p. 657-660.

calculated and found to be statistically highly significant in all cases, indicating the high degree of reliability of the estimates of frequency pattern variation. Rank correlations were then computed between I.Q. and the EEG frequency pattern variation for four areas of the brain for the 27 subjects. Unfortunately all of these were negligible.

Netchine<sup>10</sup> tried to correlate a combination of several EEG variables with intelligence. The subjects were 30 adults of low intelligence but without clinical signs or organic damage. The EEG variables were alpha index, frequency scatter index, spatial organization and amplitude. Two correlations were reported as significant. Verbal I.Q. and frequency scatter index (0.37) and Performance I.Q. and frequency scatter index (0.49). The 0.37 correlation is touted as significant at the .01 level of confidence, this may be an inadvertent error. Tables show that for significance at the .01 level of confidence, based on 30 subjects, the correlation coefficient must be at least 0.483.

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<sup>10</sup> S. Netchine, I. Talan, G.C. Lairy and W. Zazzo "EEG et Niveau Mental", L'Année Psychologique, Vol. 2, 1959, p. 355-372.

It is difficult to explain the inadequacy of research effort in this important area. The above studies show that in the thirty-two years since the discovery of the EEG only one experiment, by Shagass<sup>11</sup> deals with a large sample of normal adults and that only two EEG variables, alpha index and alpha frequency are considered by more than one author. Some light may be thrown on the reason for this inadequacy of research effort by the following quotation from Lindsley<sup>12</sup>:

Why have not EEG and psychological correlations been pursued more systematically and persistently? Why has there been so little success in relating neurophysiological data to subjective states and behavioural manifestations? There are probably many reasons. Almost from the start, the lure and excitement of new clinical discoveries was a distraction to serious effort in this direction. Secondly, the premature if not actually grandiose hope that the mysterious and ubiquitous alpha rhythm might be related to intelligence, personality and other similarly broad and in themselves undefined parameters, soon exhausted interest in that direction.

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11 Charles Shagass, Op. cit. p. 86-92.

12 D.B. Lindsley, "Psychological Phenomena and the EEG", EEG and Clinical Neurophysiology, Vol. 4, No. 4, Nov. 1952, p. 443-456.

## 2. Delay and Detection of Evoked Cortical Responses.

Reaction times to light have been found to vary from .15 to .5 seconds depending on the conditions of the experiment.<sup>13</sup> According to Lansing<sup>14</sup> approximately .05 seconds of the total reaction time is utilized in transmission to and from the cortex; the remainder involves an indeterminate central transmission time. Another estimate of central transmission time was given by Monier<sup>15</sup> in a very carefully executed study. He calls it opto-motor integration time, or cortical integration time and estimates this delay at about .075 seconds. He recorded simultaneously the Electroretinogram, the EEG and the Electromyogram, from 3 subjects and was able to define the time relations of retinal, cortical and motor responses to a light flash in man. The electrode placements were as follows; the Electroretinogram was derived from the cornea, the EEG from bipolar electrodes disposed sagittally above and below theinion and the

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13 John J. Stamm, "On the Relationship Between Reaction Time to Light and Latency of Blocking of the Alpha Rhythms", EEG and Clinical Neurophysiology, Vol. 4, No. 1, Feb. 1952, p. 61-68.

14 R.W. Lansing, "Relation of Brain Tremor Rhythms to Visual Reaction Time", EEG and Clinical Neurophysiology, Vol. 3, No. 3, Aug. 1957, p. 497-504.

15 Marcel Monier, "Retinal, Cortical and Motor Responses to Photic Stimulation in Man", Journal of Neurophysiology, Vol. 15, No. 6, 1952, p. 469-486.

Electromyogram from needle electrodes inserted into the hypothenar muscle of the palm. The time relations observed by Monier<sup>16</sup> were as follows: (a) stimulus to retinal response 30 milliseconds, (b) stimulus to first response of visual cortex 35 milliseconds, (c) retino-cortical time (b-a) 5 milliseconds, (d) stimulus to muscle responses 120 milliseconds, (e) Estimated time for conduction of efferent impulses from motor cortex to muscle, based on 100 meters per second conduction velocity and one meter distance from motor cortex to palm, was 10 milliseconds. (f) Alpha blocking time 210 milliseconds. (g) opto-motor integration time (d-b-e = 120-35-10) or 75 milliseconds. In addition to describing the above time relationships the study makes it clear that the blocking reaction of the alpha rhythm cannot be interpreted as the specific response of the visual cortex, as it is much too long. This is also confirmed by Cohn's<sup>17</sup> work, who found that specific responses of the visual cortex range from 35 to 120 milliseconds which is well outside the observed range (160-600 milliseconds) for alpha blocking times.<sup>18</sup>

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<sup>16</sup> Marcel Monier, Op. cit. p. 469-486.

<sup>17</sup> Robert Cohn, "A Visual Analysis and a Study of the Latency of the Photically Driven EEG", EEG and Clinical Neurophysiology, Vol. 4, No. 3, Aug. 1952, p. 297-301.

<sup>18</sup> John S. Stamm, Op. cit. p. 61-63.

Monier<sup>19</sup> also stated that the time of the efferent discharge of the motor cortex into the muscle cannot be measured transcranially. Bates<sup>20</sup> in an experiment specifically designed to measure such a motor discharge corroborates Monier, when he failed to observe any potential change from the motor cortex preceeding the onset of a voluntary movement. These observations are of the utmost importance to the present study as all measurements are based on the assumption that the arrival of information at the motor cortex from other areas of the brain can be detected. In order to avoid confusion it must be stated here, that the arrival of information is not considered equivalent to the efferent discharge of the motor cortex preceeding a voluntary movement. This point is elaborated on page 36 of this report.

The failure to detect the moment of discharge of the motor cortex is generally attributed to there being an insufficient number of neurons discharging simultaneously to produce a detectable potential change.<sup>21</sup> From this explanation it is evident that the existence of such a motor cortex discharge is not disputed. If it is admitted that the

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19 Marcel Monier, Op. cit. p. 469-486.

20 J.A.V. Bates, "Electrical Activity of the Cortex Accompanying Movement," Journal of Physiology, Vol. 113, No. 2, April 1951, p. 240-257.

21 J.A.V. Bates, ibid., p. 240-257.

motor cortex initiates and controls voluntary movement, then it is obvious that the command to move must precede the movement and that some electrical change will be associated with this command. An electrical change in the motor area is the object of this study, but it is attributed to the arrival of information and it may or may not be associated in time with a voluntary movement.

The techniques and instruments presently available are sensitive enough to detect voltages of the order of one microvolt and time delays of almost any desired accuracy. The variety and ingenuity of these techniques and instruments are too numerous to be included here, however there is one basic assumption underlying all these instruments. The assumption is that evoked cortical responses in the same individual have almost identical delays and similar wave forms. Thus all the instruments designed to detect evoked cortical responses select a specific event or events from a large number of random events. The specific event is identified because it occurs regularly and has a characteristic wave form. This assumption is well supported by the literature for relatively simple stimulus-response processes. For example Larsson<sup>22</sup> applied a stimulus to the ulnar nerve at the elbow

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<sup>22</sup> Lars Erik Larsson, "EEG Responses to Peripheral Nerve Stimulation in Man," EEG and Clinical Neurophysiology, Vol. 5, No. 3, Aug. 1953, p. 377-384.

and recorded the responses of the motor cortex using Dawson's<sup>23</sup> superimposition technique. In this technique the stimulus triggers the sweep of the oscilloscope and a number of successive sweeps are photographed superimposed in a single record. In this way random activity is cancelled out, whereas the periodic responses are reinforced. Measurements made on the records reproduced in Larsson's<sup>24</sup> article show that the individual responses which were averaged by this method could have a delay of plus or minus 5 milliseconds. It is thus clear that evoked responses do not have identical delays, however their mean delay and the range of their delays tends to be stable and the averaging technique works for this reason. It should be noted here that there is no problem in detecting the motor cortex response when a muscle is strongly stimulated by artificial means. The difficulty arises in detecting the spontaneous discharge of the motor cortex prior to a voluntary movement. This problem is avoided in this study as no attempt is made to measure the motor cortex discharge prior to a voluntary movement.

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<sup>23</sup> G.D. Dawson, "Cerebral Responses to Nerve Stimulation in Man", British Medical Bulletin, Vol. 6, No. 4, 1950, p. 326-329.

<sup>24</sup> Lars Erik Larsson, Op. cit., p. 377-384.

There is further evidence in the literature that not only the delay, but the amplitude and wave form of evoked responses is variable. Pampiglione<sup>25</sup> reports that responses to flashes of light could be modified by factors other than drugs. Natural stimuli, auditory, kinesthetic, olfactory and mental calculation are capable of disturbing the regularity of the responses. Bates states that "It would be an oversimplification to picture the cortical responses as some consistent wave form superimposed on unrelated random activity."<sup>26</sup> He illustrates this point by a series of ten consecutive cortical responses to median nerve stimulation, demonstrating a progressive change in the wave form, which would be obliterated in the superimposition technique, or any other technique based on the assumption of regularity in evoked responses.

Dawson<sup>27</sup> also found variations in the size of the cortical response to peripheral nerve stimulation. At the same time he criticises his own method of superimposition as having the disadvantage of masking variations in size

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25 G. Pampiglione, "Some Observations on the Variability of Evoked EEG Activity", EEG and Clinical Neurophysiology, Vol. 5, No. 1, Feb. 1953, p. 123-124.

26 J.A.V. Bates, Op. cit., p. 240-257.

27 G.D. Dawson, Op. cit., p. 328-329.

and form of responses to successive stimuli. In addition to experimental confirmation of variability in cortical responses, from a theoretical point of view, it is difficult to conceive of any regularity in a network of ten billion neurons. The variability in the delay, amplitude and form of cortical responses is stressed in order to justify the method of delay measurement used in the present study.

### 3. Summary and Hypothesis.

Studies relating a number of EEG variables to intelligence were reviewed. It was noted that no significant correlations between any EEG variable examined and intelligence was reported in any study dealing with a large sample of normal adults. The inadequacy in numbers, scope and results of studies dealing with this problem was stressed. It was proposed that the failure to find significant correlations is due to the nature of the EEG variables considered. Preoccupation with the mysterious alpha rhythm and the lure of new clinical discoveries, proposed as an explanation for the inadequacy of research effort in this area by Lindsley<sup>28</sup> was also accepted. It was noted, that no studies have been reported relating intra-cortical delay to intelligence.

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<sup>28</sup> D.B. Lindsley, "Psychological Phenomena and the EEG", EEG and Clinical Neurophysiology, Vol. 4, No. 4, Nov. 1952, p. 443-456.

Two estimates of the probable magnitude of intracortical delay were examined and the problem of measuring this delay directly, was discussed. The major difficulty appears to be the detection of the spontaneous discharge of the motor cortex prior to a voluntary movement. It was stated that this approach would not be used in the present study, however the techniques for detecting evoked responses were considered relevant and were analysed. It was concluded that the basis of these techniques is the assumption of a high degree of regularity in the cortical responses. Evidence was presented which supports this assumption for relatively simple stimulus-response processes, however it was also shown that there may be considerable variability in the delay, amplitude and wave form of evoked cortical responses.

The theoretical background involved in the formulation of the hypothesis is based on certain assumptions regarding the brain; (1) probabilistic laws govern the propagation of electrical activity in the brain. This leads immediately to an explanation of the variability observed in the delay, amplitude and wave form of the cortical responses. There are a large number of pathways by which information can be propagated from one area of the brain to another and it would be too much to expect that this information arrive always after an identical delay.

In assumption (2) it is proposed that the shorter the central delay in responding to a given stimulus the greater the efficiency of the organism, i.e., the more intelligent. This assumption is directly related to the hypothesis and the theoretical implications are discussed on page 56 of this study.

Stated in the null form the hypothesis proposed is that there is no significant relationship between intra-cortical delay and intelligence as measured by the Wechsler Bellevue test.

Chapter II in addition to describing data relevant to the experimental design, serves the major function of demonstrating statistically the feasibility of measuring intra-cortical delay. In doing so a foundation is laid for discussing the validity and reliability of the EEG variable, which is to be correlated with intelligence. In order to be valid the EEG variable (intra-cortical delay) must first be shown to be a non random phenomenon. This must be done before proceeding with the correlation of intelligence and intra-cortical delay. In fact, if the EEG variable is found to be a random phenomenon there would be no adequate reason for proceeding with this study. Elaboration of this problem is therefore properly included in Chapter II before the discussion of the main results in Chapter III.

## CHAPTER II

### EXPERIMENTAL DESIGN

The basic problem in testing the hypothesis proposed is the measurement of intra-cortical delay. It was shown in the review of the literature that the detection of the motor cortex discharge prior to a voluntary movement, using a variety of averaging techniques, has failed. A different approach is used in this study. No attempt will be made to measure the motor cortex discharge prior to a voluntary movement, but rather the delay in the spread of cortical activity from the visual area to the motor area will be measured. In order to do this it must be assumed that information<sup>1</sup> is transmitted from one area of the brain to another and it must be proved that information arriving at the point of measurement is not a random phenomenon. In more precise terms amenable to statistical proof, the problem is to show that a particular event following a stimulus is not due to chance, but is a true response of the brain.

After describing the sample population in section one, the instrumentation in section two and the experimental

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<sup>1</sup> The physical meaning of information transmission with regard to the brain, is the propagation of electrical activity from one area to another.

procedure used in section three, an attempt will be made to resolve the problem outlined above, in section four dealing with the analysis of data.

### 1. The Sample Population.

Ten postgraduate students in the faculty of psychology of the University of Ottawa volunteered for this experiment. Their ages ranged from 19 to 35 and I.Q.s, measured on three forms of the Wechsler Bellevue test, (Ottawa Wechsler, Wechsler Bellevue and W.A.I.S.) ranged from 106 to 139 with a mean I.Q. of 120. There was also one television technician aged 27 with a Wechsler Bellevue I.Q. of 105. In only one case (the T.V. technician) was the intelligence test administered by the experimenter. The other ten subjects were all tested by senior students or staff members of the faculty of psychology. All subjects were in good health at the time of testing and were presumed free of brain damage. EEG records taken from the motor and occipital areas of all subjects were normal.

### 2. The Instrumentation.

EEG records were obtained from a two channel system. The output of two preamplifiers was led into a dual beam cathode ray oscilloscope and the traces photographed by a continuous motion oscilloscope camera. The camera was

equipped with a timing light which produced timing marks at the rate of one every 1/60th second. Film speed was also variable but only two speeds were used. For maximum resolution short periods at 400 inches per minute were used for each subject. The remaining recording was done at 165 inches per minute. Needle electrodes made of 27 or 30 gauge hypodermic needles were used. The wiring connecting the subject to the preamplifiers and the amplifiers to the oscilloscope were shielded to minimize 60 cycle interference. The stimulus light was generated by a photostimulator which was connected to one channel of the oscilloscope so that the onset of the stimulus could be recorded. It was also necessary to use a second monitor oscilloscope for observing the brain waves during recording, because on the recording oscilloscope the electron beam moved up and down only, while the film was moved horizontally.

Considering such factors as line voltage fluctuation, thickness of the trace, film speed etc., the best time resolution obtainable at 165 inches per minute was found to be plus or minus 5 milliseconds. At 400 inches per minute an accuracy of plus or minus 1 millisecond was easily obtained.

### 3. Experimental Procedure.

Monopolar technique was used throughout, with the ear lobe as the common reference electrode. One electrode was placed approximately two centimeters to the right of theinion and the other over the motor area on the right side. The subject was lying in a darkened room with the eyes closed. The recording equipment and the experimenter were in an adjoining room. Before recording was started the brain waves were observed and if too much alpha activity was seen in the motor channell the electrode was moved, usually forward, untill activity of higher frequency was present. The lamp of the photostimulator was moved within one foot of the subject and a few trial flashes were given at medium intensity (setting 4 on the photostimulator).

The instructions to the subject were simply to relax, keep the eyes closed and to move as little as possible. The monitor oscilloscope was connected to the occipital channell and recording was started at a film speed of 166 inches per minute. When good alpha activity was seen on the monitor a single stimulus was given. Alpha activity was generally blocked. It was allowed to return and then another single stimulus was given. Regardless of the state of the alpha activity stimuli were not given more frequently than one every 5 seconds, otherwise the timing of the

stimulus was irregular. Thirty stimuli were given at this film speed. The film speed was then increased to 400 inches per minute and another ten to fifteen stimuli were given. Total recording time varied from subject to subject but was at least two minutes in each case.

#### 4. Analysis of Data.

Intra-cortical delay was measured on the records as the delay between the onset of the stimulus and the beginning of the motor cortex response to that stimulus. There are two reasons for adopting this particular delay as a measure of intra-cortical delay. First, it will be generally admitted that one cannot respond to a light stimulus without sensing the light. This is self evident, however it makes it clear that the motor cortex cannot respond directly to a light stimulus. Thus the only possible pathway by which the motor cortex can respond to a visual stimulus is via the primary sensory area for vision. It is clear therefore, that in measuring the motor cortex response to a light stimulus what is actually being measured is the time taken for information to be processed and propagated from the retina through the visual area to the motor cortex. The first part of this pathway, namely retina to visual area will be regarded as a constant of approximately

35 milliseconds duration,<sup>2</sup> leaving the remainder, visual to motor area as the intra-cortical delay defined on page one of this report. Secondly the anatomical pathways involved have been described as follows:

The optic nerve fibers have two major terminal stations. Some fibers terminate in the superior colliculi, where connections are made to the motor nuclei of cranial nerves III, IV and VI serving reflex eye movements. The other fibers by far the largest in number, travel to the lateral geniculate bodies in the thalamus where they synapse with the cortical projection fibers. The latter go directly to the cortex of the occipital lobes (area 17) which is the primary sensory area for vision.<sup>3</sup>

From this it is clear that with the exception of reflex eye movements, information is propagated directly to the visual areas. It is further postulated that when information arrives at the visual area, it does not just remain there but spreads to other areas of the brain. The most probable area for proximal reception is presumed to be the motor cortex, as almost any response involves some kind of voluntary movement as the adequate response to a stimulus.

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2 Marcel Monier, Op. cit., p.469-486.

3 M.A. Wenger, F.N. Jones and M.H. Jones, Physiological Psychology, Henry Holt, New York, 1956, viii-472 p.

The first step in measuring intra-cortical delay is its identification on the records. The following set of criteria were devised for locating and identifying the motor cortex response:

1. There must be no alpha activity present in the motor channel 500 milliseconds before and 500 milliseconds after the stimulus.
2. The event (i.e. the motor cortex response) may have a delay of not more than 200 milliseconds. Thus attention will be focused on an area of record representing not more than 200 milliseconds after the stimulus.
3. The event is identified as a distinct change in the wave form of the brain waves. This change may be positive or negative, an increase or decrease in amplitude. If there is more than one such change in the 200 millisecond interval, the first one after the stimulus only shall be measured. The term change is relative to the wave form between the onset of the stimulus and the point where the suspected change is seen.
4. All measurements are understood to represent the beginning of the event, not its peak or trough or duration or termination.

The reasons for adopting these criteria are:

- (1) Alpha activity is characteristic of the occipital area and should not be present in the motor area when measurements are made. It is hoped that a change in the characteristic rhythm of the motor area can be detected as a result of transmission from the visual area. (2) Two hundred milliseconds was considered adequate to allow for theoretically possible intra-cortical delays. The 75

millisecond estimate of Monier<sup>4</sup> for cortical interaction time may be too short. It is expected that intra-cortical delay will be shorter than visual reaction times which were found to range between 150 and 500 milliseconds<sup>5</sup>. On this basis an upper limit of 200 milliseconds was marked on the records and the brain waves analysed during this interval. Criterion (3) is better explained by referring to figure 1A and figure 2 on pages 24 and 25 respectively. A number of EEG epochs taken from the same subject are reproduced and the event indicated by an arrow. Figure 1A was taken at a film speed of 166 inches per minute and figure 2 at 400 inches per minute. It will be noted that there is considerable variety in changes that are classified as events. The delays in figure 1A appear almost constant, however an error of measurement of plus or minus 5 milliseconds at this film speed must also be considered. In figure 2 the variability in the delay of events is greater in terms of distances on the record. But with an error of measurement of less than one millisecond the cortical phenomenon is remarkably constant. Visual inspection alone indicates that such regularity could not be due to chance, however this remains to be proven statistically.

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4 Marcel Monier, Op. cit., p. 469-488.

5 John A. Stamba, Op. cit., p. 61-65.

Figure 1A.-

Figure 1B.-

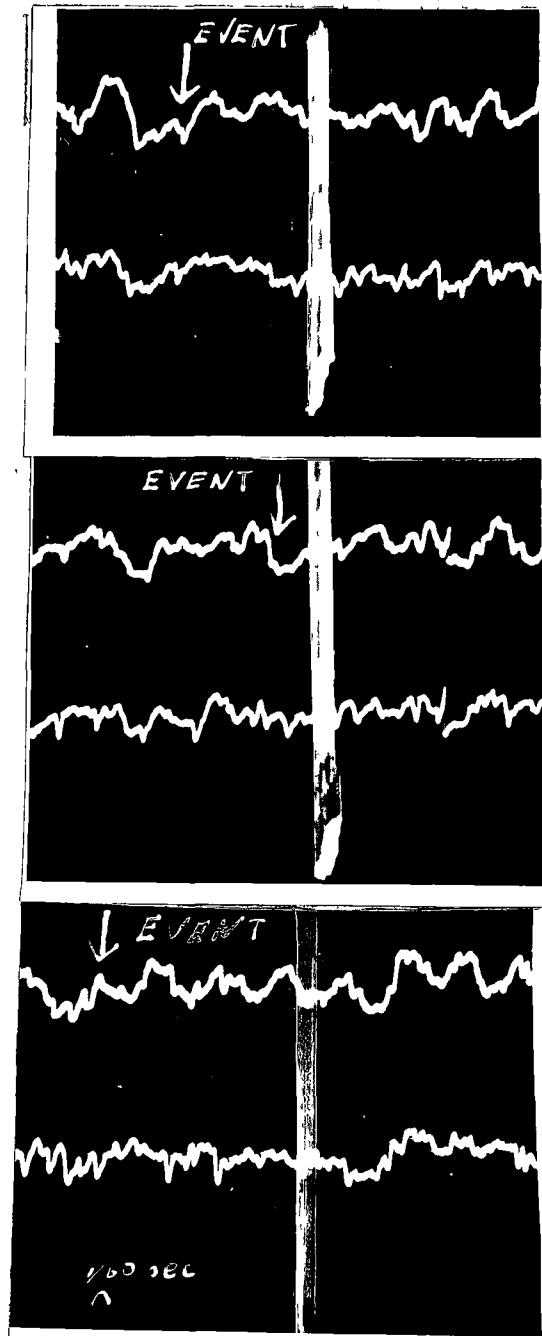
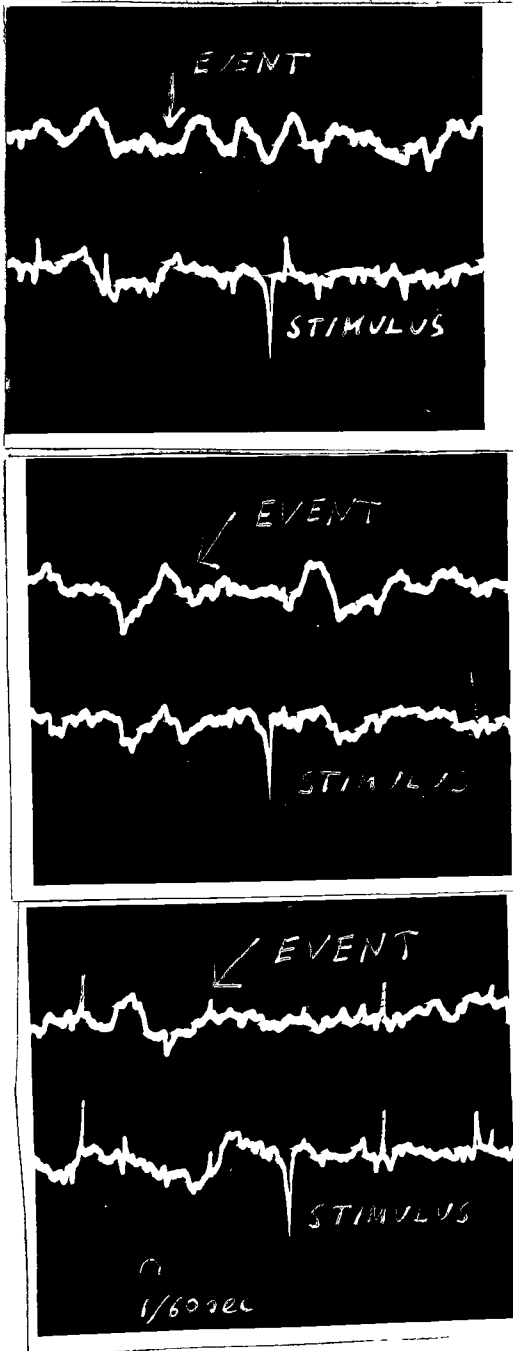


Figure 1A, 1B.- Comparison of EEG Records With and Without Stimulation.

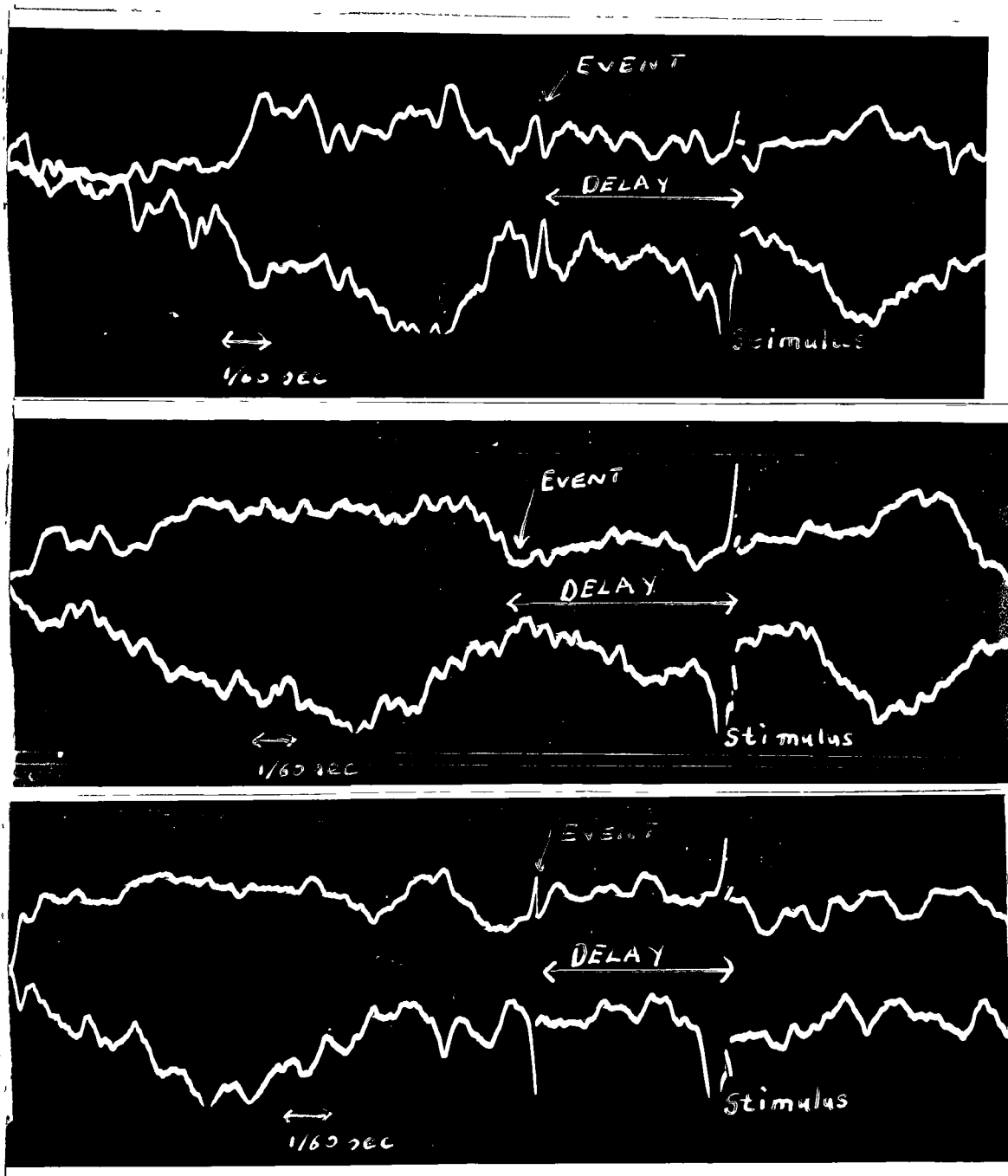


Figure 2.- EEG Records at 200 Inches . or Minute with Stimulation.

In figure 1B EEG records of the same subject are shown while no stimulus was present. Lines were drawn randomly on the record and measurements of intra-cortical delay made applying the same criteria as when measuring with the stimulus present. Fifty such measurements were made for each subject and the standard deviation computed. The significance of differences between standard deviations with the stimulus present and without the stimulus were then calculated and are shown in table I on page 27. It is clear that the variability of events without a stimulus is significantly greater in all cases than with the stimulus present. From this the conclusion may be drawn that the event being measured following a stimulus is not due to chance, but is a true response of the brain to the visual stimulus. The inference that these delays are actually measures of intra-cortical delay is not validly tenable on the basis of this study. Nevertheless the term intra-cortical delay will be used in referring to these delay measurements.

Once it is established that the EEG variable (i.e. intra-cortical delay) is not due to chance, the correlation with intelligence may be attempted. The Pearson product moment correlation was used and details and the discussion of results follows in chapter III.

Table I.-  
 Variability in the Delay of Events<sup>a</sup> With and Without  
 Stimulation.

Subject	With stimulus		Without stimulus		$\sigma_2 - \sigma_1$	t	Significant at .01 level
	N <sup>b</sup>	$\sigma_1$	N	$\sigma_2$			
1	7	5.9	50	22.3	22.4	6.7	yes
2	15	2.5	50	28.3	25.8	8.3	yes
3	6	6.6	50	31.9	25.3	7.3	yes
4	10	5.5	50	26.6	21.1	5.5	yes
5	5	7.3	50	34.9	27.6	7.1	yes
6	13	4.3	50	33.7	29.4	6.4	yes
7	8	5.5	50	28.3	22.8	7.1	yes
8	6	6.6	50	27.1	20.5	5.5	yes
9	15	5.9	50	30.1	24.2	7.6	yes
10	10	5.9	50	33.7	27.8	8.1	yes
11	8	8.7	50	30.1	21.4	5.5	yes

a An event represents a change in electrical activity at the measuring electrode and its delay from the onset of the stimulus is the intra-cortical delay.

b Number of stimuli meeting criteria and used in the measurement of intra-cortical delay.

c Standard deviations are in milliseconds.

## CHAPTER III

### RESULTS AND DISCUSSION

Having established the feasibility of measuring intra-cortical delay, by demonstrating its periodicity, the correlation with intelligence will be presented in section one of this chapter. In evaluating this correlation additional data obtained from a second sample will be introduced. Conclusions drawn will be confined to the original group. In section two the discussion will center around the validity and reliability of the EEG variable. In section three the possible relationship of intra-cortical delay to biological intelligence will be discussed.

#### 1. Intra-cortical Delay and Intelligence.

For significance at the .01 level of confidence with 9 degrees of freedom ( $N-2$ ) the correlation required is .735. The obtained correlation, shown in table II on the following page, is  $-.68$  which indicates a statistically significant inverse relationship between test intelligence and intra-cortical delay. Despite its statistical significance this degree of relationship cannot be accepted as a true measure of the relationship between the two variables. Apart from the inadequate sample, there are other reasons for rejecting the significance of the obtained correlation.

Table II.-  
Intra-cortical Delay and Intelligence.

Subject	I.Q. <sup>a</sup>	Intra-cortical delay <sup>b</sup>
1	139	45
2	127	54
3	127	60
4	118	60
5	129	65
6	122	67
7	116	69
8	116	69
9	114	73
10	106	102
11	105	108

r = -0.88 significant at  
the .01 level of confidence

a Full scale Ottawa Wechsler, Wechsler Bellevue or W.A.I.S. scores were used.

b Delays are in milliseconds and are mean scores.

Considering the two variables, intra-cortical delay and Wechsler test scores, it will be noted that the influence of many uncontrolled factors are operating. In terms of realistic and attainable controls the experiment in its present stage may perhaps not be criticised too severely. However in terms of theoretically desirable controls, with respect to the EEG variable, there are two major shortcomings; (1) as delay is a function of velocity and distance it would be necessary to place the electrodes in such a way that the path length from the retina to the motor area is the same for each subject. This is practically impossible. (2) The physical and mental state of the subject during measurement was unknown and uncontrolled and the influence of these factors on intra-cortical delay not predictable.

Introduction of the second sample while complicating the problem, also serves to reduce the pessimism dictated by the small original sample. The second group consisted of 33 female Hospital<sup>1</sup> patients suffering from a variety mental illnesses. Their ages ranged from 18 to 63 and their full scale I.Q. measured by the Wechsler Bellevue test ranged from 45 to 125 with a mean of 88. The experimental procedure was essentially the same, though not performed by the author. A six channel ink writing EEG machine was used and photic

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<sup>1</sup> Ontario Hospital, Brockville Ontario.

stimulation was included as part of standard EEG procedure. Photic stimulation was routinely started at the rate of one per second and then gradually increased to about thirty per second. The record from the motor area channel was analyzed in the manner previously described, measurements of intra-cortical delay being made only from stimuli given at the rate of one per second. The paper speed used by the hospital's EEG laboratory was 6 centimeters per second which allowed a time resolution of plus or minus 10 milliseconds. The correlation of  $-.26$  between intra-cortical delay and Wechsler scores shown in table III on the following page is not significant. This is not surprising, for in a mentally disturbed individual the validity of an intelligence test is questionable. In addition to this 25 of the 33 subjects were given drugs before and/or during EEG examination.

It is interesting to note that if a single criterion of selection is applied to this group, namely the elimination of all subjects with I. Qs. below 85, the correlation between intelligence and intra-cortical delay is  $-.72$  which is significant at the  $.01$  level of confidence. This criterion for selection is probably valid as the subjects with I. Qs. below 85 may be suspected of organicity or severe mental deterioration due to psychosis. In view of the large number of uncontrolled factors operating a correlation

Table III.-

Intra-cortical Delay and Intelligence in a Group of Mental Hospital Patients.<sup>a</sup>

EEG code no.	I.Q. <sup>b</sup>	Intra-cortical delay <sup>c</sup>
983	66	116
315	82	132
1076	48	133
1203	97	63
1099	107	66
1210	101	132
756	78	60
1078	109	66
732	75	99
1052	78	116
1051	108	66
1116	107	60
1318	91	83
1149	98	99
1043	80	87
988	103	59
937	71	103
1092	92	106
1110	98	99
216	109	80
1362	100	96
1105	74	83
1120	58	69
1885	75	106
1028	45	80
941	76	83
1073	119	60
1322	72	83
1119	91	83
701	125	53
1236	60	129
1097	94	116

$r = -.265$   
N = 33

a Ontario Hospital, Brockville Ontario.

b Wechsler Bellevue full scale scores.

c Mean delay in milliseconds.

of this magnitude is surprising unless some degree of relationship is admitted between intelligence and intra-cortical delay. Taking the original group and the hospital group into consideration it may be concluded with a little more confidence that some degree of relationship exists. However in view of the problems outlined above the magnitude of these correlations cannot be accepted at face value. At the same time there is sufficient evidence to warrant further research.

## 2. Validity and Reliability of the EEG Variable.

The validity of intra-cortical delay as a measure of test intelligence cannot be computed, as the reliability coefficient for the EEG variable is not obtainable from the data available. The only technique which would yield a valid reliability coefficient is the test retest method. This is due to the theoretical importance of the placement of the electrodes. Thus it is possible to measure intra-cortical delay reliably with the electrodes in one place, but this does not imply that in a different position the same delay will be measured. Since it is not possible to repeat this experiment without some variation in the position of the electrode, in order to demonstrate reliability it must be shown that a small change in the position of the electrode does not influence the delay. This can only be

done by the test retest method with a systematic variation in the position of the electrode over the motor area. Such measurements are now in progress and will be reported in a later paper.

A definite indication of the reliability of the EEG variable with the electrodes in one place is the periodicity of the delays demonstrated in table I on page 27 of this study. It will be noted that the standard deviation of the EEG variable for each subject is small, ranging from 2.86 to 6.87 milliseconds. When this range is compared to the error of measurement (plus or minus 5 milliseconds) it can be stated with some confidence that the delay of whatever is being measured is reliable when the factor of the position of the electrode is held constant.

### 3. Intra-cortical Delay and Biological Intelligence.

The shorter the central delay in responding to a given stimulus the greater the efficiency of the organism, i.e., the more intelligent. This assumption was proposed as the basis of the hypothesis which was tested in this study. Furthermore a stochastic brain model was accepted. An effort must now be made to link intra-cortical delay and biological intelligence. The term biological intelligence is used because intelligence as it is understood in psychology is so far removed from intra-cortical delay that

it cannot be discussed in the frame work of this study. If the correlation found is significant then this must be accepted as a fact, but why intra-cortical delay should be related to psychometric test intelligence is far from clear. Biological intelligence and efficiency of the organism are interchangeable concepts and this is the meaning given to biological intelligence in this study. The purpose is to reduce the extent of the meaning of intelligence to manageable proportions.

Any brain model which is not based on the known anatomical and physiological facts is regarded with scepticism and the concept of efficiency or biological intelligence will therefore be related to a neuron network.

Consider a network of receptor cells, neurons, synapses and effectors. In a stochastic model where connections between the elements of the network are random there may be a large number of pathways by which a stimulus can cause a response. These pathways will be unequal in length and will therefore produce varying delays in the duration of the stimulus-response process. The pathway where the delay is the shortest is the most efficient and the organism is said to act intelligently in this particular stimulus-response situation. The problem of judging what is an adequate response still remains and no way is seen to resolve this problem without introducing criteria outside the organism. For simple reflexive activity the adequacy of the

response is easily judged in terms of internal physiological criteria. But when complex human behaviour is considered an efficient response is not necessarily the shortest one. There are however relatively simple voluntary acts such as the situation involved in this experiment. Perception of a diffuse flash of light requires no complex response and yet there are undoubtedly non-reflexive responses involved. The mechanism is thought of as a transmission of information from the visual area to the motor area, resulting in a general preparedness to act in the motor area. The electrical characteristics of this preparedness to act is not yet clear from the data gathered. It can however be said that it is not similar to the alpha blocking reaction and that it is not interpreted as the motor cortex discharge prior to a voluntary movement which previous authors have failed to detect. A distinct change does occur in the motor area rhythm and at present this change is assumed to represent the arrival of information.

Time is a fundamental parameter in the functioning of the elements of the brain. Temporal patterns when the organism functions as a whole are equally important. There is thus good reason to hope that the measurement of various central delays in response to a variety of stimuli may serve to reveal physiological correlates of intelligence or other psychological phenomena.

## SUMMARY AND CONCLUSIONS

It was shown that measurement of the delay in the transmission of information from one area of the brain to another is feasible. This was done by demonstrating statistically a periodicity in the responses of the motor area to a visual stimulus which could not be due to chance. Having established this, the hypothesis of a significant relationship between intra-cortical delay and intelligence was tested. A statistically significant relationship was found, however the degree of significance when based on the data available was rejected. Sufficient evidence, both experimental and theoretical, was presented to indicate the probability of the existence of a true relationship and to justify further research.

The immediate research need is for reliability studies of the EEG variable. With a multi channel instrument the entire cortex could be mapped with respect to delay and a large number psychological variables correlated. There is also a need for investigating the nature of the stimulus in relation to delay. From a theoretical point of view it is probable that more complex stimuli would be associated with longer delays.

## BIBLIOGRAPHY

Bates, J.A.V., "Electrical Activity of the Cortex Accompanying Movement", Journal of Physiology, Vol. 113, No. 2, April, 1951, p. 240-257.

The failure to detect a potential change from the motor cortex preceding the onset of a voluntary movement is corroborated and an explanation offered. This approach to the measurement of intra-cortical delay is avoided.

Dawson, G.C., "Cerebral Responses to Nerve Stimulation in Man", British Medical Bulletin, Vol. 6, No. 4, 1950, p. 326-329.

A basic technique for the detection of evoked cortical responses is described. Variations in the size of cortical responses was also noted which partly justifies the method of measurement used in the present study.

Ellingson, R.J., H.C. Wilcott, J.C. Mineps and F.J. Dudek, "EEG Frequency Pattern Variation and Intelligence", EEG and Clinical Neurophysiology, Vol. 9, No. 4, Nov. 1957, p. 657-660.

A new EEG variable is correlated with intelligence. Although results were negative the feasibility and the need for investigating new EEG variables is demonstrated. This confirms the opinion expressed in the present study that the key to further progress in finding EEG correlates of psychological phenomena is the investigation of new EEG variables.

Knott, J.R., H. Friedman and A. Bardsley, "Some Electroencephalographic Correlates of Intelligence in Eight Year and Twelve-Year Old Children", Journal of Experimental Psychology, Vol. 33, 1942, p. 380-391.

Alpha index and alpha frequency are the EEG variables correlated with intelligence. One of several papers illustrating the overconcentration of research effort on these two EEG variables.

Kreezer, George L., and Franklin S. Smith, "The Relation of the EEG and Intelligence Level in the Non-Differentiated Familial Type of Mental Deficiency", The Journal of Psychology, Vol. 29, 1950, p. 47-51.

Alpha index and alpha frequency are the EEG variables and the population is organic. Relevant to the present study only in showing the type of EEG variables previously correlated with intelligence.

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Larsson, Lars Erik, "EEG Responses to Peripheral Nerve Stimulation in Man", EEG and Clinical Neurophysiology, Vol. 5, No. 3, August, 1953, p. 377-384.

Measurement of evoked cortical responses to peripheral nerve stimulation is described. The content of the work is not directly relevant, but the EEG records reproduced show that even in relatively simple stimulus-response processes the delay of cortical responses is variable. This also justifies the method of measurement used in the present study.

Lindsley, D.B., "Psychological Phenomena and the EEG", EEG and Clinical Neurophysiology, Vol. 4, No. 4, Nov. 1952, p. 443-456.

An attempt to show how psychological and neurophysiological data may be related through time relationships. An explanation for the inadequacy of research effort in this area supports the opinions expressed in the present study.

Monier, Marcel, "Retinal, Cortical and Motor Responses to Photic Stimulation in Man", Journal of Neurophysiology, Vol. 15, No. 6, 1952, p. 489-486.

A major work defining the time relations of retinal, cortical and motor responses to a light flash in man. Although intra-cortical delay was not measured directly an indirect estimate of its probable magnitude was given and therefore this work is relevant and most important to the present study.

Dundy-Castle, A.C., "Electrophysiological Correlates of Intelligence", Journal of Personality, Vol. 26, No. 2, June, 1958, p. 184-199.

Alpha index and alpha frequency are again the EEG variables, but unlike other authors a small positive correlation was found. Relevant as a review of previous work on relating EEG variables to intelligence.

Netchine, J., I. Talan, G.C. Lairy and R. Zazzo, "EEG et Niveau Mental", L'Année Psychologique, Vol. 2, 1959, p. 355-372.

A new EEG variable (frequency scatter index) is introduced and positive correlations with intelligence were found. Illustrates the fruitfulness of a new approach to the problem.

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Pampiglione, G., "Some Observations on the Variability of Evoked EEG Activity", EEG and Clinical Neurophysiology, Vol. 5, No. 1, Feb. 1955, p. 123-124.

A report on observations that a variety of factors could modify the cortical responses to flashes of light. By confirming irregularity in cortical responses the method of delay measurement used in the present study is justified.

Shagass, Charles, "An Attempt to Correlate the Occipital Alpha Frequency of the EEG with Performance on a Mental Ability Test", Journal of Experimental Psychology, Vol. 36, Feb. 1946, p. 88-92.

A large scale study of the relation of alpha frequency to intelligence in normal adult subjects. The conclusively negative results clearly indicate the futility of further research along these lines.

Stamm, John S., "On the Relationship Between Reaction Time to Light and Latency of Blocking of the Alpha Rhythm", EEG and Clinical Neurophysiology, Vol. 4, No. 1, Feb. 1952, p. 61-68.

Content relevant only inasmuch that a range for reaction times to light is mentioned. This range places an upper limit to the expected duration of intra-cortical delay.

## APPENDIX I

### ABSTRACT OF

### Intra-cortical Delay and Intelligence<sup>1</sup>

The foremost need in the search for EEG correlates of psychological phenomena is the investigation of new EEG variables. The time parameter is undoubtedly of major importance at the neuronal and the behavioural level. Thus intra-cortical delay was introduced, defined and measured, as an EEG variable related to time and promising to yield further insight into the electrophysiological basis of intelligence.

The literature revealed an inadequacy of research effort in this area and generally negative results with respect to the electrophysiological basis of intelligence.

The major aims of this study were first, to show the feasibility of measuring intra-cortical delay. This was done by demonstrating a periodicity in the motor cortex response which could not be due to chance. The second aim was to relate intra-cortical delay to intelligence. The correlation found was statistically significant but the degree of significance was rejected in view of the many uncontrolled

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<sup>1</sup> John P. Ertl, Master's thesis presented to the School of Psychology of the University of Ottawa, Ontario, May 1961, viii-41 p.

factors operating. Sufficient evidence was presented to warrant further research and in this area the immediate need is for reliability studies of the ALG variable. It will also be necessary to evaluate the influence of the electrode position on intra-cortical delay

A theoretical basis for the findings was also proposed and an attempt made to relate intra-cortical delay to network efficiency and finally to biological intelligence.