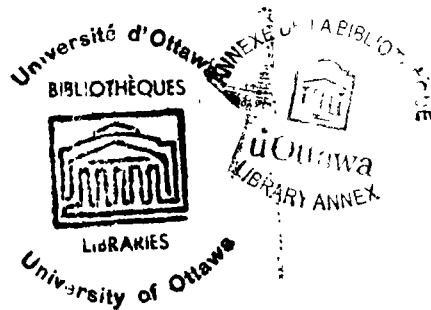


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EVOKED POTENTIAL LATENCIES AND PSYCHOMETRIC INTELLIGENCE

by **Neville A. Taylor**

Thesis presented to the Faculty of
Psychology and Education of the
University of Ottawa, as partial
fulfillment of the requirements
for the degree of Master of Arts



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CURRICULUM STUDIORUM

Neville A. Taylor was born in Kingston, Jamaica, on September 10, 1933. He received his Bachelor of Arts degree in Liberal Arts from Sir George Williams University, Montreal, Quebec, in November, 1963.

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INTRODUCTION

A great deal of research has been done, with conventional techniques of electroencephalography, on the possible relationships between the electrical activity of the brain, and psychological variables. To date, these studies have proved to be generally inconclusive. However, within the last decade, an alternative approach to the problem has been made possible by the development of techniques which permit the detection and analysis of Evoked Potentials. These are changes in electrical potential, which occur in the brain, in response to sensory stimulation. Although the precise nature of these variables is still unknown, recent studies indicate that they may represent a very fruitful field of research, for those interested in the neurological correlates of human behavior.

Evidence now exists which suggests that the later components of Evoked Potentials may be related to data processing activity in the brain. Of particular interest, in this connection, is the recent work done at the University of Ottawa which demonstrates a relationship between human intelligence and the latency times of Evoked Potentials. It is felt that this work is of sufficient importance to warrant further investigation.

Because the work done at Ottawa involved a new and quite revolutionary technique, it was felt that it would be

useful to re-investigate the relationship between intelligence and Evoked Potential latencies, using an alternate and more widely known method. This is the first objective of this study. The second objective is an attempt to extend the above findings by investigating two dimensions of intelligence which may be of importance in determining the overall relationship to Evoked Potentials. To this end, the complex factors of Speed and Power, in intelligence, will be related to the latency times of four components of Evoked Potentials.

The first chapter of this thesis presented a review of the literature, and states the theoretical bases for the experiment. It begins by referring to a paper which gives a very comprehensive review of literature on the relationships between test intelligence and conventional EEG variables. A presentation is then made of literature concerning the properties of certain Evoked Potential variables and their possible relation to data processing activity in the brain. Of particular importance is the study on the relationship between human intelligence and Evoked Potential latencies. Following this, a theoretical discussion is offered concerning problems in the measurement of Speed and Power. The insertion of such a discussion in the first chapter is, admittedly, a departure from the usual format of thesis writing. It was considered necessary because, so far as the writer can determine, the problems discussed have not been dealt with

adequately in the literature. Furthermore, the solutions offered not only affect the design of this experiment, but also determine the selection of papers on Speed and Power which are subsequently reviewed. The chapter concludes with a statement of the experimental hypotheses.

Chapter two describes the procedures employed to isolate and measure the variables in the experiment, and describes the statistical procedures used to test the hypotheses stated in the first chapter.

In chapter three the findings of the study are presented and discussed, and some suggestions are offered concerning possible future research in this area.

CHAPTER I

REVIEW OF THE LITERATURE

This chapter begins with a reference to the present status of work on the relationship between conventional EEG¹ variables and test intelligence. Section two discusses the nature of Evoked Potentials, and reviews literature which suggests that they are related to information processing activity in the brain and, in particular, to psychometric intelligence. Section three discusses theoretical questions relating to the measurement of Speed and Power in psychometric tests. Section four reviews literature on the relationships of these variables to each other, and to intelligence as a whole. The fifth and last section summarizes the theoretical bases for this study, and concludes with a statement of the experimental hypotheses.

1. EEG and Test Intelligence.

A recent review of the literature, by Vogel and Broverman,² indicates that attempts to relate conventional EEG

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

2 William Vogel and Donald D. Broverman, "Relationship between EEG and Test Intelligence: A Critical Review", Psychological Bulletin, Vol. 62, No. 2, August 1964, p. 132-144.

variables (usually the Alpha Rhythm) to test intelligence have been generally inconclusive. The authors do state that significant correlations have been found, and further point out that:

Evidence for the relationship between these two variables seems strongest for samples of children, institutionalized geriatric patients, mental deficient, and brain damaged persons; and weakest for samples of normal adults.³

However, they also point out that the results from different studies are often contradictory and, furthermore, that many of these studies which show positive results involve methodological difficulties which limit the extent to which generalization of findings is possible.

Most recently, a study by Edwards,⁴ on the relationship between EEG wave amplitude and WAIS intelligence, did not show statistically significant results.

The inconclusive nature of these findings suggests the need for a different approach to the problem of relationships between intelligence and brain activity. Such an approach appears to lie in the study of Evoked Potentials.

3 Ibid., p. 132.

4 Henry P. Edwards, "EEG and WAIS Intelligence in a Sample of Cultural-Familial Deficients", unpublished Master's thesis presented to the Faculty of Psychology and Education of the University Ottawa, Ontario, 1965, vii-47 p.

2. Evoked Potentials and Information Processing Activity in the Brain.

An Evoked Potential may be described as a series of detectable changes in electrical potential, occurring within the brain, in response to supra-threshold stimulation, administered via any one of the senses. The most distinctive feature of the Evoked Potential is the appearance of its component wave forms at fixed intervals in time following the stimulus to which it is a response. In a conventional EEG record the Evoked Potential is difficult or impossible to detect, due to the relatively greater amplitude of the ongoing, "random", brain activity in which it is imbedded.

In papers published in 1947⁵ and 1954,⁶ Dawson proposed a solution to this problem. Simply stated, his method involved super-imposing samples of EEG recordings immediately following a series of stimuli. By this procedure, he was able to distinguish between random activity and those wave forms which always appeared at fixed time intervals following the stimulus. Dawson's work, together with refinements suggested by others in the field, has provided the basis for the development of a modern computer technique which is now used in virtually all

⁵ G.D. Dawson, "Cerebral Responses to Electrical Stimulation of Peripheral Nerve in Man", Journal of Neurology, Neurosurgery and Psychiatry, Vol. 10, 1947, p. 134-140.

⁶ -----, "A Summation Technique for the Detection of Small Evoked Potentials", Electroencephalography and Clinical Neurophysiology, Vol. 6, 1954, p. 85-84.

studies on Evoked Potentials, including the present one.⁷ In principal, this technique consists of the administration of a number of discrete stimuli, and the algebraic summation by the computer, of samples of brain activity immediately following each stimulus. The EEG activity not related to the stimulus occurs randomly, and thus tends to average toward zero, while potentials time locked to the stimulus (i.e., the Evoked Potential) tend to summate, and so become readily distinguishable.

The precise origin and nature of Evoked Potentials are not definitely known. Bickford et al.⁶ suggest that Evoked potentials, recorded from the scalp, are mainly due to involuntary movements of the cranial muscles in response to the stimulus. The authors demonstrate variations in evoked response patterns corresponding to variations in the tension of neck muscles. In the discussion published with Bickford's paper, G.D. Geisler disagrees with the authors' conclusions and suggests that Evoked Potentials are cortical in origin.

7 A notable exception is the alternate method which has been devised and successfully employed by Ertl, at the University of Ottawa, Faculty of Psychology and Education. See: J.P. Ertl, "Detection of Evoked Potentials by Zero Crossing Analysis", Electroencephalograph and Clinical Neurophysiology, Vol. 18, 1965, p. 630-631.

6 Reginald G. Bickford, James L. Jacobson, D. Thane, R. Cody, "Nature of Average Evoked Potentials to Sound and Other Stimuli in Man", Annals of the New York Academy of Sciences, Vol. 112, Art. 1, May 1964, p. 204-223.

In a study designed to test the findings of Bickford, Domino and Corssen⁹ analyzed Potential recordings obtained from twelve surgical patients under three different conditions. Responses to visual stimulation were recorded from a number of scalp electrodes while the subjects were: 1) awake; 2) lightly anesthetized; 3) in a state of complete muscle paralysis induced by the administration of Succinylcholine. A variety of differences in the Evoked Potentials were observed between the first two conditions. However, the paralysis of all skeletal muscles, following anesthesia, produced no further changes. The authors conclude that the skeletal muscle component, in visually evoked responses, is negligible. Unfortunately, the findings of this study are weakened by a lack of suitable controls. Nevertheless, the overwhelming weight of evidence and opinion reported in the literature supports the conclusion of the authors, and opposes the position taken by Bickford.

Amassian et al.,¹⁰ in a study on cats, recorded Evoked Potentials from micro-electrodes implanted in somatosensory areas I and II of the cortex and, simultaneously, from scalp

9 Edward F. Domino and Guenter Corssen, "Visually Evoked Response in Anesthetized Man With and Without Induced Muscle Paralysis", Annals of the New York Academy of Sciences, Vol. 112, Art. 1, May 1964, p. 226-237.

10 V.E. Amassian, H.J. Waller, J. Macy, Jr., "Neural Mechanism of the Primary Somatosensory Evoked Potential", Annals of the New York Academy of Sciences, Vol. 112, Art. 1, May 1964, p. 5-32.

electrodes placed over the same areas. Recordings were made at various drug induced levels of consciousness and, in some cases, with the cortical recording areas completely anesthetized. The discussion of findings, in this study is lengthy and complicated, and will not be fully reported here. It is noted, however, that the authors believe that Evoked Potentials, recorded at the surface, are the result of post-synaptic potentials occurring in cortical neurons. They further suggest that the amplitude of these post-synaptic potentials is determined by the spread of activity between cortical and sub-cortical structures. They conclude that Evoked Potentials do not represent simply the simultaneous discharge of groups of cortical neurons, but are also determined by the interaction of cortical and sub-cortical networks.

Uttal and Cook¹¹ studied Evoked Potential from human subjects, using electrical stimulation applied to the wrist, and surface contact electrodes. The authors identified three major wave forms, occurring at approximately 25, 45 and 150 milliseconds after stimulation, which they labeled respectively the "M", "N", and "O" waves. The authors observed that the latency times of these waves were stable within individuals and differed between individuals. They also observed that

11 William R. Uttal and Louella Cook, "Systemics of the Somatosensory Cortical Potential: A Psychophysical-Electrophysiological Comparison", Annals of the New York Academy of Sciences, Vol. 112, art. 1, May 1964, p. 60-60.

the "O" wave, in addition to its longer latency time, was more diffuse in shape, was less stable than the other waves, could be recorded from all areas of the head, varied markedly with respect to latency and amplitude in relation to the subjects' subjective state, and disappeared almost entirely during sleep. By contrast, the "K" and "N" waves were more stable, appeared to be relatively independent of the subject's state of consciousness, and could be detected with certainty only over the somato-sensory area contralateral to the stimulated wrist. In the discussion of their findings, the authors agree with Amassian et al. in stating that, "the evoked potential is not only the summation of many thousands of neuronal potentials but also appears to be the summated responses of several major neurological systems."¹² They go on to point out the similarity between the characteristics of the "O" wave, and the classical reticular activation response observed in conventional EEG studies. On this basis, they hypothesize that the "O" wave may be mainly the result of activity emanating from the reticular formation. With considerably less certainty, they speculate that the "K" and "N" waves may be due to activity in the spinothalamic and medial lemniscal pathways respectively.

¹² Ibid.

It is possible that a connection exists between the above hypothesis concerning the "O" wave, and work being done by Schafer, on the effects of the drug "Methedrine" on Evoked Potential latencies.¹³ This drug is generally believed to act upon the reticular formation, as well as other brain centers, and has the subjective effect of increasing alertness. Schafer has found that "Methedrine" significantly shortens the latency time of the third component which corresponds to the negative peak of the "O" wave, but does not affect the earlier components corresponding to the "M" and "N" waves.

In a very carefully controlled study using forty anesthetized cats, Fox and O'Brien¹⁴ investigated the relationship between the distribution of spike firings of a single cortical neuron and the wave form of the Evoked Potential recorded from the same area. Stimulation consisted of short duration light flashes, and recordings were made from both the visual and somatic sensory areas of the cortex. A single micro-electrode was inserted into the cortex in such a way that, with the use of complicated instrumentation, it

13 E. Schafer, "The Effects of Methamphetamine HCl on Human Evoked Cortical Potentials", study carried out at the University of Ottawa, Faculty of Psychology and Education; submitted for publication to Science.

14 Stephen S. Fox and James H. O'Brien, "Duplication of Evoked Potential Waveform by Curve of Probability of Firing of a Single Cell", Science, Vol. 147, February 1965, p. 886-890.

was possible to record the spike firings of only one cell immediately preceding and following approximately four thousand 10-microsecond light flashes. These recordings were fed directly to a computer which made a frequency distribution of the number of spike firings, plotted against time. The individual cell was then destroyed by tapping on the electrode and an Evoked Potential recording was made, from the surrounding cortical area, using the same electrode and approximately two hundred stimuli. In repeated trials, and in different cortical areas, it was found that the distribution of single cell spike firings, across time, was almost exactly duplicated, in terms of both the latency and amplitude of its positive and negative peaks, by the corresponding Evoked Potential. It is further stated that this relationship holds for both visual and somatic stimuli, and for cases where two sensory stimuli are administered close together. The hypothesis that Evoked Potentials represent the summated potential changes from many cells acting together is defended on the grounds that all the cells in a given localized area have approximately the same firing pattern. The conclusions of the authors are given in the following quotation:

We conclude from these data that no component (positive or negative, early or late) of the asynchronous evoked potential recorded in this way is uniquely related to responses of specific cell populations or to specific portions of cells, since from each cell a probability curve can be obtained which closely resembles the waveform of the entire evoked response. This outcome suggests, therefore, that whatever potential sources contribute to the evoked potential, they are directly related to or reflected in the firing of a single cell.¹⁵

It might appear at first glance that this conclusion is directly opposed to the hypothesis of Uttal and Cook, that the third component, or "O" wave, is determined by activity radiating from the reticular formation. That this is not necessarily the case may be seen by considering a number of points. In the first place, the authors do not rule out the possibility that Evoked Potentials may have their origin in the graded post-synaptic/dendritic potentials. In fact, they specifically state that the observed relation between the pattern of spike firings (which occur only in the axon) and Evoked Potentials may be due to the fact that there is an "important relationship between dendritic activity and the production of spikes from the cell body."¹⁶ If this is the case, then at least the contentions of Amassian et al. remain

¹⁵ Fox and O'Brien, Op. Cit., p. 690.

¹⁶ A recent telephone conversation between Fox and the writer's thesis advisor, J.P. Ertl, confirms that the authors do in fact subscribe to this view. The use of the term "cell body" in this quotation may represent a confusion in terminology; it is generally believed that spike firings occur only in the axon.

tenable. That is to say, it may still be argued that the Evoked Potential, as a whole, is influenced by activity radiating from many brain centers, on the grounds that it is this activity which determines the characteristics of dendritic potentials.

Further argument is made possible by considering two findings reported by Walter.¹⁷ In a study on humans, he observed that: 1) Evoked Potentials recorded from the same site, in a single individual, showed marked differences related to the type and intensity of the stimulus used to elicit the response. These differences were seen in recordings from both scalp electrodes and electrodes implanted in the brain. (Evoked Potentials resulting from repeated trials with any one stimulus were found to be stable within individuals.) 2) Any single stimulus activates neurons in many areas of the brain in addition to those in the primary receiving area, and this activity is reflected in the Evoked Potential wave form. In summary, it may be said that each type of stimulus appears to produce a relatively unique Evoked Potential wave form, which is stable within the individual. Differences between the characteristic wave forms of various stimuli are the result, Walter believes, of the

¹⁷ W. Grey Walter, "The Convergence and Interaction of Visual, Auditory and Tactile Responses in Human Nonspecific Cortex", Annals of the New York Academy of Sciences, Vol. 112, Art. 1, May 1964, p. 320-361.

fact that each stimulus activates a different combination of brain centers and neural pathways. On the basis of these and other observations quoted above, it is possible to formulate a theory of Evoked Potentials in relation to information processing in the brain.

The interaction of impulses from various brain centers activated by a given stimulus determines the pattern of post-synaptic potential changes of the single cells in the Evoked Potential recording area. This activity is reflected in both the Evoked Potential and the related spike firing pattern of the single cells. Impulses arriving via direct neural pathways, or from adjacent cortical areas, act first upon the cells in the recording area and, therefore, are reflected in the earlier components of the Evoked Potential. Impulses arising in more widely separated areas and transmitted by more indirect pathways act later upon the cells in the recording area and thus are reflected in the later components. It has been observed that different stimuli produce different, yet stable, Evoked Potential wave forms within the individual. This fact suggests the hypothesis that these wave forms reflect the "codes" by which the brain is able to differentiate between stimuli; the "code" itself being the spatial and temporal interaction of impulses, from the particular combination of brain centers and pathways, activated by the stimulus. If this hypothesis is granted, then it may also be assumed that

the later Evoked Potential components are of greater significance, in terms of the "meaning" attached to stimuli, on the grounds that these components reflect the integration of impulses from more widely distributed brain areas. Intra-individual differences in Evoked Potentials may be attributable to variations in the background activity of the brain centers involved, resulting from a wide variety of causes such as fatigue, illness, attention, etc. Observed differences in the responses of different subjects to the same stimulus may be due to inter-individual differences in the basic structural and physiological properties of the nervous system as a whole.

Due to the extreme complexity of the subject, the foregoing discussion has presented a model of Evoked Potentials which is, necessarily, both over-simplified and incomplete in many areas. Nevertheless, it has been included in an effort to provide a theoretical basis for the connection between Evoked Potentials and information processing activity in the brain. It was felt that no such theory could be acceptable which did not attempt to integrate the recent findings of Fox and O'Brien with those of other writers in the field.

Evidence in support of this theory is to be found in a study by John et al.¹⁸ In this study, in which Evoked Potentials were recorded from cats by means of intra-cranial electrodes, it was noted that there was an alteration in wave shape of the later components as conditioning to a visual CS proceeded. As a further dimension to their experiment, the authors applied disruptive electrical stimulation directly to the brain during the period of the Evoked Potential. They noted that, if the earlier component was interrupted, the CS elicited a correct CR in 59.5 per cent of the trials. If the disrupting stimulus was administered during the later components, only 20.8 per cent of the trials resulted in correct CR's. These results appear to be particularly significant in relation to the hypothesis that it is the later components which are of greatest significance in the process of ascribing meaning to a stimulus.

The ability to differentiate reliably among individuals, on the basis of Evoked Potentials, is demonstrated by the findings of Shagass and Schwartz.¹⁹ Evoked Potentials, in

¹⁸ E.R. John, D.S. Ruchkin, J. Villegas, "Experimental Background: Signal Analysis and Behavioral Correlates of Evoked Potentials in Cats", Annals of the New York Academy of Sciences, Vol. 112, Art. 1, May 1964, p. 362-420.

¹⁹ C. Shagass and M. Schwartz, "Evoked Cortical Potentials and Sensation in Man", Journal of Neuropsychiatry, Vol. 2, 1960, p. 262-270.

response to visual and electrocutaneous stimulation, were recorded from the visual and somatic-sensory areas of fifty-six male and female subjects, using scalp electrodes. It was noted that the components of the Evoked Potentials were highly stable within individuals with respect to latency times and differed markedly between individuals. The correlation for intra-individual consistency was .87, while correlations calculated for the responses of different subjects to the same stimulus approached zero.

These findings are supported by those of Dustman and Beck,²⁰ who obtained recordings from seven adult males, by means of mono-polar electrodes placed four centimeters anterior and lateral to theinion. In all subjects, it was possible to detect eight components, four positive and four negative, occurring in the first 300 milliseconds after stimulation. All these components were observed to be stable within individuals, while those occurring after 300 milliseconds showed greater variability. For components occurring in the first 300 milliseconds, test-retest correlations for each subject showed a median correlation of .68. Correlations calculated for the latencies of different individuals showed a median correlation of .37.

²⁰ Robert E. Dustman and Edward C. Beck, "Long Term Stability of Visually Evoked Potentials in Man", Science, Vol. 142, December 1963, p. 1480-1481.

As early as 1961, Ertl²¹ hypothesized that the shorter the response time of the brain to a light flash, the greater is the efficiency of the organism and, therefore, the higher will be its intelligence. Due to the difficulties involved in identifying the response in a conventional EEG record, the correlation of $-.88$, found in this study, could not be accepted with certainty. In 1965, on the basis of this original idea, plus studies mentioned above, Chalke and Ertl²² hypothesized that:

[...] a biologically efficient organism should process information more rapidly than a less efficient organism and that the delay of components of the evoked potentials is a measure of the efficiency of this process.

With a total sample of forty-eight subjects, using photic stimulation, and a technique of Zero Crossing Analysis for detecting Evoked Potentials, Chalke and Ertl were able to demonstrate a statistically significant difference between the mean latency times of three groups of high, middle and low IQ. It is of interest to note that, in accordance with the findings of John et al., quoted above, this difference in latency times was observed only for the third, fourth and fifth components of the Evoked Potential, and not for the first and second (i.e., the earlier) components.

21 J.P. Ertl, "Intracortical Delay and Intelligence", unpublished Master's thesis presented to the School of Psychology and Education, University of Ottawa, 1961, p. viii-41.

22 F.C.R. Chalke and J. Ertl, "Evoked Potentials and Intelligence", Life Sciences, Vol. 4, 1965, p. 1319-1322.

This section has included evidence which suggests that: 1) Evoked Potentials may be related to information processing activity in the brain, and that the later components are of greater importance as indicators of this process. 2) Evoked Potentials are stable within individuals, and the latency times of the various components may be used to differentiate among individuals. 3) The latency times of the later components are related to psychometric intelligence.

3. Speed, Power and Intelligence: A Theoretical Discussion.

The hypothesis of Chalke and Ertl, quoted in section two, would seem to imply that the observed relationship between Intelligence and Evoked Potential latency is due to a relationship between neurological efficiency and mental efficiency. If this is the case, then speculation arises concerning what sort of mental efficiency is involved. Specifically, it may be asked: 1) Is latency time related to the individual's ability to solve difficult problems accurately? 2) Is latency time related to the speed with which the individual is able to arrive at conclusions, irrespective of the accuracy of those conclusions? In an attempt to answer these questions, it was decided to investigate two factorially complex dimensions of Intelligence, namely, Speed and Power. Before reviewing literature on the

relationship of these dimensions to each other, and to intelligence as a whole, it is necessary to give consideration to the ways in which they may be measured.

As a preliminary definition, the term Power is used to refer to the individual's problem solving ability. Guilford²³ describes a Power test as one in which the items are graduated in difficulty and the subject has sufficient time in which to attempt all items. He refers to Thurstone,²⁴ when he states that the Power of an individual is, "that level of difficulty of tasks at which his probability of success is .50, when given infinite time." In practice, infinite time is all the time the subject will take. Guilford goes on to state that the level of difficulty, or Limit Score, is almost perfectly correlated with the Summation Score, or number of items answered correctly, when the individual has sufficient time in which to attempt all items. Since these two scores may be used interchangeably in correlations with other variables, the Power of an individual may be defined as being his Summation Score in unlimited time. This definition will be adopted in this study.

23 J.P. Guilford, Psychometric Methods, McGraw Hill Book Co., New York, 1954, 2nd Ed., p. 368.

24 L.L. Thurstone, "Ability, Motivation, and Speed", Psychometrika, Vol. 2, 1937, p. 249-254.

As a preliminary definition, the term Speed, considered as a dimension of Intelligence, refers to the rate at which an individual works, irrespective of the accuracy of that work. In the physical sciences, as well as in Psychology, speed in a task is expressed as the number of items, of equal difficulty, completed per unit of time, without regard for accuracy, and is obtained from the formula:

$$S = I / T$$

where I = the total number of items completed
T = the total elapsed time

When defined in this way, Speed may be measured by two methods:

1) The Time Score Method which measures the time taken to complete a fixed number of items; 2) The Work Score Method which measures the number of items completed in a fixed time interval.

The comparison of these two methods will be made easier by considering the example of a test in which all items are of equal difficulty. If five individuals obtain Work Scores of 5, 10, 15, 20 and 25 items in a ten-minute time interval, the corresponding Time Scores, i.e., the times taken by each individual to complete a fixed number of items, say twenty items, will be respectively 40, 20, 13.33, 10 and 8 minutes. Speed Scores calculated from the Work Scores (by means of the formula $S = I/T = I/10$) will be respectively, .5, 1, 1.5, 2 and 2.5 items per minute. Speed Scores calculated

from Time Scores (by means of the formula $S = 1/T = 20/T$) are also found to be respectively, .5, 1, 1.5, 2 and 2.5 items per minute.

On the basis of the above figures, the following observations may be made concerning the Time Score and Work Score Methods, in a test composed of items of equal difficulty:

1. Speed calculated from Work Scores is identical with Speed calculated from Time Scores.
2. Speed is a direct linear function of Work Scores.
3. Speed is an inverse curvilinear function of Work Scores.
4. Time Scores are an inverse curvilinear function of Work Scores.

On the basis of these observations, the following further statements may now be made:

1. If Speed Scores are normally distributed in a sample, the corresponding Work Scores will also be normally distributed. Thus, in a correlation with an outside variable, Work Scores could be used to represent Speed Scores without changing either the magnitude or the sign of the correlation.
2. If Speed Scores are found to be normally distributed in a sample, the corresponding Time Scores will be skewed, and reversed in order of magnitude. If these Time Scores are to be used to represent Speed Scores in a correlation

with an outside variable, they must first be normalized, and the sign of the resulting correlation must be changed.

3. If Time Scores are found to be normally distributed in a sample, the corresponding Speed Scores will be skewed. If these Speed Scores were to be correlated with an outside variable, they would first have to be normalized, or, what amounts to the same thing, the raw Time Scores could be used and the sign of the correlation changed.

In summary, if suitable procedures for normalizing skewed distributions are employed, Time, Work and Speed Scores may be used interchangeably in correlations with outside variables.

The foregoing discussion has shown the relationships between Time, Work and Speed Scores when all test items are of equal difficulty. It remains to be seen what happens to these relationships in a test where the items are graduated in difficulty. Tate²⁵ tested thirty-six high school sophomores, using specially constructed tests composed of items of increasing difficulty. The tests were administered individually, and separate time measurements were recorded for each test item. The individual's Speed on a test was represented by the mean of the times for all items. Simple calculation will show

²⁵ Marie E. Tate, "Individual Differences in Speed of Response in Mental Test Materials of Varying Degrees of Difficulty", Educational and Psychological Measurement, Vol. 5, No. 3, Autumn 1948, p. 353-374.

that the scores obtained in this way are directly proportional to scores obtained by the Time Score Method described above. Tate found that the relative positions of individuals, in terms of Speed, remained the same at all levels of difficulty. Thus, if one subject is twice as fast as another at one level of difficulty, he will still be twice as fast at a higher level of difficulty, although both will take longer to complete the item.

With these findings in mind, an example may now be considered of the Time Score Method used in a test whose items are graduated in difficulty. Four individuals have obtained Speed Scores of 5, 10, 15, and 20 items per minute, on a test in which all items are of uniform difficulty level X. They are then given a second test composed of eight items (measuring the same mental function) in which the first item is also of difficulty level X, and each successive item is twice as difficult as the preceding item. The entries in Table I show the times taken by each individual to complete each test item. The Time Scores in Table I show the total times taken to complete all eight items. The corresponding Speed Scores of .16, .31, .48, and .63 items per minute (from the formula $S = I/T = 8/T$) represent the average number of items completed per minute over the whole test. On the basis of the figures shown in this example, the following general statements may be made:

Table 1.-

An Example of the Time Score Method Applied to a Test with Items Graduated in Difficulty.

Subjects	Test Items								Time Scores
	1 (x)	2 (2x)	3 (4x)	4 (8x)	5 (16x)	6 (32x)	7 (64x)	8 (128x) ^a	
A	.2	.4	.8	1.6	3.2	6.4	12.8	25.6	51.00 min.
B	.1	.2	.4	.8	1.6	3.2	6.4	12.8	25.50 "
C	.06	.13	.26	.52	1.04	2.08	4.16	8.32	16.57 "
D	.05	.1	.2	.4	.8	1.6	3.2	6.4	12.75 "

Cell entries indicate the time taken, in minutes, to complete each item.

^a The difficulty levels of the items.

1. In a test composed of items graduated in difficulty, Speed Scores are an inverse curvilinear function of Time Scores.
2. Speed Scores, calculated from Time Scores in a test of graduated difficulty, are directly proportional to the Speed Scores obtained from a test, of the same function, in which all items are of uniform difficulty.
3. The relationship of Time Scores to Speed Scores is unaffected either by variations in difficulty level, or the number of items in the test.

In summary, the Time Scores obtained from a test of graduated difficulty may be used as before to represent Speed Scores, either from the same test, or from a test in which all items are of uniform difficulty.

The following example illustrates what happens when Work Scores are calculated for the same four subjects, on the same eight item test of graduated difficulty. The entries in Table II show the number of items completed by each subject at the end of each time interval (i.e., the subject's Work Score for that time interval). Speed Scores, calculated for the four subjects, at the ten-minute time interval ($S = I/T = I/10$) are .5, .6, .7 and .7 items per minute. At the fifteen-minute time interval the Speed Scores become respectively ($S = I/T = I/15$) .4, .46, .46 and .53 items per minute. It is immediately apparent from these figures that, in a test

Table II.-

An Example of the Work Score Method Applied to a Test With
Items Graduated in Difficulty.

Subjects	Time Intervals (in minutes)						
	1	3	5	10	15	20	25
A	2	4	4	5	6	6	6
B	3	4	5	6	7	7	7
C	4	5	5	7	7	8	8
D	4	5	6	7	8	6	8

Cell entries indicate the number of items completed by each subject, at the end of each time interval.

of graduated difficulty, neither Work Scores nor the Speed Scores derived from them, differentiate between subjects in the same way at the various time intervals. Furthermore, these scores do not vary in a fixed manner in relation to Work and Speed Scores, derived from a test, of the same function in which all items are of uniform difficulty. It follows, therefore, that in a test in which all items are graduated in difficulty, the Work Score Method cannot be used to estimate the Speeds of the individuals taking the test.

The foregoing discussion of Speed was intended to show that when Speed is to be derived from a test of graduated difficulty, the Time Score Method is to be preferred. The decision to use a graduated test results from the necessity of measuring Speed and Power from the same test. The use of different tests was ruled out on the grounds that confounding variables arising from differences in the test contents would make it impossible to generalize concerning the relationships of Speed and Power to outside variables. This objection might be overcome, at least in part, by the use of alternate forms of the same test. It was felt, however, that if subjects were aware that they were being marked for Speed alone, they would tend simply to guess at the more difficult items without seriously attempting to solve the problems. It is doubtful if Speed Scores obtained in this way could be considered as measures of "Speed-of-Intellectual-Functioning".

However, if subjects are given as much time as they need to attempt all items, and are instructed to work for both speed and accuracy, then Power may be measured by the number of items answered correctly, and Speed may be represented by the times taken to complete all items on the test, irrespective of accuracy. Intelligence, which is a combination of Speed and Power, may also be measured in the same test by the number of items answered correctly in a limited time.

This section has presented theoretical arguments in an attempt to show that Speed and Power, considered as dimensions of Intelligence, can be measured from a single test of graduated difficulty. Furthermore, when using such a test, Speed (defined by the formula $S = I/T$) can best be measured by the use of the Time Score Method. The literature concerning Speed, Power and Intelligence, measured in this way, is limited.

4. Relationships between Speed, Power and Intelligence.

Baxter²⁶ tested one hundred university undergraduates using the Otis SA, Higher Examination, Form A. At the end of twenty minutes, subjects were stopped, given a different

²⁶ Brent Baxter, "An Experimental Analysis of the Contributions of Speed and Level in an Intelligence Test", Journal of Educational Psychology, Vol. 32, No. 4, April 1941, p. 285-298.

colored pencil, and told to complete the test. Speed was defined as the number of minutes taken to complete all seventy-five items on the test, irrespective of accuracy. Power was defined as the total number of items answered correctly, and Intelligence as the number of items answered correctly in twenty minutes.²⁷ The following correlations were obtained: Speed and Intelligence, .75; Power and Intelligence, .62; Speed and Power, -.06. The coefficient of multiple determination for Speed and Power vs. Intelligence was .996. The zero order coefficients of determination for Speed and Power were .56 and .39. Baxter concludes that Speed and Power vary independently and that, between them, they account for virtually all the variance in Intelligence, Speed contributing approximately 60 per cent and Power the remaining 40 per cent.

Davidson and Carrol²⁸ factor analyzed the results from a battery of tests administered to ninety-one psychology undergraduates. Speed, Power and Intelligence scores were obtained for each test in the battery. The operations used to define these variables were the same as those used by Baxter, except for two variations: 1) Subjects worked straight

²⁷ Baxter and other authors quoted below use different terms in referring to these operations. In order to avoid confusion, the words Speed, Power and Intelligence are used in all cases to denote these operations.

²⁸ William M. Davidson and John B. Carrol, "Speed and Level Components in Time Limit Scores: A Factor Analysis", Educational and Psychological Measurement, Vol. 5, No. 4, Winter 1945, p. 411-427.

through the test, attempting each item once, and each subject recorded his own time to complete. 2) After recording his own time, each subject was then allowed to go back and check his answers. The authors found that in all cases Speed Scores were independent of Power Scores and "time limit (i.e. Intelligence) scores could be represented as factorially complex measures having loadings on both speed and level (i.e., Power) dimensions of ability."²⁹ In addition, they found a general speed factor involving nearly all of the separate speed scores obtained from the various tests in the battery.

Tate³⁰ tested thirty-six high school students, using four specially constructed tests of Arithmetic Reasoning, Number Series, Sentence Completion, and Spatial Relations. Each test was composed of three levels of difficulty, and each item of each test was administered and timed separately. Power on a test was defined as the number of items answered correctly. Speed was defined as the mean of the times obtained for all items on the test. Findings showed that Speed and Power were independent at all levels of all tests. The relative standings of individuals in terms of Speed were not affected by changes in difficulty level. However, relative

29 Ibid.

30 Tate, Op. Cit.

standings did vary somewhat between the four tests. Late concludes that there is probably a general speed factor, plus a special speed factor linked to the function in which it is measured.

In this section studies have been cited which indicate that, when obtained from the same test of ascending difficulty, Speed and Power vary independently of each other.

5. Summary and Statement of Hypotheses.

Findings presented in section two above provide a theoretical basis for regarding Evoked Potentials as electrical signs of data processing activity in the brain. It was shown that the latency times of Evoked Potential components are stable within individuals, and differ between individuals. Further, it was hypothesized that inter-individual differences in latency times were indications of differences in the efficiency with which data processing activity is carried on. A study based on this hypothesis indicates that the latency times of Evoked Potential components are related to psychometric intelligence.

In section three, a theoretical discussion was presented which attempted to show that Speed and Power may be derived from the same test, and that when this procedure is adopted, Speed (as defined by the formula $S = I/T$) should be obtained by means of the Time Score Method. Studies

employing this method were reviewed in section four. Findings indicate that Speed and Power are independent and that, between them, they account for nearly all the variance of Intelligence.

If latency is related to Intelligence, and the variance of Intelligence is entirely accounted for by the two independent dimensions of Speed and Power, then it follows that latency must be related to one, and only one, of these two dimensions. There is no direct evidence in the literature to indicate which of these two dimensions, Speed or Power, is related to latency. However, in line with the previously stated theory of data processing activity, it may be hypothesized that the latency of Evoked Potential components is a function of the speed with which impulses travel from the various brain centers involved to the recording site. The faster the transmission of impulses, the shorter would be the time taken for the integration of information and, therefore, the faster the individual will be able to solve problems. Such thinking is doubtless greatly oversimplified. However, it does offer a theoretical basis for hypothesizing that latency is related to Speed rather than to Power.

In order to test this and other theoretical arguments presented in this chapter, four null hypotheses will be tested experimentally. Each of the second, third and fourth null hypotheses will contain four sub-sections which may be considered separately.

1. There is no significant correlation between Speed (represented by Time Scores) and Power Scores.
2. There are no significant correlations between the latency times of the first four components of visually Evoked Potentials (E1, E2, E3 and E4) and Intelligence Scores.
3. There are no significant correlations between the latency times of the first four components of visually Evoked Potentials (E1, E2, E3 and E4) and Power Scores.
4. There are no significant correlations between the latency times of the first four components of visually Evoked Potentials (E1, E2, E3 and E4) and Speed (as represented by Time Scores).

The following chapter describes the experimental procedures used to test these null hypotheses.

CHAPTER II

EXPERIMENTAL DESIGN

This chapter presents the experimental design employed to test the hypotheses of this study. Section one refers to the instrumentation used for detecting and recording Evoked Potentials and discusses the choice of the psychometric tool. Section two describes the sample studied. Section three explains the experimental procedures employed, and section four deals with the methods used in analyzing the obtained data.

1. Tools.

Evoked Potentials from all subjects were recorded from the surface of the scalp. Remonde type, bipolar, saline-pad electrodes were used for the majority of recordings. The last twenty subjects were tested using Lexington Silver-Chloride-Sponge electrodes. The substitution was made because it was found that, with the Lexington electrodes, it was easier to obtain a good contact with the scalp. Repeated tests on one subject showed no difference in the recordings from the two types. Raw EEG activity was amplified by means of a Sandborne Model 55 EEG/ECG pre-amplifier and a Grass Model P.5 AC pre-amplifier connected in series. For all recordings, filters were set 3 DB down at 7 and 100 cycles

per second. This was done because it was found that changes in filter settings, particularly at the upper end of the frequency band, produced changes in the latency times of Evoked Potentials recorded from the same individual. Half second samples of amplified EEG activity immediately following each stimulus were fed to an Enhancetron 1C24 Computer of Average Transients. The Enhancetron digitizes each sample of EEG activity and records the amplitudes of its component wave forms at a number of successive reference points. The amplitudes of all samples are added at each of these points to produce a single wave pattern which is an average of all the EEG samples stored in the computer's memory. Random activity tends to average toward zero, while the Evoked Potentials, which are time-locked to the stimulus, tend to summate and so become readily distinguishable.

The output of the Enhancetron following one hundred stimuli was displayed on the screen of a Tecktronix Model 502, Dual Beam Oscilloscope and permanently recorded by means of a Polaroid Land Camera. The stimulus consisted of very short duration light flashes (of the order of 3 microseconds) generated by a Grass Model PS-2 Photo-stimulator. The stimulus intensity control was set at position 4, except for subjects who showed a marked tendency to blink, in which case it was lowered to position 2. In tests carried out on ten subjects, intensity changes of this magnitude produced no

observable changes in the configurations of Evoked Potentials. The photo-stimulator was connected so that the Enhancetron was triggered by the onset of each light flash. As a result, the start of each recording indicates the point at which the stimuli were administered.

The psychometric measures of Speed, Power and Intelligence were obtained from the Otis SA Test of Mental Ability, Higher Examination, Form A. Form B of the same test was used to establish the reliability of these measures. The discussion of Speed and Power given in the previous chapter points out the need to measure these variables from a single test of graduated difficulty. Since it is the intention of this study to investigate intelligence as a global phenomenon, rather than a composite of "pure" factors, it was felt that a multi-factor test should be used. Finally, if Speed and Power are to be considered in relation to Intelligence, it is necessary to define Intelligence in terms of these two dimensions, i.e., by a Time Limit Score which is the number of correct answers in a limited time. The Otis test not only satisfies all of these requirements, it also enjoys wide acceptance in the field as an overall measure of intellectual functioning.

2. The Sample.

One hundred and two subjects were tested with both the psychometric and neurological tools. Of these, twelve were rejected because their Evoked Potential recordings were not clearly interpretable,¹ and six others were eliminated because of language problems in taking the psychometric and/or because of histories which indicated the possibility of brain damage. The final sample consisted of eighty-four adults, 72 males and 12 females, ranging in age from 18 to 55, with a mean age of 24.9 years and a standard deviation of 8.19. Otis IQ's ranged from 71 to 133, with a mean of 109 and a standard deviation of 15.17. The sample was divided in terms of occupation as follows: 40 high school students in academic or commercial grades 9 and 10 (these were all former school drop-outs who had resumed their education under the program sponsored by the National Employment Service); 18 university undergraduates in divinity and philosophy; 20 graduate students in education; and 6 graduate students in psychology. All subjects were tested with the Otis, Form A and twenty-four were retested for reliability with the Otis, Form B. All subjects were volunteers. The forty high school students were paid \$2.00 per testing session; the remainder offered their services without charge.

¹ See section four, p. 43, for the analysis of Evoked Potential recordings.

3. Experimental Procedures.

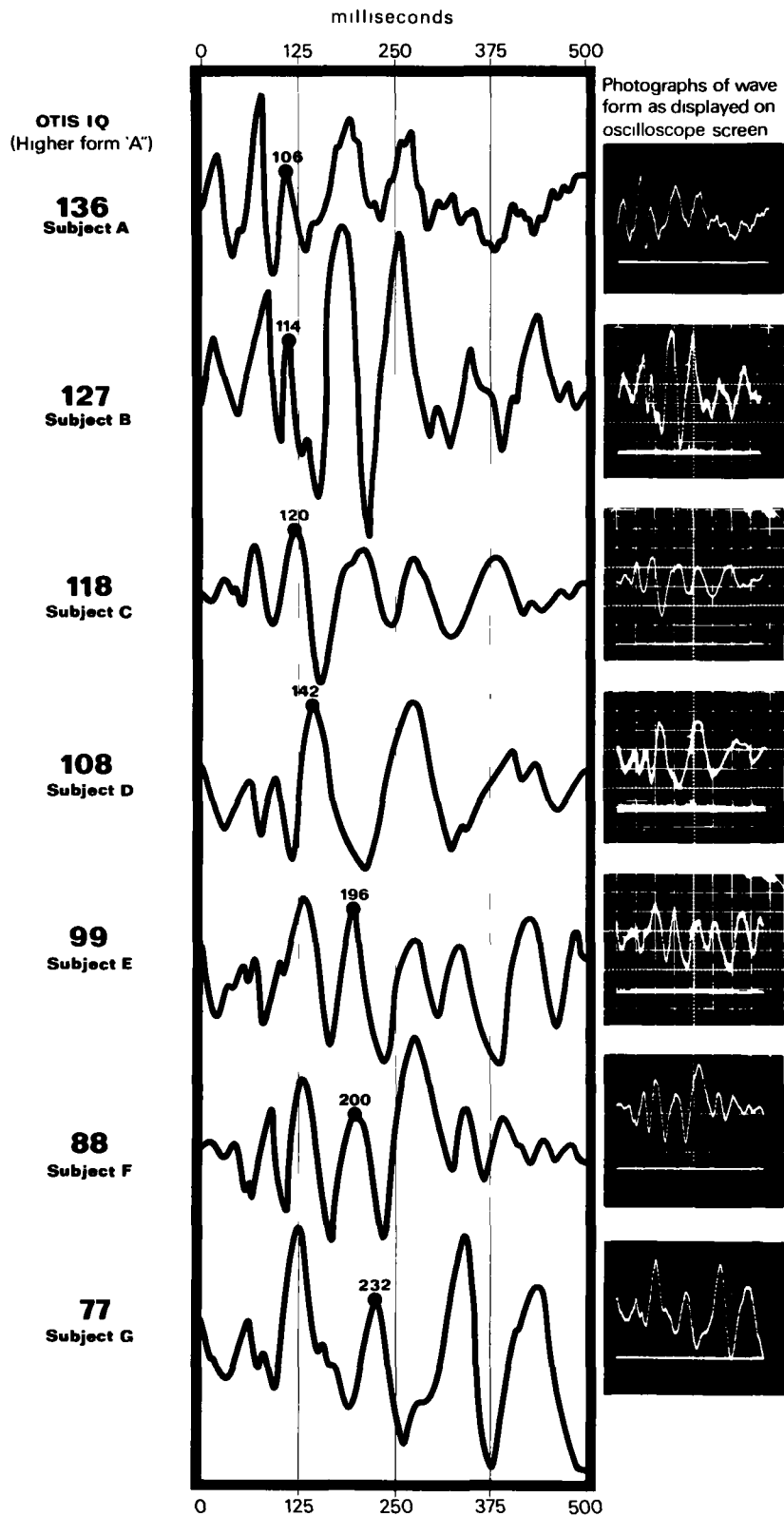
Evoked Potential recordings for all subjects were made by the writer using equipment at the Faculty of Psychology and Education of the University of Ottawa. Bipolar electrodes were placed on the surface of the scalp parallel to, and six centimeters to the right of the mid-sagittal line, and three centimeters on either side of a line joining the centers of the ears. A ground electrode was placed six centimeters below the two live ones. All three electrodes were mounted on a rigid piece of acetate and were held in place by means of a strap passed under the chin. Prior to application of the electrodes, the scalp was prepared with Sandborne Electrode Jelly. The subject was seated in a straight-backed chair, and the stimulus light was positioned level with the eyes and twenty inches from the forehead. Instructions were to relax completely, keeping the eyes open and fixed on the floor, and to avoid blinking as much as possible. The "eyes open" procedure was adapted because it would found that, with eyes closed, many subjects displayed a strong Alpha Rhythm which distorted the Evoked Potential recordings. In some cases, when good contact with the scalp could not be readily obtained, it was necessary to change the subject's position by asking him to rest his elbow on a table and apply pressure to the electrodes with his hand.

A single recording consisted of the average of one hundred light flashes administered in a random sequence with not less than one second between flashes. At least two and sometimes as many as five recordings were made in this way for each subject. A rest period of three to four minutes was given between recordings, while the oscilloscope display was being photographed. The period of analysis was one-half second immediately following the stimulus. In cases where interpretation was difficult, a one-quarter second recording was made in order to show the earlier components more clearly. Figure 1 is a photograph of a display board used to illustrate the type of Evoked Potential records obtained. The Otis IQ's shown were derived from Intelligence Score by means of tables given in the Otis manual.

The psychometric test was administered in groups with no more than twenty-five subjects being tested at one time. Each seat in the room was given a number which was also written on the occupant's test paper. The standard Otis instructions were read to the subjects, with the exception of the last paragraph which refers to time limitations. The following special instructions were then given:

This test contains seventy-five items and you will have as much time as you need to attempt all items. You will be marked for both the speed with which you work, as well as the accuracy of your answers. Make an honest attempt to answer each item, but do not spend too much time on any one item. You are to attempt each item in order. When you

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reach the end of the test, put down your pencil and do not recheck your answers. If you are unable to answer a question, you may leave it blank and go on to the next one. On a number of occasions during the test, I will interrupt you and say: Stop, circle the number of the question you have just completed. After circling the question number, you are to wait until I tell you to begin again. When you have attempted all seventy-five items, hold up your hand and make sure that I notice that you have finished. Remember, do not go back and check your answers. After you have finished, sit quietly and wait until everyone has finished working. Are there any questions? If so, ask now as I will not be able to answer questions during the test.

Subjects were interrupted four times: at 5, 15, 20 and 30 minutes. At each interruption the watch was stopped and started again when the subjects were instructed to recommence working. As each subject finished and held up his hand, his time to complete was noted down opposite his seat number.

The Otis Form B was administered approximately six weeks following the administration of Form A. The same procedure was used on both occasions. By means of this method, it was possible to obtain measures for Speed, Power and Intelligence which are defined as follows:

Speed is defined by the formula $S = I/T$ and is represented by the number of minutes taken to attempt all items on the Otis SA. Test of Mental Ability, Higher Examination, Form A, irrespective of accuracy.

Power is defined as the number of items answered correctly on the Otis SA. Test of Mental Ability, Higher Examination, Form A, when the subject has sufficient time in which to attempt all items.

Intelligence is defined as the number of items answered correctly in a twenty-minute time interval, on the Otis SA. Test of Mental Ability, Higher Examination, Form A.

4. Analysis of Data.

Evoked Potentials were recorded on photographs which show the Time Base of the Enhancetron, as well as the wave form itself. The Time Base which is accurate to ± 0.5 per cent,² was measured for each photograph in order to establish the number of milliseconds represented by each millimeter on that particular photograph. This standard was then used in measuring the latency time of the various components of the Evoked Potential. This procedure was necessary to eliminate errors of measurement arising from fluctuations in the length of the oscilloscope trace caused by fluctuations in line voltage.

Only the first four negative going components of the Evoked Potential, designated E1, E2, E3 and E4, were measured for the purposes of this study.³ It was found that the resolving power of the equipment did not permit the identification of later events with any degree of certainty. In order for a wave to be designated as an "event", i.e., a true component of the Evoked Potential, it had to satisfy the following

² Nuclear Data Inc., "Instruction Manual, Model ND-800, Enhancetron 1024", published by Nuclear Data Inc., Palatine, Ill., 1965, p. 2.

³ Conventional EEG terminology is used here. (i.e., upward deflections of the wave are designated as negative, downward deflections as positive.)

criteria:

1. An "event" must be clearly reproduced on at least two photographs within a range of ± 10 milliseconds for E1, E2, and E3, and within a range of ± 15 milliseconds in the case of E4.
2. An "event" could not be closer than 17 milliseconds to another event; 17 millisecond being the period of line frequency.

Latency times were calculated by measuring from the start of the trace which marks the onset of the stimulus to the peaks of the various components. In cases where the wave was rounded at the top, or double peaked due to the presence of extraneous "noise" in the recording, the center of the peak was estimated by measuring the width of the wave as near the top as possible and finding the center point.

Using these procedures, the known sources of measurement error include: the 0.5 per cent accuracy specification for the Kihancetron itself; errors in measuring the base line; errors in estimating the peak of the wave; errors in measuring the actual latency time. Considering that all measurements were made to the nearest half millimeter, the writer estimates that all of the above factors taken together would produce an error factor of approximately ± 5 milliseconds in calculating latency times. No effort was made to make more precise calculations because it was felt that, in a sample

of eighty-four people, a random error of this magnitude would not have an appreciable effect upon the size of correlations.

In order to reduce the possibility of incorrect identification of "events", all peaks which might be considered to be an "event" were measured by the writer and the latency times were recorded on the photograph. All photographs for all subjects were spread out on tables and subjects were identified by numbers only. Three judges, familiar with work on Evoked Potentials, were then asked to examine the photographs independently of each other, and identify the third "event" for each subject. If a judge was unable to reach a decision, or if one judge disagreed with the others in identifying the third event of an individual, then that individual was eliminated from the sample. Twelve subjects were eliminated in this way. In only six cases out of the final sample of eighty-four did the three judges disagree with the writer's previous identification of E3. The decision of the judges was accepted as final in all cases.

Coefficients of reliability for all four events were obtained by calculating Pearson Product Moment Coefficients of Correlation between the latency times on the first and second photographs of all subjects. A further measure of the intra-individual stability of Evoked Potential latencies was derived from recordings obtained from a single individual

on 101 different days spread over the ten month period in which the experiment was carried out.

The reliabilities of the psychometric measures of Speed, Power and Intelligence were estimated by means of Spearman Rank Correlation Coefficients calculated between the scores of twenty-four subjects on Forms A and B of the Otis SA Test of Mental Ability, Higher Examination.

In order to discover the relationships between Evoked Potential latencies and the psychometric variables, Pearson Product Moment Coefficients of Correlation were calculated between the latencies of each of the four events and the scores for Speed, Power and Intelligence. In these correlations, an individual's "true" latency time for any given event was estimated by the mean of his latency scores for that event across all photographs. Correlation Ratios (η^2_{yx}) were also calculated, and F Tests of Linearity were made for each of the relationships mentioned above, using the formula:

$$F(\text{lin}) = \frac{(\eta^2_{yx} - r^2_{xy}) / (k_x - 2)}{(1 - \eta^2_{yx}) / (N - k_x)}$$

The F tests showed that only the relationships between E3 and Intelligence, and E3 and speed were significantly non-linear. It was found that, by converting the E3 latency scores to common logarithms, these relationships could be made sufficiently linear to permit the use of the Pearson r. In

an attempt to further clarify the relationships under investigation, partial correlations were computed between the latencies of all four events and Speed with Power partialled out, and Power with Speed partialled out.

In order to determine possible effects of the variables of Age and Sex in this study, an examination was made of the differences between the mean latency times of all four events for: 1) two groups differing in sex and matched for age and Intelligence; and 2) for two groups differing as much as possible in age and matched for Intelligence.

This chapter has presented the procedures used to test the experimental hypotheses stated at the end of chapter one. In chapter three the findings of this study are presented and discussed.

CHAPTER III

PRESENTATION AND DISCUSSION OF RESULTS

Section one of this chapter presents findings on the reliability of all variables under study. Section two contains data on the possible effects of age and sex in relation to this sample. Section three presents the correlations obtained between the variables mentioned in the experimental hypotheses. In section four the findings of the study are discussed and suggestions for further research are offered in section five. The final section contains a brief summary and statement of conclusions.

1. Reliability of Psychometric and Neurological Variables.

The reliability of the psychometric measures of Speed, Power and Intelligence was estimated by means of Spearman Rank Correlation Coefficients. The obtained coefficients were: Speed, .93; Power, .94; Intelligence, .93. The reliability coefficient of .93 obtained for intelligence scores on Forms A and B closely approximates the correlation of .917 given in the Otis manual¹ for the relationship between IQ scores on the same two forms.

¹ Arthur S. Otis, Otis Self-Administering Test of Mental Ability: Manual of Directions and Key (Revised) for Intermediate and Higher Examinations, Harcourt Brace and World, New York, 1928, p. 12.

Pearson Coefficients of Correlation were calculated for the reliabilities of all four Evoked Potential components using the first two photographs recorded for each subject. The obtained Reliability Coefficients were: E1, .85; E2, .93; E3, .99; E4, .97. These figures show the reliability of Evoked Potential latencies recorded on a single occasion without removing the electrodes. The day-to-day variability of the latencies of all four components in a single subject over ten months is shown by the figures in Table III.

The Reliability Coefficients obtained for all variables are significant above the .01 level of probability. The presence of stimulus induced artifacts observed at the beginning of some Evoked Potential records may account for the lower reliability of E1 in relation to the later components. The figures in Table III show that day-to-day variability is roughly the same for the first three components, while the variability of E4 is more than twice as great. These findings agree well with the statement by Dustman and Beck² that the earlier components show greater intra-individual stability. It should be noted, however, that these authors consider that a significant increase in variability occurs only in events appearing 300 milliseconds or more after the stimulus.

² Robert E. Dustman and Edward C. Beck, "Long Term Stability of Visually Evoked Potentials in Man", Science, Vol. 142, December 1963, p. 1480-1401.

Table III.-

The Variability of Evoked Potential Latency Times^a Recorded
from a Single Subject, on 101 Days, over a Ten Month
Period.

Events	Range	M	σ_M	σ
E1	11 - 32	22	.41	4.14
E2	63 - 81	74	.39	3.88
E3	106 - 129	116	.47	4.71
E4	177 - 217	196	.97	9.69

^a Measured in milliseconds.

2. Effects of Age and Sex.

The figures in Tables IV and V were calculated in order to determine if the variables of age and sex were affecting the latency times obtained in this sample. In Table V, a greater difference between the mean ages of the two groups could not be obtained because the sample is relatively homogeneous in terms of age, with only twelve subjects older than thirty years. A t-test calculated for significance of the difference between the means of the E4 latency times of the two age groups in Table V was not found to be significant. All other differences were found to be within the estimated error of measurement. These figures indicate that age and sex are not relevant variables affecting latency times recorded in this sample.

3. Relationships between Psychometric and Neurological Variables.

Pearson Correlation Coefficients were calculated between all variables mentioned in the experimental hypotheses. The correlations obtained between the psychometric variables Speed, Power and Intelligence were: Intelligence and Power, .95; Intelligence and Speed, $-.58$; Speed and Power, $-.48$.³

³ Time scores were used to represent Speed (defined by the formula $S = 1/T$) in correlations with other variables. Positive correlations were obtained and their signs were reversed for reasons given in the Review of the Literature, p.20-21.

Table IV.-

Differences in the Mean Latency Times^a of Males and Females
Matched for Age and Intelligence.

Groups	N	Mean Age	Mean Intelligence	Mean Latencies			
				E1	E2	E3	E4
Males	10	28.3	43.0	46	89	142	212
Females	10	30.4	44.0	47	91	146	210
Differences		1.6	0.2	1	2	4	2

^a Measured in milliseconds.

Table V.-

Differences in the Mean Latency Times^a of Two Age Groups
Matched for Intelligence.

Groups	N	Age Range	Mean Age	Mean Intelligence	Mean Latencies			
					E1	E2	E3	E4
Older	10	55-33	44.3	49.7	37	81	128	196
Younger	10	22-18	19.9	49.8	40	76	125	186
Differences			24.4	0.1	3	5	3	10

^a Measured in milliseconds.

All correlations are significant above the .01 level of probability. The correlation of $-.48$ found between Speed and Power is not in accordance with the findings quoted in the Review of the Literature which indicate that Speed and Power vary independently of each other. The first null hypothesis, there is no significant correlation between Speed, represented by Time Scores, and Power Scores, is therefore rejected. Further discussion of the relationships obtained between Speed, Power and Intelligence will be given in the following section.

The obtained correlations between Speed, Power and Intelligence and the first four Evoked Potential components are given in Table VI. All correlations are significant above the .01 level of probability. The second, third and fourth null hypotheses stated on page 32 of the Review of the Literature are therefore rejected. These findings do not support the original hypothesis that one, and only one, of the variables, Speed and Power, would be related to Evoked Potential latency times. This hypothesis was based upon the expectation that Speed and Power were independent variables, which is not the case in this study.

In an attempt to clarify the relationships between psychometric and neurological variables, Partial Correlations were computed between all four Evoked Potential components and Power, with Speed partialled out, and Speed with Power partialled out. These correlations are shown in Table VII. Power, with

Table VI.-

Correlations^a between Evoked Potential Latency Times and Psychometric Variables. (N=84)

Psychometric	Evoked Potential Components			
	E1	E2	E3	E4
Intelligence	-.42	-.65	-.68	-.64
Power	-.37	-.63	-.66	-.62
Speed	-.31	-.41	-.45	-.43

^a Pearson Product Moment Coefficients of Correlation.

Table VII.-
 Partial Correlations between Evoked Potential Latency Times and
 Speed and Power.

Psychometric	Evoked Potential Components			
	E1	E2	E3	E4
Power (with Speed out)	-.27	-.53	-.55	-.52
Speed (with Power out)	-.16	-.16	-.19	-.18

Speed partialled out, is significantly correlated with all four components (the correlation with E1 is just significant at the .01 level of probability). None of the correlations with Speed, with Power partialled out, is significant at the .01 level. These findings do not support the general hypothesis that the latency of Evoked Potentials is related to Speed rather than Power.

4. Discussion of Results.

As stated above, the correlations obtained between the psychometric variables are not in agreement with the findings quoted in the Review of the Literature, in particular the findings of Baxter.⁴ Of special interest is the fact that Speed and Power were not found to be independent. A possible explanation of this fact is suggested by the very high correlation, .95, obtained between Power and Intelligence. The virtual identity between these variables means that, if Speed is related to Intelligence, it must also be related to Power. The high correlation between Power and Intelligence may result from faults in the instructions which caused subjects to concentrate on Speed rather than accuracy, and did not permit them to go back and check their answers. It should

⁴ Brent Baxter, "An Experimental Analysis of the Contributions of Speed and Level in an Intelligence Test", Journal of Educational Psychology, Vol. 32, No. 4, April 1941, p. 285-296.

also be noted, however, that none of the authors who found Speed and Power to be independent, sampled the full range of IQs in their studies. It may be that in a sample such as the present one, which contains both extremes of the IQ range, Speed and Power are not in fact independent. Unfortunately, the high correlation obtained between Intelligence and Power makes it impossible to resolve the question on the basis of this data.

The highly significant correlations obtained between Intelligence and the latency times of all four Evoked Potential components clearly support the original work of Chalke and Ertl⁵ in this area. The relatively lower correlation between E1 and Intelligence would seem to support the hypothesis of John et al.⁶ that it is the later components which are of greatest significance, in terms of data processing activity in the brain. However, this interpretation must be accepted with caution due to the possibility that the position of E1 may have been influenced in some records by the presence of stimulus artifacts. The fact that Chalke and Ertl did not find a relationship between IQ and the latency times of the

⁵ F.C.R. Chalke and J. Ertl, "Evoked Potentials and Intelligence", Life Sciences, Vol. 4, 1965, p. 1319-1322.

⁶ E.R. John, D.S. Ruchkin and J. Villegas, "Experimental Background: Signal Analysis and Behavioral Correlates of Evoked Potentials in Cats", Annals of the New York Academy of Sciences, Vol. 112, Art. 1, May 1964, p. 362-420.

first two components may be due to the fact that his sample was skewed toward the high end of the IQ range. Once again, this interpretation is by no means certain.

The findings on Speed and Power are not clear for the reasons stated above. However, the Partial Correlations shown in Table VII indicate that Speed is not of great importance in determining the relationship between latency and Intelligence. This finding in no way contradicts the basic theory that Evoked Potential latencies are related to data processing activity in the brain. At the same time, this theory is not sufficiently developed to offer an explanation for the observed relationship between latency and Power. The answer to this question must await further research.

As indicated above, the findings of this paper support the conclusion of Chalke and Srtl that Evoked Potential latency is related to intelligence. Both of these papers may also be considered to support the basic hypothesis that Evoked Potentials are related to data processing activity in the brain on the grounds that such activity is an essential component of intellectual functioning in general. In the first chapter of this thesis an attempt was made to give credence to the hypothesis that Evoked Potentials are related to data processing activity by offering a theoretical explanation of how this connection might come to exist. While the findings of this thesis may be said to support the basic hypothesis, they

cannot be regarded as a vindication of the theoretical explanation itself. In order to test this theory directly, further research will be required. Suggestions for such research are offered in the following section.

. . . Suggestions for Further Research.

The theory, proposed in the first chapter, states that the Evoked Potential wave form is determined by the pattern of post-synaptic/dendritic potential changes occurring in the single cells of the recording area. This pattern of potential changes is, in turn, determined by the spatial and temporal interaction of impulses arriving from the various brain areas activated by the stimulus. This pattern of interaction is thought to be unique for each stimulus and is hypothesized to be the "code" by which the brain is able to distinguish between stimuli. Disruption of this "code" might be expected to produce both perceptual/cognitive changes and concomitant Evoked Potential changes. Changes in the Evoked Potential might occur, not only in latency, but also in a number of other variables such as amplitude, frequency, etc. not studied in the present paper.

Such changes might be induced in a number of ways. First, in animals the pattern of neuronal interaction might be altered by the surgical destruction of specific, stimulus related, brain areas. The same surgical procedures performed

on a number of animals might yield behavioral changes which would show a significant correlation with Evoked Potential changes.

Secondly, if drugs could be found which are known to act only upon certain brain centers and not on others, then it might also be expected that a correlation would be found in humans between Evoked Potential and perceptual/cognitive changes.

Again in humans attempts might be made to relate perceptual and other variables in intellectual functioning to Evoked Potential changes preceding and following leucotomy and lobotomy operations.

Finally, it has been theorized that the dramatic changes in perceptual and cognitive functioning produced by psychedelic drugs, notably LSD-25, result from drug-induced alterations in the normal patterns of neuronal transmission in the brain.⁷ A study by Rodin and Luby⁸ indicates that LSD causes a shortening of the latency and a decrease in the amplitude of Evoked Potential components. An experiment which related these variables to specific, quantifiable, perceptual

⁷ Albert A. LaVerne, "Compendium of Neuropsychopharmacology: Psychotomemetic Drugs", Journal of Neuropsychiatry, Vol. 4, No. 1, October 1962, p. 63-67.

⁸ E.A. Rodin and E.D. Luby, "The Effects of Some Psychosomemetic Agents on Visually Evoked Responses and Background EEG", Electroencephalography and Clinical Neurophysiology, (Society Proceedings), Vol. 19, No. 3, September 1965, p. 319.

changes produced by LSD might provide results valuable both for the understanding of the drug action itself, as well as providing additional support for the theory of data processing activity.

It must be added, however, that all the experiments suggested above can serve only to make the proposed data processing theory more probable as an explanation. Truly direct evidence in its support can be supplied only by advances in neurology which will permit the examination and detailed mapping of the brain centers and pathways themselves.

The Partial Correlations computed in this study indicate that the latency times of Evoked Potentials are related primarily to Power in Intelligence. This finding suggests that significant results may be obtained by investigating the relationships between latency and a variety of "pure factor" components of Power, such as abstract reasoning, verbal and arithmetic reasoning, etc. In particular, it would be of interest to discover the relationship of latency to Spearman's "g" factor.

In addition to work with Evoked Potentials, the findings of this study suggest the need for further work on the relationship of Speed to Power. If difficulties arising from the instructions could be eliminated, and a full range of intelligence were tested, it should be possible to arrive at more definite conclusions.

SUMMARY AND CONCLUSIONS

The present study was an attempt to support the findings of Chalke and Ertl on the relationship between psychometric intelligence and the latency of components of human Evoked Potentials. Secondly, an attempt was made to extend these findings by examining the relationship of Evoked Potential latency to two dimensions of Intelligence, namely, Speed and Power.

Literature was presented in support of the hypothesis that Evoked Potentials are related to information processing activity in the brain. Of particular interest in this connection was a study on the relationship of Evoked Potential latency to psychometric intelligence. Problems in the measurement of Speed and Power were discussed and evidence was presented which indicated that these variables are independent of each other and, furthermore, that between them they account for all the variance of Intelligence.

On the basis of these studies it was hypothesized that the latencies of the first four Evoked Potential components are related to Intelligence. Secondly, it was hypothesized that Speed and Power are independent dimensions of Intelligence. Finally, it was hypothesized that Evoked Potential latencies would be related to Speed and not to Power. In an attempt to answer the questions raised in this way, four null hypotheses were tested experimentally.

Pearson Product Moment Coefficients of correlation were used to discover the relationships between the variables mentioned in the hypotheses. Results showed a relationship between Evoked Potential latencies and Intelligence, significant above the .01 level of probability. It is felt that these findings lend support to the earlier work done by Chalke and Ertle in this area. Contrary to evidence given in the literature, a significant correlation was found between Speed and Power. Because of this finding, the relationships of Speed and Power to Evoked Potential latencies could not be clearly evaluated. In an attempt to overcome this difficulty, Partial Correlations were computed between the latencies of the first four Evoked Potential components and Power, with Speed partialled out, and Speed with Power partialled out. These correlations indicate that latency is related to Power and not to Speed.

Suggestions have been made for further research on relationships between Evoked Potentials and other factors of intelligence, and also to other perceptual variables. In addition, it has been suggested that further work is needed to clarify the relation of Speed to Power.

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Amassian, V.E., H.J. Waller and J. Macy, Jr., "Neural Mechanism of the Primary Somatosensory Evoked Potential", Annals of the New York Academy of Sciences, Vol. 112, Art. 1, 1964, p. 9-32.

The conclusions of this study indicate that Evoked Potentials result from activity in many different brain centers. A valuable contribution to the understanding of possible origins of Evoked Potentials. It is used here to provide theoretical support for the relation of Evoked Potentials to data processing activity in the brain.

Baxter, Brent, "An Experimental Analysis of the Contributions of Speed and Level in an Intelligence Test", Journal of Educational Psychology, Vol. 32, No. 4, April 1941, p. 285-296.

This study provides evidence that Speed and Power are independent, when both are measured on the Otis Test of Mental Ability. The operational definitions used in the present work are essentially the same as those given by Baxter.

Bickford, Reginald G., James L. Jacobson, D. Thane and R. Cody, "Nature of Average Evoked Potentials to Sound and Other Stimuli in Man", Annals of the New York Academy of Sciences, Vol. 112, Art. 1, May 1964, p. 204-223.

A paper suggesting that Evoked Potentials are mainly due to cranial muscle potentials. The weight of opinion in the literature opposes this conclusion.

Chalke, F.C.R. and J. Ertl, "Evoked Potentials and Intelligence", Life Sciences, Vol. 4, 1965, p. 1319-1322.

This paper is a pioneer work of great importance to psychology and is the main basis of the present study. The results which demonstrate a relationship between Evoked Potentials and psychometric intelligence are weakened by the very small number of low IQ subjects studied.

Davidson, William and John B. Carroll, "Speed and Level Components in Time Limit Scores: A Factor Analysis", Educational and Psychological Measurement, Vol. 5, No. 4, Winter 1945, p. 411-427.

Further evidence for the independence of Speed and Power in Intelligence. Complete understanding of this paper requires a thorough knowledge of factor analytic theory.

Lawson, G.D., "Cerebral Responses to Electrical Stimulation of Peripheral Nerve in Man", Journal of Neurology, Neurosurgery and Psychiatry, Vol. 10, 1947, p. 134-140.

The pioneer work on Evoked Potentials. Of interest mainly in terms of historical background.

-----, "A Summation Technique for the Detection of Small Evoked Potentials", Electroencephalography and Clinical Neurophysiology, Vol. 6, 1954, p. 63-84.

Although the technique described has been superceded by more modern methods, it provides the basis for most of the work now being done in this field. This paper is essential for a complete understanding of Evoked Potentials.

Domino, Edward and Guenter Corssen, "Visually Evoked Responses in Anesthetized Man with and without Muscle Paralysis", Annals of the New York Academy of Sciences, Vol. 112, Art. 1, May 1964, p. 226-237.

An experiment designed to test the findings of Bickford et al. The findings oppose those of Bickford, but conclusions are weakened by a lack of suitable controls.

Lustman, Robert E. and Edward C. Beck, "Long Term Stability of Visually Evoked Potentials in Man", Science, Vol. 142, December 1963, p. 1480-1481.

This article provides evidence for the intra-individual stability of Evoked Potentials. Results would carry more authority if a larger sample had been used.

Edwards, Henry P., "EEG and WAIS Intelligence in a Sample of Cultural-Familial Deficients", unpublished Master's thesis presented to the Faculty of Psychology and Education, University of Ottawa, 1965, vii-47 p.

This well designed study yielded no statistically significant results. A further example of the difficulty of finding relationships between test intelligence and conventional EEG variables.

Ertl, J.P., "Intracortical Delay and Intelligence", unpublished Master's thesis presented to the School of Psychology and Education, University of Ottawa, 1961, viii-41 p.

This thesis represents a first attempt to relate intelligence to evoked responses in the brain, and serves as background material for the paper of Chalke and Ertl. Due to problems in the analysis of EEG recordings, the findings of this study must be accepted with caution.

Ertl, J.P., "Detection of Evoked Potentials by Zero Crossing Analysis", Electroencephalography and Clinical Neurophysiology, Vol. 18, 1965, p. 630-631.

This is a technical article which describes in greater detail the method of Evoked Potential detection used in the study by Chalke and Ertl.

Fox, Stephen S. and James H. O'Brien, "Duplication of Evoked Potential Wave Form by Curve of Probability of Firing of a Single Cell", Science, Vol. 147, February 1965, p. 886-890.

A well designed and ingenious experiment of great importance to the understanding of Evoked Potentials in relation to single cell activity. No theory of the nature and origin of Evoked Potentials can afford to ignore this work.

Guilford, J.P., Psychometric Methods, McGraw Hill Book Co., New York, 1954, 2nd Edition, 597 p.

Only the portion concerned with the measurement of Speed and Power was referred to in the present study. This portion defines Power in terms of Limen scores and shows their identity with summation scores.

John, E.R., D.S. Ruchkin and J. Villegas, "Experimental Background: Signal Analysis and Behavioral Correlates of Evoked Potentials in Cats", Annals of the New York Academy of Sciences, Vol. 112, Art. 1, May 1964, p. 362-420.

A very important article which provides experimental evidence in support of the theory that Evoked Potentials are related to data processing activity in the brain.

LaVern, Albert A., "Compendium of Neuropsychopharmacology: Psychometric Drugs", Journal of Neuropsychiatry, Vol. 4, No. 1, October 1962, p. 63-67.

A list of drugs and their effects. The theory of LSD action is stated without support as being the "commonly accepted" view.

Rodin, E.A. and E.D. Luby, "The Effects of Some Psychometric Agents on Visually Evoked Responses and Background EEG", Electroencephalography and Clinical Neurophysiology, (Society Proceedings), Vol. 19, No. 3, September 1965, p. 319.

This is a brief report of a paper. The study involved only a small sample and is valuable mainly for its implications for further research.

Schafer, E., "The Effects of Methamphetamine HCl on Human Evoked Cortical Potentials", a study carried out at the Faculty of Psychology and Education, University of Ottawa, 1966, submitted for publication to Science.

This study indicates that certain drugs act selectively to change the latency of some but not all Evoked Potential components. The findings may be interpreted as supporting the conclusions of Uttal and Cook.

Shagass, C. and M. Schwartz, "Evoked Cortical Potentials and Sensation in Man", Journal of Neuropsychiatry, Vol. 2, 1960, p. 262-270.

This article provides evidence of intra-individual consistency and inter-individual differences in the latencies of Evoked Potentials.

Tate, Merle E., "Individual Differences in Speed of Response in Mental Test Materials of Varying Degrees of Difficulty", Educational and Psychological Measurement, Vol. 8, No. 3, Autumn 1948, p. 353-374.

A very well designed and carefully carried out study which shows the independence of Speed and Power in various tests of graduated difficulty. These findings are important in providing a justification for the use of a test of graduated difficulty in the present study.

Uttal, William and Louella Cook, "Systemics of the Somatosensory Cortical Potential: A Psychophysical-Electrophysiological Comparison", Annals of the New York Academy of Sciences, Vol. 112, Art. 1, May 1964, p. 60-80.

This paper demonstrates changes in Evoked Potentials in relation to psychophysical states and suggests, without actually proving, that particular Evoked Potential components are the result of activity in different neural pathways. A good study which forms part of the theory that Evoked Potentials are related to data processing activity in the brain.

Vogel, William and Donald M. Broverman, "Relationship Between EEG and Test Intelligence: A Critical Review", Psychological Bulletin, Vol. 62, No. 2, August 1964, p. 132-144.

A very comprehensive review of the literature which includes earlier reviews as well as more recent studies in this area. It is quoted here to show the need for a different approach to the problem of relating brain activity to intelligence.

Walter, W. Grey, "The Convergence and Interaction of Visual Auditory and Tactile Responses in Human Nonspecific Cortex", Annals of the New York Academy of Sciences, Vol. 112, Art. 1, May 1964, p. 320-361.

A very complicated study valuable mainly for its theoretical contributions to the understanding of many aspects of Evoked Potentials. In the present study it provides part of the theoretical chainlinking Evoked Potentials to data processing activity in the brain.

APPENDIX 1

PSYCHOMETRIC DATA (OTIS, FORM A)

APPENDIX 1

PSYCHOMETRIC DATA (OTIS FORM A)

Subject ^a	Sex	Age	Speed ^b	Power	Intelligence	Otis IQ ^c
1	M	29	39	34	24	89
2	F	22	38	49	38	107
3	M	18	37	27	19	82
4	M	24	31	26	23	88
5	M	23	35	65	53	123
6	M	35	37	56	42	112
7	M	19	50	37	24	89
8	F	25	19	50	50	121
9	F	22	25	71	62	129
10	F	23	46	25	16	76
11	F	23	43	45	34	102
12	M	24	50	54	39	108
13	M	27	21	73	69	132
14	M	33	21	62	58	127
15	M	26	59	44	31	98
16	M	24	44	43	32	99
17	M	20	32	51	37	106
18	M	25	27	70	56	127
19	M	22	53	40	30	97
20	M	27	34	64	51	122
21	M	21	39	53	39	108
22	F	50	27	51	47	118
23	F	30	21	74	71	133
24	F	48	27	65	62	129
25	F	26	19	71	71	133
26	M	21	50	21	16	78
27	M	25	43	36	27	93
28	M	50	27	67	56	126
29	M	20	30	69	52	122
30	M	42	28	70	58	127
31	M	19	30	42	39	108
32	M	16	35	34	27	93
33	M	18	24	19	17	80
34	M	26	25	55	47	118
35	M	18	58	53	32	99
36	M	18	32	67	50	121
37	M	24	55	36	22	86
38	F	25	33	26	22	86
39	M	19	26	57	53	123
40	M	19	32	27	24	89

Subject	Sex	Age	Speed	Power	Intelligence	Otis IQ
41	M	20	44	30	24	89
42	M	23	34	51	43	113
43	M	22	34	37	33	101
44	M	20	28	60	54	124
45	M	18	33	64	42	112
46	M	22	34	61	48	119
47	F	28	37	54	39	108
48	F	20	30	54	45	116
49	M	31	26	65	28	127
50	F	29	47	57	40	109
51	M	20	38	64	42	112
52	M	20	26	70	19	128
53	M	19	39	54	40	109
54	M	23	47	51	38	107
55	M	19	36	47	36	104
56	M	24	26	65	27	126
57	M	46	30	50	46	117
58	M	27	47	53	34	102
59	M	21	33	61	46	117
60	F	15	13	32	26	91
61	F	19	37	61	44	114
62	F	39	32	67	33	123
63	F	19	28	67	54	124
64	M	23	11	32	22	36
65	M	21	26	61	13	123
66	M	19	33	15	10	71
67	M	26	31	43	37	106
68	M	27	26	69	61	129
69	M	23	20	62	62	129
70	M	18	31	47	40	109
71	M	18	34	57	47	116
72	M	17	42	42	36	104
73	M	21	41	57	39	100
74	M	23	37	53	38	107
75	M	22	32	40	41	111
76	M	18	33	59	41	111
77	M	21	46	52	34	102
78	F	20	35	26	23	88
79	F	18	29	49	43	113
80	M	21	23	64	59	128
81	M	22	28	57	48	119
82	F	45	48	69	49	120
83	M	20	34	43	37	106
84	M	18	12	50	33	101

Subject	Sex	Age	Speed	Power	Intelligence	Otis IQ
N: 472)						
F: 12)	♂					
A		24.9	35.5	51	41.4	109
σ		8.2	9.75	14.5	13.75	15.17
Range		10-59	19-59	15-74	10-71	71-133

a Filing order of Evoked Potential Photographs at Faculty of Psychology and Education.

b Actually the Times Scores, i.e., number of minutes to complete all items.

c Calculated from twenty-minute Time Scores using adult norms in Otis manual.

APPENDIX 2

PSYCHOMETRIC DATA (OTIS FORM B)

APPENDIX 2

PSYCHOMETRIC DATA (OTIS, FORM B)

Subject	Speed	Power	Intelligence	Otis IQ
7	46	42	23	88
10	46	25	16	78
12	48	22	30	97
13	19	73	73	133
14	20	60	60	128
15	49	38	26	91
16	38	47	41	111
19	44	39	25	90
23	20	71	71	133
25	19	67	67	132
27	40	44	27	93
28	25	66	28	127
31	37	49	33	101
32	43	32	27	93
41	40	26	17	80
42	35	46	31	98
53	30	51	43	113
58	41	52	35	103
60	53	34	20	84
61	38	62	41	111
70	30	50	43	113
71	26	51	47	118
83	30	41	34	102
84	52	47	33	101
N: (M=23) F= 1) 24				
M	36.2	40.5	38.4	105
σ	10.5	12.9	16.3	16.61
Range	19-53	21-73	16-73	78-133

APPENDIX 3

EVOLED POTENTIAL LATENCIES

APPENDIX 3

EVOKED POTENTIAL LATENCIES^a

Subject	E1	E2	E3	E4
1	65	92	184	268
2	47	103	145	184
3	40	123	209	283
4	40	89	130	196
5	59	106	150	187
6	52	84	133	227
7	33	65	141	196
8	46	80	121	160
9	31	54	111	200
10	61	132	207	357
11	76	146	228	297
12	57	98	141	273
13	51	97	130	171
14	28	85	114	184
15	84	116	153	187
16	58	135	197	266
17	58	109	147	181
18	53	94	142	189
19	42	89	146	199
20	16	67	106	151
21	23	50	105	186
22	36	87	129	201
23	25	65	118	193
24	38	74	122	185
25	32	66	118	191
26	67	126	218	362
27	39	81	136	187
28	36	96	150	198
29	39	80	113	154
30	32	69	132	215
31		92	130	206
32	36	71	124	183
33	50	117	199	275
34	67	101	127	198
35	38	112	151	199
36	54	59	114	157
37	65	122	230	292
38	66	90	186	275
39	36	85	123	194
40	69	123	225	304

EVOKED POTENTIAL LATENCIES

Subject	E1	E2	E3	E4
41	42	121	175	232
42	18	93	146	219
43	24	92	129	201
44	30	65	112	153
45	60	85	147	194
46		50	96	146
47	35	85	159	222
48	39	101	158	256
49	23	76	117	207
50	67	94	139	184
51	62	94	124	
52	57	87	113	147
53	41	96	140	210
54	56	113	153	232
55	56	113	179	261
56	27	69	103	162
57	42	80	145	194
58	28	97	179	279
59	28	81	131	233
60	37	77	136	202
61	28	67	129	232
62	35	53	118	174
63	36	76	125	166
64	59	117	212	289
65	57	82	118	180
66	67	144	262	345
67	54	95	135	177
68	28	84	131	199
69	61	92	134	179
70	35	78	129	264
71	25	68	119	203
72	39	96	165	231
73	50	113	149	271
74	34		126	198
75		79	123	220
76	43	83	151	196
77	62	111	144	184
78			118	194
79	43	55	118	175
80	50	82	117	182
81	35	89	151	197
82	32	63	101	178
83	67	122	181	255
84	51	92	149	245

Subject	E1	E2	E3	E4
N: M=72) F=12) 84				
M	46	94	145	213
σ	15.59	21.35	33.57	48.27
Range	16-84	34-146	96-262	146-357

APPENDIX 4

ABSTRACT OF

Evoked Potential Latencies and Psychometric Intelligence

APPENDIX 4

ABSTRACT OF

Evoked Potential Latencies and Psychometric Intelligence¹

There is evidence in the literature to suggest that Evoked Potentials are related to information processing activity in the brain. Of special interest in this connection is the work of Chalke and Ertl which shows a relationship between test intelligence and the latency times of visually Evoked Potentials. This paper has two objectives, the first of which is to re-examine the relationship revealed by Chalke and Ertl. Secondly, it is hoped that these findings may be extended by investigating the possible relations of Evoked Potential latencies to two factorially complex dimensions of intelligence, namely, Speed and Power. In connection with this second objective, it was hypothesized that Speed and Power vary independently of each other when derived from the same test of graduated difficulty. Furthermore, it was hypothesized that Evoked Potential latencies are related to Speed, and not to Power.

The psychometric measures of Speed, Power and Intelligence were derived from a single administration of the Otis Test of Mental Ability, Higher Examination, Form A, given with

¹ Neville A. Taylor, Master's thesis presented to the Faculty of Psychology and Education of the University of Ottawa, Ontario, 1966, ix-76 p.

special instructions. Evoked Potentials, in response to visual stimulation, were detected by means of an Enhance-tron 1024 computer of average transients. For the purposes of this study, only the first four negative components were measured to determine their latency times. The sample consisted of eighty-four adults ranging in Otis IQ from 71 to 133.

The results of this study show correlations significant above the .01 level of probability between Evoked Potential latencies and overall Intelligence Scores on the Otis. These findings are considered to provide direct support for the work of Chalke and Krtl. A significant correlation was also found between Speed and Power with the result that the null hypothesis of no significant correlation between these variables could not be rejected. Because of the existence of this correlation, the relationships of Speed and Power to Evoked Potential latencies could not be evaluated with certainty. However, Partial Correlations computed between Evoked Potential latencies and Speed, with Power partialled out, and Power with Speed partialled out, indicate that latency is related to Power and not to Speed.

It is felt that these findings not only demonstrate a relationship between Evoked Potential Latency and overall test intelligence, but also show promise that future research on the relations of Evoked Potentials to the "pure factor" components of Power will yield positive results.