Individual Differences in Intelligence: Event-Related Potentials Recorded Concurrently with Reaction Time Tasks

by

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"Tell me, and I'll forget.

Show me, and I may not remember.

Involve me,

and I'll understand."

Native American saying

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CURRICULUM STUDORIUM

Patricia Ann McGarry-Roberts was born in Sault Ste. Marie, Ontario on July 21st 1962. In April 1986 she completed her Honours B.A. in Psychology at the University of Ottawa. Her graduate studies began immediately at Ottawa University in May 1986 and were supported by the Natural Science and Engineering Research Council and the University or Ottawa Merit Scholarship.

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Stelmack, R. M., Houlihan, M., and McGARRY-ROBERTS, P.A., Personality, reaction-time and event related potentials. Journal of Personality and Social Psychology. (in press).

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ABSTRACT

Event-related potentials (ERPs) and reaction time (RT) were recorded concurrently during the performance of six simple cognitive tasks for subjects (N=30) who varied in mental ability as assessed by the Multidimensional Aptitude Battery (MAB). Results showing negative relationships between reaction time measures and mental ability were consistent with previous findings (Vernon, 1983). For the first stimulus in paired stimuli tasks, both P300 amplitude and latency were affected by task difficulty. Mental ability group differences were noted for P300 amplitude only. For the target stimulus, P300 latency increased with increasing task difficulty in the same manner as reaction time and it was inversely related to mental ability, in particular for the more difficult tasks. P300 amplitude varied between tasks, but was not related to mental ability. First unrotated factors were extracted from the intercorrelations of each variable. Results showed that each factor accounted for considerable variance. Correlations between factor scores revealed significant negative relationships between intelligence and P300 measures and between RT and P300 amplitude. Five predictor variables produced a multiple correlation of .583 with IQ. Results suggest that P300 latency and reaction time may assess respectively the stimulus evaluation time and response production time components of cognitive information processing that vary inversely with general intelligence.

Literature Review

Introduction

This review outlines key developments in the endeavour to better understand human intelligence. The chapter begins with a review of important issues in intelligence research and discusses the historical approaches to the problem of intelligence, the influence of factor analysis and the concept of "g", the advancement of further theories, and the measurement of intelligence. This section of the review will also elaborate on the debate regarding genetic and environmental influences on intelligence, the issue of "biological intelligence" and recent research into the speed of information processing. In general, the aim of this introductory review is to provide the context and general background for the specific problem investigated in this thesis, namely whether individual differences in mental ability depend on speed of information processing. The specific problem addressed here emerges from research that has examined intelligence with reaction time (RT) measures. This literature on intelligence and research with RT measures will be reviewed. This will include the initial focus on individual differences in reaction time, and follow with the development of research into speed of information processing and its relationship to intellectual abilities. A review of intelligence and event-related potential (ERP) measures will outline the functional significance of P300 and the relation between P300 and RT. Research on the psychophysiology of intelligence will then be discussed, including both early and recent studies of ERP research into mental ability. Finally, the present study will be briefly outlined and the hypothesis will be stated. The study investigates the differences between average and above average intelligence groups in RT and ERP measures during the performance of RT tasks.

Significant Issues in Intelligence Research

This overview will focus on some of the significant issues and developments which have helped shape the questions which continue to be asked in modern day research on intelligence. One of these matters concerns the structure of intelligence, whether mental ability is best described as unitary (Galton, Spearman), as a set of faculties (Binet, Cattell, Guilford, Thurstone) or as being hierarchically ordered (Burt, Vernon). The substantial contribution of factor analysis to the development of these perspectives and in particular to the concept of "g" is also addressed. Another issue, also related to the structure of intelligence, is how it is best measured. The issue is also important in the debate regarding the influences of heredity and the effects of the environment on intelligence. In recent years, these issues have been discussed in the context of cognitive information processing models. This perspective is also adopted in the present study.

Intelligence: approaching the phenomenon.

In Darwin's view, nature was seen as a dynamic process governing the development of life forms requiring various interactions between species and between environment and species. Darwin concluded that the ability to adapt to a highly complex changing environment was the selection criterion for higher forms of organization. For some, it was logical to assume that if heredity played an important role in the development of a species in order to adapt to a changing environment, then the development of mental ability, regarded as an adaptive function, was also hereditary.

Towards the end of the 19th century, the science of psychology was beginning to develop in Europe. The areas of physiology, biology and experimental psychology were prominent in this new discipline. For example, Wundt applied procedures from experimental science, particularly physiology, to study the individual human mind. His psychology was called "Ganzheit" psychology, meaning "holistic" psychology. It referred to the scientific study of immediate experience, the mind as the totality of conscious experience at a given moment (Leahy, 1991). Measures such as RT and sensory thresholds were introduced to provide quantitative indices of sensory and motor experiences.

Also, Galton, a younger cousin of Darwin, postulated that the development of mental ability in humans followed the same laws of evolution as did the development of a species. In his 1869 publication, Hereditary Genius, Galton stated "I propose to show in this book that a man's natural abilities are derived by inheritance, under exactly the same limitations as are the form and physical features of the whole organic world" (p. 45). Galton (1869, 1883) considered intelligence as a general cognitive ability that was, in part, biologically determined. A primary research objective was to demonstrate the heritability of mental ability and to make a case for the biological basis of mental ability. He promoted the study of twins to sort out the contributions of nature and nurture to many aspects of human behaviour including human intellect. Adapting procedures from experimental psychology at the time, he applied psychophysical methods to measure sensory capabilities and other differences between people. He is also credited with the invention of the correlation statistic. Galton used tasks and procedures from experimental psychology that would endorse his hereditary, biological perspective of mental ability.

In the early 1880s, Alfred Binet was asked by the French government to devise a way to detect children who would have difficulty with the school curriculum, as compulsory attendance at school became law. In Binet's view intelligence involved complex, developed activities that evolved over time. Intelligence was a compound of a number of separate abilities

(Binet, 1903, 1907). Although Binet did not deny the influence of heredity, he was primarily concerned with practical abilities. Because of this concern with children experiencing difficulties in school, he, along with Simon, developed the first "successful" intelligence test known as the Binet-Simon Intelligence Test. It was revised in 1908 and again in 1911. This view prevailed in North America, becoming and remaining the principal method for the assessment of intelligence.

In the 1920s Piaget focused on developmental changes that altered the quality of children's perceptions, comprehension and environmental operations (Leahy, 1991). He conceived of knowledge as a set of cognitive structures that allowed a child to adapt to the environment. He administered various tasks to children. Although there is no Piagetian "intelligence test", positive correlations were found between Piagetian tasks and intelligence tests in children of various ages (Sattler, 1988).

American psychology focused on a science of intelligence with specific, practical aims. Cattell conducted investigations into mental measurement using basic Galton tests of RT. Cattell reasoned that Binet was testing what could eventually be reduced by analysis to the simpler functions that Galton himself had been testing (Peterson, 1925). Cattell named Galton's sensory motor tasks "mental tests". One of the practical applications involved setting up clinics to diagnose children with problems in school (Leahy, 1987). The earliest tests were used specifically with retarded children. However, it is noted that they were later replaced by the Binet test, introduced to the U.S. by Henry Goddard in 1905 (Leahy, 1987). Psychologists began giving tests to people in order to deal with many social issues. For example, they were used during World War I to recruit individuals for the US army (Leahy, 1987). By the end of World War I intelligence testing in the tradition of Binet had prevailed as the predominant focus of the psychology of intelligence. Further work also led to the development of the Wechsler Adult Intelligence Scale (WAIS) (Wechsler, 1955). Progressively, the assessment of mental ability with psychometric tests became established. During this period, the question "what is the structure of intelligence?" was an important research issue.

The concept of "g".

Although most psychologists would agree that the definition of "intelligence" is not consistent throughout the literature, the psychometric definition, as pioneered by Spearman, has been helpful in advancing our understanding of intelligence. Kline (1991) noted that Spearman asked the following question: "why is it that individuals who are good at one thing, are good at others?". In addressing this question, Spearman developed a statistical method from correlations that offered a solution to the problem. As Kline outlines, the question could be accounted for by a general factor of intelligence or "g".

Perhaps this development can be outlined in more detail.

The correlational technique, first developed by Galton, was later improved by Pearson. A correlation is an index of the relation between two variables. If a correlational matrix is constructed and the relations between correlations observed, factors, defined as statistical measures or indices of the exent to which items or tests measure the same concept or share the same covariation, can be extracted. This method of factor analysis developed by Spearman is the general statistical method which tries to determine the smallest number of dimensions that can be ordered from a matrix of correlational scores on a number of variables. Some data preparation and assumptions must hold for it to be used appropriately. For example, if one is interested in inferring from sample results to universal factors, the number of cases should exceed variables. The minimum ratio of cases to variables has been suggested (ex. 4:1, Cattell, 1952). However, if the interest is in describing data variability or summarizing data, factor analysis is appropriate (Rummel, 1970).

The factor analysis of intelligence tests and conceptions of ability using factors became prominent in researching intelligence (Berger, 1982). Factor analysis allowed the testing of certain hypotheses and helped establish explanatory concepts. As mentioned, factor analysis became a significant influence on intelligence research and theories which were further developed. This method has improved upon and facilitated the development of constructs as well as the summarization and aggregation of data for further interpretation.

Factor analysis was a prominent statistical tool in Spearman's research into the nature of mental ability and the concept of "g". Spearman spoke of intelligence in terms of a "general ability" which was common to all tasks requiring ability (Spearman, 1904). This general factor was a hypothetical entity assumed to account for the communality existing among all possible measures of human intellectual functioning. The best tests of "g" were those which involved "grasping of relations", with relations being perceived connections between things or "fundaments". A second class of factors, "g_s", contained specific factors unique to each test or form of intellectual activity. For example, mechanical ability depended on "g" plus a particular "mechanical" component. Spearman saw intellectual abilities as being hierarchically ordered and he analyzed thinking and problem solving behaviour as shown on IQ tests by referring to "neogenetic factors", factors creating novel mental content, and specified their accommodation by three major "neogenetic laws". The "Law of apprehension of experience" specified that before a problem can be dealt with, the basic facts relating to it must be apprehended. The "Law of induction of relations" related to the act of seeing in what ways the different parts of a problem are related to each other. Finally, the "Law of eduction of correlates" states that given the observed relations, the new items to be discovered must be extrapolated.

Although Spearman spoke of a general factor, this is not to say that others have not proposed theories involving minor factors of intelligence. However, evidence for a "g" factor remains strong. Other theories have included multiple factor theories and hierarchical models of intelligence. In multiple factor theories of mental ability primary factors were regarded as fundamental components which were distinct yet overlapped. For example, Spearman's emphasis on general intelligence was contested by Thurstone who argued that intelligence could be broken down into a number of primary abilities. He applied factor analysis to results from many tests employing many types of items in hopes of finding a better way to group intelligence test items (Thurstone, 1938). Thurstone found seven primary abilities which were not independent and were unordered. They included verbal abilities, perceptual speed, number, rote memory, word fluency, space or visualization and inductive/deductive reasoning. His battery of tests is known as the "Test of Primary Mental Abilities". In other work, Guilford's "structure of intellect theory" outlined three facets crucial to intelligence (Guilford, 1967). These were named "operations", "content" and "product". Guilford found 150 possible correlated mental abilities, and defined each facet independently. However, when these abilities were correlated with "g", the reported correlations were high and positive (Eysenck, 1979). This finding seems to contradict Guilford's theory of independent factors, and supports the concept of a general factor "g".

Although hierarchical models of intelligence include lower order major and minor group factors as well as lower specific factors, they retain a "g" like factor as the largest source of individual differences. For example Burt (1940) developed a hierarchical model consisting of five levels: human mind, relations, associations, perception and sensation. Vernon (1965) suggested that removing the general factor "g" reveals the positive residual correlations of verbal educational factors and spatial mechanical factors. These can be further subdivided into primary classifications of similar tests.

The presence of a "g" factor remained prominent in many theories although early researchers varied in terms of their ideas about the structure of intelligence. Researchers also varied in terms of their ideas about the measurement of intellectual ability. Some early tests were derived from experimental laboratories, and like Galton's, measured sensory and motor processes and memory. Other tests, such as those of Ebbinghaus and Binet, focused on higher mental processes. The development of an intelligence scale which produced a total score is most often attributed to Binet and Simon (1905). In 1935 William Stern suggested that a quotient of Mental age to Chronological Age be used, with the assumption that the normal child's intelligence quotient or IQ was 100. In the United States, Terman assumed intelligence was distributed normally and interpreted its measurement as that of a fixed, innate intellectual capacity. Like Galton, his interest was in testing untaught abilities involving innate general intelligence. These types of measures met with criticisms that the tests were ambiguous, used arbitrary units and yielded vague results (Thorndike, 1927). Others criticized the scoring procedures for "throwing a miscellaneous collection of tests indiscriminantly into a single pool" (Spearman, 1927). Instead, Spearman, bearing in mind the idea of intelligence as a general ability, preferred tests homogeneous in content. He stressed the difference between physical measurement and the more error prone psychological measurement. Further developments in the study of intelligence were limited to IQ test measures which followed Binet's conception, i.e., tests with an educational thrust, such as the Stanford-Binet and Wechsler-Bellevue. Since the original version of the WAIS, a version for children has been developed (Wechsler Intelligence Scale for Children or WISC) as well as a revised version of the original test for adults (WAIS-R). Other tests have also been developed and used in intelligence research including the Raven's Progressive Matrices (including Standard, Coloured and Advanced editions) and a group test designed after the WAIS, the Multidimensional Aptitude Battery or MAB (Jackson, 1983). In many cases norms have been developed, and according to individual specific scores a person can be placed into IQ categories such as retarded, borderline retarded, low average, average, above average, superior, etc. Many of the original tests were attractive to the social values and needs of an industrialized, education oriented, growing Western Society (Wigdor & Garner, 1982). It has been suggested that this concentration on the psychometric properties of intelligence was easy and practical (Eysenck, 1985) and led to operational definitions of intelligence (Boring, 1957; Bridgman, 1927). Kline (1991) comments:

> "Suffice it to say now that in psychometry, intelligence is equated with this general ability or "g", the factor common to all problem-solving abilities. Since the best intelligence tests are deliberately constructed to measure this "g" factor it does make sense to define intelligence as what intelligence tests measure, provided that the "g" factor can be specified." (p. 4)

A review of the structure of intelligence would not be complete without mentioning the contribution of Cattell. Cattell used factor analysis and distinguished between fluid intelligence, "g_f", i.e., the capacity for new conceptual learning and problem solving independent of education and experience, and crystallized intelligence "g_c", i.e., an ability which is more a precipitate of experience, drawing on acquired skills and knowledge (Cattell, 1971). Whereas "g_f" displayed a steady rapid growth reaching its maximum in late teens or early twenties, "g_c" would increase from infancy to maturity and slow its acceleration during the teens (Horn, 1980, 1987). Hendrickson (1982) suggested that since these two types of intelligence correlate within individuals, it is convenient to speak of the composite measure of Cattell's "g_f" and "g_c" as a single continuum, referred to as general intelligence or Spearman's "g".

In general, there is substantial support for a general factor of intelligence,"g". Kline (1991) suggests that there is now a need to carry this a step further. He notes that

> "Even if it is admitted that a common factor can be found in many problem solving tasks, labelling it as "g" or reasoning ability, or any other descriptor does not explain it. The cognitive processes involved in problem solution are not thereby understood. At best the factor is descriptive. What is necessary, therefore, is a study of the processes employed in problem solution". (p. 4)

Kline notes that this step could not be carried out had an ability factor not been firmly established. What is promising is that contemporary research is beginning to provide good evidence for a general factor of intelligence as well as insight into its processes and relevant measurement.

The influences of heredity and environment.

Another issue throughout the literature on intelligence research involves the extent of the contribution of an individual's environment and heredity to individual differences in mental ability. Some researchers have stressed the importance of the social environment in the process of natural selection. They argue that man is a unique product of evolution because of his escape from physical and biological limits to a complex social environment which influences evolutionary change via mutation, selection, etc. Success in survival would demand the ability to evolve behaviour patterns which suit imposing diverse conditions. Education and experience would be beneficial in this regard. The social-environmental approach implies development or growth and a flexibility to learn from life and from science. Extreme environmentalists use these arguments to support interventions and social policies which would enable an individual to enhance his or her intelligence (Spitz, 1986).

The biological, evolutionary perspective argues that genetic influences are important and that intelligence is an inborn aptitude to learn. "Heritability", a technical term symbolized as "h^2" in quantitative genetics, has been defined as the proportion of the total variation of a certain trait in a population due to genetic variation (Lawler, 1978). The proportion of non-genetic variance is "$1-h^2$" (Jensen, 1989). In general, there is substantial evidence that "g" is inherited. It has been reported that the heritability of measures of general intelligence is estimated at 0.50 (Plomin, DeFries, & McClearn, 1980). Heritabilities of specific cognitive abilities have been reported between 0.20 and 0.70 (DeFries, Johnson, Kuse, McClearn, Polovina, Vandenberg, & Wilson, 1979). Others have reported that the overall average of the best estimation of variance in intelligence due to broad heritability is between 0.60 and 0.70 (Jensen, 1989). In extreme cases, hereditarian arguments have been used to defend racial supremacy in terms of intelligence and to challenge intervention programs such as Head Start (Weinberg, 1989).

Although there is evidence for both environmental and hereditary influences on intelligence, there are criticisms for both sides of the debate. Studies of Burt (1958), often cited to support the heritability of intelligence and having reported a correlation of 0.80 between identical twins reared apart, have been criticized for use of fraudulent data (Weinberg, 1989). Some have suggested that the influence of heredity on differences in intelligence as measured by traditional tests is about 50% (Plomin, 1986), leaving substantial room for the influence of the environment and other factors, whereas others have discussed the importance of genetic influences on environmental measures (Plomin & Bergeman, 1991). Jensen (1989) discussed the causes for the consistent finding of racial and class differences in IQ, specifically for black children who consistently score approximately 15 points below white children. Although environmentalists charge that socioeconomic disadvantages would be the cause and that compensatory educational programs should equalize opportunities, Jensen argues that compensatory education has tried and failed. Other researchers have argued that shared environment has little effect on IQ. In one study of a large group of unrelated pairs of adolescents adopted before one year of age and reared together in families ranging widely in socioeconomic levels, it was found that by late adolescence, the effect of environmental differences between families was not significant (Scarr & Weinberg, 1978). Some authors have tried to sift through the arguments to offer plausible explanations for the differential contribution of nature and nurture. Weinberg suggests that "genes do not fix behaviour. Rather, they establish a range of possible reactions to the range of possible experiences that environments can provide. Environments also can affect whether the full range of gene reactivity is expressed.

Thus, how people behave or what their measured IQs turn out to be or how quickly they learn depends on the nature of their environments and on their genetic endowments bestowed at conception." (p. 101) (Weinberg, 1989).

In general, there seems to be support for the view that genetic influences on mental ability are important. As mentioned, however, Kline (1991) suggests that what is necessary is a study of the cognitive processes relevant to "g". Cognitive psychology in the latter part of this century has focused on mental processing. However, intelligence literature seemed to give minimal importance to information processing and "mental speed" which have been suggested as significant cognitive determinants of mental test scoring ability (Eysenck, 1967). What is needed therefore, and what this study tries to explore, is a study of the processes which are relevant to "g", examining speed of processing using psychophysiological measures.

Limited capacity and speed of information processing.

Some progress has been achieved in understanding intelligence in the context of cognitive information theory. Jensen and others have exploited the Erlangen school's theoretical "limited capacity model" of information processing (Jensen, 1982b; Lally & Nettelbeck, 1977). In general, this model assumes that the conscious brain acts as a one channel or limited capacity information processing system. In this view, the number of operations that can be performed simultaneously on the information entering the system from external stimuli or from retrieval of information stored in short or long term memory is restricted. To compensate for limited capacity and decay, individuals trade off between storage and processing of incoming information. A loss of information means a breakdown and the failure to grasp relations among elements.

Vernon's work is also based on the principles of limited capacity, the importance of rehearsal and a storage-processing trade off (Vernon, 1983, 1985, 1987). However, he suggests further that rapid mental operations are advantageous because more operations per unit of time can be executed without overloading the system. Speed of processing thus becomes an important element in problem solving. Speed provides an advantage when there is rapid decay of stimulus traces and information. There is also a greater advantage of speed with the increased complexity of information and operations required. Correlations between measures of simple RT and measures of intelligence such as the Ravens Progressive Matrices have been reported in the mid -.20s (Jensen, 1980, 1982a), while choice RT correlations have been around -.30 (Jensen, 1982a). Vernon has also presented data suggesting a substantial heritable component for various RT measures of speed and consistency of speed of information processing (Vernon, 1989b). Thus, Vernon stressed the importance of speed of information processing and efficiency with respect to successful problem solving. In studying the processes related to intelligence, the present research also places importance on speed of information processing.

A new look at intelligence.

From a different viewpoint, Eysenck (1985) outlines intelligence in terms of "social intelligence", "psychometric intelligence" and "biological intelligence". Eysenck identifies "social intelligence" as the product of influence by many unrelated constituents like health, experience, socioeconomic status, motivation, nutrition, culture, education, personality, etc. It is similar to intelligence B (Hebb, 1949). Intelligence B is deemed intellectual problem solving behaviour as observed in everyday life. It is determined by the interaction of genetic factors and educational, cultural and socioeconomic determinants. It is the focus of most of Sternberg's research (1982, 1985). "Psychometric intelligence" denotes intelligence as measured by IQ tests. Success in IQ tests is also cultivated by cultural factors, family upbringing, education, etc. It is estimated to contribute 30% of the variance to individual differences in intelligence (Eysenck, 1985). It is similar to Intelligence "C" (Vernon, 1955), the intelligence quotient measurement of ability. Eysenck suggests that the most fundamental aspect of intelligence is "biological intelligence". It relates to the physiological, neurological, biochemical and hormonal background of cognition. For example, one could say that structures and functions of the cortex could allow for individual differences in intelligence. Eysenck suggests that what is inherited is a predisposition towards a certain level of intelligence and that change and variation come through interaction with environment. Possible measures of biological intelligence include ERPs, electroencephalograyphy (EEG), RT, movement time, inspection time, galvanic skin response and contingent negative variation. The concept is similar to that of intelligence A, introduced by Hebb (Hebb, 1949) which denotes the genetic basis of cognitive functioning and ability differences. Eysenck contends that social intelligence embraces psychometric intelligence which embraces biological intelligence. As outlined in the brief history on intelligence research, the last 50 years has seen intelligence defined mostly in terms of its social and adaptive components and their effects. Eysenck argues that if the nature of intelligence is to be understood, then the approach must be towards its most fundamental aspect, biological intelligence.

Neural bases of information processing have been explored. The focus becomes the biological components of the organism's constitution which contribute to performing at a particular speed or the production of errors. Studies have included research into speed of neural transmission and the latency of certain reflexes, biochemical aspects and electrical aspects such as alpha waves, EEG and ERPs. These studies will be discussed in greater detail later in this review. In general these issues lend support to the Galtonian ideas that physiological measurement is a valuable tool in the study of specific activity such as neural transmission, cortical activity, sex and age influences, and their relations to mental ability.

Significant issues: summary.

In summary, the nature of intelligence and its measurement have confounded psychologists for years. Granted, a review of the literature reveals many accounts of studies conducted, the postulation of numerous theories and the development of numerous tests. However, the progress towards better understanding has been riddled with controversial issues and debates. Even an agreement on the definition of intelligence has eluded researchers, the question being whether mental ability is a unitary general concept or a set of specific abilities. Authors have argued on both sides, even though recent work has provided substantial evidence for "g". The measurement of intelligence remains a contentious issue, with some theorists favouring simple sensory tests and others supporting practical tasks related to everyday living. As in any area of research there have also been methodological concerns involving research samples, the use of a total score, control for age and ability levels, etc. Recent research has included a direct focus on mental processes contributing to cognitive task performance. Authors of recent work are successfully applying information processing and cognitive models to study intelligence. Research seems to have come full circle, with the idea of the biological basis of intelligence having developed out of the concepts of Galton's early work. This review of various issues in the study of intelligence leads to the next step, a review of the relation between IQ and different measurable aspects of biological intelligence.

Intelligence and RT Measures

Significant research on intelligence using RT measures has spanned more than 150 years. Early work which addressed individual differences in RT will be briefly outlined. Later work, during the twentieth century, has focused on methodological refinement, information theory, RT and its relation to intelligence, various RT paradigms and the importance of information processing speed. It has been suggested that complex information operations on the brain would be facilitated by speed which would prove advantageous as more information is processed (Jensen, 1982b). The rationale for this view will be elaborated. A review of these issues as well as results from studies using behavioral measures to study intelligence will be outlined.

19th century: individual differences in RT.

There was a substantial body of research done in the nineteenth century which focused most specifically on individual differences in RT. The major findings will be outlined, beginning with the Prussian astronomer Bessel in 1823 until Gilbert's contribution in 1894.

Earliest contributions to studies in individual differences in RT begin with Bessel, who is known for coining the term "personal equation". This term referred to "consistent variations among different telescopic observers in recording the exact instant that the transit of a star crossed a hairline in the visual field of the telescope" (Jensen, 1982a). In essence, this was a reference to individual differences in RT. This observation led Respold to invent the chronograph in 1828, a device for measuring RT in fractions of a second. In 1850, von Helmholtz measured speed of nerve conduction in frogs and found that the speed of neural transmission was less than one-third the speed of sound. It was postulated that the bases of mental events, the brain and neurons, acted with infinite speed.

Basic attempts to relate RT to mental ability followed. Galton was the first to suggest that individual differences in general mental ability could be measured by means of RT (Galton, 1869). As was previously outlined, he was one of the first to conceive of intelligence as a "general" mental ability, anticipating Spearman's "g". Galton believed this general ability to be a product of biological evolution. In 1868, Donders, a Dutch physiologist, found that choice RT was longer than simple RT. He invented the "subtraction method" of mental chronometry, i.e., choice RT minus simple RT equalling a measurement of the speed of purely mental events. In 1873 Exner, an Austrian physiologist, coined the term "reaction time" and discovered the importance of "preparatory set" and the preparatory interval, the interval between a warning signal and the actual reaction stimulus (RS). He found that if the preparatory interval is not controlled by using a "ready" or "warning" signal, intraindividual variability in RT is increased. Because of this, a preparatory signal became standard practice in RT studies. Galton invented an RT apparatus which measured simple RT to an auditory stimulus and found a low correlation between intelligence and key press RT (Galton, 1883).

In 1885, in Wundt's lab, it was found that RT increased systematically as a function of the increasing number of choice alternatives in the stimulus and response arrangement (Merkel, 1885). This anticipated Hick's law later in 1952 showing that the time for mental activity, as reflected in RT, is systematically related to the objective complexity of the task. Gilbert (1894) subsequently demonstrated the relation of RT and intelligence, being the first to show a very regular, negatively accelerated decrease in RT with increased age (from 6 to 17 years) and a decrease in trial to trial intraindividual variability of RT with age. This suggested that RT was related to mental age.

As previously outlined, Galton felt that speed of solving very easy problems was a good measurement of intelligence, especially since solving an easy task was more dependent on biological elements than experience. This supported the use of behavioral RT as a measurement. His rationale was that more intelligent individuals should be able to solve easy problems faster, hence showing shorter RTs. Less intelligent individuals would solve the problems slower, resulting in longer RTs.

<u>20th century: speed and its relation to intelligence</u>.

Early endeavours to associate intelligence with simple mental processes such as sensory detection, discrimination and RT met with limited success. More recently, further evidence has been reported which supports the early objectives. In this section, work throughout the 20th century, beginning with Binet and Simon to recent work (Nettelbeck & Lally, 1976; Nettelbeck, 1987; Jensen, 1979; Vernon, 1983, 1985, 1987, 1989a) will be explored. In general, negative correlations between general intelligence as measured by tests such as Raven's Progressive Matrices and the WAIS and a wide range of RT tasks have been consistently reported. High ability subjects display faster RTs than lower ability subjects (Vernon, 1987). The strength of the correlations have ranged considerably and, particularly, with RT separated from movement time, the correlation between ability and RT is generally lower on easier than on more difficult tasks (Eysenck, 1987). The relation between RT and intelligence will be discussed.

RT research at the beginning of this century.

There have been few significant attempts to correlate RT with actual intelligence test scores. For example, Lemmon (1927) used 100 subjects in an attempt to find a relation between both simple RT (responding to a single stimuli) and choice RT (responding to one of two stimuli) and scores on an intelligence test. He demonstrated that choice RT was more highly correlated with IQ (-.25) than was simple RT (-.08). This was the first rudimentary demonstration of the relation of intelligence to task complexity and the last study of RT and its relation to intelligence until 1964.

Jensen is well known for his significant contributions to research with RT. His suggestion for methodological refinement was perhaps one of the most important. He argued that individuals with greater speed of information processing acquire more cognitively integrated knowledge and skill per unit of time when they interact with the environment. However, he proposed that the "RT" in Roth's procedure be divided into "reaction time" (RT) and "movement time" (MT) and he invented "Jensen's box" to incorporate this idea (Jensen, 1982a). With this apparatus, a subject holds down a central "home" button with the forefinger. When any one of eight lamps in the circumference of lamps above the home button lights up, the subject is instructed to move the finger to depress the button in front of the illuminated light. RT is defined as the time from stimulus onset to release of the "home" button. MT is defined as the time from releasing the "home" button to the depression of the button in front of the light. RT and MT are experimentally independent. RT can be simple RT or choice RT, measured in ms by electronic timers. The subject receives 15 or 30 trials spaced at 10 to 15 s intervals on each level of information. The levels of information in the array are always presented in their order of magnitude and practice trials are used.

Research on RT within the information theory framework (Shannon & Weaver, 1949) revealed that multiple choice RT increased as a linear function of the increase in the amount of information in the stimulus array when information is measured in bits (bits = $\log_2$ of the number of choices). This is now known as Hick's law (Hick, 1952). The slope of this function could be interpreted as a measure of the speed or rate of information processing expressed as the number of milliseconds (ms) per bit of information. When the reciprocal of this slope is multiplied by 1000 the result expresses the rate of information processing in terms of the number of bits per second (Hyman,1953; Roth, 1964).

Using Jensen's box, research on the basic phenomena of the Hick paradigm has led to five major conclusions (Jensen, 1980, 1982a, 1982b, 1987a, 1987b; Jensen & Munro, 1979; Jensen, Schafer & Crinella, 1981; Jensen & Vernon, 1986). These conclusions are with respect to RT and MT as functions of bits of information, RT and Hick's law without response selection, intraindividual variation in RT and MT, the random nature of RT variability and the relation of RT and MT parameters to age.

First, Hick's law, that the linear increase in RT is a function of the number of bits of information conveyed by the reaction stimulus, is robust (Jensen 1979, 1980, 1982a, 1982b). The consistent finding has been that when individual median RTs are plotted as a function of bits the linear correlation between median RT and bits for individual subjects averages .97. Clearly, RT increases as a function of bits of information. In all subjects but the severely retarded, MT is much shorter than RT. However, MT never shows significant increases as a function of the bits of information (Jensen & Munro, 1979). RT increases only to a maximum value because it is limited by peripheral factors such as sensory receptor activation times, neural conduction speed (60 - 80 ms), and processing in the central nervous system (50 - 60 ms). This leaves an irreducible minimum RT of 100 to 150 ms. Individual differences in RT are not specific to response or stimulus modalities therefore indicating a general factor of RT. It would seem that RT and MT involve different processes. Individual differences in median RT and median MT correlate approximately .40. Thus they share some common source of variance among individuals for the same level of bits, but median RTs for different levels of bits are more highly correlated than MT.

Second, regarding RT and Hick's law without response selection, under a double response condition RT reflects in part the programming time for execution of the specific ballistic response required. This anticipates Fitts' law which states that the time for beginning the execution of a movement is related to the required precision of the movement (Fitts, 1954). The slope of RT over bits is mainly a function of uncertainty about the response stimulus (RS). It is not a sensory phenomenon per se because the signal/noise ratio of the RS is so great that it minimizes any between subject or within subject variance due to discriminability of RS. (It seems likely that "g" is related to the RS uncertainty aspect of RT rather than to a small movement programming component).

Third, conclusions have been made regarding intraindividual variation in RT and MT. The average speed of RT can be seen as a consequence of variability of RT, with median RT correlating about .40 with mean intraindividual variability in RT (SDRT). With respect to the amount of information (bits), Hick claimed that intraindividual variance in RT would increase as a negatively accelerated function of bits. Jensen says he found that SDRT increased as a positively accelerated function of bits. MT is consistently unrelated to bits of information.

Fourth, it was concluded that RT is less stable from day to day than from trial to trial. During trial to trial analysis, each subject's RT appears to be generated by a strictly random process showing consistent variability about the subject's mean RT over "n" number of trials. A "random generator" would lead one to expect that values of RT will show no consistent trend over trials in sessions of 15 to 30 trials. Therefore there exists the equivalence of RT from trial to trial except for random fluctuation. The average intercorrelation of RT between days is .75 and it does not seem to vary as a function of bits. The average intercorrelation of MT is .90. Even though there are no changes in the average RT of the group, some form of non-random variation in individual median RTs occurs over the course of the test days.

Finally, there is a developmental trend in RT that parallels the developmental trends in physical growth and in other indices of mental development. The slope of regression of mean RT and/or the standard deviation on age increases as a function of the number of bits conveyed. Performance on more complex RT tasks (i.e., with greater number of bits) reflects age differences better than performance on simpler RT tasks. MT, on the other hand, shows significant but smaller changes with age than RT. The slope of regression of mean MT and standard deviation on age shows no relation to task complexity.

The effect of practice on RT in the Hick paradigm is uncertain. Some researchers reported negligible effects of practice with the Hick paradigm (Kranzler, Whang & Jensen, 1988). However, other researchers argued that they had found significant linear effects of order and practice on the slope relating RT and MT to bits of information and nonsignificant effects on RT and MT intercept (Widaman & Carlson, 1989). Nevertheless, significant gains have been made in RT research beginning with Peak and

Boring's (1927) first study to the extensive work done with the Hick paradigm by Jensen and others. This has led to further studies which then focused on RT and its relation to intelligence. Overall, it seems clear that RT has provided a reliable measure of the speed of simple information processing.

The relation between RT and intelligence.

It has been proposed that the more complex the information and operations on the brain and the more time that is required, the greater the advantage of speed (Jensen, 1982b). If information required to solve a problem is somehow lost, however, this would result in a failure to grasp relations among elements and perhaps a failure to solve the problem. In a task, items that threaten the information processing system because of their complexity may be different for different individuals. Eysenck elaborated on this point by noting that if individual differences in the speed of information processing could be measured in tasks so simple as to rule out information processing failure (as is true in several RT paradigms), then one should be able to predict individual differences in the point of breakdown for more complex tasks (Eysenck, 1985). Jensen believes that this is the basis for the observed correlation between RT variables and scores on complex "g" loaded tests. It would account for the Hick paradigm which is essentially a model involving a central search process to resolve uncertainty to zero. The greater the uncertainty about a particular stimulus, the greater the search required for resolution.

RT and MT show reliable individual differences which are significantly correlated with intelligence as measured by the Raven's Standard Progressive Matrices (Jensen & Munro, 1979). In a 6 choice task, the correlation between RT and IQ was -.49. SDRT is one of the best correlates of "g". For example, in homogeneous groups at every ability level there is an average correlation between mean SDRT and "g" of -.55 (Jensen, 1982a). Intraindividual variability in MT (SDMT) shows the least correlation with "g".

The simplest RT paradigms include simple RT (SRT) and choice RT (CRT). As mentioned, the SRT task involves the speed of decision making when only one stimulus will appear. The CRT task involves speed of simple decision making when two stimuli, or a choice, are involved. The correlation between RT and intelligence is -.20 for SRT and -.30 to -.40 for CRT. CRT is usually longer than SRT, is more highly correlated with "g" (Roth, 1964), and shows more pronounced developmental trends (Keating & Bobbitt, 1978).

The Hick paradigm also demonstrates the increasing relation of RT with "g" as the complexity of RS increases (Lally & Nettelbeck 1977; Spiegel & Bryant, 1978). It has also been shown that more difficult test items, when answered correctly, have longer average response times, but that the response times barely correlate with intelligence as measured by the Ravens

Advanced Progressive Matrices (Jensen, 1979; Snow, Marshalek & Lohman, 1976; White, 1973; Elliott & Murray, 1977). This test-speed paradox holds for test items answered correctly and shows that nominal information in the RS is not linearly related to RT beyond a certain point, and that personality factors enter the picture when test items involve time and persistence in answering questions. Jensen found that high IQ subjects responded faster even at 0 bits. The intercept of regression of RT on bits of information showed a significant correlation with "g" in children and retarded adults who scored in the lower, 25th percentile. The slope of this same function showed more discriminability for "g" in more intelligent groups although it was less stable from day to day. Variability in RT correlated -.40 to -.50 when weighted for number of subjects and when corrected for restriction of range. In the Hick paradigm, MT discriminated IQ but not as much as RT. MT was always faster than RT but did not increase significantly over bits. Severely retarded groups (scoring lower than the 25th percentile on the Raven's Progressive Matrices) with IQ between 14 to 60 (mean of 39) fail to manifest Hick's law and their MT is slower than RT.

Some of these findings with the Hick paradigm have been disputed. In early work, it was difficult to generalize findings due to methodological problems such as practice and order effects, response bias effects and attentional factors (Longstreth, 1984). Further criticism addressed the inclusion of simple RT into calculation of slope, and the independence of RT and MT (Longstreth, 1984). However, recent research has addressed these issues. Individual differences in RT and in the slope of the regression of RT on stimulus set size (scaled in bits) show negative relations with IQ. The strength of the relation is a linearly increasing function of stimulus set size in bits (Jensen & Vernon, 1986).

In the Sternberg short term memory (STM) scanning paradigm (1966, 1969), the speed at which an individual scans and processes STM for information is measured. The subject is shown a series of two to seven digits or letters followed by a probe. In half of the trials the probe is a member of the series and the subject's task is to respond to the probe with a yes (it was in the series) or no (it was not). Results show that RT increases linearly with the size of the series. As information increases, it takes longer for an individual to scan and process that information in STM. The ordinal position of the probe in the set has no effect on RT, but changing it ensures that the scanning process is exhaustive. McCauley, Dugas, Kellas & DeVellis (1976) showed that the relation between intercept and slope of RT is a function of set size and mental scores. When testing children there have been main effects of age, with older children obtaining faster overall RTs (Keating & Bobbitt, 1978). This indicates the importance of controlling for age. Using a sentence verification paradigm, correlations of -.36 to -.48 between RT and Full Scale IQ have been reported, (Vernon & Kantor, 1986; Jensen, Larson & Paul, 1988). Again, in this paradigm RT is increasingly correlated with "g" as task complexity increases.

In the Posner long term memory (LTM) access paradigm (Posner 1969, Posner, Boies, Eichelman & Taylor, 1969) the time it takes a subject to access a highly overlearned item of information stored in LTM is measured. Experimentally, it involves comparing a subject's discriminative RTs to pairs of stimuli which are the same or different either physically or semantically. The physical discrimination is similar to the classical two choice discrimination RT task, but semantic discrimination RT involves access to semantic codes in LTM. Hunt (1976) related RT in Posner's paradigm to mental ability. He found that high and low groups on SAT-V scores show mean differences in RTs on the physical task, and that the average RT difference between semantic encoding time was 75 ms. This latter finding is similar to the difference in RT between 0 and 3 bits of information in the Hick paradigm for the same ability group. The same study was replicated with children and interactions of the task (physical vs semantic) with age and IQ level, as assessed by the Raven's Progressive Matrices, were found (Keating & Bobbitt, 1978).

The inspection time (IT) paradigm (Nettelbeck & Lally, 1976, Nettelbeck, 1987) is tangential to the present work but is of interest to note. IT is a threshold measure of the speed with which quite obvious differences in the length of two lines can be apprehended by the subject. The two lines are exhibited for a brief period of time on a tachistoscope, followed by a backward masking stimulus. What is to be determined is the exposure time at which the subject recognizes the correct position of the longer line 97.5% of the time. Data have shown that the threshold is lower for subjects in the IQ range of 81 to 119, as assessed by the WAIS, compared to subjects in the 47 to 80 IQ range (Nettelbeck & Lally, 1976). The median correlation between IT and IQ is -.80. With small samples and the inclusion of MR (total IQ range from 59 to 135 as assessed by the Mill Hill Vocabulary test) these results have been replicated (Brand, 1979; Brand & Deary 1982; Deary, 1980). Problems with this paradigm include the duration of the test and the difficulty involved in constructing the apparatus. These problems result in variable findings. Nevertheless, IT seems to reflect the basic level of simple stimulus encoding. This is similar to Spearman's (1927) first neogenetic law, the apprehension of experience.

Combination paradigms (Keating & Bobbitt, 1978) include CRT, SRT, the Posner paradigm and Sternberg paradigm in various orders and are designed to study the multiple correlation between speed of processing and IQ. These paradigms are valuable because they allow the researcher to look at aspects of information processing simultaneously and their relation to mental ability. For example, Vernon (1983) regressed WAIS IQ scores on RTs and intraindividual standard deviations for several speed of processing tests and found a correlation of .464. It has been argued that if a substantial proportion of the true score variance in highly "g"-loaded psychometric tests can be "accounted for" by optimally weighted combinations of variables derived from these or other RT paradigms, it would warrant intensive investigation into the nature of individual differences in these paradigms as the basis for developing an adequate theory of RT paradigms and their parameters (Jensen, 1982a; 1987a).

RT experiments using minimal judgements in STM and LTM have also been employed. One example is the "odd-man-out" paradigm. Three lights are shown on the Jensen RT box simultaneously, two close together and one (the odd one) further away. The subject is to press the button next to the odd one. A correlation of -.60 between RT and IQ as measured by the Raven's Advanced Progressive Matrices has been reported (Frearson & Eysenck, 1986). However, no correlation between the Hick slope and IQ, nor any increase in correlation between IQ and RT with increased number of bits was found.

Eysenck (1985) observed that an increase in the complexity of the task from SRT to CRT shows an increase in the correlation with IQ, suggesting that differences in mental speed are cumulative. In other words, as RT tasks become more difficult, involving more elementary cognitive factors, speed requirements of the various processes are additive or multiplicative. This suggests that the more complex the task, the stronger the relation to intelligence (Vernon & Jensen, 1984). Other work, such as that of Furneaux (1952, 1961) dealt with this problem in terms of item difficulties and various aspects of problem solving, incorporating speed as a central focus.

Others have also studied discriminant RT tests and their relations with "g" (Ackerman, 1986; Ackerman & Schneider, 1985). They used a battery of 10 tests as a measure of "g". They obtained (by factor analysis) measures of verbal, spatial and perceptual motor speed scores. They used two RT tasks. The first was a verbal task, a visual category search procedure (Fisk & Schneider, 1983). On each trial, three taxonomic category labels were presented on a terminal screen to memorize for five seconds. Three probe words were presented and remained on the screen until the subject responded within the time limit of five seconds. The subject had to press one of three buttons depending on the target word's position, the target word being defined as the only word to fit into one of the categories. The second task was a spatial task. Two levels of stimulus consistency were used, a consistent level mapping of targets and distracters and a varied level of targets and distracters. In this case, the latter involved a large number of cognitive processes. One experiment had eight two hour sessions and another had five one hour sessions to study the effects of practice. Results showed that consistent mapping levels gave lower correlations with "g" than the varied level. The sample may have a slightly larger variance in ability than a random sample, yet corrections would have a minimum effect. This work serves as good evidence that discrimination RT tasks correlate highly with intelligence. Eysenck (1987) points out that even more complex tests of cognitive ability involving short RTs (card sorting or trail making) have high correlations with IQ tests. In any case, it would appear that the best paradigms to study the relation between intelligence and variables involving cognitive aspects of information processing are those which have tasks which vary in complexity and length.

Researchers have raised the question as to whether RT variables from various paradigms relate to the central core of intelligence as measured, for example, by the first (general) factor extracted from intercorrelations of Wechsler tests. In one study with 59 school children, 12 subtests of the WISC-R correlated negatively with Hick's slope (Hemmelgarn & Kehle, 1984). When the subtests were loaded on the "g" factor of the WISC-R, and individual differences in Hick's slope were correlated with scores on each of the 12 WISC-R subtests, a rank order correlation of -0.83 was found. Guilford (1947) analyzed data from an Air Force Aviation psychology program of World War Two. The test had a 65 variable correlational matrix (classification test battery and 40 research tests). Thorndike's designation of six batteries of eight tests was used and the last 17 tests were inserted into each of these six batteries one at a time yielding nine test batteries. A factor analysis was done and "g" loadings for each test and battery calculated. It was found that the "g" loadings were stable, median value of .82 even when a given test was embedded into the context of different batteries. More specifically, a certain discriminant RT test had loadings on the 6 batteries of .52, .55, .61, .59, .60 and .61, with an average of .58. A spatial orientation test had a mean "g" loading of .60. Factor loading of the CRT exceeded those for general information, arithmetic reasoning, number operations and reading comprehension, all known to be good measures of "g". Thus it seems that "g" loadings are independent of the specific battery used, and that discriminant RT has a high "g" loading. This finding also reinforces the idea that cognitive tasks varying in complexity should be included in a suitable paradigm for studying intelligence.

It has been noted that comparing means of various RT variables obtained in groups differing in intelligence has been shown to be a more efficient exploratory method than correlational analysis (Jensen, 1982a). The day to day instability of individual differences in RT parameters means that using a group's mean allows a more stable measure for all RT parameters. Small samples can also be used to establish relations between RT and general intelligence. These RT-IQ correlations are always consistent in demonstrating that high "g" predicts faster overall RT, low intercept, less slope or RT when complexity of RS is varied over two or more levels and there is a smaller intraindividual variability in RT over trials (Jensen, 1982a). Thus, in studying intelligence it is best to use different RT variables measured from groups of individuals who vary in intelligence, as well as tasks that vary in complexity.

Eysenck (1985) suggests that the correlation between different measures of RT and IQ depends on the IQ test used, the population ability range and the precise details of experimental paradigms. For example, if a study uses a group of students with extreme IQ scores such as low average IQ or MR and high average or superior IQ, there will be an undue inflation of the correlation, especially since individuals at the lower IQ range and MR have a more variable RT distribution (Campbell & Cullum, 1985). It has also been suggested that MR may have an attentional deficit (Nettelbeck & Brewer, 1981; Carlson, Jensen & Widaman, 1983) and perform differently. Brewer and Smith (1984) conducted the Rabbitt trial-by-trial tracking experiment and tried to explain the slower, more varied performance of the retarded subjects. They found that the MR (range of IQ between 43 to 69, mean 56, as assessed by the WAIS) compensated by adjusting RT levels to track bands which allow sequences of error-free responding. They also noted that MR fail to profit from past experience. Nevertheless, even individuals selected over a very wide range of IQs (an artificial group) do not represent a sample of any population. Jensen prefers to report raw correlations found within samples of "natural" populations, however restricted in range the IQs are. He also suggests observation of mean differences in RT parameters between natural groups that differ in mean IQ level. Issues such as IQ test used, the ability range of the sample, and the experimental paradigm must be considered for research to properly develop a theory of intelligence and individual differences in RT (Jensen, 1982a; Woodworth & Schlosberg, 1956).

Intelligence and speed of processing.

The question on which recent research on intelligence and RT has tried to focus is whether individual differences in intelligence may be the result of differences in information processing efficiency and speed of performance. This work suggests that more intelligent individuals process information faster than less intelligent individuals. The following summary will serve to lay the groundwork for further study of these hypotheses in this investigation.

Results from factor analyses on the high positive correlations between RTs on speed of processing tests suggest that there exists a single mental speed factor accounting for 65.5% of the variance in these tests (Vernon 1983). Similar factors extracted from the correlations between intraindividual standard deviations account for 57.9% of the variance. The question still remains whether this represents a general consistency or efficiency of processing. Later analyses which used combinations of RTs designed to tap specific cognitive processes did not support the single factor finding. The first unrotated factor accounted for 30.2% of the variance and the variable loadings did not warrant interpretation as a strong general factor. In fact, Varimax rotation yielded 3 factors: storage processing trade off in STM, LTM retrieval and STM processing.

Also, analyses carried out with the IT paradigm revealed that whatever is common to other RT tests is not shared by this variable (Vernon, 1983). IT correlated negatively and insignificantly with all RTs and did not load on the first factor. IT was the only cognitive variable which did not correlate with IQ. Nettlebeck and Lally (1981) suggested that IT may not vary to any large extent among samples of average or above average intelligence, but it does vary between samples of average and below average intelligence. In other words it seems to be a threshold variable which can successfully distinguish between retarded and non-retarded samples.

Multiple regression analyses in the literature have supported the hypothesis that the speed with which persons can perform different cognitive processes is significant and highly related to their intelligence (Vernon, 1983). Intraindividual variability in RT has about the same degree of association with IQ as RT. Vernon (1983) replicated earlier studies of RT and intelligence and showed that the two points which are important regarding good performance on tests of mental ability are the speed with which a person can perform mental operations and the consistency with which one can perform at the same level over a period of time. Various theoretical explanations include influence of attention span (Carlson & Jensen, 1982) and individual differences in the frequency of oscillation of synaptic excitatory potentials (Jensen, 1979).

Vernon (1983) also argues that the relation between general intelligence and RT cannot be attributed to common verbal and numerical test content, test difficulty nor the fact that sections of the WAIS are timed. He argues that what accounts for the majority of the relation between intelligence and RT is "g" common to all psychometric variables, and that the bulk of the variance in "g" is attributable to variance in speed and efficiency in performing a small number of basic cognitive processes. This would support the view that IQ tests measure more than just problem solving strategies, opportunities to learn or accumulated knowledge. Vernon proposes that in terms of speed of processing, the individual who possesses more knowledge and better strategy has acquired these due to a basic information processing capacity. Support can be found in later work (Vernon & Jensen, 1984) where a multiple correlation of .465 was the result of regressing Armed Services Vocational Aptitude Battery (ASVAB) factor scores on RTs and intraindividual standard deviations. A storage processing trade-off factor made the greatest contribution to this relation. They also found that university students obtained significantly faster RTs and less intraindividual variability on speed of processing tests when compared to vocational college students. They found that the largest differences between groups was on more complex speed of processing tests (complexity represented in terms of group mean RTs on tests). The Pearson correlation between group mean RTs on each test and differences in RT between groups was .97.

Further work by Jensen (1982) and Vernon (1983; 1985) revealed significant correlations between speed of processing and intelligence within groups. Other studies have found that higher ability groups (with IQs in the 90th to 95th percentile range as assessed by the Raven's Progressive Matrices) have faster mean RTs than lower ability groups (40th to 45th percentile range) (Baumeister & Kellas, 1968; Hunt, 1976; Keating & Bobbitt, 1978). Vernon, Nador and Kantor (1985) compared three groups on RTs using tests of STM processing, LTM retrieval and STM storage-processing. Group one included students whose mean Full Scale IQ, as assessed by the WAIS, was the 93rd percentile. Group two included individuals with a mean Full Scale IQ, as assessed by the Multidimensional Aptitude Battery, in the 87th percentile. Group three included individuals whose ability level fell at the 50th percentile as assessed by the ASVAB. These researchers hypothesized that the group of intermediate ability, Group two, should fall between the other two groups in speed of processing performance. They found that Group one, the higher ability group, had shorter mean RTs and less intraindividual variability than the lower ability groups. For Groups two and three the correlation between speed of processing and IQ within groups increased as a function of task complexity. Individual differences in IQ should show the largest differences on the more complex RT tasks. However, for Groups one and two the difference between these groups' mean RTs were negatively correlated with test complexity. Group one performed faster than group two on five out of seven RT tests, but didn't perform faster on the speed of processing variable. Even though each group's IQ was tested using different IQ tests (group one with WAIS, group two with MAB and group three with ASVAB) the timed or untimed aspects could not account for the results. As has been shown (Vernon, Nador & Kantor, 1985; Berger, 1982; Vernon & Kantor, 1986; Jensen, Larson & Paul, 1988) the correlation between RT and IQ did not depend on the timed or untimed nature of the intelligence test, and although timed and untimed tests impose different information processing demands, the speed at which cognitive processes necessary for each test are executed is related to the success with which these different demands are met. Timed and untimed tests measure the same concept of "g".

The speed-accuracy trade off is another issue in need of discussion regarding intelligence and speed of processing. Characteristics of RT performance include the finding that average or above average intelligence subjects trade off speed and accuracy resulting in slower responding for high levels of accuracy and faster responding for low levels of accuracy (Brewer & Smith, 1982). When performance accuracy is high, small differences in error rates between individuals or groups of subjects may be associated with substantial differences in speed of responding. Campbell (1985) raises the point that some authors report error rate in performance on RT tests. Few report mean error RT. He contends that the speed-accuracy trade off affects processes underlying response production. In the case of research into individual differences in RT, Campbell (1985) suggests that most authors are in fact examining the stimulus evaluation process. RT as well as error rate values represent decision free performance under a specific decision criterion applied to a constant perceptual process. At least two speed-accuracy conditions are needed to get a good measure. Rabbitt (1979, 1981) studied "error" and found that with practice and over time RT became shorter. He suggested a "go fast but avoid error" instruction and trial by trial tracking. Campbell (1985) suggested that even if "stimulus evaluation" is constant, "response production" may vary. "Stimulus evaluation" has been defined as the general class of processes for obtaining information regarding stimuli, permitting the discrimination of one stimulus from another. "Response production" has been defined as the general class of processes for choosing overt responses based on current perceptual information and the subject's prior expectancies for both the occurrence of various stimuli and the anticipated outcome contingencies of response to these stimuli. Campbell suggests that what is being measured by RT in part is the duration of stimulus evaluation and response production. It is clear from these comments regarding a speed-accuracy trade-off that recording errors and considering a trade off function in studies of RT and intelligence are necessary to avoid errors of interpretation.

In general, there is overwhelming evidence in the literature that more intelligent individuals perform faster than less intelligent individuals and that this is indicative of differences in information processing efficiency and speed. What seems to account for the relation between intelligence and RT is "g", and most of the variance in "g" seems to be attributable to variance in cognitive speed and efficiency.

Intelligence and reaction time: summary.

In general, there is substantial evidence which suggests that there is a significant negative relation between intelligence and RT measures on a variety of simple cognitive information processing tasks that assess speed of decision making and speed of retrieval from STM and LTM. Advances in the research have been made in many areas, e.g., Jensen's proposal to divide RT measures into RT and MT and the development of Jensen's box. The literature also shows the development and refinement of paradigms, including a trend towards combination paradigms using tasks varying in difficulty. Despite the diversity of tasks, factor analysis of the intercorrelations of scores across tasks indicates that the first factor accounts for a substantial portion of the variance, and the factor scores of this general RT factor have been found to be significantly correlated with general intelligence (Vernon, 1983).

Although there is substantial research which supports the negative relation between IQ and RT measures, there are still a number of issues concerning RT measurement which new research needs to address. RT can vary for many reasons besides differences in speed of information processing. These reasons include age, non-random daily variation, response strategy and practice effects. Another problem is that in some areas of the cognitive literature studies include a measure of RT, whereas in other studies RT is measured in terms of RT and MT. This can lead to some confusion. As mentioned, many researchers who have studied the nature of intelligence, such as Jensen, Eysenck and Vernon, recommend uniform procedural variables in terms of stimulus modality, intensity and duration of preparatory stimulus, intensity and discriminability of RS, and type, distance and strength of movement required for response (the latency of which is RT).

In general, the evidence tends to support the view that intelligence can be referred to simple psychological functions and that individual differences in mental ability depend in part on the speed or efficiency with which individuals perform these simple functions (Jensen, 1982b).

Intelligence and Event-Related Potential (ERP) Measures.

Significant research using psychophysiological measures has taken place over the last 30 years. This has included work with EEG, and ERPs. At this point the parameters of this research will be explored. The relation between these psychophysiological measures and intelligence, reviewing both early and recent work, will also be outlined.

Psychophysiology: EEG and ERPs.

The 20th century has seen further development measures such as biochemical measures, galvanic skin response (GSR), cardiovascular measures -- such as heart rate and blood pressure -- and neural conduction velocity. Psychophysiological measures including EEG and ERPs have also been developed with considerable research having been reported over the years. Spontaneous EEG involves electrical brain activity measured over various time periods. Parameters involve electrical power in voltage or amplitude and waveform frequency. ERPs are indices of electrocortical activity occurring over very brief periods of time. They are evoked by presentation of well defined stimuli or by requiring cognitive performance such as attending to sounds and lights, discriminating semantic stimuli and remembering pictures and words. By averaging the electrocortical activity that is contingent on the repeated occurrence of these events, a characteristic ERP waveform is extracted from background EEG activity. ERPs are sensitive to the age and gender of individuals (Oken, 1989; Ditraglia & Polich, 1991).

During the past 15 years there has been considerable progress in the development of ERP recording procedures for application to problems in cognitive psychology. In general, the earlier in the waveform that a peak emerges, the more it is influenced by the physical characteristics of stimulation. Later peaks, such as positive going waves between 300 to 600 ms (P300), are reliable indices of selective attention and decision-making activity (Picton & Hillyard, 1974). At the present time, a good deal is known about both the functional significance and neural generators of several ERP waveforms (Naatanen & Picton, 1987; Ruchkin, 1988). These data have enabled the development of independent ERP measures that complement behavioral and physiological measures of perceptual and cognitive phenomena and that focus on their neurological bases. The P300 ERP wave has been examined in several cognitive paradigms (Duncan-Johnson & Donchin, 1982) and the correspondence between P300 and RT measures of information processing has been extensively explored (Kutas, McCarthy & Donchin, 1977). In general, the literature suggests that ERPs are able to provide evidence about speed of processing which is complementary to RT. In the present research, individual differences in the P300 wave are examined during the performance of simple cognitive tasks that have been shown to vary with tests of general intelligence.

Characteristics of P300 waveform: amplitude.

Current ERP research clearly demonstrates that the P300 wave is a signature of the analysis, storage and time course of certain cognitive events. It is a manifestation of the intracranial activity of a specific functional entity (Donchin & Coles, 1988). The functional role of P300 in human information processing may be the updating of neurocognitive models concerning future events (Pritchard, 1981).

It has been established in several demonstrations that P300 amplitude varies inversely as a function of the sequential and temporal probability of occurrence of an event, an effect that reflects the attentional demand of stimulation (Friedman, Hakerem, Sutton, & Fleiss, 1973; Fitzgerald & Picton, 1981). The more unexpected an event, the larger is P300 amplitude. In a series of innovative experiments, it has also been shown that P300 varies inversely as a function of the subjective probability of the occurrence of an event, independent of the objective probability of occurrence (Horst, Johnson, & Donchin, 1980). That is, the subjective probability or expectancy that the subject assigns to the occurrence of a particular event also influences P300 amplitude. The lower the subjective probability of an event, the larger will be the P300 it elicits (Duncan-Johnson & Donchin, 1977).

It has been suggested that the P300 amplitude reflects the information that the stimulus delivers to the subject (Donchin, Ritter & McCallum, 1978; Sutton, Braren, Zubin & John, 1965; Sutton, Tueting, Zubin & John, 1967). Further, there is good evidence that P300 increases in amplitude in response to task relevant or meaningful stimuli compared to the same items when instructed to ignore them (Chapman, 1965; Donald & Goff, 1971). P300 may be a manifestation of a process where the subject interacts with the environment (Donchin, et al., 1978; Donchin &

Coles, 1988). A stimulus initiates the processes of response selection and context updating (Pribram & McGuinness, 1975) which both depend on stimulus evaluation (Kutas, McCarthy & Donchin, 1977).

It is also the case that P300 amplitude to a target stimulus is attenuated in more difficult paired-stimuli tasks involving memory search and stimulus discriminations where memory workload is increased (e.g., Brookhuis, Mulder, Mulder, & Gloerich, 1983) or where the difficulty of discriminations is increased (Kok & Looren de Jong, 1980). P300 amplitude also reflects allocation of a subject's resources to a task. This view emerges from studies examining the effects of mental workload on P300 amplitude (Gopher & Donchin, 1986). It was shown that the more demanding the primary task, the lower the P300 amplitude elicited by the concurrently presented oddball stimuli. Others have shown that increasing the motor demands of the primary task does not affect P300 (Israel, Chesney, Wickens & Donchin, 1980). These data imply that the processing manifested by P300 is sensitive to the use of a limited-capacity system that can be allocated to serve one task or another (Donchin & Coles, 1988). Finally, it has been found in several memory paradigms, including demonstrations of von Restorff (Karis, Fabiani, & Donchin, 1984) and picture superiority effects (Noldy, Stelmack, & Campbell, 1990, that items that are remembered elicit larger P300 amplitude than items that are not remembered. Johnson (1985) presented a triarchic model of P300 amplitude suggesting that the subjective probability and stimulus meaning dimensions have independent yet additive effects on the amplitude of P300, and that the amplitude contributions of these are dependent on the amount of stimulus information which is transmitted (Johnson, 1985).

The relation between P300 amplitude and RT has been given relatively little attention in the literature. Data from some of the research using visual stimuli in a simple RT task have shown that shorter RT trials elicited larger P300 amplitudes (Morrell & Morrell, 1966). Similar negative correlations were found using an auditory paradigm (Roth, Ford, & Kopell, 1976; Karlin, Martz, Brauth, & Mordkoff, 1971). This evidence conflicts with the data supporting a positive relation, where unexpected events elicit a larger P300 and a slower response compared to expected events. It has been suggested that the smaller P300 amplitude for longer RT can be attributed to the greater variance in latency distribution as both RT and P300 latency increase (Donchin, et al., 1978; Roth, et al., 1976). It has also been suggested that separating amplitude changes from latency variability is difficult and that correlations between RT and P300 amplitude should be interpreted with caution (Donchin, et al., 1978). When taken together, these data indicate that the amplitude of the P300 waveform is a reliable expression of electrocortical activity that occurs during the processing of novel, task relevant cognitive events and that these events tend to be remembered.

Characteristics of P300 waveform: latency.

The latency of the P300 wave can serve as an index of the time required to perform the analysis of certain cognitive events. Several investigations have shown that P300 latency reflects stimulus evaluation independent of response production (Gomer, Spicuzza & O'Donnell, 1976; Kutas, McCarthy & Donchin, 1977; Donchin, 1979). There is a good deal of evidence demonstrating that P300 latency increases with increasing task difficulty. Specifically, P300 latency increases in auditory and visual discrimination tasks when the discriminations are made more difficult (Squires, Donchin, Squires & Grossberg, 1977; Duncan-Johnson & Kopell, 1981). Similarly, several authors have shown that P300 latency increases when stimulus set size is increased in the Sternberg memory paradigm (Sternberg, 1969; Gomer, Spicuzza, & O'Donnell, 1976; Ford, Roth, Mohs, Hopkins, & Kopell, 1979; Ford, Mohs, Pfefferbaum, & Kopell, 1980).

The relation between P300 latency and RT has also been explored more extensively than that between RT and P300 amplitude. It is in some of these studies that RT paradigms have benefitted from the measure of ERPs. For example, there is evidence which shows that P300 latency corresponds with RT on simple and choice RT tasks, in particular when accuracy instructions are assumed or emphasized (Duncan-Johnson & Donchin, 1982). However, it has been shown that the effect of instructions to respond as fast as possible has a marked effect on RT but a minimal effect on P300 latency, suggesting that the P300 latency is a consequence of stimulus evaluation that is independent of response production (Kutas, McCarthy, & Donchin, 1977; McCarthy & Donchin, 1981, 1983). This view was affirmed with a choice RT task examining stimulus and response compatibility (Ragot & Renault, 1981; Ragot, 1984). Subjects were required to respond to stimuli on the left or right side of a screen with their right or left hands in either crossed or uncrossed positions. When the stimulus and the required response were positioned on opposite sides, both RT and P300 latency were longer than when the stimulus and response were located on the same side. However, P300 latency was not increased when the hands were crossed, whereas the RT was substantially increased. These results implicated both RT and P300 latency in the analysis of the stimulus location, but only RT was implicated in the response production. Similar results, demonstrating that variation in P300 latency is a consequence of stimulus evaluation independent of response production, were obtained using the Stroop test (Warren & Marsh, 1979). In general there appears to be a consensus that P300 latency and RT, although positively correlated on some tasks and under some conditions, are largely independent of each other (Pritchard, 1981).

In general, ERPs have been useful in the study of cognitive processes. In particular, it has been shown that P300 amplitude is an expression of electrocortical activity which occurs during the processing of new, task-relevant cognitive events which tend to be remembered. The processing manifested by P300 is sensitive to the workload of the task. Also, P300 latency has been shown to increase with increasing task difficulty. The literature supports the idea that P300 latency reflects stimulus evaluation independent of response production. P300 latency is independent from RT, although positive correlations can be found under some conditions as mentioned. In general, ERPs provide evidence about speed of processing which complements RT. The information provided by P300 amplitude and P300 latency supplements information provided by RT. For these reasons, ERPs remain valuable in studying intelligence and speed of processing.

Psychophysiology and intelligence.

In recent years, studies of intelligence have included measures such as biochemical indices, galvanic skin response (GSR) and neural conduction velocity, as well as EEG and ERPs. Research into the nature of intelligence using each of these measures will be discussed in this section, but particular emphasis will be placed on intelligence and ERP analyses. In general, the literature reveals that early studies using EEG and ERPs to study intelligence, left much to be desired.

In general, many reviews of biochemical substances suggested that glucose (de Leon, Ferris, George, Christman, Fowler, Gentes, Reisburg, Gee, Emmerich, Yonekura, Brodie, Kricheff & Wolf, 1983; Chase, Foster, Brooks, DiChiro & Mausi, 1984), glutamic acid

(Weiss, 1982, 1984) or calcium (Abalan 1984) and others responsible for cortical energy supply and neurotransmitter production may have an influence on mental ability (Hughes & Zubeck, 1956; Albert & Warden, 1944; Zimmerman & Ross, 1944). The GSR can be regarded as a measure of cortical arousal activated by the reticular formation. A significant positive correlation between palmar conductance and the Wechsler IQ in children (Bastendorf, 1960) has been reported. Research using speed of neural transmission, "nerve conduction velocity", has found an inverse relation with RT and a positive relation with mental ability as measured by the MAB (Mori, 1989), and suggests that higher mental ability is related to faster speed of processing and faster nerve conduction velocity. Many of these results have yet to be replicated.

Research into intelligence using spontaneous EEG addressed four general hypotheses. First it was predicted that there would be small but consistent correlations between resting EEG and IQ scores. Second, it was predicted that correlations would be larger for marginally mentally retarded groups compared to other groups. It was also hypothesized that correlations would be related to maturation of brain functions. Finally, it was proposed that the frequency distribution of EEG activity would contribute more to the size of the correlations than the topographical distribution (Gasser, Mocks, Lenard, Bacher & Verleger, 1983).

Early work with the frequency distribution of spontaneous

EEG has yielded mixed results. For example work with alpha activity (8-12 Hz), has not demonstrated a clear, simple relation with ability measures in adults (Lindsley 1961). However, some correlations have been found, showing that slower gamma waves (30-50 Hz) give way to faster alpha in individuals with temporal lobe disorder (Ostow, 1954). If one takes a compound index of alpha frequency with amplitude and certain EEG patterns, it has been suggested that correlations with parameters such as mental age become high (Netchine & Netchine, 1962) but this has not been explored (Barrett & Eysenck, in press). Alpha frequency has been found to correlate with mental age in normal children when sex and age are constant (Vogel & Broverman , 1964). With new EEG techniques, including EEG spectral analysis, correlations between spectral power and IQ (as assessed by WISC verbal subtest) averaged 0.5 in normal children and 0.6 in mentally retarded children (Gasser, Mocks, Lenard, Bacher, & Verlager, 1983; Gasser, Von Lucadou-Muller, Verleger & Bacher, 1983). Again, these studies have not been consistently replicated (Barrett & Eysenck, in press).

There are a number of discrepancies in the research which may have led to inconsistent results. These involve inclusion of mentally retarded individuals in subject samples, poor quantitative characterization of EEG, concentration on alpha EEG and posterior derivations, visual analyses, heterogenous subject samples with respect to age, and inadequate measures of intelligence (Ellingson, 1956; Vogel & Broverman, 1964; Gasser, Lucadou-Muller, Verleger & Bacher, 1983).

Although early work with EEG was riddled with inconsistencies, there is evidence that ERP measures allow researchers to demonstrate biological causality in individual variations in intelligence (Campbell, 1985). Further, ERPs can contribute information before, during and after the decision making process. Considerable literature has accumulated since Chalke and Ertl (1965) first reported a negative correlation between a short latency visual ERP wave and intelligence. Similar ERP effects have subsequently been observed on a number of occasions using simple repetitive light flashes and brief tones. However, other studies have failed to observe the effects. Both early and recent research using ERPs to study intelligence will be outlined at this time beginning with results of early work, then leading to recent findings and models.

Results of early research with ERPs.

Substantial research into intelligence using ERPs has taken place over the last three decades. Most of the early work was examined with short latency visual averaged evoked potentials in the latency range of about 100 to 250 ms. Other work included the auditory modality. An outline of these studies will follow along with criticisms of the research found in subsequent literature.

Early work conducted by Chalke and Ertl (1965), Ertl (1971, 1973), Ertl and Schafer (1969), and Bennett (1968) has been summarized by Callaway (1975) and by Eysenck and Barrett (1985). Work with visual stimuli involved bright photic stimuli or light flashes. Varying measures of intelligence were also used including measures of fluid and crystallized intelligence, subtest and total scores from Intelligence tests, etc. Ertl contended that mental age and IQ would correlate positively with amplitude and negatively with latency and variability. Although vague as to his IQ measures, he reports that short latency, visual ERPs correlated with high IQ in 48 subjects (Chalke & Ertl, 1965). These results were replicated by others using a variety of intelligence measures (Ertl & Schafer, 1969; Ertl, 1971, 1973; Bennett, 1968; Shucard & Horn, 1972).

Negative correlations of between -.2 and -.4 were reported between ERP measures and intelligence (Shucard & Horn, 1972). This study used 108 subjects ages 16 to 68, including 60 males and 48 females. Results showed a small but negative correlation (-.15 to -.32) between latency of ERPs from fronto-parietal sites and intelligence as measured by a battery of 16 ability measures including cancelling numbers, common analogies, vocabulary, number spans, etc. There was no relation between an attentional index (N100) and IQ. It was found that both measures of intelligence, fluid and crystallized, correlated approximately the same with ERP latency measures. There were also significant correlations between measures representing simple cognitive processes and ERP latency. Further replication supported the conclusion that 10% of the variance could be accounted for by the correlation between ERP latency and IQ (Galbraith, 1970; Gucker, 1973; Everhart, Chin, & Auger, 1974). An average correlation across studies was found to be -.30 (Eysenck & Barrett, 1985).

As previously mentioned, much of this early work with visual ERPs has been criticized. For example, Ertl's studies have been criticized for his use of non-standardized bipolar electrode placement in small samples of subjects with extreme IQ scores. His studies paid little attention to the fact that ERP latency is sensitive to age, state of arousal and methodological problems (Eysenck & Barrett, 1985). Ertl has been criticized for his definitions of amplitude and latency (Eysenck & Barrett, 1985). For example, to obtain ERP latency, Ertl counted the number of zero voltage crossings in the ERP in discrete, sequential time interval bins. He then constructed a histogram from bin counts to serve as the ERP and from which to derive the latencies. Ertl did not account for eyeblink artifact. Some researchers found zero or slightly positive correlations between latency and IQ but could not conclusively confirm Ertl's hypotheses nor replicate his results (Rhodes, Dustman & Beck, 1969; Dustman & Beck, 1972) Davis (1971) attempted to replicate Ertl's work but failed.

Early work (Ertl, 1971; 1973; Ertl & Schafer, 1969; Bennett, 1968; Callaway, 1975) examined auditory evoked potentials using sound clicks and tones of varying intensities. Callaway (1975) reported a positive correlation between auditory latency and IQ, a relation which was opposite to that found with the visual modality! Hendrickson (1972) found a negative correlation between IQ and latency (from -.30 to -.5) and a positive correlation between IQ and amplitude (.3 to .45) of ERPs in response to sounds of different intensities. Use of a combined score of latency and amplitude correlated .5 to .6 with IQ. Rust (1975) failed to find similar results with the auditory modality. However, the literature also reveals that there were many methodological differences between studies, including varied sound intensities and interstimulus intervals. Other criticisms of these early studies include the use of different measures of intelligence, the inclusion of very low IQ subjects in the sample, and poor specification of instructions to subjects.

In general, criticisms of the early work have led to suggestions for standardization of variables such as number of stimuli, proper sweep time, stimulus intensity, measures of IQ, subject selection and instructions to subjects (Eysenck & Barrett, 1985). Although early studies into intelligence and ERPs demonstrated negative relations between IQ and latency and between ERP variability and ERP symmetry, and positive relations between IQ and ERP amplitude, the negative correlations were low, falling between -.20 and -.30. In general, unstandardized experimental procedures and lack of theoretical sophistication in early ERP studies of intelligence led to difficulties in replication and little consistency in results.

Recent studies.

Recent ERP paradigms have tried to address some of the criticisms of earlier work. Many studies have been based on specific models, including the Hendricksons' paradigm, the Schafer paradigm and the Robinson model. Data from this research will be described in greater detail.

Hendrickson and Hendrickson (1980) proposed that an individual with a low IQ would show a greater propensity for errors in an information processing system. Many errors would lead to greater variability in ERPs and less complexity of the ERP trace. Complexity involved measuring the contour perimeter of the ERP waveform with a string, a procedure known as the "string measure". The more intelligent the individual, the less variable the ERP, the more complex the ERP, the longer the contour (positive correlation with intelligence). This meant an ERP showing multiple deflections related to a stable pulse train coding of stimulus information. Variance was the average variability of each sample point on the ERP over a number of epochs. It involved measuring each point across a number of stimulus waveform epochs. The greater the variance the less intelligent the individual (negative correlation with intelligence). Finally, a composite measure, variance-complexity for the total ERP could be calculated.

Obtaining ERPs from children, the Hendricksons found that WAIS IQ correlated .72 with complexity (string), -.72 with variance and .83 with the composite measure (Hendrickson, 1982). When looking at specific performance and verbal variables, Performance IQ correlated .53 with complexity, -.53 with variance and .60 with the composite measure, while Verbal IQ correlated .68 with complexity, -.69 with variance and .78 with the composite measure. The Hendricksons suggested that the ERP parameters are most highly correlated with the most "g" loaded subtests of the WAIS. Similar results have been found using Ravens Advanced Progressive Matrices (Blinkhorne & Hendrickson, 1982; Robinson, Haier, Braden, & Krengel, 1984; A. E. Hendrickson, 1982; D. E. Hendrickson, 1982; Stough, Nettelbeck, & Cooper, 1990). It has been noted that intensity of stimulus is also important in determining the magnitude of the relation between complexity and amplitude and IQ scores (Haier, Robinson, Braden & Williams, 1983).

The Hendricksons' model has been criticized on many levels (Campbell & Cullum, 1985). First, the rejection criteria for ERPs, which is necessary to determine a clear waveform, are unclear. Also, there is no indication of instructions to subjects or the subject's activity, especially with respect to attention. Lack of attention to these variables, which are considered important in the ERP literature, lead to questions as to the reliability, validity and generalizability of the Hendricksons' results.

The Schafer paradigm is based on a model of selective attention, information processing workload and cognitive modulation of EEG or "neural adaptability" (NA) (Schafer 1979, 1982; Schafer & Marcus, 1973). Schafer hypothesized that individual differences in NA would relate to individual differences in intelligence and he developed paradigms to study these phenomena. Results from his studies showed that level of IQ, as assessed by a battery of 15 psychometric tests including the Sonoma Neurological Assessment Battery, the Stanford-Binet and Figure Copying Test, correlated with indices of NA (.64), habituation to experimental stimulation and orientation to unexpected stimuli in a sample of 54 severely retarded adults with IQ of less than 50 (Jensen, Schafer & Crinella, 1981). Factor loadings of WAIS subtests correlated with ERPs at .90! Schafer interpreted these data to mean that an intelligent individual would show efficient use of limited neural energy and functions, allowing greater expenditure on other mental operations, and the ability to deal efficiently with both expected and unexpected stimuli. For several reasons the Schafer paradigm has not met with popular success. For example, it introduces a self-stimulation condition which lends itself to problems regarding inconsistent or random stimulus presentation and individual variability. In ERP studies proper stimulus presentation is an important aspect which can greatly affect ERP waveforms and subject performance.

The literature also describes another more complicated model based on the work of Robinson (1982). It deals with Pavlovian excitatory and inhibitory processes with reference to oscillatory

EEG. Robinson presented a very elaborate model to obtain a measure "V" and used visual steady state responses from diffuse white light at different frequencies. Robinson reported a correlation of .35 between "V" and subscales of the WAIS, suggesting that superior mental performance would depend on the values of both of these parameters, specifically when they take intermediate and similar values. However, like the Hendrickson and Schafer studies, results do not account for important ERP parameters usually addressed in cognitive psychology such as the use of other modalities, consistent stimulus presentation, and attention to subject activity and artifact, to name a few.

Work has also been done using a component of the ERP called the contingent negative variation (CNV). The CNV is represented by the sum of a group of negative slope potentials which develop between a warning signal and a second imperative signal requiring a response. Trimmel (1985, 1986), in unpublished data, showed an interaction between the prewarning stimulus baseline EEG positivity or negativity and the CNV amplitude and the velocity of amplitude change. The measure used correlated .59 with IQ. Other work with ERPs and children (Molfese & Molfese, 1985) found that the ERPs of 36 hour infants related to a verbal intelligence of age three years.

Recent work with ERPs and intelligence, although commendable in terms of effort and creativity, has been plagued by inconsistencies, non-replicable results and methodologies which deviate from the standards and theories found in ERP studies of cognitive processes. Barrett and Eysenck (in press) attempted to replicate the results from the Hendrickson and Schafer paradigms. They found most of their results to be inconsistent with both studies. Indeed, as they suggest, attention must be paid to methodological quality, subject arousal, artifact removal, subjective bias in epoch selection, stimulus character and delivery schedule, the filtering of EEG and the effects of age and gender.

Intelligence and ERPs: summary.

In general, the literature consistently shows that there are negative relations between IQ and ERP variability and latency measures. The correlation between IQ and ERP variability is consistently negative from -.72 to -.20 (Barrett & Eysenck, in press). The correlation between IQ and ERP latency and complexity measures is about-.30 (Barrett & Eysenck, in press). Several investigators have speculated that their results reflect some form of neural efficiency that favours high ability subjects (Ertl & Schafer, 1969; Hendrickson and Hendrickson, 1980; Robinson, 1982).

However, the IQ-ERP research outlined in the literature leaves much to be desired. For example, several failures to observe a negative relation between IQ and ERP measures have been reported (Rhodes, Dustman, & Beck, 1969; Davis, 1971; Dustman & Beck, 1972; Shucard & Callaway, 1973). With respect to the "neural efficiency" hypothesis, there exists little research linking neural efficiency to ERP waveforms and there has yet to be an agreed upon measure of what is called "neural efficiency". Other researchers contend that there is little evidence that ERPs themselves provide a measure of intelligence (Campbell & Cullum, 1985). The convergence between intelligence and stimulus conditions employed to elicit ERPs in some of the studies seems nebulous. For example, the association between intelligence and sensory sensitivity or simple RT to light flashes and brief tones seems consistently low. In other cases, ERPs were not recorded concurrently with performance of the task at hand during the experimental procedures. Work with ERPs and intelligence has not explained results found with RT and in some cases RT was not recorded concurrently. Finally, further clarification is necessary with respect to issues such as measurement, subject selection, controlling arousal and attention to artifact (Eysenck, 1985).

Although the results of early studies of IQ using ERPs have been inconsistent, recent investigations and the study of other cognitive processes using ERPs have met with success. They have given new life to the potential to explore the nature of intelligence with ERPs. For example, it has been noted that ERPs, specifically P300, can be useful to study stimulus evaluation and response production in information processing when recorded with RT (Kutas, McCarthy, & Donchin, 1977). Dividing RT into RT and MT, a practice seen in RT-IQ research, can easily be adapted to ERP-IQ research. Recent advances in technology, including computer programming, can allow easier identification of artifact as well as single trial analysis. In turn, this provides an opportunity to observe errors and note any speed-accuracy trade-off strategy. Newer research should also account for muscle and eye movement artifact, gender differences and age. In conclusion, although early IQ-ERP research is inconclusive, there is still the potential to further explore evidence from research which suggests that a negative relation exists between cognitive performance (IQ measures) and ERPs of the brain.

Literature Review: Summary.

In general the review of the literature has outlined important issues and developments in intelligence research. From much of the early work on intelligence grew a strong mental testing movement. However, research has also provided an increase in the amount of evidence for a general factor of intelligence "g". Further, in the search for the nature of intelligence there have been investigations which have emphasized an information processing approach to intelligence, exploring the process underlying intelligent behaviour and individual differences in task performance. The advantages of rapid mental operations, efficiency of information processing and speedy response were seen to relate to higher mental ability. Although early endeavours to associate intelligence with simple mental processes met with limited success, recent work consistently reports negative correlations between general intelligence and a wide range of RT tasks that assess speed of decision making and speed of retrieval from STM and LTM. Further, work conducted with ERPs suggests that there is a consistent negative correlation between IQ and ERP measures. Investigations using ERPs have been successful in the study of cognitive processes, including the processing of information. Specifically, data indicate that P300 amplitude is a consistent expression of electrocortical activity that occurs during the processing of new, task-related cognitive events which tend to be remembered. P300 latency has served as an index of the time required to perform certain cognitive processes, such as stimulus evaluation, and it is sensitive to task difficulty. There is a consensus that P300 latency and RT are largely independent, and when measured concurrently, may provide a clearer picture of some cognitive processes and task performance, than if measured alone.

The literature also clearly presents some of the problems which have plagued past research into intelligence. The nature of intelligence and its measurement has confounded psychologists for years. Research with RT has shown that more intelligent individuals have faster RTs than less intelligent individuals. However, studies have yet to show consistency in addressing factors such as individual response strategies, stimulus modality, stimulus intensity and distance and strength of movement required for a response. Some studies measure RT whereas others divide measures into RT and MT, thus making generalizability from one study to another difficult. Few studies monitor or account for response error. Results found using ERP measures have not been consistently replicated and the convergence between stimulus conditions used to elicit ERPs and intelligence seems vague. Many studies do not note control for eye or muscle artifact. In many studies, ERPs were not recorded concurrently with performance of the specific task. Few studies of intelligence record ERPs and RT measures concurrently during task performance, making it difficult to discern relations or interactions with intelligence. Few studies help explain why more intelligent individuals perform faster in cognitive tasks than less intelligent individuals.

In the present study, ERPs were recorded concurrently during the performance of a number of simple cognitive tasks that have been related to tests of psychometric intelligence (Vernon, 1983). In so doing, this study contributes a number of original elements to the research on intelligence and speed of processing. The RT tasks are those commonly employed in information processing theory approaches to cognitive processing. However, there is prima-facie relevance of the tasks performed to process underlying IQ tests. The tasks were selected because of their compatibility with ERP recording requirements. They have repeated trials, discrete stimulus onsets and relatively brief trial durations. The tasks have been shown to vary with IQ and vary with respect to task difficulty as indicated by error rate and increased RT. They vary in terms of information processing demands, ranging from simple to more difficult tasks, allowing observation of whether individuals of differing intelligence levels can be better differentiated with tasks varying in complexity. In some instances the tests have been slightly modified to accommodate concurrent ERP recording. In this study, ERPs and RTs will be measured concurrently during task performance by individuals varying in IQ. This investigation regards IQ from the perspective of intelligence as a general factor "g". This is a perspective which, although still somewhat controversial, appears to be gaining more widespread acceptance.

This study also makes some important contributions with respect to ERPs and intelligence, and the need for such considerations has been underscored in the literature (Gale & Edwards, 1983). Controls for age and subject gender are included. Single trial analysis was also carried out to allow controls for artifact and error. The ERP component, P300, was studied. It is an independent measure of "speed of processing" that can demonstrate that speed of processing is a characteristic that distinguishes between high and low IQ subjects. As mentioned, P300 has some important advantages over RT as it is not influenced by instructions to subjects, a speed-accuracy trade off or response production. Finally, use of P300 as an independent measure of speed of processing supports the view that intelligence can be referred to a simple (unlearned) psychological function.

In general, it was expected that previous results with RT and intelligence would be replicated. More intelligent individuals were expected to perform faster than less intelligent individuals. Furthermore, since P300 latency has been found to increase with increased task difficulty, it was expected that P300 latency would lengthen as the tasks became more difficult. This should also be seen with RT. Given that P300 latency can index the time required to perform the analysis of certain cognitive events, it was expected that P300 latency would correlate negatively with psychometric intelligence measures. In other words, more intelligent individuals would show shorter P300 latencies than those less intelligent. Moreover, it has been shown that P300 reflects information the stimulus delivers to the subject. The higher the subjective probability of an event, the smaller the P300 amplitude. It is also known that increased memory workload attenuates P300. More intelligent individuals should show smaller P300 amplitudes to target stimuli.

Method

Introduction

This section begins with a description of subject selection. An outline of the procedure will follow that describes stimulus presentation, an elaboration of simple, choice and paired stimuli RT tasks, response recording, EEG recording and ERP analyses.

Subject Selection

Subjects were recruited from a class of first year university students. Data gathered enabled selection of fifty-six subjects who were right handed females, age 18 to 25 years of age, who were at the undergraduate level of education and whose first language was English. Restricting the subject selection to females in a specific age range allowed controls for gender and age which, as the literature review points out, can affect ERP and RT measures. This subject selection also included consistency in education level, language spoken and handedness. Each of the subjects was given a brief explanation of the research project and each provided written consent with respect to the use of her data in this research (Appendices A and B).

Mental ability was assessed using the Multidimensional Aptitude Battery (MAB) (Jackson, 1983). This IQ test is a group test modelled after the Wechsler Adult Intelligence Scale -

Revised (WAIS-R) (Wechsler 1955, 1981). Like the WAIS-R, the MAB contains subtests, including Information, Comprehension, Arithmetic, Similarities, Vocabulary, Digit Symbol, Picture Completion, Spatial, Picture Arrangement and Object Assembly. The MAB was chosen to measure intelligence because it is a sound measure. Reports of internal consistency reliability estimates for different age groups for Full Scale IQ are in the range of .96 to .98 (Jackson, 1984). Test-retest reliability estimates for the Verbal Scale, the Performance Scale, and Full Scale IQ scores are .95, .96 and .97 respectively. The MAB norms are comparable to the WAIS-R and the MAB has high mean correlations with the Verbal (.94), Performance (.79) and Full Scale IQ scores (.91) of the W.A.I.S.-R (Jackson, 1984). This test was also chosen because it can be administered in groups.

Each subject was asked to refrain from drinking coffee or smoking cigarettes for two hours prior to the individual session of the experiment. This was to control for the stimulant effects of caffeine and nicotine. Each subject completed a questionnaire (Appendix C) to facilitate further screening for medication histories and auditory, visual and motor impairment, so as to control for possible effects of medication or sensory and motor impairments on performance. ERPs were recorded concurrently with the performance of the cognitive tasks. Subjects received 20 dollars for participating in both intelligence testing and ERP recordings of the experiment (Appendix D).

In order to describe the interaction of task difficulty and mental ability on the RT and the ERP measures across task conditions, subjects who had successfully completed all tasks were classified into above average ability (AAA) and average ability (AA) groups on the basis of full scale MAB scores (FIQ). The AAA group (N = 15) obtained FIQ scores greater than 110, (the cut-off score between above average and average groups according to the WAIS-R and MAB) ranging from 111 to 134 with a mean of 119 (SD = 7.07). For the AAA group, the mean verbal score (VIQ) was 112 (SD = 6.85) and the mean performance score (PIQ) was 125 (SD = 7.34). The AA group (N = 15) obtained FIQ scores of less than 110, ranging from 86 to 107 with a mean of 102 (SD = 5.67). For the AA group the mean VIQ was 100 (SD = 5.57) and the mean PIQ was 104 (SD = 7.34).

Procedure

The stimulus presentation and response recording took place in a sound attenuated chamber. Communication between experimenter and subject was possible via intercom. A combination of six cognitive tasks were presented in random order across the individual subject sessions. There was a two minute interval between the presentation of each task. At the beginning of the session, the subject was instructed to respond quickly and accurately and to refrain from moving or blinking during the trials. A practice period of 10 trials ensured that the subject understood the procedures before performing each of the tasks.

As mentioned in the literature, combinations of tasks such as those described below are designed to study the relations between speed of processing and IQ. Combining tasks is valuable because it allows the researcher to simultaneously observe various aspects of information processing and their relations to mental ability.

Stimulus presentation.

Presentation of stimulus items was controlled by an IBM compatible XT computer (RAWDATA program, RTMT program, Makasare 1988) and displayed on a video monitor located 0.5 m in front of the subject. The stimuli were displayed in the centre of the monitor in reverse video, black characters on an amber background, in order to minimize stimulus persistence. A warning stimulus (**) 50 ms in duration that appeared in the centre of the video monitor signalled the beginning of each trial. Stimulus lists for each task are provided in Appendix E.

Simple Reaction Time (SRT) and Choice Reaction Time (CRT).

In both the SRT and CRT tasks, the target stimulus was presented at a random interval of 50 ms to 2010 ms after the onset of the warning stimulus. The duration of the target stimulus was 1590 ms. The duration of each trial, from the onset of the warning stimulus to the onset of the warning stimulus of the next trial varied randomly between 4 to 6 seconds (Appendix F). In the SRT task, subjects were instructed to press a button, indicating yes, as soon as the target stimulus, X, appeared. Seventy trials were presented. In the CRT task, subjects were asked to press the yes button when the target stimulus was the letter X and to press the no button when the target stimulus was the letter O. The two target stimuli were presented 70 times each in random order. The SRT and CRT tasks provide indices of speed of decision making.

Paired-stimuli tasks.

The Sternberg Digit Recognition Test is regarded as a task that assesses the speed and efficiency of short-term memory storage and processing (Sternberg, 1969). Physical Similarity, Semantic Similarity and Category Matching are tasks that assess efficiency of linguistic processing (Vernon, 1983). In these paired-stimuli tasks, the first stimulus was presented 950 ms after the offset of the warning stimulus for a duration of 200 ms. The target stimulus was presented 700 ms after the offset of the first stimulus for a duration of 1600 ms. The duration of each trial was 5 seconds (Appendix G). Each of these tasks will be described in more detail.

Sternberg Digit Recognition Task (DIG).

In this task, subjects were instructed to respond yes when the target stimulus, a single numerical probe digit, had appeared in the preceding string of digits and no when it was not. The target stimulus appeared in the digit string on 50 per cent of the 140 trials. An equal number of digit strings, from one to seven digits in length, was presented in random order. No digit was repeated within strings of two or more digits. The position of the target stimulus in the string was also randomly determined. This task is described in the literature as Sternberg's STM scanning paradigm (Sternberg, 1966; 1969) and measures the speed at which an individual scans and processes STM or information.

Physical Similarity Task (SD2).

The subject was instructed to respond yes if the target stimulus (e.g., cat) was physically the same as the first stimulus word and to respond no when the target stimulus (e.g. mat) was physically different. On 70 trials, the word pairs were physically the same and on 70 trials they were physically different. The words were two to eight letters in length. Word pairs were always the same length. In the literature, this task is described as part of the Posner LTM access paradigm (Posner, 1969) and it measures the time it takes a subject to access an item stored in memory. The physical discrimination is similar to the classical two choice discrimination task (Vernon, 1987).

Semantic Similarity Task (SA2).

When the target stimulus had the same meaning (was a synonym) for the first word, the subject was instructed to respond yes. When the target word had the opposite meaning (was an antonym), the subject responded no. There were 70 pairs of synonyms and 70 pairs of antonyms presented in random order. Word pairs were not necessarily the same length. This task is described in the literature as part of the Posner LTM access paradigm (Posner, 1969) measuring the time it takes a subject to access an item stored in LTM. The semantic discrimination involves access to semantic codes in LTM (Vernon, 1987).

Category Matching Task (CAT).

Subjects were instructed to respond yes when a target stimulus was a member of the category of the preceding word, and to respond no when it was not. Five categories were employed, animal, fruit, furniture, sport and clothing. Each category was presented an equal number of times in a random order across 140 trials. On 70 trials, the target stimulus matched the category and on 70 trials it did not. This task also measures the time it takes for a subject to access items stored in LTM (Vernon, 1987).

Response recording.

The subject responded on a three-button Logitech mouse, model C7-3F-95 (Appendix H). The warning stimulus signalled the subject to press the centre home button of the mouse with the index finger of her dominant hand. The subject released the home button and pressed the left button with her index finger if the response to the target stimulus was yes and she pressed the right button to respond no. All responses were recorded on disk.

Following Jensen (1982a; 1982b), RT was defined as the time from the onset of the target stimulus to the release of the home button. MT was defined as the time from the release of the home button to the onset of the yes or no button press. Only trials where a correct response occurred within the 1600 ms target stimulus duration were included in the calculation of RT and MT (and in the ERP averaging series). Both the mean and median RT and MT were computed for each subject from the trials within each task. However, Pearson correlations between mean RT and median RT ranged from .94 to .99 across tasks and from .89 to .97 between mean MT and median MT. To avoid redundancy, only mean RT and MT analyses are reported. The frequency and response time of fast and slow errors were also tabulated. Fast errors were incorrect responses that had latencies that were faster than the median RT. Slow errors were incorrect responses that had latencies slower than the median RT.

EEG recording.

The EEG was recorded from Ag/AgCl electrodes placed at midline frontal (Fz), central (Cz), parietal (Pz), and occipital (Oz) sites (Jasper, 1958) and that were referenced to a non-cephalic sterno-vertebral electrode (Stephenson and Gibbs, 1951) (Appendix I). The electro-oculogram (EOG) was monitored on a single channel from the infra-orbital and supra-orbital ridges of the left eye. A ground electrode was placed on the forehead. Electrode sites were cleansed and abraded (Picton & Hillyard, 1972). Inter-electrode impedances were below 2 kOhms.

EEG signals were amplified using Nihon Kohden EU/5d polygraph amplifiers. The EOG was recorded at half the gain of the other channels. The EEG and EOG channels had a high filter set at 30 Hz and a time constant set at 2 seconds. A calibration signal of 50 uV was passed through the system. A/D conversion was carried out at a 6 ms sampling rate. For the SRT and CRT tasks, the sweep time began 320 ms prior to the onset of the target stimulus and continued for 1600 ms post-stimulus onset. For the paired stimuli tasks, the sweep time began 500 ms prior to the onset of the first stimulus and continued for 2500 ms post-stimulus onset. Single trials were stored on disk and ERP averages were computed offline. Trials were rejected from the averaging series where EEG or EOG signals exceeded $\pm$ 100 uV, and where the subject failed to respond or responded incorrectly.

ERP analyses.

The P300 waveform of the ERP was scored using a computer algorithm. The scored data were subsequently verified and when necessary scored manually using a graphic display and cursors. This only occurred on several occasions and was conducted by the primary researcher only who, at that time, was unaware of group membership. The ERP waveforms to the target stimuli across all tasks, and to the first stimulus in the paired-stimuli tasks, were characterized by a positive wave having a latency between 300 and 900 ms (late positive component, LPC) that was evident at all electrode sites. For the paired-stimuli tasks, the onset of the waveform to the target stimulus was preceded by a negative wave that developed in anticipation of the motor response (CNV; Rohrbaugh & Gaillard, 1983). The morphology of the ERP waves across all of the electrode sites are illustrated in Figures 1 through Figure 6 with waveforms obtained during the SRT, CRT, SD2, CAT, DIG and SA2 tasks, respectively.

-----------------insert Figure 1 to 6 about here---------

In the SRT and CRT tasks, the ERP peak amplitude measurements for the target stimulus were referred to a 320 ms pre-stimulus baseline. In the paired-stimulus tasks, amplitude measurements for the first stimulus were referred to a 500 ms pre-stimulus baseline and the amplitude of the target stimulus waves were measured from the preceding 100 ms epoch. In all tasks, the amplitude of the LPC for the target stimulus was maximum at the parietal site (Pz) and was consistent with the scalp topography characteristic of the P300 wave (Donchin, Ritter, & McCallum, 1978). The amplitude and latency of the P300 wave at Pz was employed in all statistical analyses. Examples of ERP waveforms for 1 subject from each mental ability group are illustrated in Appendices J1, J2 and K1, K2.

Results

Introduction

This chapter begins with an outline of the analyses performed in order to look at the differences in the dependent measures across tasks and between mental ability groups, as well as the convergence of these dependent variables. The results of each variable are then reported, beginning with mental ability and simple and choice RT, and mental ability, RT and paired stimuli RT tasks. Next, P300 data will be reported and will include P300 and simple and choice RT, and P300 and paired stimuli tasks. Finally, the relations between mental ability, RT variables and P300 variables will be elaborated.

Analyses

The analysis of the data began with an examination of the performance on the cognitive tasks in terms of speed and accuracy of responding. The relative difficulty of the tasks was then determined. The response times across tasks, RT and MT, variability of RT, and the concurrently recorded ERPs, P300 amplitude and latency, were illustrated by comparing AAA and AA mental ability groups. The convergence of the performance measures, ability measures, and ERP measures was also determined.

For ability group comparisons on SRT and CRT, two-way ANOVA (group x task) with repeated measures across task conditions was applied to each of the dependent measures. This was done using programs from SPSS-X (Nie et al, 1986) and BMDP (Dixon, 1985) statistical software manuals. For ability group comparisons on the paired-stimuli tasks, an additional repeated factor, response type (yes and no), was analyzed in a three-way ANOVA. Conservative degrees of freedom were employed for ANOVA factors with repeated measures (Geisser-Greenhouse, 1958). The Tukey Test was employed for individual comparisons between means. The .05 level of confidence was applied to all statistical tests unless noted otherwise. The association between the RT and ERP measures and their relation to intelligence within tasks was assessed using correlations and factor analysis. Multiple regression analyses were also performed to examine contributions of RT and ERP variables to the prediction of IQ.

Task Difficulty

In order to affirm the validity of the RT and MT as measures of speed of information processing, it was necessary to establish that faster responding was not achieved at the expense of more frequent errors. In general, few errors were observed in the five tasks where errors could be made (CAT, SA2, SD2, DIG, CRT). As shown in Table 1, the percentage of fast errors ranged from .36 % to 1.76 % and the percentage of slow errors ranged from 0.10 % to 2.78 %. Phi coefficients were calculated between RT and the total number of errors, each dichotomized as above or below the median score. Negative phi coefficients would indicate that faster responding subjects (those who had shorter RTs than the median RT) made more errors. Positive phi coefficients would indicate that slower subjects (those who had longer RTs than the median RT) made more errors. In this analysis no relation between errors and RT was observed for CRT (.20), SD2 (.07) or CAT (-.13). Negative phi coefficients were observed for DIG (-.33) and SA2 (-.33) indicating a modest speed-accuracy trade-off for the two tasks that displayed more frequent (albeit negligible) errors and longer RT. However, there were no differences between ability groups in their frequency of fast and slow errors on any of the tasks, $F < 1.0$.

------------------insert Table 1 about here----------------

Although the frequency of errors was slight, the tasks were differentiated by both fast errors, $F(4, 112) = 24.59$, and slow errors, $F(4, 112) = 68.06$, according to the following hierarchy which serves as a scale of increasing task difficulty: CRT, SD2, CAT, DIG and SA2. As shown in Table 2, basically the same pattern of results was observed with the RT and MT measures. A notable exception to the pattern is the juxtaposition of the RT measures in DIG and CAT for the correct (both yes and no) responses.

----------------insert Table 2 about here-----------------------

One issue in the RT literature has focused on which RT measure, mean or median, best represents a measure of central tendency (Jensen, 1982a). Data from this study indicated that the correlation between mean RT and median RT ranged from .94 to .99 over RT tasks. Correlations between mean and median MT ranged from .89 to .97. For the purpose of this analysis the mean will be reported only.

<u>Mental Ability and Simple and Choice RT Tasks</u>

Mean RT was faster for SRT (340 ms, SD=53) than for CRT (454 ms, SD = 58), $F(1, 28) = 333.24$. Differences between the AAA and AA groups were not statistically significant, and there was no interaction between groups and the tasks. The ANOVA table for mean RT for SRT and CRT is illustrated in Appendix L.

MT also differentiated CRT (122 ms, SD = 39) and SRT (99 ms, SD = 29), $F(1, 28) = 26.37$. Mean MT was faster for the AAA group on both SRT (87 ms, SD = 34 ms) and CRT (108 ms, SD = 43) compared to the AA group on SRT (113 ms, SD = 24) and CRT (133 ms, SD = 35), $F(1, 28) = 4.53$.

Intraindividual variability in RT did not differentiate the two tasks. No main effect of group nor any interactions was apparent, $F < 1.0$. Table 3 illustrates average intraindividual variability in RT on RT tasks.

------------------insert Table 3 about here--------------------

Mental Ability, RT and Paired Stimuli RT Tasks

Individual comparisons between means indicated that, with the exception of CAT and SA2, mean RT differences between paired stimuli tasks were significantly different, $F(3, 84) = 120.5$. Mean RT for SD2, CAT, DIG and SA2 were 478 ms (68 ms), 672 ms (119 ms) 561 ms (111 ms) and 669 ms (118 ms), respectively. Post hoc testing revealed significant differences between all tasks with the exception of CAT and SA2. The yes response (569 ms, SD = 94) was significantly shorter than the no response (621 ms, SD = 101), $F(1, 28) = 99.7$. Analysis of the interaction between task and response type indicated that negative response RTs in the SA2 and CAT tasks were longer than for affirmative responses in those tasks, $F(3, 84) = 13.7$.

The AAA group displayed faster mean RT (562 ms, SD = 94) than the AA group (627 ms, SD = 102 ms) across all cognitive tasks, $F(1, 28) = 4.00$, $p < .0553$. Individual comparisons between means indicated that these effects were primarily determined by the faster RT for both yes and no responses on the SA2 and DIG tasks, and for the no response RT on the CAT tasks. Group mean RTs observed during the cognitive tasks are illustrated in Figure 7. The ANOVA table for mean RT in paired stimuli tasks is illustrated in Appendix M.

--------------------insert Figure 7 about here-------------

Differences in mean MT between tasks were also observed, $F(3, 84) = 8.24$. Mean MT was 136 ms (43 ms), 152 ms (50 ms), 147 ms (45 ms) and 162 ms (54 ms) for SD2, CAT, DIG and SA2, respectively. Individual comparisons indicated that differences between SD2 and SA2 primarily determined the effect. There were no main effects or interactions with mental ability or response type for the MT measure.

Differences in intraindividual variability in RT (SDRT) between tasks were observed, $F(3, 84) = 80.2$. Post hoc testing revealed significant differences between all tasks. Mean SDRT for the yes response (134 ms, SD = 38) was also significantly less than for the no response (145 ms, SD = 40), $F(1, 28) = 25.18$. The interaction between task and response type was significant, $\underline{F}(3, 84) = 11.32$ with exceptions found in yes compared to no responses within SD2, DIG, CAT and in CAT no compared to SA2 yes responses.

A main effect of ability group was significant, $\underline{F}(1, 28) = 3.77$ at $\underline{p} \leq .06$. SDRT was greater for the AA group (151 ms, SD = 35) than for the AAA group (129 ms, SD = 43). No other interactions were significant. For the ability groups the mean MT and mean SDRT during the tasks are illustrated in Figure 8 and Figure 9, respectively.

---------------------insert Figure 8 and 9 about here-----------

Mental Ability, P300 and Simple and Choice RT Tasks

The P300 wave effectively differentiated the SRT and CRT tasks on both the amplitude, $\underline{F}(1, 28) = 21.50$, and the latency measures, $\underline{F}(1, 28) = 24.05$. For example, for the yes response, P300 amplitude was greater (14.4 uV, SD = 6.9) and the latency was longer during CRT (457 ms, SD = 45) than during SRT (11.05 uV, SD = 6.7 and 422 ms, SD = 27, respectively). There were no significant main effects or interactions for ability groups on these tasks, $\underline{F} < 1.0$. The ERP waveforms obtained by AAA and AA groups from the parietal site (Pz) during performance on SRT And CRT tasks are shown in Figure 10. The ANOVA tables for mean P300 amplitude and latency to target stimulus in SRT and CRT are illustrated in Appendices N and O, respectively.

---------------insert Figure 10 about here---------------------

Mental Ability, P300 and Paired Stimuli Tasks

The ERP waveforms obtained by the AAA and AA groups from the central parietal site (Pz) during the performance of the paired stimuli tasks are shown in Figure 11. The ERP analysis allows an assessment of the first stimulus in these cognitive tasks. This feature distinguishes the ERP analysis from the RT analysis that focuses solely on the response to the target stimulus. Between task differences were observed in the P300 amplitude to the first stimulus, $F(3, 84) = 57.47$. Mean P300 amplitude for SD2, CAT, DIG and SA2 were 3.1 uV SD = 3.6, 7 uV SD = 3.4, 10.3 uV SD = 4.4 and 3.1 uV SD = 3.6, respectively. This is illustrated in Table 4. Individual comparisons between means indicated that P300 amplitude to the first stimulus was larger during the DIG and CAT tasks than during SD2 and SA2 tasks. Differences between the AAA and AA groups were also noted, $F(1, 28) = 3.64$, $p < .06$. Individual comparisons between means indicated that the between group differences were determined by the larger P300 amplitude displayed by the AAA group (4.3 uV, SD = 5.2) to the first stimulus in the SA2 task for the yes response and in the SD2 (4.6 uV, SD = 4.1) and DIG task (11.4 uV, SD = 10.4) for the no response. Figures 12 and 13 illustrate mean P300 amplitude to the yes response across tasks to the first stimulus and target stimulus, respectively.

----------insert Table 4, Figures 11, 12 and 13 about here------

The latency of the P300 wave to the first stimulus also differentiated the paired-stimuli tasks, $F(3, 84) = 4.68$. Mean P300 latency to the first stimulus in SD2, CAT, DIG and SA2 were 471 ms, SD = 45, 474 ms, SD = 51, 490 ms, SD = 34, and 497 ms, SD = 40, respectively. These data are illustrated in Table 5. Individual comparisons between means indicated that P300 latency to the first stimulus was longer during SA2 than during SD2. No other main effects or interactions were observed, $F < 1.0$. The ANOVA tables for P300 amplitude and latency to the first stimulus in paired stimulus tasks are illustrated in Appendices P and Q, respectively.

---------------insert Table 5 about here-------------------

P300 amplitude to the target stimulus varied between tasks, $F(3, 84) = 27.38$. Individual comparisons between means indicated that P300 amplitude to the target stimulus was larger during SD2 (13.8 uV, SD = 6.15) than during SA2 (10.4 uV, SD= 6.2), CAT (8.4 uV, SD = 7.25) and DIG (6.8 uV, SD = 5.9). Further, P300 amplitude during SA2 was larger than during DIG. No other main effects or interactions were observed for P300 amplitude to the target stimulus.

As illustrated in Figure 14, the differences between the cognitive tasks in P300 latency to the target stimulus paralleled the RT responses, $F(3, 84) = 172.3$. Significant differences in P300 latency were evident between all tasks except SA2 and CAT. Mean P300 latency to the target stimulus in SD2, CAT, DIG and SA2 were 490 ms, SD = 73, 685 ms, SD = 41, 556 ms, SD = 58, and 679 ms, SD = 50, respectively. The mean P300 latency for yes responses (583 ms, SD = 57) was faster than for no responses (622 ms, SD = 54), $F(1, 28) = 41.62$. Analysis of the interaction between tasks and response type indicated that this effect was determined primarily by the faster P300 latency for the yes response in the SD2 (440 ms, SD = 71) and DIG (582 ms, SD = 69) tasks, $F(3, 84) = 14.22$. P300 latency to the target stimulus distinguished between the ability groups at the .07 level of confidence, $F(1, 38) = 3.38$. A priori, contrasts indicated that the AAA group had faster latency (660 ms, SD = 46) than the AA group (699 ms, SD = 51) for the yes response at SA2. Figures 15 and 16 illustrate mean P300 latency to the yes response across tasks to the first stimulus and target stimulus, respectively, comparing the two mental ability groups. ANOVA tables for P300 amplitude and latency to the target stimulus in paired stimuli tasks are illustrated in Appendices R and S, respectively.

_______________insert Figure 14, 15 and 16 about here----------

Mental Ability, RT and P300 Latency

From the analyses of variance of the RT and ERP measures it is clear that they are differentially sensitive to the task demands and, in particular, that the RT and P300 latency increase in a similar fashion across tasks. Some consistency between the AAA and AA groups across tasks was also evident. Compared to the AA group, the AAA group displayed faster RT and P300 latency to the target stimulus, smaller P300 amplitude to the target stimulus, and larger amplitude to the first stimulus in the paired-stimuli tasks.

The association between the RT and ERP measures and their relation to mental ability within tasks was assessed with correlation and factor analyses. In these analyses, RT and ERP measure the average of the yes and no response categories within each task for each subject. It has been a tradition in the literature to use factor analysis to help summarize and aggregate data (Vernon, 1983; 1987). The factor analyses of intelligence tests and conceptions of ability using factors have been prominent in the intelligence literature (Berger, 1982). Although in this case the total number of subjects was 30, factor analysis was seen to be helpful in summarizing the data.

---------------insert Table 6 and Table 7 about here------

An overview of the relation between mental ability and the RT measures is presented in Table 6 which shows that the correlations of the full scale MAB IQ (FIQ) with RT, SDRT and MT measures to the target stimuli are generally negative. The RT correlations with FIQ tend to be rather low and insignificant, particularly for the easier tasks. The exception is the significant correlation of -.34 between FIQ and RT in CAT. The SDRT correlations with FIQ follow the same trend, with a significant negative correlation found in CAT of -.33. Half of the MT correlations with FIQ are significant including -.38 in SRT, -.33 in SD2 and -.30 in DIG.

The correlations between the ERP latency and amplitude measures and the mental ability, RT, SDRT and MT measures are presented in Table 7. For P300 latency of yes responses to the target stimuli, the correlations with FIQ are negative, with significant correlations of -.38 in CAT and -.32 in DIG. With the exception of a significant positive correlation between P300 latency and RT during CRT, correlations between P300 latency and RT, SDRT and MT are not significant. For P300 amplitude of yes responses to the target stimuli the correlations with FIQ are negative with the only significant correlation of -.37 found in SA2. Negative correlations are also observed between P300 amplitude and RT, with significant correlations of -.36 and -.37 in CAT and DIG, respectively. There is a significant correlation of -.35 in CAT and -.42 in DIG between P300 amplitude and SDRT, but no significant correlations evident with MT.

The generality of the mental ability, RT and ERP measures, and their convergence, was assessed by subjecting the intercorrelation of the MAB subtests, the RT measures to the target stimuli in the six cognitive tasks, and the corresponding

P300 ERP latencies and amplitudes to an independent principal component factor analysis. For these analyses, the yes and no responses were averaged within each task for each subject. For each analysis, factor scores were determined for the first unrotated factor. The factor scores obtained from the intercorrelation of the MAB subtests define a general intelligence score (IQg). The factor scores obtained from the intercorrelation of RT on the RT tasks define a general reaction time score (RTg). The factor scores obtained from the intercorrelation of SDRT and MT on the RT tasks define a general SDRT score and MT score, SDRTg and MTg, respectively. Similarly, the P300 factor scores define general P300 latency (P300Lg) and amplitude scores (P300Ag).

--------insert Tables 8, 9, 10, 11, 12 and 13 about here---------

The intercorrelation matrices and first factor loadings of the MAB subtests, the RT to the target stimuli, the SDRT, the MT to the target stimuli, and the corresponding P300 latencies and amplitudes are shown in Tables 8 to 13, respectively. For the MAB subtests, all significant correlations are positive. The first MAB factor, IQg, accounts for 43% of the variance. The RT intercorrelations, all significant, range from .36 to .89. RTg accounts for 75% of the variance. The SDRT intercorrelations are all significant and range from .61 to .94. SDRT accounts for 84% of the variance. The MT intercorrelations are all significant and range from .92 to .97 and MTg accounts for 96% of the variance.

The intercorrelations of P300 amplitude and P300 latency to the target stimulus, shown in Tables 12 and 13, respectively, are generally positive, though only a third are significantly correlated. For P300 latency, P300Lg accounts for 41% of the variance. All six of the tasks have loadings greater than .55 on the first factor. For P300 amplitude, P300Ag accounts for 56% of the variance. All four of the paired stimuli tasks have loadings greater than .86 on P300Ag, but the loadings are lower for SRT (.39) and CRT (.29).

The intercorrelation of the IQg, RTg, SDRTg, MTg, P300Lg and P300Ag factor scores are shown in Table 14. Negative correlations are apparent between IQg and RTg (-.27, $p < .15$), P300Lg (-.36, $p < .05$) and P300Ag (-.30, $p < .10$). Non-significant negative correlations exist between IQg and MTg (-.14) and SDRTg (-.18). There is a positive non-significant correlation between RTg and SDRTg (.20, $p < .30$) and a non-significant correlation between RTg and MTg (-.18, $p < .35$). The correlations between SDRTg and MTg are positive and highly significant (.76, $p < .0001$). A negative correlation between RTg and P300Ag is also apparent (-.31, $p < .09$), however the correlation between RTg and P300Lg is negligible (.07, $p < .72$).

----------------------insert Table 14 about here-----------

Multiple regression analyses were also performed in order to examine the contributions of RT and ERP variables to the prediction of IQ. IQg was regressed on RTg and P300 latency g and a multiple correlation of .435 was found (squared R = .19). Beta coefficients were -.25 and -.34, respectively. When RTg was replaced by P300 amplitude g, IQg regressed on P300 latency g and P300 amplitude g led to a similar multiple correlation of .435 (squared R = .19). Beta coefficients were similar at -.32 and -.26 respectively. When P300 latency g was replaced by RTg and IQg regressed on RTg and P300 amplitude g, a multiple correlation of .479 was calculated (squared R = .24). Beta coefficients were -.40 and -.43, respectively. It would appear that the RT variable and P300 amplitude variable were better predictors of mental ability than either both P300 variables or both latency variables (RT and P300 latency) together, $F(2, 27) = 4.2$, $p < .05$.

When IQg was regressed on RTg, P300 latency g and P300 amplitude g, a larger multiple correlation of.56 was found (squared R = .31). Beta coefficients equalled -.37, -.28 and -.38, respectively. Adding the P300 amplitude variable made a significant contribution to predicting IQ and resulted in a multiple correlation significantly different that 0, $F(3, 26) = 3.99$, $p < .01$. When the MTg variable was added, a multiple correlation of .583 was found (squared R = .35). Beta coefficients were -.40, -.27, -.38 and - .18, respectively. This multiple correlation was significantly different than 0, $F(4, 25)$

= 3.32, $p < .05$. Finally adding the SDRTg variable, an identical multiple correlation was found as .583. Regressing this fifth variable on IQ did not significantly add to the prediction of mental ability. Thus 5 predictor variables produced a maximum multiple correlation with IQ of .583

Summary

In summary, analysis of RT measures yields results consistent with previous findings (Vernon, 1983). RT measures show negative relations with task difficulty and mental ability. A significant RT correlation with Full Scale IQ includes -.34 for Category Matching. MT correlations with IQ are all significant in the Simple Reaction Time, Physical Similarity and Sternberg Digit tasks. A significant correlation of SDRT with Full Scale IQ is found in the Category Matching task.

P300 measures to both the first stimulus in the paired stimuli tasks and the target stimulus in the RT tasks are significantly affected by task difficulty. P300 latency to the target stimulus is negatively related to mental ability, especially as the tasks become more difficult. Correlations between P300 latency of the responses to the target stimuli are significant in the Category Matching and Sternberg Digit tasks. Correlations between P300 latency and RT variables are not significant except for a significant correlation between P300 latency and RT during Choice Reaction Time. The P300 amplitude measure to the target stimulus is negatively correlated with Full Scale IQ, but generally not significant, except for a significant correlation in the Semantic Similarity task. Significant negative correlations exist between P300 amplitude and RT and SDRT but not with MT.

In general, the first unrotated factor extracted from intercorrelations of each of the RT measures define RT measure factors accounting for between 75% to 96% of the variance. The same principal components analysis for P300 measures defined factors accounting for 41% (latency) and 56% (amplitude) of the variance. Relations between factor scores reveal a more significant relation between mental ability and P300 measures than between mental ability and RT measures. The relation between P300 latency and RT is negligible, as are other relations between variables. Multiple regression analyses reveal that together, RT and P300 amplitude are better predictors of mental ability than either both P300 latency and amplitude or both P300 latency and RT. Five predictor variables produce a maximum multiple correlation with IQ of .583.

Discussion

Introduction

The results from the present research demonstrate significant relations between RT and intelligence and provide new information regarding the relation between ERPs and intelligence.

This chapter will begin by summarizing the study's findings, starting with task difficulty, followed by discussion of results from RT data, P300 latency and RT and P300 amplitude. Other issues will be addressed, including use of RT in ERP literature, recording ERPs concurrent with RT, and the interactions involved when a first stimulus and target stimulus are presented to a subject. Subsequently, theoretical issues will be elaborated, including the importance of speed of responding to intelligence, the prediction of IQ and the general factor of intelligence "g". Limitations in the present research such as methodological issues and concerns for future research are included. Finally, a general discussion will conclude that ERPs provide valuable insight into information processing and intellectual abilities.

Summary of Findings

The present study set out to examine the performance on various RT tasks by groups differing in intelligence. Its purpose was to determine relations in task difficulty, RT, P300 latency and P300 amplitude measures.

Task difficulty.

The cognitive tasks employed in this study were simple and relevant to intelligence, varying in terms of task difficulty as noted by error rate and increased RT. Overall, few errors were made by the subjects. However, the frequency of errors did differentiate the tasks, indexing levels of task difficulty that, in general, were paralleled by increases in RT, MT and SDRT. The exception to this pattern was the juxtaposition of the Sternberg Digit Recognition task and the Category Matching task. The ability groups did not differ significantly in number of errors on any tasks. Analyses performed to examine a possible speed-accuracy trade off revealed that, in general, faster responding did not lead to more errors. The latency of the P300 response to the target stimulus was similarly sensitive to differences in task difficulty and was analogous to the pattern of the mean RT and MT measures. For the most part, mean RT and mean P300 latency were nearly identical on five of the six tasks.

<u>RT and MT</u>.

Overall, the AAA group displayed faster mean RT than the AA group across the cognitive tasks and, in particular, on the more difficult tasks. Both the magnitude and direction of the association between mental ability and RT were consistent with previous reports (Vernon, 1983, 1987). As confirmed in previous research, differences in RT between groups increased as the complexity of the response stimulus increased (Jensen & Munro, 1979). Also as expected from previous literature, there were significant uncorrected correlations between RT measures on paired stimuli tasks for both yes and no responses. However, the limited range of mental ability within this small, restricted sample of university students may have contributed to an underestimation of the relation between RT and mental ability. SDRT appeared to be greater for the AA group, replicating previous findings (Jensen & Munro, 1979).

For MT, there were significant uncorrected correlations with IQ found on the RT tasks. This has been found previously (Frearson & Eysenck, 1986). However, group differences in MT were not significant in the results from the ANOVA. Although there is evidence for a relation between MT and intelligence, further research is needed to evaluate that relation.

P300 latency.

As expected, P300 latency increased with increasing task difficulty, replicating earlier research (Squires, et al., 1977; Duncan-Johnson & Kopell, 1981). In general, the AAA group displayed faster mean P300 latencies than the AA group to the target stimulus across the tasks.

Also, the correlation between mental ability and P300 latency was negative and modest, on average -.23. This finding of a negative relation is similar to a recent study using an auditory oddball paradigm with and without task demands (O'Donnell, Friedman, Swearer, & Drachman, 1992). They found that P300 latency was correlated with different psychometric factors, reporting a correlation of -.44, ($p<.01$) between active P300 latency and intelligence as assessed by the WAIS-R. They note that the relations persisted even after accounting for age, and suggest that active P300 latency is associated with individual differences in performance on tests of intelligence, concentration and working memory.

In this study, a significant correlation between P300 latency and RT was only observed within the CRT task, with most other tasks showing a near zero correlation. It would appear that P300 latency and RT measures are weakly associated within the tasks. In general, reaction time and P300 latency appear to assess different aspects of cognitive information processing that distinguish individual differences in mental ability. The literature indicates some agreement that P300 latency can serve as an index of stimulus evaluation independent of response production. Results from the present research support this suggestion. Given the pattern of results obtained in this study, it is possible that the P300 latency and RT measures observed from performance on these tasks assess the processes of stimulus evaluation and response production, respectively.

P300 amplitude.

Results observed for the P300 amplitude measure between tasks, between the first and second stimulus in the paired-stimuli tasks, and between mental ability groups were not as consistent as those seen for the RT measures and P300 latency. For example, between tasks, for both the AAA and AA groups, P300 amplitude evoked by the first stimulus during the SD2 and SA2 tasks was smaller than during the DIG and CAT tasks. However, the opposite effect was observed with respect to the target stimulus. That is to say, for both mental ability groups, P300 amplitude evoked by the second stimulus during SD2 and SA2 tasks was larger than during the DIG and CAT tasks. Within tasks, the P300 amplitude for the target stimulus was larger than for the first stimulus in the physical similarity task (SD2) and the semantic similarity task (SA2). However, in the Sternberg Digit Recognition task (DIG) and the Category Matching task (CAT), the P300 amplitude for the first stimulus was larger than for the target stimulus. The pattern of P300 amplitude differences across tasks did not correspond to the pattern of errors, RT or P300 latency on these tasks. It would also be misleading to suggest that the amplitude effects can be attributed to differences in task difficulty as indicated by number of errors, as in the case with the other variables. Between groups, the AAA group displayed larger P300 amplitude to the first stimulus than did the AA group. However, for the target stimulus, it was the AA group which displayed consistently larger P300 amplitude than the AAA group. These observations require further discussion.

Little ERP research has investigated the interactive effects of stimuli in paired-stimuli tasks. However, a recent study has demonstrated that the P300 amplitude to the first stimulus is larger when it is more informative, i.e., it is indicative of greater uncertainty (Gratton, Bosco, Kramer, Coles, Wicken &

Donchin, 1990). This result may apply to the present case. In the SD2 and SA2 tasks, the first stimulus signals a second stimulus that holds only one alternative choice (e.g., physically identical or not). However, in both the DIG and CAT tasks, the first stimulus signals that the second stimulus will be one of several alternative possibilities (e.g., from the string of several digits presented, one of them will be subsequently presented). Thus in these two tasks, the first stimulus indicates greater uncertainty and indeed the P300 amplitude to this initial stimulus is larger.

There is some evidence from previous work that P300 amplitude to the target stimulus is reduced in tasks that involve greater memory load or search (Brookhuis, Mulder, Mulder & Gloerich, 1983) or that require more perceptual processing (Israel, Chesney, Wickens & Donchin, 1980; Kok & Looren de Jong, 1980). The P300 amplitude to the target stimulus was smaller during the DIG and CAT tasks than during the tasks that predicted a single alternative choice. It can be argued that the differences in P300 amplitude between the present tasks may be due to similar differences in processing demand (Polich, 1987).

Differences in processing demand, however, cannot account for the differences in P300 amplitude that were observed between the AAA and AA groups. The AAA group displayed larger P300 amplitude to the first stimulus than the AA group. It would appear that the AAA group is more attentive to the information given by the first stimulus compared to the AA group. The relation between P300 amplitude to the target stimulus and mental ability was significant at -.37 in the SA2 task. This task measures the time it takes a subject to access an item stored in LTM. P300 amplitude to the target stimulus was consistently smaller for the AA group than for the AAA group. It makes no sense to attribute the smaller amplitude of the AAA group to greater processing demand. Perhaps the smaller P300 amplitude of the AAA group is due to their greater preparedness or expectancy to respond to the target stimulus, since P300 amplitude is inversely related to expectancy (Squires, 1976). However, the tasks were performed equally well by both groups with few errors, thus the benefits of this greater preparedness did not manifest itself in this study by a significant increase in correct responses by the AAA group, even though responses are generally faster. This suggests that perhaps there is little difference in stimulus probability expectancy between groups for the target stimulus in this study.

Although, as previously mentioned, the relation between RT and P300 latency was negligible, it is interesting to note that the relation between RT and P300 amplitude was significant at -.31. Faster RTs resulted in larger P300 amplitude to the target stimulus in paired stimuli tasks. Other investigations have found this as well, using simple tasks in both the auditory and visual stimulus modalities (Roth, Ford, & Kopell, 1976; Morrell & Morrell, 1966). As mentioned in the review of the literature, this conflicts with data supporting a positive relation between

RT and P300 amplitude (Fitzgerald & Picton, 1981; Duncan-Johnson & Donchin, 1977). Explanations for these findings may follow the suggestion that the smaller amplitude in the AA group may be due to the greater variance in latency distribution as RT and P300 latency increased (Donchin, Ritter & McCallum, 1978). In any case, these results should be interpreted with caution until further information can be obtained in future research.

Supplementary Findings

Other findings encountered in this research were supplemental to those of the original hypotheses tested. They include issues regarding the use of RT in ERP research and adaptations available while recording ERPs and RT concurrently, and new information available from presentation of, and observable interactions between, a first and second stimulus.

Use of RT and ERPs in intelligence research.

As outlined in the literature review, the use of RT and ERPs recorded simultaneously in intelligence research presents a number of advantages. RT can vary due to factors such as age, daily variation, response strategy, practice effects and information processing. This makes it difficult to gather details regarding information processing based solely on RT. If more intelligent individuals display faster RT than less intelligent individuals when performing cognitive tasks, it is possible to say they respond faster, but it is difficult to generalize that they process information faster, based only on RT measures. ERP measures which are recorded concurrently with RT can provide more information. They allow observation of processes before, during and after a subject's response, depending on the goals of a particular study. ERPs, unlike RTs, are not necessarily affected by some of the factors affecting the production of a response. For example, it has been shown that the effect of instructions to subjects to respond as fast as possible has a marked effect on RT, but minimal effect on P300 latency and that P300 latency is an index of stimulus evaluation independent of response production (Kutas, McCarthy & Donchin, 1977). Although positively correlated on some tasks and in some conditions, P300 latency and RT are independent (Pritchard, 1981). When it can be demonstrated that more intelligent individuals have faster RTs than less intelligent individuals when performing a task, it is possible to suggest that they produce a response more quickly. In turn, when P300 latencies are also shorter, one can suggest that stimulus evaluation is also faster.

In ERP studies when RT is recorded, it is called simply "RT". In the ERP research, RT has been defined as the period from the onset of the stimulus to the onset of the response key. In this work, variation in P300 latency is attributed to stimulus evaluation and RT to response production since instructions that increase RT have little effect on P300 latency. None of the previous ERP studies makes the distinction between RT and MT that is advocated and widely used in recent mental ability RT research. This sets the stage for potential confusion. In distinguishing between RT and MT, it has been assumed that RT, the period from stimulus onset to the release of the home button, indexes stimulus evaluation time, whereas MT, the period from release of the home button to the press of the response key, indexes response time (Jensen, 1982a). In research similar to the present case where ERPs are recorded concurrently with RT and MT, one may consider that the measures distinguish stimulus evaluation time (P300 latency), response production time (RT) and MT.

Information about the first stimulus.

Recording ERPs during the presentation of each stimulus in a pair allows an assessment of the response to the first stimulus separate from the target stimulus. This study showed that this distinguished the ERP analysis from simple RT analysis that provides information only on the response to the target stimulus. Using ERPs, information can be collected with respect to both ERP latency and amplitude to the first stimulus. Furthermore, results from this study revealed that recording ERPs concurrently with RT provides information with regards to interactions between responses to the first stimulus and the target stimulus. This information is not available when recording only RT and MT to the target stimulus. For example, in this study, between-task differences were observed in the P300 amplitude and latency to the first stimulus. For the first stimulus, differences between the ability groups was noted for P300 amplitude but not for P300 latency. If there was no access to information regarding processing of the first stimulus, which is the case with RT measurement only, these observations could not be noted. ERP measures, specifically P300 amplitude, indicate that the ability groups are processing the first stimulus differently, with the AAA group displaying larger P300 amplitude to the first stimulus than the AA group. This information can then be compared to information processing of the target stimulus. In this case there seems to be different processing between the first stimulus and the target stimulus. Interestingly, it was the AA group which displayed larger P300 amplitude to the target stimulus than the AAA group. When considering latency, however, P300 latency to the target stimulus was shorter for the AAA group compared to the AA group. As was shown in this study, information about processing during the first stimulus sheds new light on possible differences between cognitive tasks or research groups.

Theoretical Issues

The findings of the present study have shed some light on aspects of the theoretical issues surrounding present day research on intelligence. Some of the contributions which will be discussed include the issue of speed of responding and its importance to intelligence (more intelligent individuals respond faster than less intelligent individuals), the prediction of IQ and structure of intelligence.

Speed of responding.

It has been an interest in recent literature to establish the extent to which the speed or efficiency of responding during different cognitive processing tasks is associated with general intelligence (Vernon, 1983). In the present study, the six tasks that were employed were chosen to assess different facets of cognitive information processing. For example, the simple and choice RT tasks are regarded as indices of speed of information processing. The Sternberg DIG test assesses STM, whereas the Posner SD2, SA2 and the CAT tasks involve perceptual analysis and retrieval from LTM. Vernon (1983) has suggested a theory to explain the importance of speed of responding for intelligence given that a number of conditions are met. He suggests that cognitive operations are carried out in some sort of short term or working memory system, characterized by a limited capacity to hold information. He suggests that there is a rapid decay or loss of information in the absence of rehearsal, and that there is a trade-off between the amount of information that can be held and processed simultaneously. He suggests that the speed or efficiency with which individuals can execute the cognitive operations involved in a given task or problem might be expected to have a considerable effect on the success of their performance on the task. As noted in the literature review, many studies have shown that there is evidence that more intelligent individuals perform faster than less intelligent individuals and that this may be the result of differences in information processing efficiency and speed (Jensen, 1982; Vernon, 1983; Vernon, Nador & Kantor, 1985).

The findings from this study indicate that the first unrotated factor extracted from the intercorrelation of the RT latencies to the target stimulus in these tasks accounts for 75% of the variance. This is indicative of a robust speed of responding factor common to all of the tasks. The first unrotated factors extracted from the intercorrelation of SDRT to the target stimulus and intercorrelation of MT latency for the target stimulus account for 84% and 96% of the variance, respectively. The correlation between the first unrotated factors extracted from the intercorrelation of the MAB subtests and the target stimulus RT on the cognitive tasks is -.27 ($p < .15$), a value at the low end of the range for similar studies reported (Vernon, 1989). Minimal, non-significant correlations of -.18 and -.14 were found between the first unrotated factors extracted from the intercorrelation of the MAB subtests and target stimuli SDRT and MT, respectively. Interestingly, the relation between these last two variables is high (.76, $p < .0001$), suggesting that increases in variability affect increases in MT, particularly for the more difficult tasks. Generally, mental ability tends to be negatively associated with speed of responding on these cognitive tasks, but the association of the general factors of these measures is rather low and not significant.

The first factor for the P300 latency to the target stimulus accounts for 41% of the variability on the cognitive tasks and is of similar magnitude to the general factor extracted from the intercorrelation of the MAB subtests. This analysis describes a general P300 latency factor that accounts for a substantial part of the variance on these tasks. The factor scores of the first unrotated factors extracted from the MAB subtests and the P300 latency to the target stimulus on the cognitive tasks correlated significantly at -.36. These analyses suggests that the speed with which persons process, or evaluate, the stimuli on these tasks, as indicated by P300 latency, is significantly related to their intelligence.

The first factor scores of the P300 latency and the RT measures tend to display negative relations with mental ability, but no relation with each other. This may suggest that the P300 latency and RT general factors are measurements of different components of the general mental ability factor. As previously mentioned, the P300 latency and RT general factors may refer to general stimulus evaluation and response production components of cognitive information processing that distinguish individual differences in general intelligence.

The factor scores of the first unrotated factor extracted from the intercorrelation of the P300 amplitude to the target stimulus were significantly negatively correlated with the RT (-.31) and mental ability (-.30) first factor scores at the same level of confidence ($p<.10$). As expected, their correlation with MT and SDRT first factor scores was negligible. As previously noted, the basis for these interesting relations, in particular as they related to mental ability, is not clear.

Prediction of IQ and structure of intelligence.

Another issue in the literature which this study may have shed some light on concerns the prediction of intelligence and its structure. A series of multiple regression analyses were calculated to estimate the power or prediction of full scale MAB IQ which was found in each of the performance variables. When IQ was regressed on RT and P300 latency together, the multiple correlation was .435. A similar multiple correlation was found when IQ was regressed on the ERP measures P300 latency and P300 amplitude. However a multiple correlation of .583 was found when five predictor variables were regressed on IQ. The results of other studies which found that subjects' SDRT had the same degree of association with IQ as did their RTs were not replicated here (Jensen, 1979; Vernon, 1983). Nevertheless, the results support the hypothesis that the speed of performance on cognitive tasks is indeed related to intelligence and confirm previous literature (Vernon, 1983). Moreover, the findings support the idea that speed of information processing as indexed by P300 is related to intelligence.

Another issue relates to the structure of intelligence and there has been considerable evidence in the literature to support a general ability factor "g". As Kline (1991) outlines, it seems that individuals who are good at one thing are also good at others. Indeed, in this study, general factor scores were extracted from MAB subtest intercorrelations, notably IQg. General RT factor scores were also extracted from intercorrelations of RT measures on RT tasks, as well as factor scores for ERP measures P300 latency and P300 amplitude. Intercorrelations amond these variables showed that although some of the measures correlated with the general mental ability factor, IQg, they did not all correlate with each other. As noted, it may be that P300 latency and RT, for example, are measures of different components of "g". Notwithstanding, one of the goals of this study was to further explore aspects related to some of the processes underlying intelligence, such as speed of processing, stimulus evaluation, response production, etc. Contemporary research should continue the study of the structure of intelligence as well as the processes involved.

Limitations of the Present Study

As mentioned in the literature review, a number of criticisms of previous studies were addressed in this research. However, in any study it is important to note factors which may limit interpretations and generalizations to other populations. In this investigation, these concerns include sample characteristics, the nature of research recording ERPs concurrently with RT, and the nature of the tasks.

Sample characteristics.

Characteristics of the sample which limit generalizations made to other groups are important to note. In this study, the sample size was small at 30, compared to other RT research which utilizes 60, 100 or more subjects. This was due to the time involved and the large amount of information generated from each subject when ERPs were recorded. This sample size is also rather limited when using factor analytic techniques. This study also used only right handed females ranging in age from 18 to 25, which allowed for consideration of the sensitivity of ERPs to sex, age and handedness, but limits the interpretation of these results to females of this age group. Other parameters which could be controlled include arousal level and hormonal levels.

Screening for vision and hearing impairment could also be more formalized. The sample was also chosen from a university population, again limiting the ability to generalize the findings to a broader group.

Nature of ERP-RT research.

Although generally successful, measuring ERPs concurrently with RT during RT tasks introduced a number of concerns. Trials which are contaminated with ERP artifact must be dropped from the average, thus losing the corresponding RT measure as well. The need for single trial analysis to correct this becomes apparent. Some of the timing parameters for presenting stimuli in the RT tasks were slightly altered from those used by Vernon (1983). This introduced an increase in the length of time to complete the tasks and a decrease in the number of subjects used compared to some RT studies. Restriction of range becomes a factor. However, many trials (140) were required to get a clear, accurate ERP. In fact, this resulted in a considerable increase in the number of trials compared to some RT studies where the number of trials may only be 30 per task. Thus, although fewer subjects were used, the increase in number of trials per task per subject added to the increased reliability of both RT and ERP measures.

Gale & Edwards (1983) presented a list of requirements for EEG/ERP and IQ research. Along with some of the considerations which this study has taken, other issues were raised. For example, they suggest that care be taken in the assessment of intelligence and that researchers be open to the possibility that different sub-scales may relate to different hemispheres, different electrode placements, different tasks and different contexts. They also suggest that researchers make use of more heterogenous groups which represent the full ability range.

Nature of the tasks.

The specific tasks used in this study, and the rationale for their use, was clearly outlined in the literature review. The tasks have been related to tests of psychometric intelligence (Vernon, 1983) and are commonly employed in information processing theory approaches to cognitive processing. The tasks were also selected because of their compatibility with ERP recording requirements.

Characteristics of the tasks themselves have also provided some limitations in this research. As previously mentioned, the length of experimental session can be tiring for the subject, and the huge amounts of data produced on a single trial basis require the help of specialized computer programs for sorting, eliminating artifact, averaging, plotting, etc. It is also interesting to note that although a Full Scale IQ was used as an intelligence measure in this case, most of the cognitive tasks and stimuli are verbal, using words, letters or numbers. The study did not present non-verbal or pictorial stimuli, which may provide different results. Lastly, the tasks used were fairly easy, with few errors committed by both groups. Information regarding processing of errors and differences between groups on performance on one or two more difficult tasks is thus lacking. To confirm some of the research findings concerning the relation between intelligence and RT and ERP measures, some of these limitations should be addressed.

Future Research

Further research is necessary and would prove fruitful in providing more information regarding the association between intelligence and speed of processing variables. Several aspects of the present study lead to suggestions for these endeavors. For example, future research could adapt the advantages of ERP measures and address further issues such as cognitive processes during error trials, or specific, more detailed processes during particular tests, such as the Sternberg Digit task, where one could observe differences across different string lengths. Other research could address variables such as sex differences or age differences in ERPs recorded concurrently with RT. Sample limitations should certainly be addressed. As suggested by O'Donnell et al, (1992), future research should measure P300 latency and RT concurrently to determine their relation between aging and performance on psychometric tests. Different types of tasks could also be employed, including presentation of non-verbal or picture stimuli in addition to verbal stimuli. Some tests could also leave the possibility for more error production. In light of the present results, this step may enhance differences in P300 amplitude perhaps indicating whether one group is better prepared than another. These are only some of the suggestions which would enhance research and design in the challenge to learn more about the relation between speed of processing variable and intelligence.

Summary and Conclusions: ERPs and New Information

This study set out to investigate the differences between AAA and AA groups in the performance of RT tasks. Negative relations between RT measures and mental ability were consistent with previous findings (Vernon, 1983). Task difficulty also influenced ERP measures of P300 amplitude and P300 latency for the first stimulus in paired stimuli tasks, but mental ability differences were found for P300 amplitude only. Task difficulty influenced P300 latency and RT for the target stimulus, both increasing with increasing task difficulty. P300 latency was inversely related to mental ability, especially for the more difficult tasks. P300 amplitude varied between tasks but was not related to mental ability

When first unrotated factors were extracted from the intercorrelations of each variable, each factor accounted for considerable variance, and there were significant negative relations between IQ and P300 measures and between RT and P300 amplitude. Five predictor variables produced a multiple correlation of .583 with IQ.

The ERP analysis of performance on these simple cognitive tasks demonstrates that both P300 amplitude and latency measures reliably distinguish differences between the tasks. P300 latency closely parallels effects observed with RT measures across tasks, but these chronometric measures are largely independent within tasks. A general speed of processing factor that accounts for a substantial portion of the variance was observed for both P300 latency and RT and both of these general factors are inversely related to general intelligence. The P300 latency results complement the analysis of RT and mental ability in suggesting that a substantial portion of the variance in general intelligence is attributable to the speed and efficiency with which these cognitive operations are performed. Further, because of the simple nature of the tasks, evidenced by the negligible error rates, these effects are not readily justified in terms of individual differences in specific knowledge or training.

The P300 latency analysis may also focus the functional significance of the RT measures with respect to mental ability. Throughout the literature it is generally agreed that P300 latency is a measure of stimulus evaluation time independent of response production (Donchin, 1979). It has been suggested that P300 latency may mark the time when a decision is made, offering an opportunity to examine variables affecting more stages (Ford, Mohs, Pfefferbaum & Kopell, 1980). From this perspective, the present research supports the interpretation that one may consider P300 latency primarily as a measure of stimulus evaluation time, and RT as a measure of response production time.

The P300 amplitude analysis showed some promise in distinguishing individual differences in mental ability, with P300 amplitude to the first stimulus tending to be positively related to mental ability and P300 amplitude to the target stimulus inversely related to mental ability. P300 amplitude to the target stimulus also tended to be inversely related to RT. It is known that P300 amplitude varies inversely with objective and subjective probability of occurrence of events and with task difficulty and positively with task demand to respond to signal stimuli. However, it cannot be ascertained with the tasks employed whether these determinants contributed to the variations with mental ability that were observed.

It has been suggested recently that studies of RT, IT, and ERPs are leaving little doubt that a substantial part of the "g" derived from conventional psychometric tests can be measured by means of knowledge-free tests that are so simple that the only reliable measure of individual differences is sheer speed of information processing (Jensen, 1987b). Further, although a critical question is whether "g" is a unitary process or a group of uncorrelated processes, it is apparent that evidence is somewhat paradoxical, and Jensen has likened this to puzzles in physics such as theories of light as being either waves or particles (Jensen, 1987b). Vernon suggests that in a complete theory of intelligence, "correlates of intelligence such as the speed with which different kinds of information can be processed, as measured by RT tests, and factors such as the degree of responsiveness of the brain to external stimuli, as assessed by ERPs, would each be regarded as reflecting, to a lesser or greater extent, the underlying physiological integrity or efficiency of the brain in its capacity as an information processing system" (Vernon, 1989b). Overall, it is clear that the analysis of ERPs generated during the performance of simple reaction time tasks promises to provide a rich source of information that can contribute to our understanding of the concept of intelligence.

References

Abalan, F. (1984). Alzheimer's disease and malnutrition: a new aetiological hypothesis. Medical Hypotheses, 15, 385-393.

Ackerman, P. L. (1986). Individual differences in information processing. An investigation of intelligence abilities and task performance during practice. Intelligence, 10, 101-139.

Ackerman, P. L., & Schneider, W. (1985). Individual differences in automatic and controlled information processing. In R. F. Dillon (Ed.), Individual differences in cognition, Vol.2. New York: Academic Press.

Albert, K., & Warden, C. J. (1944). The level of performance in the white rat. Science, 100, 476.

Barrett, P. T., & Eysenck, H. J. (in press). Brain electrical potentials and intelligence. In A. Gale & M. W. Eysenck (Eds.), Handbook of individual differences: Biological perspectives. New York: Wiley.

Bastendorf, W. L. (1960). Activation level, as measured by palmar conductance, and intelligence in children. Claremont Graduate School, Unpublished Ph.D. Thesis.

Baumeister, A. A., & Kellas, G. (1968). Reaction time and mental retardation. In N. R. Ellis (Ed.), International review of research in mental retardation. Vol.3, (pp. 163-193). New York: Academic Press.

Bennett, W. F. (1968). Human perception: A network theory approach. Nature, 220, 1147-1148.

Berger, M. (1982). The "scientific approach" to intelligence:

An overview of its history with special reference to mental speed. In H. J. Eysenck (Ed.), A model for intelligence. (pp. 13-43). New York: Springer.

Binet, A. (1903). L'etude experimental de l'intelligence. Paris: Schliecher, Freres.

Binet, A. (1907). La psychologie due raissonnement. Paris: Alcan.

Binet, A., & Simon, T. (1905). Methodes nouvelles pour le diagnostic due niveau intellectuelle des anormaux. L'annee psychologique. 11, 191-244.

Blinkhorn, S. F., & Hendrickson, D. E. (1982). Averaged evoked responses and psychometric intelligence. Nature, 295, 596-597.

Boring, E. G. (1957). A history of experimental psychology. Second Edition. New York: Appleton-Century-Crofts.

Brand, C. R. (1979). The quick and the educable. Bulletin of the British Psychological Society. 32, 386-389.

Brand, C. R., & Deary, I. J. (1982). Intelligence and inspection time. In H. J. Eysenck (Ed.), A model for intelligence. (pp. 133-148). Berlin: Springer-Verlag.

Brazier, M. A. B. (1964). Evoked responses recorded from the depth of the human brain. Annals of the New York Academy of Science. 112, 33-59.

Brewer, N., & Smith, G. A. (1984). How normal and retarded individuals monitor and regulate speed and accuracy of responding in serial choice tasks. Journal of Experimental Psychology: General. 113, 71-93.

Bridgman, R. W. (1927). The logic of modern physics. New York: Macmillan.

Brookhuis, K. A., Mulder, G., Mulder, L. J. M., & Gloerich, A. B. M. (1983). The P300 complex as an index of information processing: The effects of response probability. Biological Psychology, 17, 277-296.

Burt, C. (1940). The factors of the mind. London: University of London Press.

Burt, C. (1958). The inheritance of mental ability. American Psychologist, 13, 1-15.

Callaway, E. (1975). Brain electrical potentials and individual psychological differences. London: Grune and Stratton.

Callaway, E. (1979). Individual psychological differences and evoked potential variability. Progress in Clinical Psychophysiology, 6, 243-257.

Campbell, K. B. (1985). Mental chronometry I: Behavioral and Physiological Techniques. In B. Kircaldy, (Ed.), Individual differences in movement. (pp. 117-145). Lancaster, England: MTP press.

Campbell, K. B., & Cullum, N. (1985). Mental chronometry II: Individual differences. In B. Kircaldy, (Ed.), Individual differences in movment. (pp. 147-167). Lancaster, England: MTP press.

Carlson, J. S., & Jensen, C. M. (1982). Reaction time, movement time and intelligence: A replication and extension. Intelligence, 6, 265-274.

Carlson, J. S., Jensen, C. M., & Widaman, K. (1983). Reaction time, intelligence and attention. Intelligence, 7, 329-344.

Cattell, R. B. (1952). Factor analysis: An introduction and and manual for the psychologist and social scientist. New York: Harper & Row.

Cattell, R. B. (1971). Abilities: their structure, growth and action. Boston: Houghton Mifflin.

Chalke, F. C. R., & Ertl, J. P. (1965). Evoked potentials and intelligence. Life Sciences, 4, 1319-1322.

Chapman, R. M. (1965). Evoked responses to relevant and irrelevant visual stimuli while problem solving. Proceedings of American Psychological Association, 177-178.

Chase, R. N. P., Foster, N. L., Brooks, R., DiChiro, G., & Mausi, L. (1984). Wechsler Adult Intelligence Scale performance: cortical localization by flucrodeoxyglucose F18-positron emission tomography. Archives of Neurology, 41, 1244-1247.

Davis, F. B. (1971). The measurement of mental ability through evoked potential recording. Educational Record Research Bulletin, No. 1.

Deary, I. J. (1980). How general is the mental speed factor in general intelligence? Unpublished thesis for the Honour Degree (B.Sc., Med. Sci.) in Psychology. University of Edinburgh.

DeFries, J. C., Johnson, R. C., Kuse, A. R., McClearn, G. E., Polovina, J., Vandenberg, S. G., & Wilson, J. R. (1979). Familial resemblance for specific cognitive abilities. Behavioural Genetics, 9, 23-43.

de Leon, M. J., Ferris, S. H., George, A. E., Christman, D. R., Fowler, J. S., Gentes, C., Reisburg, B., Gee, B., Emmerich, M., Yonekura, Y., Brodie, J., Kricheff, I. I., & Wolf, A. P. (1983). Positron emission tomographic studies of aging and Alzheimer's disease. American Journal for Neuroradiology. 4, 568-571.

Ditraglia, G. M., & Polich, J. (1991). P300 and Introverted/ Extraverted Personality Types. Psychophysiology. 28, 177-184.

Dixon, W. T. (1985). BMDP Biomedical Computer Programs. Los Angeles: University of California Press.

Donald, M. W., & Goff, W. R. (1971). Attention-related increases in cortical responsivity dissociated from the contingent negative variation. Science, 172, 1163-66.

Donchin, E. (1979). Event-related brain potentials: A tool in the study of human information processing. In H. Begleiter (Ed.), Evoked brain potentials and behaviour. (pp. 13-88). New York: Plenum Press.

Donchin, E. & Coles, M. G. H. (1988). Is the P300 component a manifestation of context updating? Behavioural and Brain Sciences. 11, 357-374.

Donchin, E., Ritter, W., & McCallum, C. (1978). Cognitive psychophysiology: the endogenous components of the ERP. In E. Callaway, D. Tueting, & S. Koslow, (Eds.), Event related brain potentials in man. (pp. 349-412) New York: Academic Press.

Donders, F. C. (1868). On the speed of mental processes. In W. G. Koster, (Ed. and trans.), Attention and performance II.

Amsterdam: North-Holland. (1969). (pp. 412-431).

Duncan-Johnson, C. C., & Donchin, E. (1977). On quantifying surprise: the variation in event-related potentials with subjective probability. Psychophysiology. 14, 456-467.

Duncan-Johnson, C. C., & Donchin, E. (1982). The P300 component of the event- related brain potential as an index of information processing. Biological Psychology, 14, 1-52.

Duncan-Johnson, C. C. & Kopell, B. S. (1981). The Stroop effect: Brain potentials localize the source of interference. Science, 214, 938-40.

Dustman, R. E., & Beck, E. C. (1972). Relationship of intelligence to visually evoked responses. Electroencephalography and Clinical Neurophysiology, 33, 254.

Ellingson, R. J. (1956). Brain waves and problems of psychology. Psychological Bulletin. 53, 1-34.

Elliott, C. D., & Murray, D. J. (1977). The measurement of speed of problem solving and its relation to children's age and ability. British Journal of Educational Psychology. 47, 50-59.

Ertl, J. P. (1971). Fourier analysis of evoked potentials and human intelligence. Nature, 230, 525-526.

Ertl, J. P. (1973). IQ, evoked potential responses and Fourier analysis. Nature, 241, 209-210.

Ertl, J. P., & Schafer, E. (1969). Brain response correlates of psychometric intelligence. Nature, 223, 421-422.

Everhart, J. P., Chin, C. L., & Auger, R. A. (1974). Measures of

EEG and verbal intelligence: an inverse relationship. Physiological Psychology. 2, 374-378.

Eysenck, H. J. (1967). Intelligence assessment: A theoretical and experimental approach. British Journal of Educational Psychology, 37, 81 - 98.

Eysenck, H. J. (1979). The structure and measurement of intelligence. New York: Springer.

Eysenck, H. J. (1982). Introduction. In H. J. Eysenck, (Ed.), A model for intelligence. (pp. 1-10). New York: Springer.

Eysenck, H. J. (1985). The theory of intelligence and the psychophysiology of cognition. In R.J. Sternberg (Ed.), Advances in research in intelligence. Vol. 3. (pp. 1-34). Hillsdale: Erlbaum.

Eysenck, H. J. (1987). Speed of information processing, reaction time and the theory of intelligence. In P. A. Vernon (Ed.), Speed of information processing and intelligence. (pp.21-68). Norwood: Ablex.

Eysenck, H. J., & Barrett, P. (1985). Psychophysiology and the measurement of intelligence. In C. R. Reynold & V. Willson (Eds.), Methodological and statistical advances in the study of individual differences. (pp. 1-49). New York: Plenum Press.

Fisk, A. D., & Schneider, W. (1983). Category and word search: Generalizing search principles to complex processing. Journal of Experimental Psychology: Learning, Memory and Cognition. 10, 181-197.

Fitts, P. M. (1954). The information capacity of the human motor system in controlling the amplitude of movement. Journal of Experimental Psychology. 47, 381 - 391.

Fitzgerald, P. G., & Picton, T. W. (1981). Temporal and sequential probability in evoked potential studies. Canadian Journal of Psychology, 35, 188-200.

Ford, J. M., Mohs, R. C., Pfefferbaum, A., & Kopell, B. S. (1980). On the utility of P3 latency and RT for studying cognitive processes. Motivation, Motor and Sensory Processes of the Brain: Progress in Brain Research. 54, 661-667.

Ford, J. M., Roth, W. T., Mohs, R. C., Hopkins, W. F., & Kopell, B. S. (1979). Event-related potentials recorded from young and old adults during a memory retrieval task. Electroencephalography and Clinical Neurophysiology, 47, 450-459.

Frearson, W., & Eysenck, H. J. (1986). Intelligence, reaction time and a new "odd-man-out" RT paradigm. Personality and Individual Differences. 7, 807-817.

Friedman, D., Hakerem, G., Sutton, S., & Fleiss, J. L. (1973). Effect of stimulus uncertainty on the pupillary dilation response and the vertex evoked potential. Electroencephalography and Clinical Neurophysiology, 34, 475-485.

Furneaux, D. (1952). Some speed, error and difficult relationships within a problem solving situation. Nature. 170, 37.

Furneaux, D. (1961). Intellectual abilities and problem solving behaviour. In H. J. Eysenck, (Ed.), Handbook of abnormal psychology. (pp. 167-192). New York: Basic Books.

Galbraith, G., Gliddon, J., & Busk, J., (1970). Visual evoked responses in mentally retarded and non-retarded subjects. American Journal of Mental Deficiency. 75, 341-348.

Gale, A., & Edwards, J., (1983). Cortical correlates of intelligence. In A. Gale & J. Edwards (Eds.), Individual differences and psychopathology. (pp. 79-97). London: Academic Press.

Galton, F. (1869). Hereditary genius: An enquiry into its laws and consequences. London: MacMillan.

Galton, F. (1874). English men of science: Their nature and nurture. London: MacMillan.

Galton, F. (1883). Inquiries into human faculty. London: Dent.

Gasser, T., Lucadou-Muller, R., Verleger, R., & Bacher, P. (1983). Correlating EEG and IQ: A new look at an old problem using computerized EEG parameter. Electroencephalography and Clinical Neurophysiology, 55, 493-504.

Gasser, T., Mocks, J., Lenard, H. G., Bacher, P., & Verleger, R., (1983). The EEG of mildly retarded children: developmental, classifactory, and topographic aspects. Electroencephalography and Clinical Neurophysiology. 55, 131-144.

Geisser, S., & Greenhouse, S. W. (1958). An extension of Box's results on the use of the F distribution in multivariate analysis. Annals of Mathematical Statistics, 29, 885-891.

Gilbert, J. A. (1894). Studies Yale Psychology Lab., Vol. II, p. 40.

Gomer, F. E., Spicuzza, R. J., & O'Donnell, R. D. (1976). Evoked potential correlates of visual item recognition during memory-scanning tasks. Physiological Psychology, 4, 61-65.

Gopher, D., & Donchin, E. (1986). Workload - an examination of the concept. In: K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), Handbook of Perception and human performance, volume 2, Cognitive processes and performance. (pp. VII-41). New York: Wiley.

Gratton, G., Bosco, C. M., Kramer, A. F., Coles, M. G. H., Wickens, C. D., & Donchin, E. (1990). Event related brain potentials as indices of information extraction and response priming. Electroencephalography and Clinical Neurophysiology, 75, 419-432.

Gucker, D. (1973). Correlating visual evoked potentials with psychometric intelligence variation in technique. Perceptual and Motor Skills, 37, 189-190.

Guilford, J. P. (1947). Army Air Forces Aviation Psychology Program Research Reports: Printed Classification Tests. Report No. 5. Washington: U.S. Government Printing Office.

Guilford, J. P. (1967). The nature of human intelligence. New York: McGraw-Hill.

Haier, R. J., Robinson, D. L., Braden, W., & Williams, D. (1983). Electrical potentials of the cerebral cortex and psychometric intelligence. Personality and Individual Differences, 4, 591-599.

Hebb, D. (1949). The organization of behaviour. New York: Wiley.

Hemmelgarn, T. E., & Kehle, T. J. (1984). The relationships between reaction time and intelligence in children. School Psychology International. 5, 77-84.

Hendrickson, A. E. (1982). The biological basis of intelligence, Part I: Theory. In H. J. Eysenck (Ed.), A model for intelligence. (pp. 151-196). Berlin: Springer-Verlag.

Hendrickson, D. E. (1972). An examination of individual differences in cortical evoked response. Ph. D. Thesis, University of London.

Hendrickson, D. E. (1982). The biological basis of intelligence, Part II: Measurement. In H. J. Eysenck (Ed.), A model for intelligence. (pp.197-228). Berlin: Springer-Verlag.

Hendrickson, A. E., & Hendrickson, D. E. (1980). The biological basis of individual differences in intelligence. Personality and Individual Differences, 1, 3-33.

Hick, W. G. (1952). On the rate of gain of information Quarterly Journal of Experimental Psychology. 4, 11-26.

Horn, J. L. (1980) Concepts of intellect in relation to learning and adult development. Intelligence, 4, 285-317.

Horn, J. L. (1987). A context for understanding information processing studies of human abilities. In P. A. Vernon (Ed.), *Speed of Information processing and intelligence*. (pp. 201-238). Norwood, N. J.: Ablex.

Horst, R. L., Johnson, R. Jr., & Donchin, E. (1980). Event-related brain potentials and subjective probability in a learning task. *Memory and Cognition*, *8*, 476-88.

Hughes, K. R., & Zubeck, J. P. (1956). Effect of glutamic acid on the learning ability of bright and dull rats: 1 Administration during infancy. *Canadian Journal of Psychology*. *10*, 132-138.

Hunt, E. (1976). Varieties of cognitive power. In L. B. Resnick (Ed.), *The nature of intelligence*. (pp. 237-259). Hillsdale: Erlbaum.

Hyman, R. (1953). Stimulus information as a determinant of reaction time, *Journal of Experimental Psychology*. *45*, 188-196.

Israel, J. B., Chesney, G. L., Wickens, C. D., & Donchin, E. (1980). P300 and tracking difficulty: Evidence for multiple resources in dual task performance. *Psychophysiology*, *17*, 259-273.

Jackson, D. (1984). *The multidimensional aptitude battery manual*. Port Huron, MI: Research Psychologists Press, Inc.

Jasper, H. H., (1958). The ten-twenty electrode system of the International Federation. *Electroencephalography and Clinical Neuropsychology*, *10*, 371 - 375.

Jastrow, J. (1901). Some currents and undercurrents in Psychology. President's Address, American Psychological

Association. The Psychological Review, 8, 1-26.

Jensen, A. R. (1979). g: Outmoded theory or unconquered frontier? Creative Science and Technology, 2, 16-29.

Jensen, A. R. (1980). Chronometric analysis of intelligence. Journal of Social and Biological Structures. 3, 103-122.

Jensen, A. R. (1982a). Reaction time and psychometric g. In H. J. Eysenck (Ed.), A model for intelligence. New York: Springer.

Jensen, A. R., (1982b). The chronometry of intelligence. In R. J. Sternberg (Ed.), Recent advances in research on intelligence. Volume 1. (pp. 255-310) Hillsdale, N. J.: Erlbaum.

Jensen, A. R. (1987a). Process differences and individual differences in some cognitive tasks. Intelligence. 11, 107-136.

Jensen, A. R. (1987b). Psychometric g as a focus of concerted research effort. Intelligence. 11, 193-198.

Jensen, A. R. (1989). Raising IQ without increasing g? Developmental Review. 9, 234-258.

Jensen, A. R., & Munro, E. (1979). Reaction time, movement time, and intelligence. Intelligence. 3, 121-126.

Jensen, A. R., Schafer, E. W. P., & Crinella, F. (1981). Reaction time, evoked brain potentials, and psychometric g in the severely retarded. Intelligence, 5, 179-197.

Jensen, A. R., & Vernon, P. A. (1986). Jensen's reaction time studies: A reply to Longstreth. Intelligence, 10, 153-179.

Jensen, A. R., Larson, G. E., & Paul, S. M., (1988).

Psychometric g and mental processing speed on a semantic verification test. Personality and Individual Differences, 9, 243-255.

Johnson, R. (1985). A triarchic model of P300 amplitude. Psychophysiology, 23, 367-387.

Karis, D., Fabiani, M., & Donchin, E. (1984). "P300" and memory: Individual differences in the von Restorff effect. Cognitive Psychology, 16, 177-216.

Karlin, L., Martz, M. J., Brauth, S. E., & Mordkoff, A. M. (1971). Auditory evoked potentials, motor potentials and reaction time. Electroencephalography and Clinical Neurophysiology, 31, 129-136.

Keating, D. P., & Bobbitt, B. L. (1978). Individual and developmental differences in cognitive processing components of mental ability. Child Development, 49, 155-167.

Kline, P. (1991). Intelligence. The psychometric view. London: Routledge.

Kok, A. & Looren de Jong, H. L. (1980). Components of the event-related potential following degraded and undegraded visual stimuli. Biological Psychology, 11, 117-33.

Kranzler, J. H., Whang, P. A., & Jensen, A. R. (1988). Jensen's use of the Hick paradigm: visual attention and other effects. Intelligence, 12, 379-391.

Kutas, M., McCarthy, G., & Donchin, E., (1977). Augmenting mental chronometry: The P300 as a measure of stimulus evaluation time. Science, 197, 792-795.

Lally, M. T., & Nettelbeck, T. (1977). Intelligence, reaction time and inspection time. American Journal of Mental Deficiency. 82, 273-281.

Lawler, J. (1978). IQ, heritability and racism. New York: International Publishers.

Leahy, T. H. (1987). A history of psychology: Main currents in psychological thought, Englewood, N.J.: Prentice-Hall Inc.

Leahy, T. H. (1991). A history of modern psychology, Englewood, N.J.: Prentice-Hall, Inc.

Lemmon, V.W. (1927). The relation of reaction time to measures of intelligence, memory and learning. Archives of Psychology. 15, 5 - 38.

Lindsley, D. B. (1961). The reticular motivating system and perceptual integration. In D. E. Sheer (Ed.), Electrical stimulation of the brain. (pp. 331-349). Austin: University of Texas Press.

Longstreth, L. E. (1984). Jensen's reaction time investigation of intelligence: A critique. Intelligence. 8, 139-160.

McCarthy, G., & Donchin, E. (1981). A metric for thought: a comparison of P300 latency and reaction time. Science. 211, 77-80.

McCarthy, G., & Donchin, E., (1983). Chronometric analysis of human information processing. In A. W. K. Gaillard, & W. Ritter (Eds.), Tutorials in E.R.P. research: Endogenous components. (pp. 251-268). Amsterdam: North-Holland.

McCauley, C., Dugas, J., Kellas, G. & DeVellis, R. F. (1976). Effects of rehearsal training on memory search. Journal of Educational Psychology. 68, 474-484.

Merkel, J. (1885). Die zeitlichen verhaltnisse der willensthahigkeit. Philosophische Studien. 2, 73-127.

Molfese, D. L., & Molfese, V. J. (1985). Electrophysiological indices of auditory discrimination in newborn infants: The bases for predicting later language development? Infant Behaviour and Development. 8, 197-211.

Mori, M. S. (1989). Individual differences in mental ability, speed of processing, and nerve conduction velocity. Unpublished Master's thesis. University of Western Ontario, London, Ontario.

Morrell, L. K., & Morrell, F. (1966). Evoked potentials and reaction times: A study of intra-individual variability. Electroencephalography and Clinical Neurophysiology. 20, 567-575.

Naatanen, R., & Picton, T. W. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. Psychophysiology, 24, 375-425.

Netchine, G., and Netchine, S. (1967). Organisation psychologique et organisation bioelectrique, cerebrale dans une population d'arrieres mentaux. Psychologique, Francaise. 7, 241-258.

Nettelbeck, T. (1987). Inspection time and intelligence. In P.A.

Vernon (Ed.), Speed of information processing and intelligence. (pp. 295-346). Norwood, N. J.: Ablex.

Nettelbeck, T., & Brewer, N. (1981). Studies of mild mental retardation and timed performance. In N. R. Ellis (Ed.), International review of research in mental retardation. Volume 10. (pp. 61-106). New York: Academic Press.

Nettelbeck, T., & Lally, M. (1976). Inspection time and measured intelligence. British Journal of Psychology, 67, 17-22.

Nie, N. H., Hull, C. H., Jenkins, J. G., Steinbrenner, K., & Bent, D. H. (1986). SPSS-X: Statistical package for the social sciences. New York: McGraw-Hill.

Noldy, N., Stelmack, R. M., & Campbell, K. C. (1990). ERPs and recognition memory for pictures and words. Psychophysiology, 27, 417-428

O'Donnell, B. F., Friedman, S., Swearer, J. M., & Drachman, D. A. (1992). Active and passive P3 latency and psychometric performance: influence on age and individual differences. International Journal of Psychophysiology. 12, 187-195.

Oken, B.S. (1989). Endogenous event--related potentials. In K. H. Chiappa (Ed.), Evoked potentials in clinical medicine. Second Edition, (pp. 563-592). New York: Raven Press Ltd.

Ostow, M. (1954). Psychodynamic disturbances in patients with temporal lobe disorder. Journal of Man (Sinai Hospital), 20. 293-308.

Peak, H., & Boring, E. G. (1926). The factor of speed in intelligence. Journal of Experimental Psychology. 9, *International Journal of Psychophysiology*. *12*, 187-195.

Peterson, J. (1925). *Early conceptions and tests of intelligence*. Yonkers: World Books Company.

Picton, T. W., & Hillyard, S. (1972). Cephalic skin potentials in electroencephalography. *Electroencephalography and Clinical Neurophysiology*. *33*, 419 - 424.

Picton, T. W., & Hillyard, S. (1974). Human auditory evoked potentials. II. Effects of attention. *Electroencephalography and Clinical Neurophysiology*. *36*, 191-199.

Plomin, R. (1986). *Development, genetics, and psychology*. Hillsdale, N. J.: Erlbaum.

Plomin, R., & Bergman, C. S. (1991). The nature of nurture: Genetic influence on environmental measures. *Behavioural and Brain Sciences*. *14*, 373 - 427.

Plomin, R., DeFries, J. C., & McClearn, G. E. (1980). *Behavioural genetics: a primer*. San Francisco: Freeman.

Polich, J. (1987). Task difficulty, probability and interstimulus interval as determinants of P300 from auditory stimuli. *Electroencephalography and Clinical Neurophysiology*, *68*, 311-320.

Posner, M. I. (1969). Abstraction and the process of recognition. In G. H. Bower & J. T. Spence (Eds.), *The psychology of learning and motivation, Vol. 3*. (pp. 43-100) New York: Academic Press.

Posner, M. I., Boies, S., Eichelman, W., & Taylor, R. (1969).

Retention of visual and name codes of single letters. Journal of Experimental Psychology. 81, 10-15.

Pribram, K. H., & McGuinness, D. (1975). Arousal, activations, and effort in the control of attention. Psychological Review. 82, 116-149.

Pritchard, W. S. (1981). Psychophysiology of P300. Psychological Bulletin, 89, 506-540.

Rabbitt, P. (1979). How old and young subjects monitor and control responses for accuracy and speed. British Journal of Psychology. 70, 305-311.

Rabbitt, P. (1981). Sequential reactions. In D. H. Holding (Ed.), Human skills. (PP.153-175). London: Wiley.

Ragot, R. (1984). Perceptual and motor space representation: An event-related potential study. Psychophysiology, 21, 159-170.

Ragot, R., & Renault, B. (1981). P300 as a function of S-R compatibility and motor programming. Biological Psychology, 13, 289-94.

Rhodes, L., Dustman, R., & Beck, E. (1969). The visual evoked response: A comparison of bright and dull children. Electroencephalography and Clinical Neurophysiology, 27, 367-372.

Robinson, D. L. (1982). Properties of the diffuse thalamocortical system, human intelligence and differentiated vs. integrated modes of learning. Personality and Individual Differences, 3, 393-405.

Robinson, D. L., Haier, R. J., Braden, W., & Krengel, M. (1984).

Psychometric intelligence and visual evoked potentials: a replication. Personality and Individual Differences. 5, 487 - 489.

Rohrbaugh, J. W., & Gaillard, A. W. K. (1983). Sensory and motor aspects of the contingent negative variation. In A. W. K. Gaillard and W. Ritter (Eds.), Tutorials in ERP research: Endogenous components. (pp.269-310). Amsterdam: North-Holland.

Roth, E. (1964). Die Geschwindingkeit der verarbeitung von information und ihr zusammenhang mit intelligenz. Zeitschrift fur Angewandte und Experimentalle Psychologie. 11, 616-622.

Roth, W. T., Ford, J. M., & Kopell, B. S. (1976). Long-latency evoked potentials and reaction time. Paper presented at the meeting of the Society for Psychophysiological Research, San Diego.

Ruchkin, D.S. (1988). Measurement of event-related potentials: Signal extraction. In T. W. Picton (Ed.) Handbook of electroencephalography and clinical neurophysiology, Revised Series, Vol. 3, Human event-related potentials. Amsterdam: Elsevier.

Rummel, R. J. (1970). Applied factor analysis. Evanston: Northwestern University Press.

Rust, J. (1975). Cortical evoked potentials, personality and intelligence. Journal of Comparative and Physiological Psychology, 89, 1220-1226.

Sattler, J. M. (1988). Assessment of children. (3rd edition).

San Diego: Jerome M. Sattler.

Scarr, S., & Weinberg, R. A. (1978). The influence of "family background" on intellectual attainment. American Sociological Review. 43, 674-692.

Schafer, E. W. P. (1979). Cognitive neural adaptability: A biological basis for individual differences in intelligence. Psychophysiology. 16, 199.

Schafer, E. W. P. (1982). Neural adaptability: a biological determinant of behavioral intelligence. International Journal of Neuroscience. 17, 183-191.

Schafer, E. W. P., & Marcus, M. M. (1973). Self-stimulation alters human sensory brain responses. Science. 181, 175- 177.

Shannon, C. E., & Weaver, W. (1949). The mathematical theory of communication. Urbana, Il: University of Illinois Press.

Shucard, D. W., & Callaway, E. (1973). Relationship between human intelligence and frequency of analysis of cortical evoked responses. Perceptual and Motor Skills, 36, 147-151.

Shucard, D. W., & Horn, J. L. (1972). Evoked cortical potentials and measurement of human abilities. Journal of Comparative and Physiological Psychology, 78, 59-68.

Snow, R. E., Marshalek, B., & Lohman, D. F. (1976). Correlation of selected cognitive abilities and cogntive processing parameters: An exploratory study. Technical Report 3. Aptitude research project. School of Education, Stanford University. Palo Alto. California.

Spearman, C. (1904). "General intelligence", objectively determined and measured. American Journal of Psychology. 15, 201-292.

Spearman, C. (1927). The abilities of man. London: MacMillan.

Spiegel, M. R., & Bryant, N. D. (1978). Is speed of processing information related to intelligence and achievement? Journal of Educational Psychology. 70, 904 - 910.

Spitz, H. H. (1986). The raising of intelligence: A selected history of attempts to raise retarded intelligence. Hillsdale, N. J.: Erlbaum.

Squires, N. K., Donchin, E., Squires, K. C., & Grossberg, S. (1977). Bisensory stimulation: inferring decision-related processes from the P300 component. Journal of Experimental Psychology: Human Perception and Performance, 3, 299-315.

Stephenson, W. A., & Gibbs, F. A. (1951). A balanced non-cephalic reference electrode. Electroencephalography and Clinical Neurophysiology, 3, 237-240.

Sternberg, S. (1966). High speed scanning in human memory. Science. 153, 652-654.

Sternberg, S. (1969). Memory scanning: Mental processes revealed by reaction time experiments. American Scientist, 57, 421-457.

Sternberg, R. J. (1982). (Ed.) Handbook of human intelligence. London: Cambridge University Press.

Sternberg, R. J. (1984). Towards a triarchic theory of human intelligence. Behavioral and Brain Sciences. 7, 269 -315.

Sternberg, R. J. (1985). *Beyond IQ*. Cambridge: Cambridge University Press.

Stough, C. K. K., Nettlebeck, T., & Cooper, C.J. (1990). Evoked brain potentials, string length and intelligence. *Personality and Individual Differences*, *11*, 401-406.

Sutton, S., Braren, M., Zubin, J., & John, E. R. (1965). Evoked potential correlates of stimulus uncertainty. *Science*. *150*, 1187-1188.

Sutton, S., Tueting, P., Zubin, J., & John, E. R. (1967). Information delivery and the sensory evoked potentials. *Science*. *155*, 1436-1439.

Thorndike, E. L., Bregman, E. O., Cobb, M. V., & Woodyard, E. (1927). *The measurement of intelligence*. New York: Teachers' College of Columbia University.

Thurstone, L. L. (1938). *Primary mental abilities*. Chicago: University of Chicago Press.

Trimmel, M. (1985). DC potentials of the brain. In D. Papakostopoulos, S. Butler, & J. Martin (Eds.), *Clinical and Experimental Neuropsychophysiology*. (pp. 312-338). London: Croom Helm.

Trimmel, M. (1986). Slow potentials and contingent negative variation analyzed by operating characteristics. *International Journal of Psychophysiology*. *4*, 264.

Vernon, P. A. (1983). Speed of information-processing and general intelligence. Intelligence, 7, 53-70.

Vernon, P. A. (1985). Individual differences in general cognitive ability. In L. C. Hartlage, & C. F. Telzrow (Eds.), The Neuropsychology of Individual Differences. (pp. 125-150). New York: Plenum.

Vernon, P. A. (1987). Speed of information processing and intelligence. Norwood, N. J.: Ablex.

Vernon, P. A. (1989a). The generality of g. Personality and Individual Differences, 10, 803-804.

Vernon, P. A. (1989b). The heritability of measures of speed of information processing. Personality and Individual Differences. 10, 573-576.

Vernon, P. A., & Jensen, A. R. (1984). Individual and group differences in intelligence and speed of information processing. Personality and Individual Differences. 10, 573 - 576.

Vernon, P. A., Nador, S., & Kantor, L. (1985). Group differences in intelligence and speed of information processing. Intelligence. 9, 137-148.

Vernon, P. A., & Kantor, L, (1986). Reaction time correlations with intelligence test scores obtained under either timed or untimed conditions. Intelligence. 10, 315-330.

Vernon, P. E. (1955). The assessment of children. University of London Institute of Education, studies in education, vol. 7. London: Evans.

Vernon, P. E. (1965). Ability factors and environmental influences, American Psychologist. 20, 723-733.

Vogel, W., & Broverman, D. M. (1964). Relationship between EEG and test intelligence: a critical review. Psychological Bulletin. 62, 132-144.

Warren, L. R., & Marsh, G. R. (1979). Changes in event-related potentials during processing of Stroop stimuli. International Journal of Neuroscience, 9, 217-223.

Wechsler, D. (1955). Manual for the Wechsler adult intelligence scale. New York: Psychological Corporation.

Weschler, D. (1981). Wechsler adult intelligence scale-revised. New York: Psychological Corporation.

Weinberg, R. A. (1989). Intelligence and IQ: Landmark issues and great debates. American Psychologist. 44, 98-104.

Weiss, V. (1982). Psychogenetik: Humangenetik in psychologie und psychiatrie. Jena: Fisher.

Weiss, V. (1984). Psychometric intelligence correlates with inter-individual different rates of lipid peroxidation. Biomedical and Biochemical Acta. 43, 755-763.

White, P. O. (1973). Individual differences in speed, accuracy and persistence: a mathematical model for problem solving. In H.J. Eysenck (Ed.), The measurement of intelligence. (pp. 246-260). Lancaster: M.T.P. Press.

Widaman, K. F., & Carlson, J. S. (1989). Procedural effects of performance on the Hick paradigm: Bias in reaction time and movement time parameters. Intelligence. 13, 63- 85.

Wigdor, A. K., & Gardner, W. R. (Eds.) (1982). Ability testing:

Uses, consequences and controversies. Part I: Report of the committee. Washington, D. C.: National Academy Press.

Wissler, C. (1901). The correlation of mental and physical tests. Psychological Review Monographs, 3 (6, Whole No. 16).

Woodworth, R.S., & Schlosberg, H. (1956). Experimental Psychology (revised edition). New York: Holt.

Zimmerman, F. I., & Ross, S. (1944). Effect of glutamic acid and other amino acids on maze learning in the white rat. Archives of Neurology and Psychiatry, 51, 446-451.

Footnotes

* This paper is based on research that was conducted in partial fulfillment of requirements for the doctoral degree by the first author. The research was supported by the Social Science and Humanities Research Council of Canada (RMS: 410-88-0226), the Natural Science and Engineering Research Council of Canada (KBC: 8242) and by the Faculty of Social Science and the School of Graduate Studies, University of Ottawa. The assistance of M. Houlihan, I. Bell, J. Miles, M. Makasare, H. VanDenberg and R. Spratt is gratefully acknowledged.

Figure Captions

Figure 1. ERP waveforms for Simple Reaction Time task, yes (saw X), obtained from AAA and AA groups. EOG is plotted at half gain. P300 is indicated by a triangle.

Figure 2. ERP waveforms for Choice Reaction Time task, yes (saw X) and no (saw O), obtained from AAA and AA groups. EOG is plotted at half gain. P300 is indicated by a triangle.

Figure 3. ERP waveforms for Physical Similarity Task, yes (physically same) and no (physically different), obtained from AAA and AA groups. EOG is plotted at half gain. P300 is indicated by a triangle.

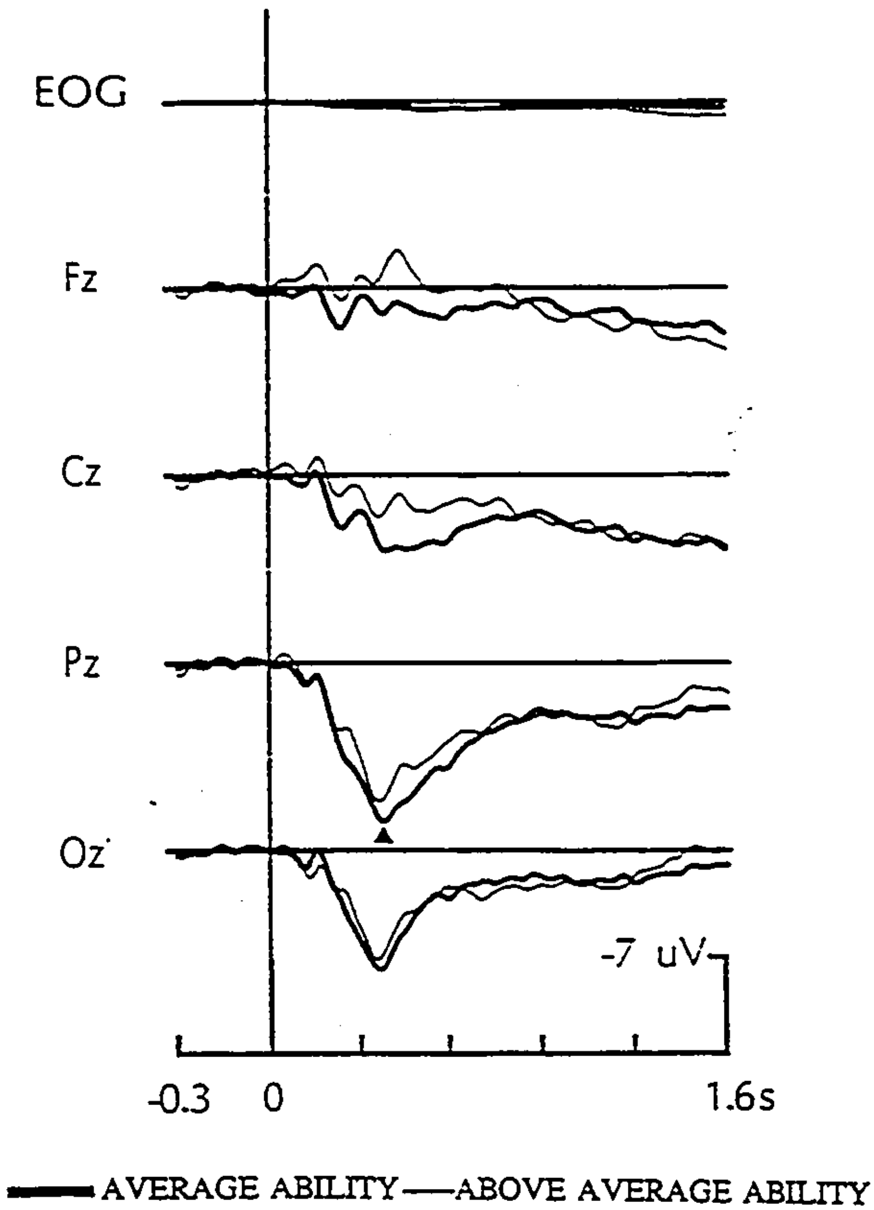
Figure 4. ERP waveforms for Category Matching Task, yes (same category) and no (different category), obtained from AAA and AA groups. EOG is plotted at half gain. P300 is indicated by a triangle.

Figure 5. ERP waveforms for Sternberg Digit Task, yes (probe in string) no (probe not in string), obtained from AAA and AA groups. EOG is plotted at half gain. P300 is indicated by a triangle.

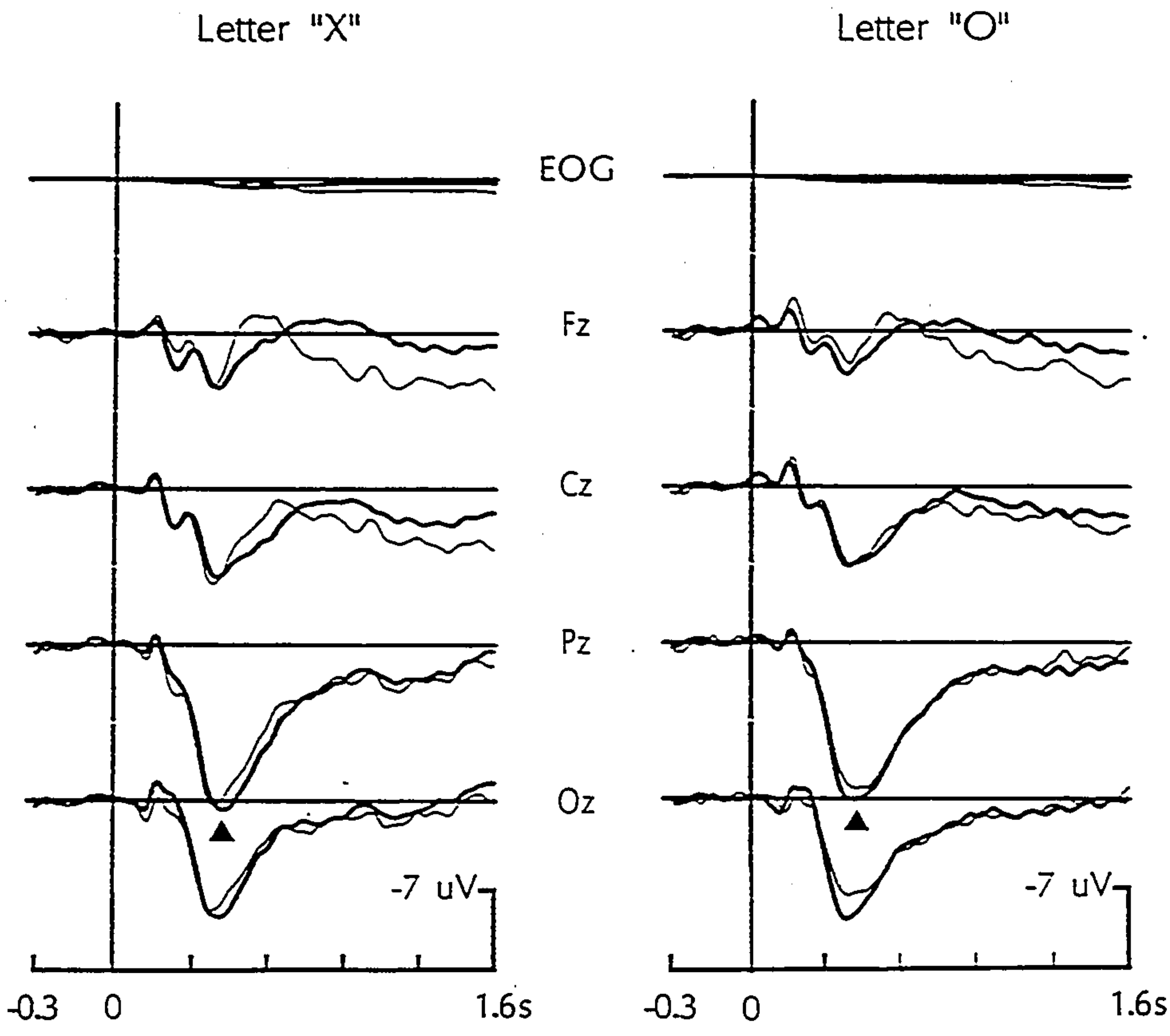
Figure 6. ERP waveforms for Semantic Similarity Task, yes (synonym) and no (antonym), obtained from AAA and AA groups. EOG is plotted at half gain.

Figure 7. Average mean reaction time (in ms) for AAA and AA groups for yes response.

SIMPLE REACTION TIME

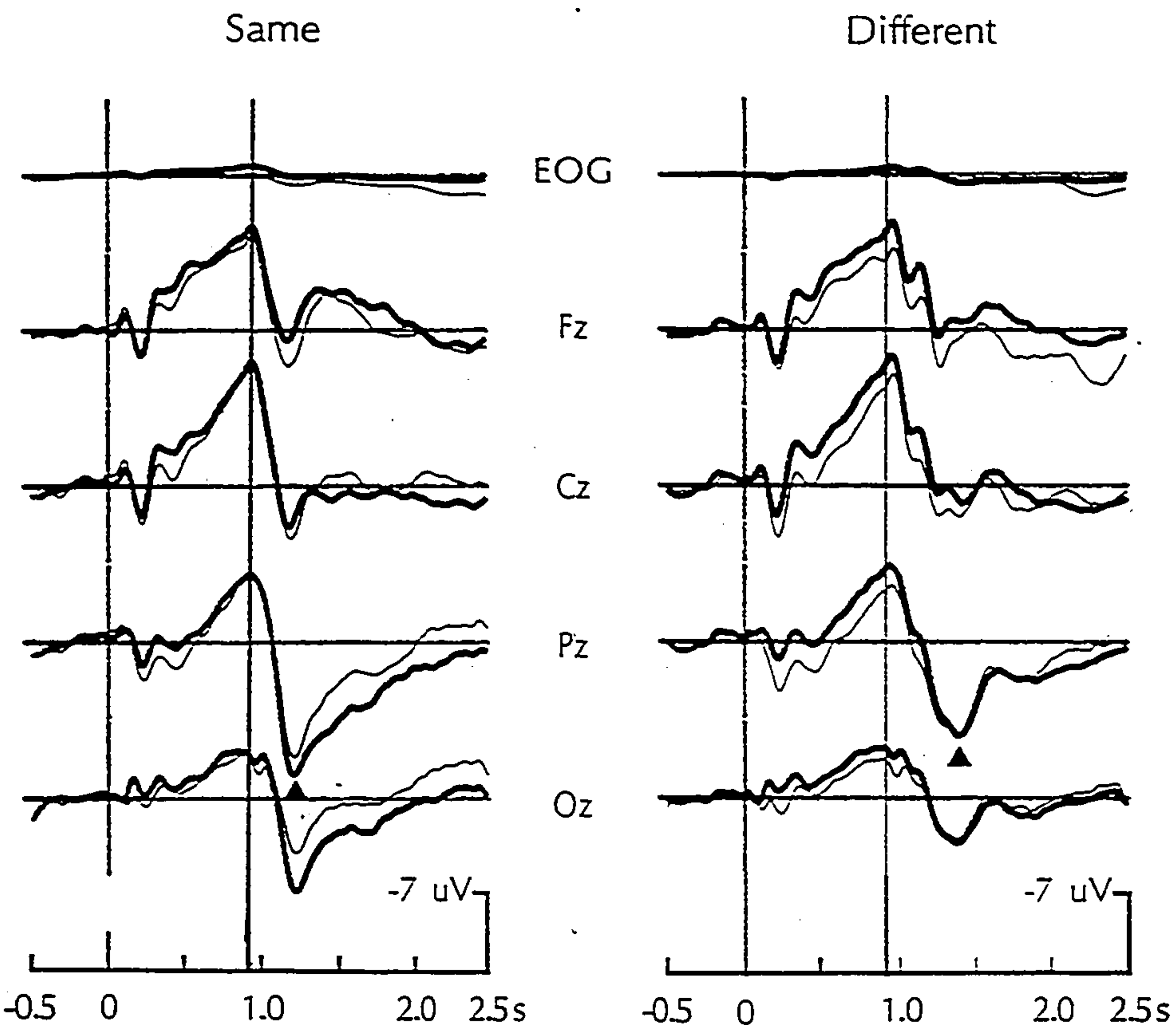


CHOICE REACTION TIME



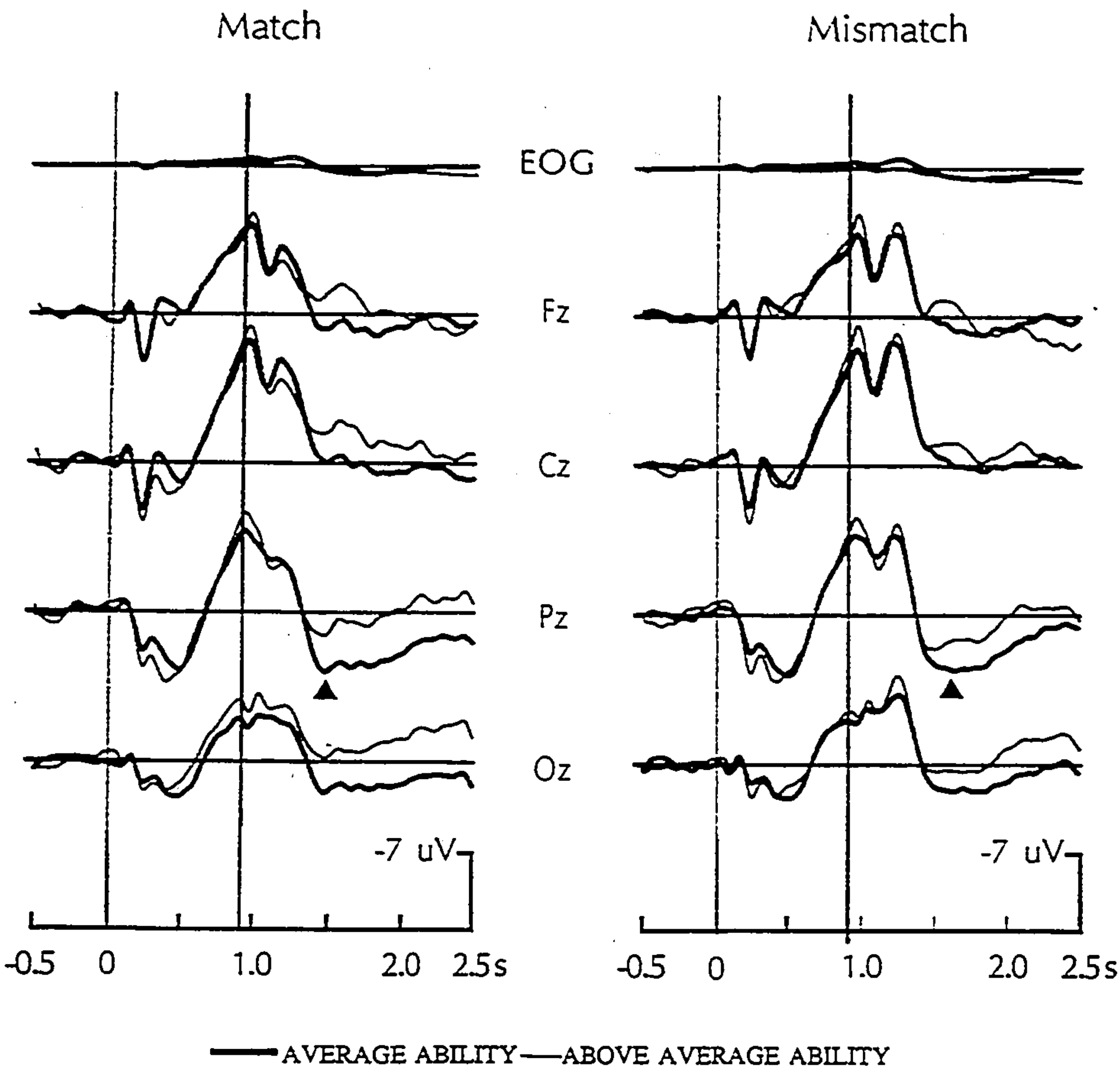
AVERAGE ABILITY —— ABOVE AVERAGE ABILITY

PHYSICAL SIMILARITY

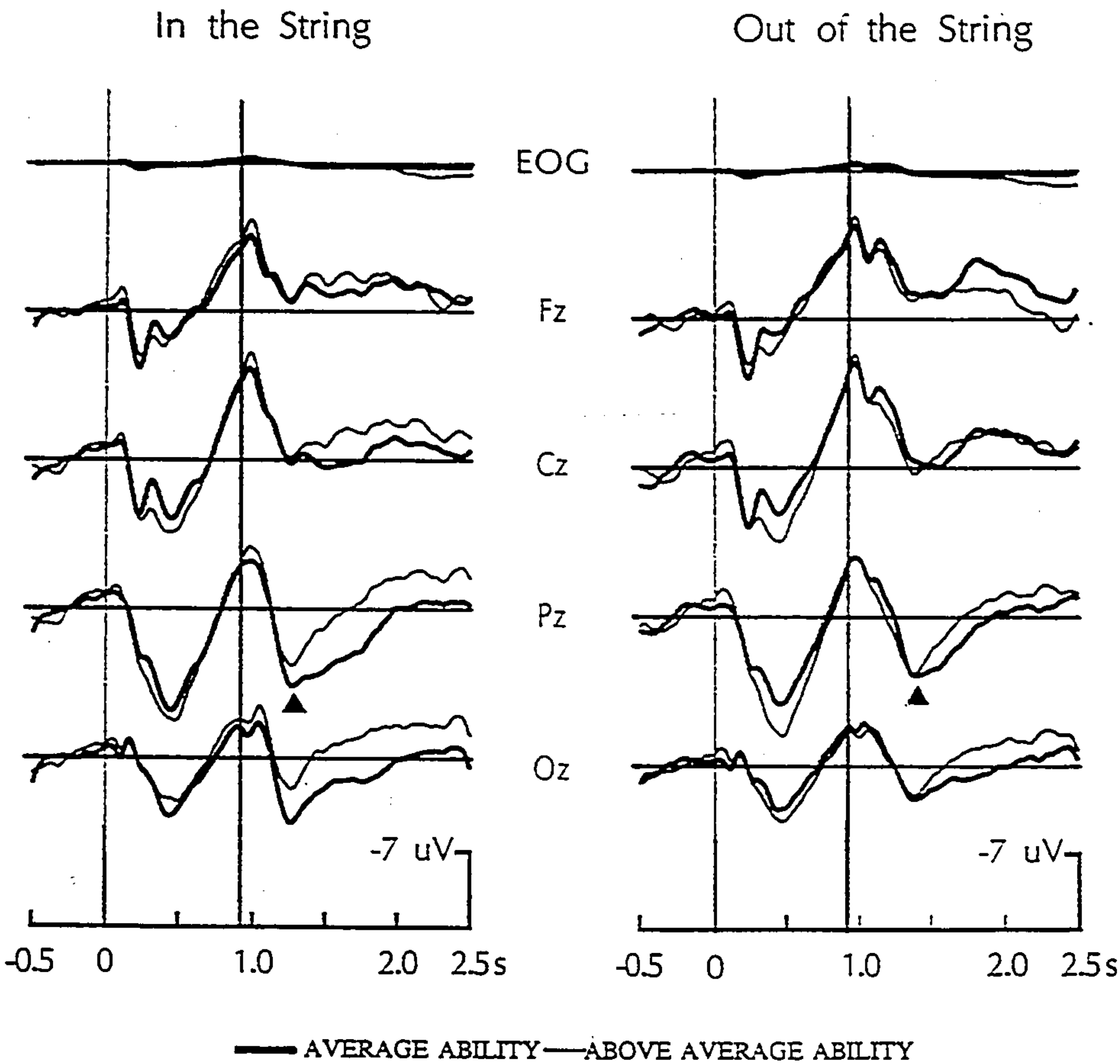


AVERAGE ABILITY —ABOVE AVERAGE ABILITY

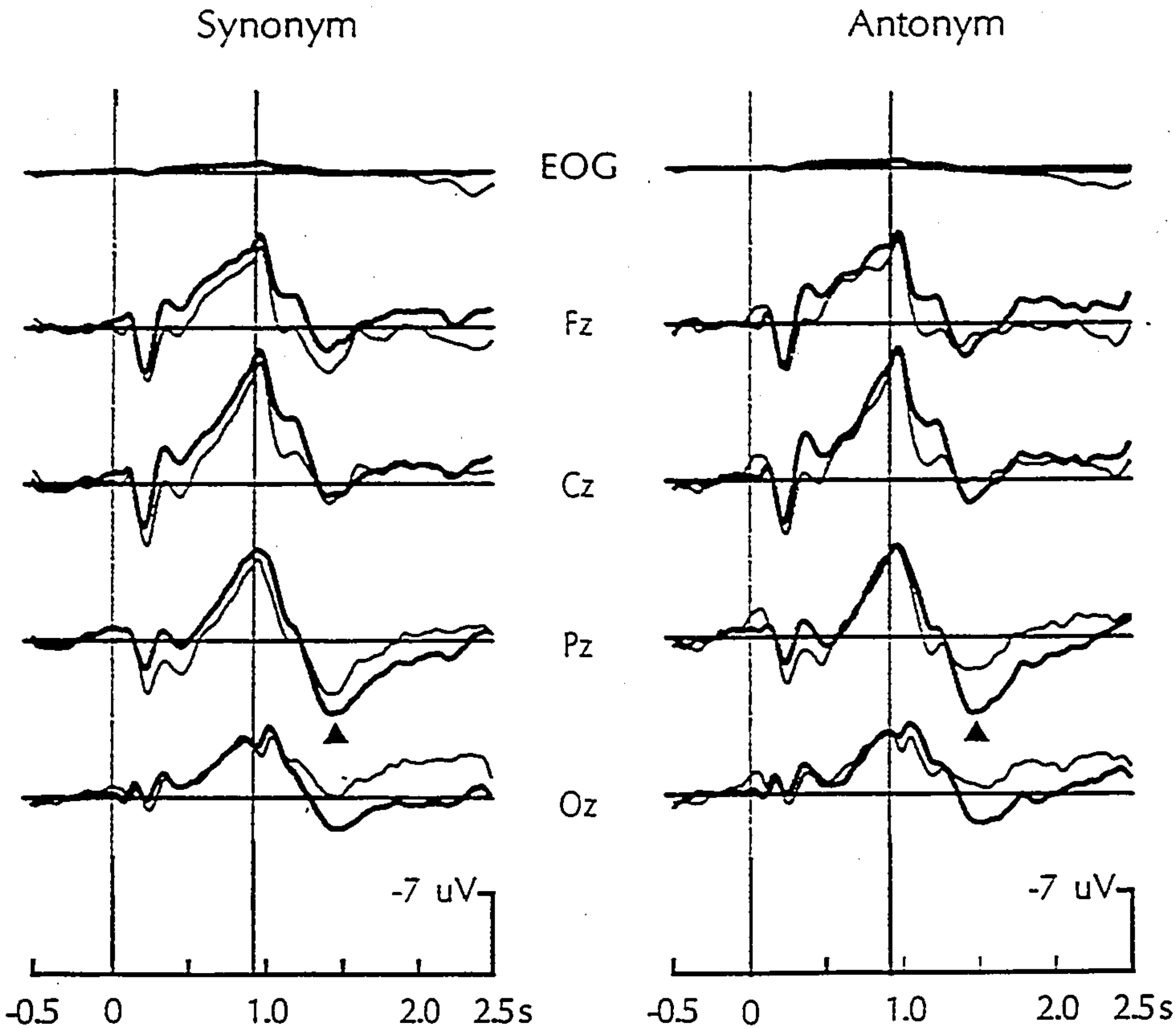
CATEGORY MATCHING



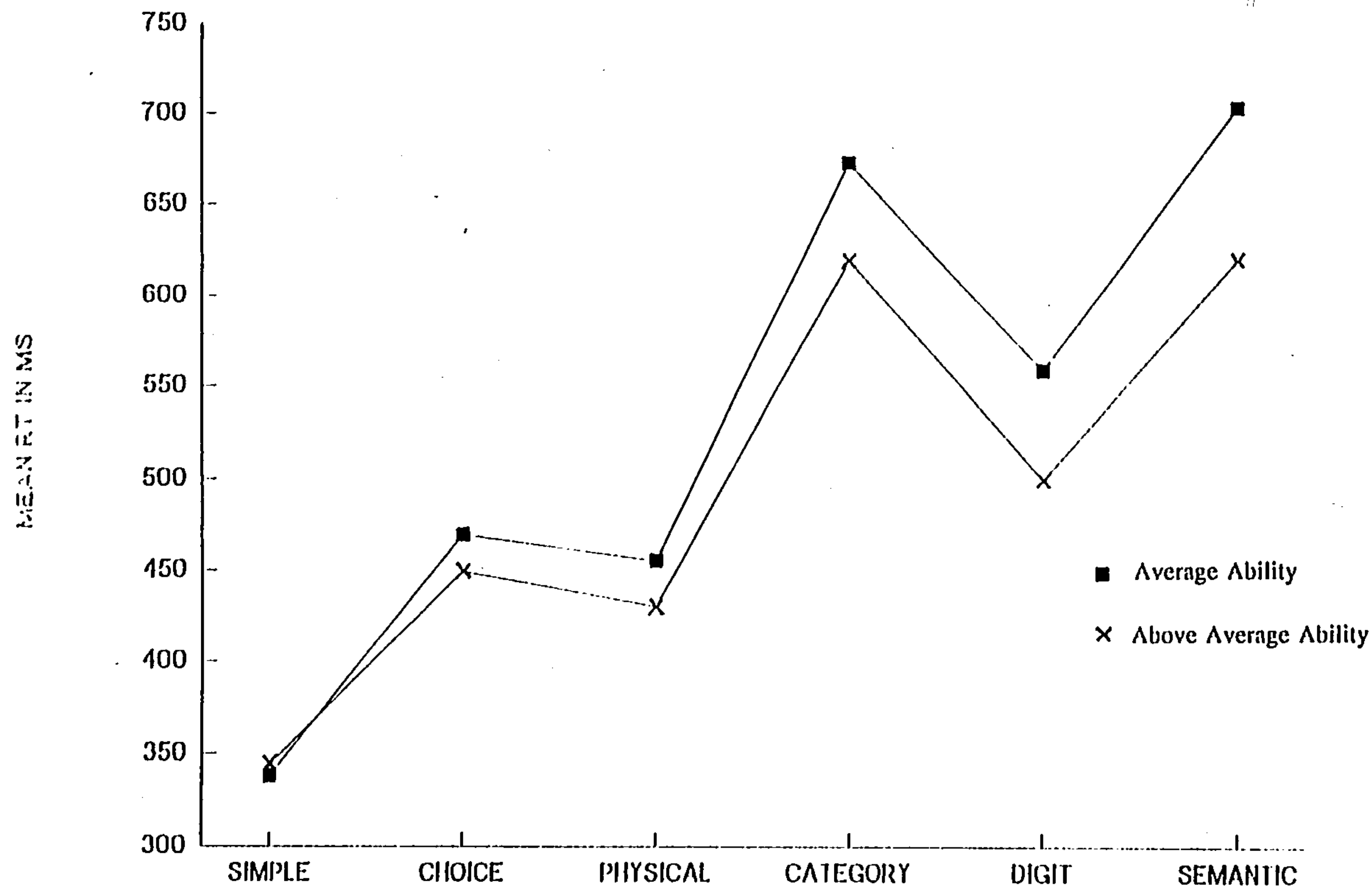
STERNBERG DIGIT

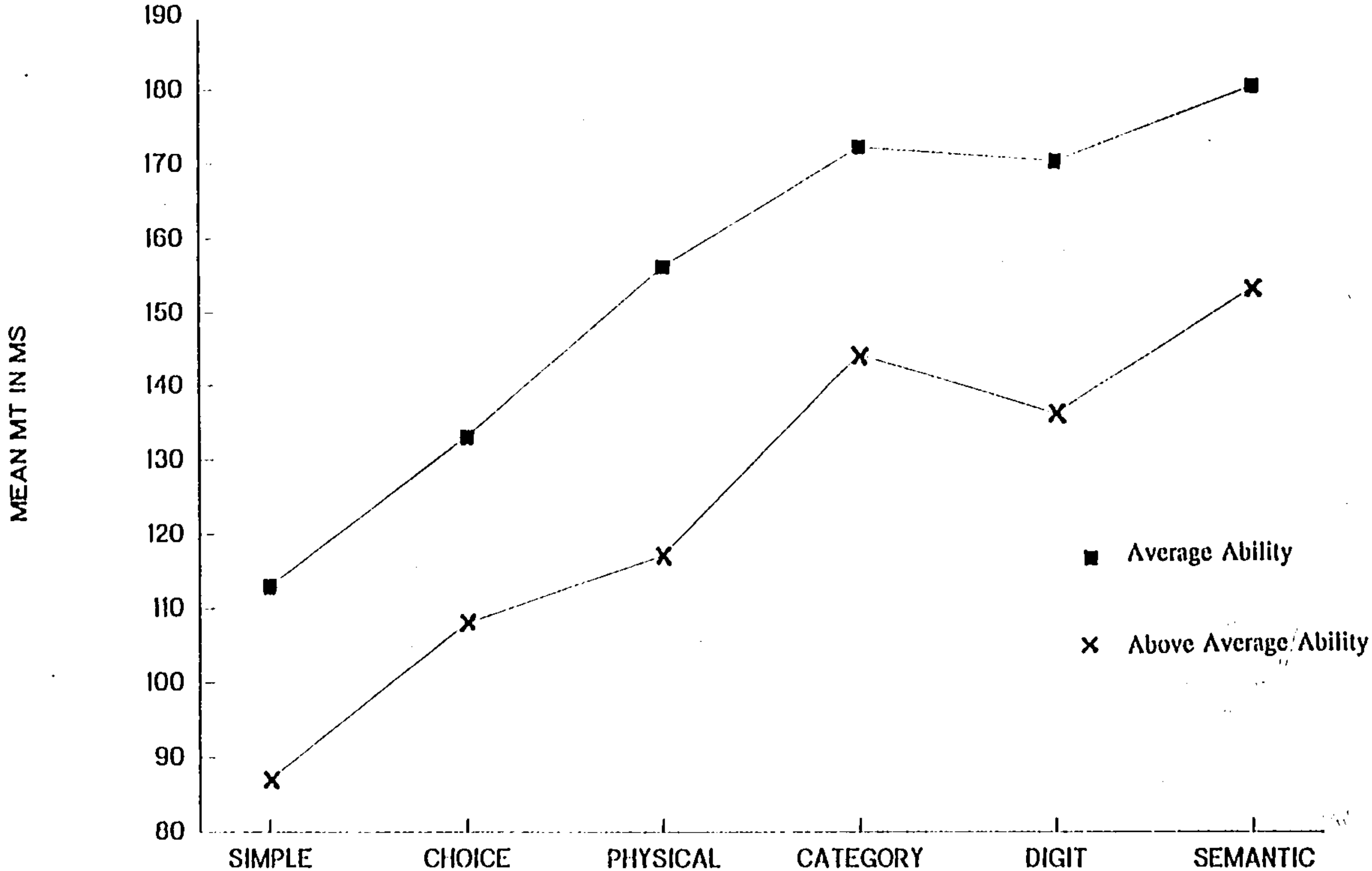


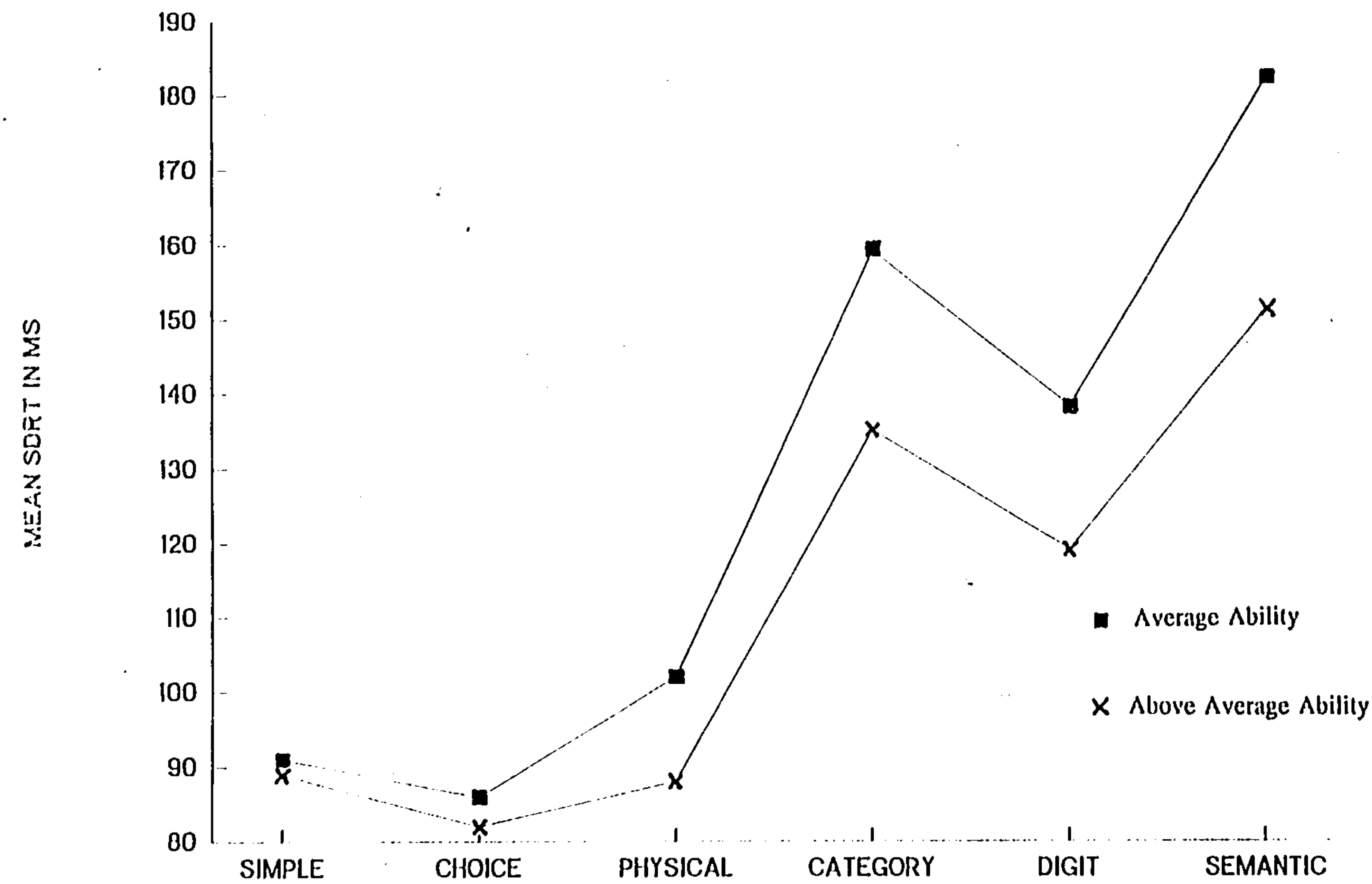
SEMANTIC SIMILARITY

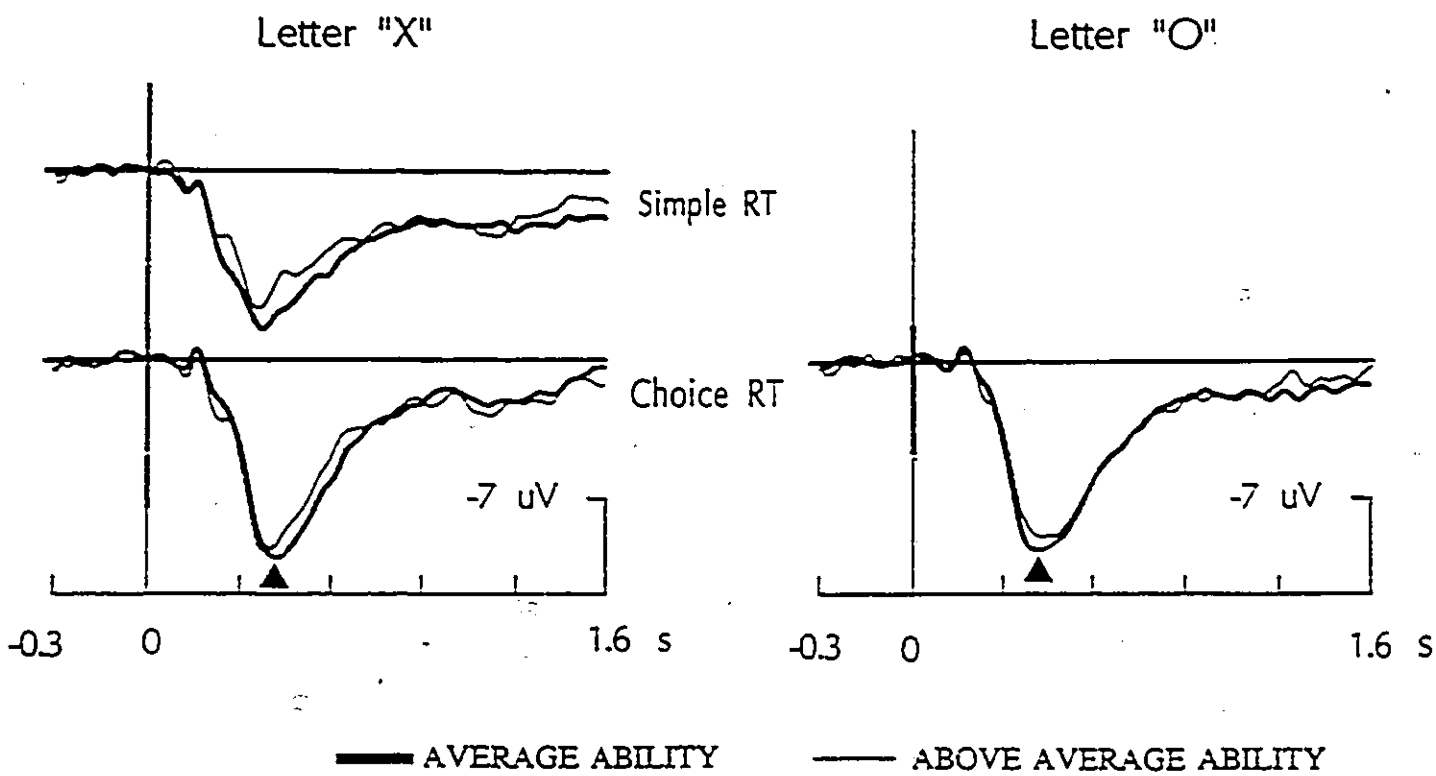


AVERAGE ABILITY — ABOVE AVERAGE ABILITY

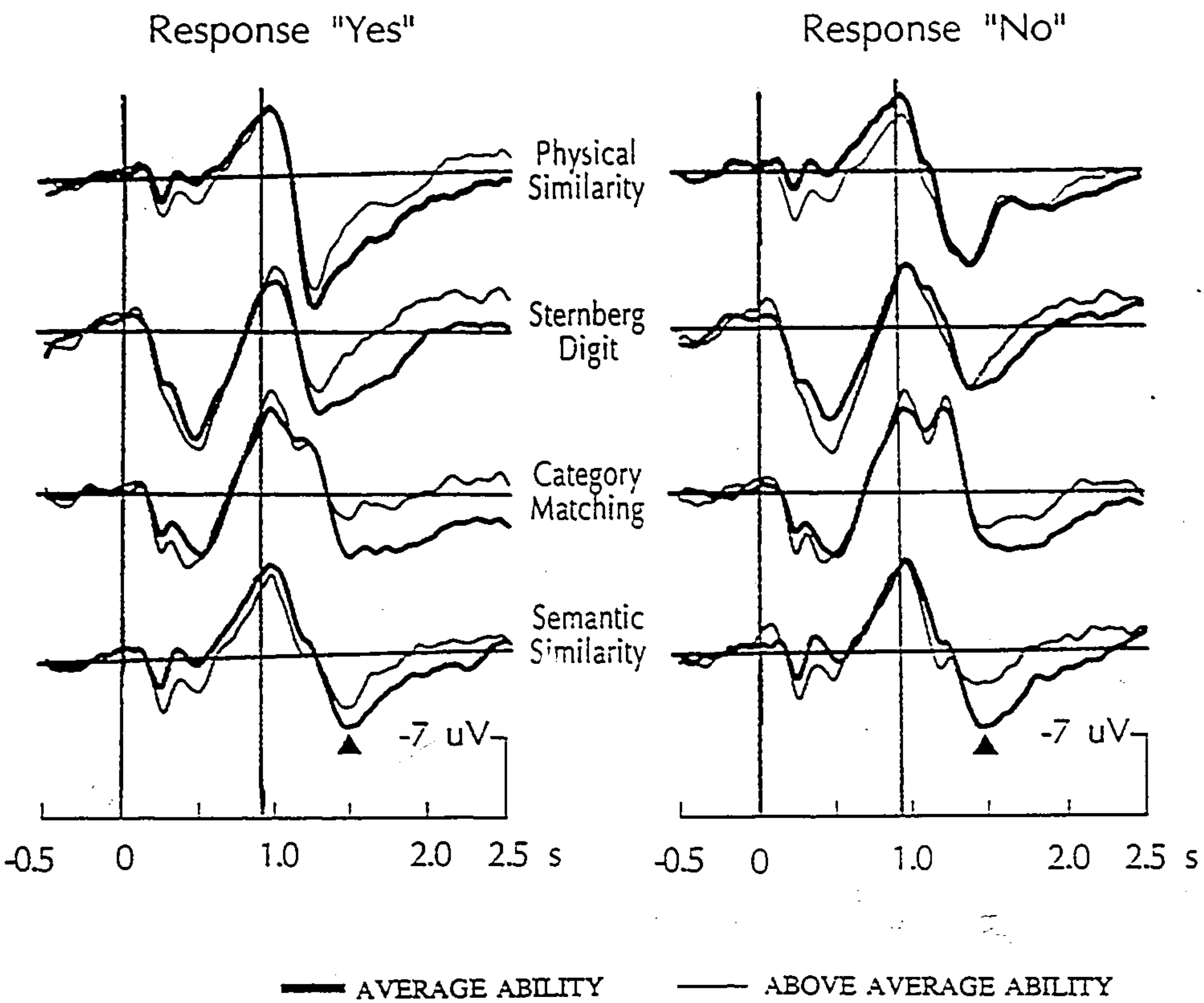

MEAN RT IN MS
750
700
650
600
550
500
450
400
350
300
SIMPLE
CHOICE
PHYSICAL
CATEGORY
DIGIT
SEMANTIC
Average Ability
Above Average Ability

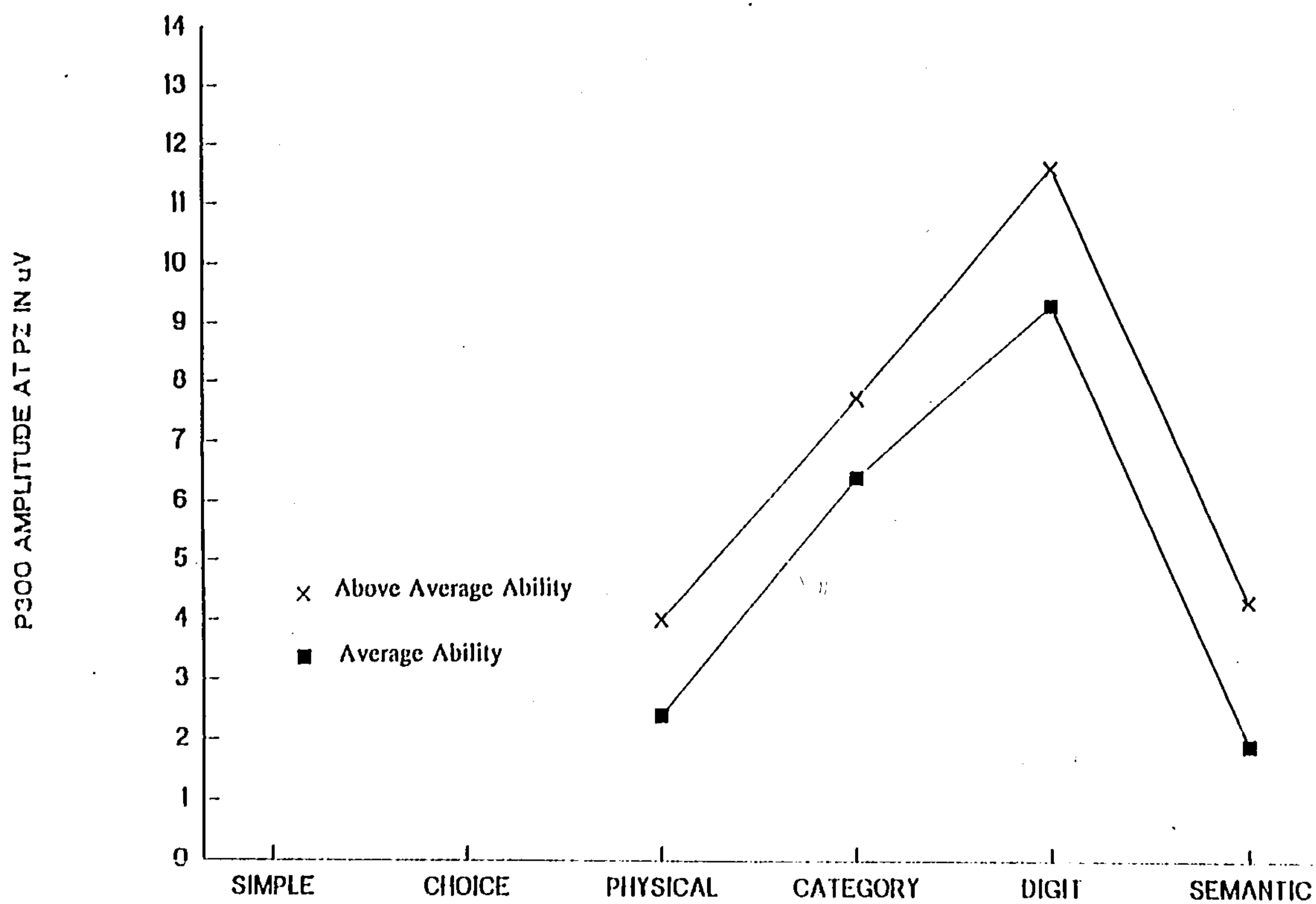

MEAN MT IN MS
190
180
170
160
150
140
130
120
110
100
90
80
SIMPLE
CHOICE
PHYSICAL
CATEGORY
DIGIT
SEMANTIC
Average Ability
Above Average Ability

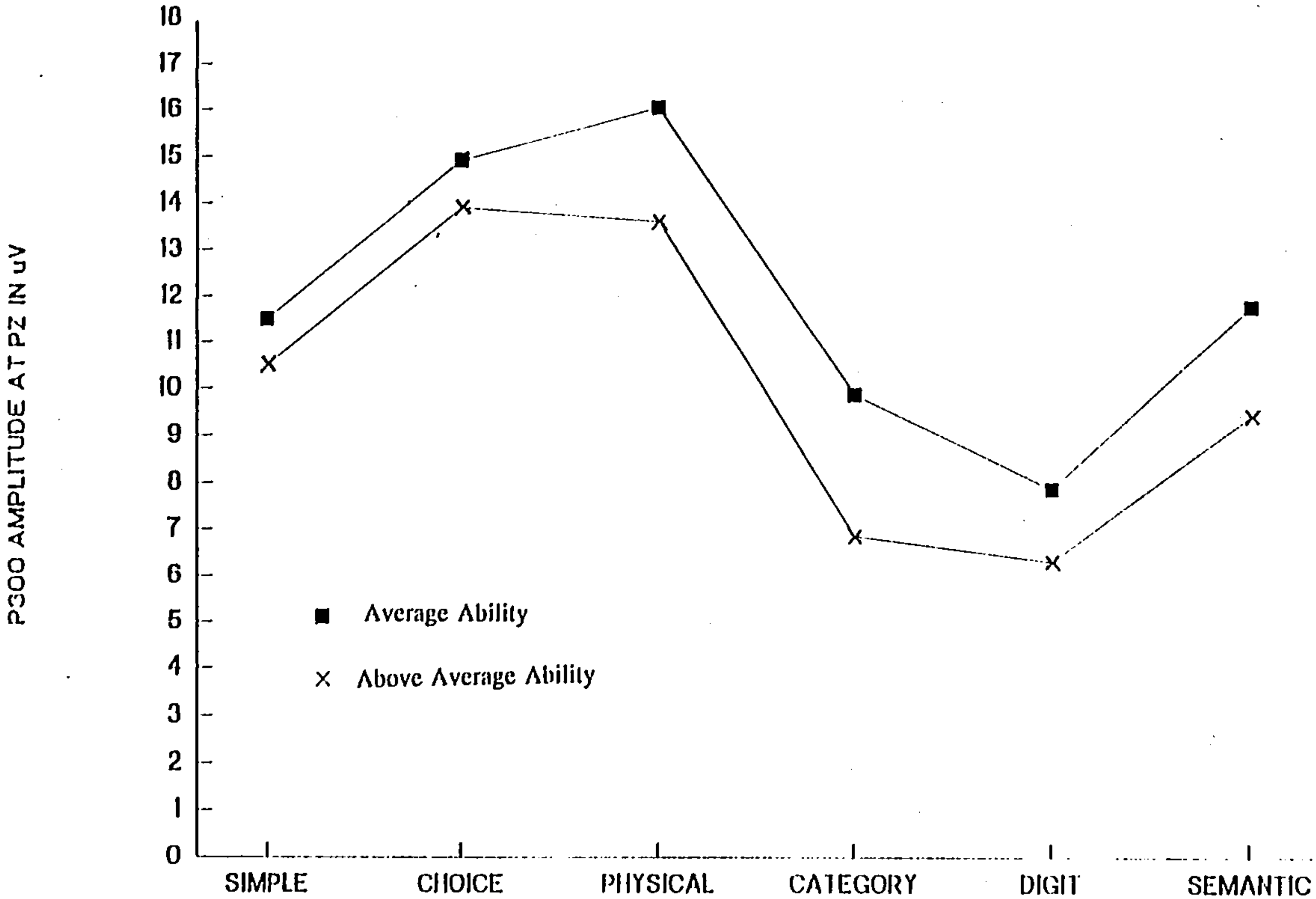

MEAN SDRT IN MS
190
180
170
160
150
140
130
120
110
100
90
80
SIMPLE
CHOICE
PHYSICAL
CATEGORY
DIGIT
SEMANTIC
Average Ability
Above Average Ability



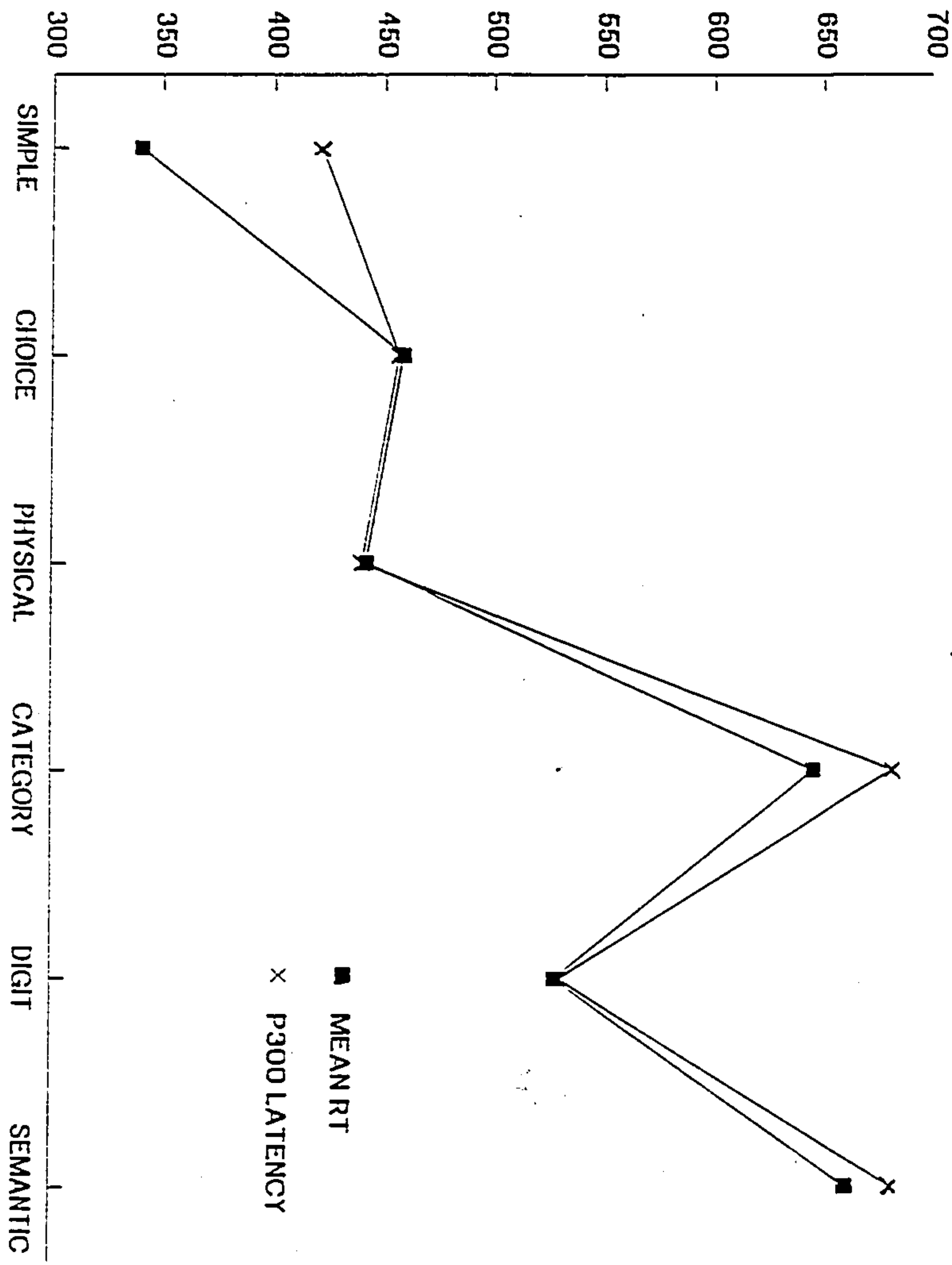
Letter "X"
Letter "O"
Simple RT
Choice RT
-7 uV
-7 uV
-0.3
0
1.6 s
-0.3
0
1.6 s
AVERAGE ABILITY
ABOVE AVERAGE ABILITY


Response "Yes"
Response "No"
Physical Similarity
Sternberg Digit
Category Matching
Semantic Similarity
-7 uV
-7 uV
-0.5
0
1.0
2.0
2.5 s
-0.5
0
1.0
2.0
2.5 s
AVERAGE ABILITY
ABOVE AVERAGE ABILITY

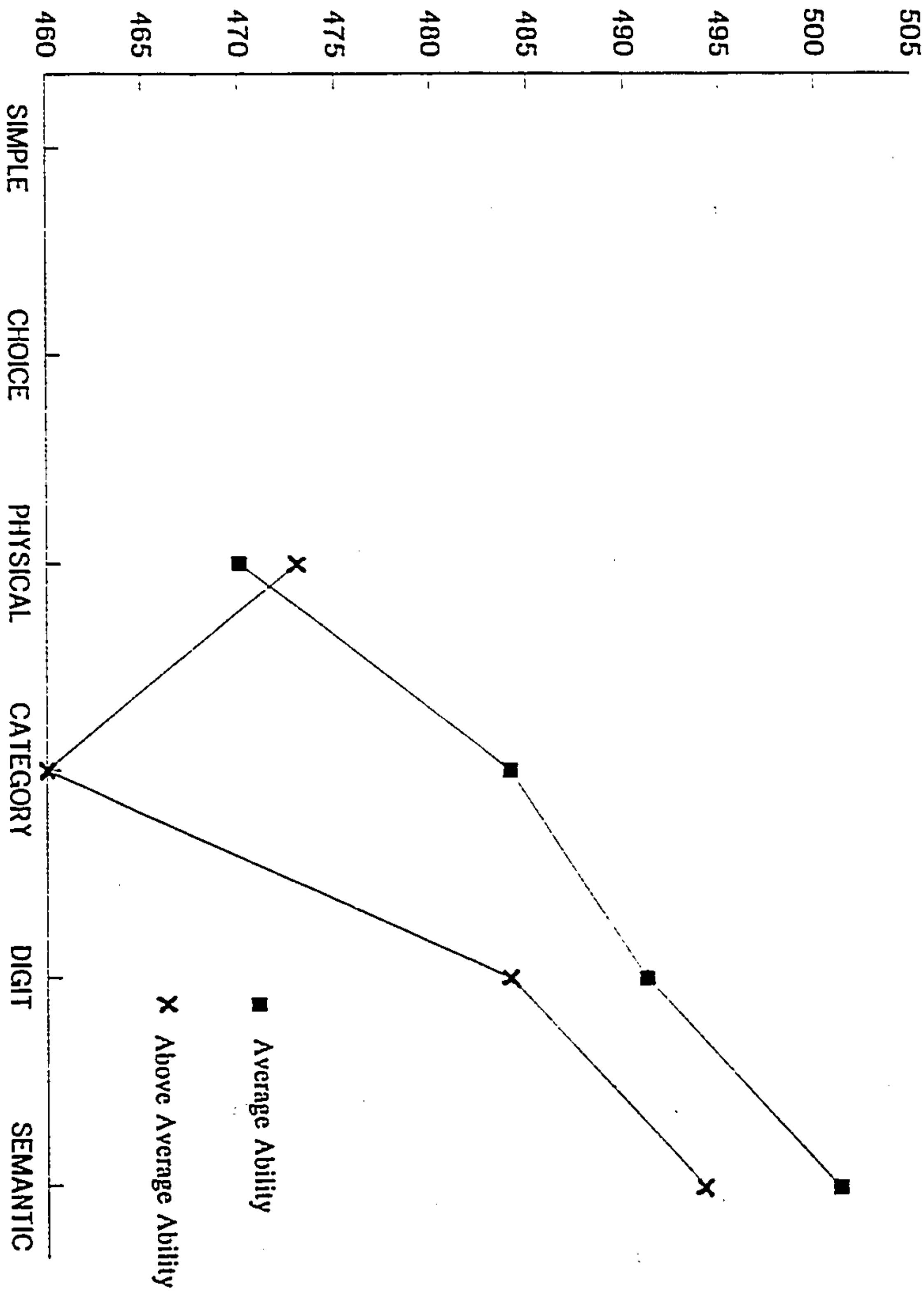

P300 AMPLITUDE AT PZ IN uV
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Above Average Ability
Average Ability
SIMPLE
CHOICE
PHYSICAL
CATEGORY
DIGIT
SEMANTIC


P300 AMPLITUDE AT PZ IN uV
10
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Average Ability
Above Average Ability
SIMPLE
CHOICE
PHYSICAL
CATEGORY
DIGIT
SEMANTIC

P300 LATENCY AND MEAN RT



P300 LATENCY AT PZ IN MS



P300 LATENCY AT PZ IN MS

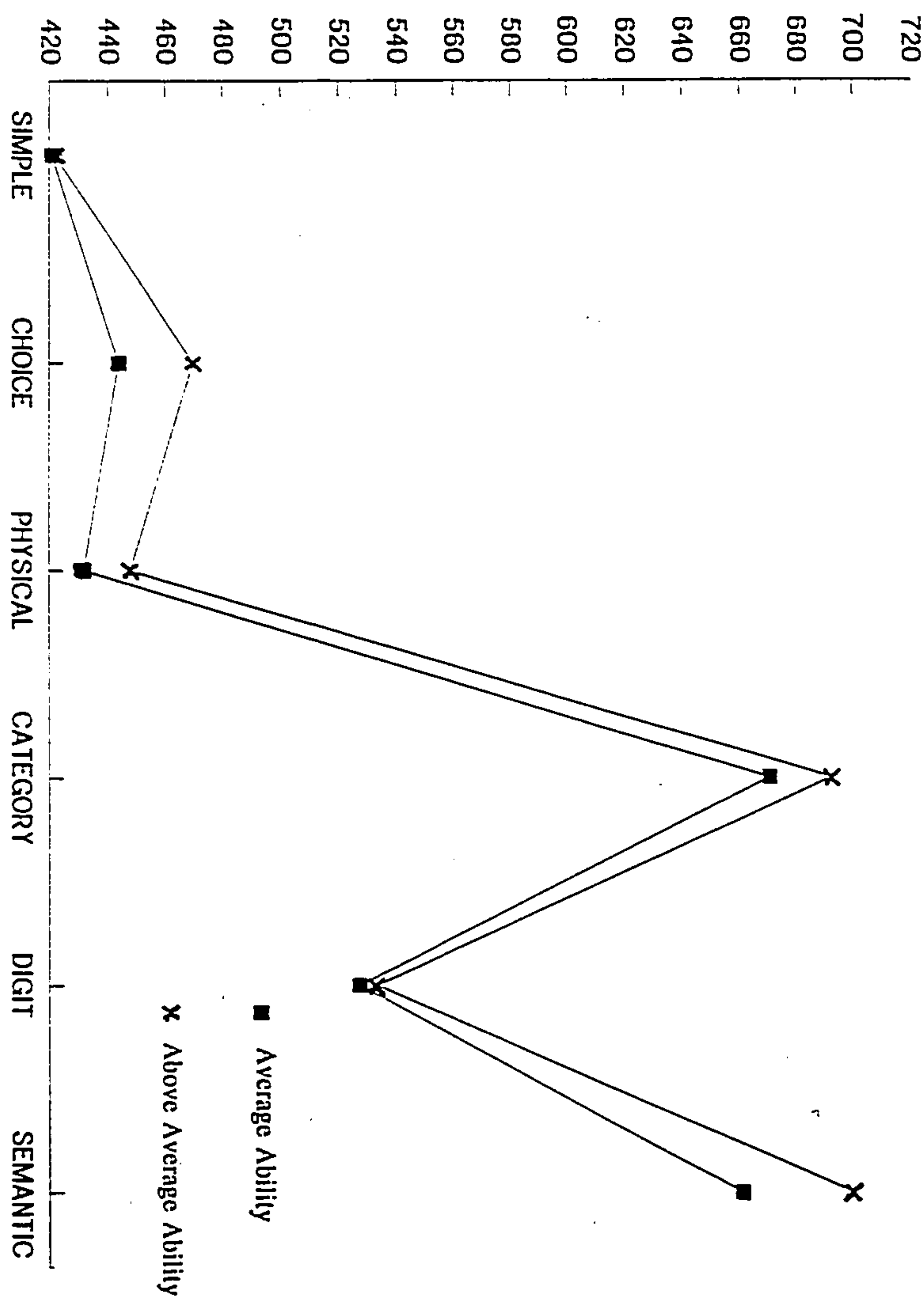


TABLE 1
Percent Errors and Mean Reaction Time (ms) and Standard Deviation for Fast and Slow Errors on Reaction Time Tasks

Task	Fast Errors		Slow Errors	
	%	RT	%	RT
Simple Reaction Time	n/a	n/a	n/a	n/a
Choice Reaction Time	.64	106 (155)	.10	33 (109)
Physical Similarity	.36	156 (185)	.32	185 (276)
Category Matching	.88	390 (277)	1.19	619 (397)
Sternberg Digit	1.68	374 (179)	2.78	691 (261)
Semantic Similarity	1.76	460 (219)	2.77	819 (275)

TABLE 2
Average (N=30) Mean Reaction Time and Movement Time (in ms) and Standard Deviation for Reaction Time Tasks

Task	Response Type: Yes	No	Combined
Reaction Time			
Simple Reaction Time	340 (53)	n/a	340 (53)
Choice Reaction Time	459 (59)	449 (57)	454 (58)
Physical Similarity	442 (57)	513 (79)	478 (68)
Category Matching	645 (110)	698 (112)	672 (119)
Sternberg Digit	528 (96)	594 (108)	561 (111)
Semantic Similarity	660 (120)	677 (109)	669 (118)
Movement Time			
Simple Reaction Time	99 (29)	n/a	99 (29)
Choice Reaction Time	121 (38)	122 (38)	122 (39)
Physical Similarity	137 (50)	135 (36)	136 (43)
Category Matching	158 (59)	147 (40)	152 (50)
Sternberg Digit	153 (50)	141 (39)	147 (45)
Semantic Similarity	166 (58)	159 (49)	162 (54)

TABLE 3
Average (N=30) Mean Intraindividual variability in RT (in ms) and Standard Deviation for Reaction Time Tasks

Intraindividual Variability in RT

Task	Response Type		
	Yes	No	Combined
Simple Reaction Time	90 (30)	n/a	90 (30)
Choice Reaction Time	84 (22)	86 (26)	85 (24)
Physical Similarity	95 (29)	95 (36)	95 (32)
Category Matching	147 (39)	159 (34)	153 (36)
Sternberg Digit	129 (41)	128 (44)	128 (42)
Semantic Similarity	167 (42)	200 (46)	183 (44)

TABLE 4
Average (N=30) Mean P300 Amplitude (in uV)
and Standard Deviation for Reaction Time Tasks

To First Stimulus						
	Response will be					
Task	Yes		No		Combined	
Simple Reaction Time	n/a		n/a		n/a	
Choice Reaction Time	n/a		n/a		n/a	
Physical Similarity	3.1	(3.0)	3.1	(3.6)	3.1	(3.0)
Category Matching	7.0	(3.3)	7.0	(3.4)	7.0	(3.3)
Sternberg Digit	10.4	(4.4)	10.0	(4.3)	10.3	(4.3)
Semantic Similarity	3.1	(3.6)	3.0	(3.5)	3.1	(3.5)
Target Stimulus						
Simple Reaction Time	11.0	(6.7)	n/a		11.0	(6.7)
Choice Reaction Time	14.4	(6.9)	13.5	(6.6)	13.9	(6.7)
Physical Similarity	14.8	(6.2)	12.8	(6.1)	13.8	(6.1)
Category Matching	8.3	(6.9)	8.5	(7.6)	8.4	(7.1)
Sternberg Digit	7.1	(6.0)	6.5	(5.7)	6.8	(5.8)
Semantic Similarity	10.5	(6.2)	10.2	(6.2)	10.3	(6.2)

TABLE 5

Average (N=30) Mean P300 Latency (in ms) and Standard Deviation for Reaction Time Tasks

To First Stimulus			
	Response will be		
Task	Yes	No	Combined
Simple Reaction Time	n/a	n/a	n/a
Choice Reaction Time	n/a	n/a	n/a
Physical Similarity	472 (45)	471 (45)	471 (45)
Category Matching	472 (53)	476 (49)	474 (50)
Sternberg Digit	487 (36)	493 (31)	490 (32)
Semantic Similarity	497 (39)	496 (41)	496 (41)
Target Stimulus			
Simple Reaction Time	422 (27)	n/a	422 (27)
Choice Reaction Time	457 (45)	457 (48)	457 (46)
Physical Similarity	440 (70)	540 (75)	490 (72)
Category Matching	681 (40)	690 (42)	685 (40)
Sternberg Digit	530 (69)	582 (46)	556 (54)
Semantic Similarity	680 (48)	678 (52)	679 (49)

TABLE 6
Correlation of Full Scale IQ with Reaction Time, Intraindividual Variability in Reaction Time and Movement Time

Task	RT	SDRT	MT
Simple Reaction Time	.03	.15	-.38**
Choice Reaction Time	-.08	-.07	-.20
Physical Similarity	-.14	-.09	-.33*
Category Matching	-.34*	-.33*	-.16
Sternberg Digit	-.21	-.21	-.30*
Semantic Similarity	-.25	-.22	-.16

Note: Yes and No responses are combined; *$p \leq .05$ (one tailed); **$p \leq .01$ (one tailed).

TABLE 7

Correlation of P300 Latency and P300 Amplitude with Full Scale IQ (FIQ), Mean Reaction Time (RT), Mean Intraindividual Variability (SDRT) & Mean Movement Time (MT)

	P300 Latency				P300 Amplitude			
Task	FIQ	RT	SDRT	MT	FIQ	RT	SDRT	MT
SRT	-.07	.02	-.24	-.10	-.20	.07	.12	-.08
CRT	-.11	.39**	.24	-.10	-.09	-.03	-.17	-.05
SD2	-.21	.03	-.01	-.01	-.27	-.27	-.10	.07
CAT	-.38**	.19	.29	-.05	-.26	-.36**	-.35*	-.20
DIG	-.32*	-.14	-.11	.05	-.22	-.37**	-.42**	.04
SA2	-.26	-.01	.04	-.09	-.37**	-.16	-.22	.20

Note: Yes and No responses are combined; *p ≤.05 (one tailed); **p ≤.01 (one tailed).

Tasks are represented as follows:

SRT: Simple Reaction Time

CRT: Choice Reaction Time

SD2: Physical Similarity

CAT: Category Matching

DIG: Sternberg Digit

SA2: Semantic Similarity

TABLE 8
Multidimensional Aptitude Battery
Subtest Intercorrelations

Test	INF	COM	ARI	SIM	VOC	DIG	PCO	SPA	PCA	OBJ	Loadings on First Principal FACTOR
INF	1	.58***	.41*	.31	.39*	.33	.35*	.47**	.46**	.51**	.751
COM		1	.41*	.09	.33	.20	.52**	.45**	.49**	.44**	.726
ARI			1	.05	.50**	.34	.47**	.39*	.46**	.66****	.760
SIM				1	.47**	.05	.04	.13	-.17	.04	.208
VOC					1	.24	.17	.42*	.21	.52**	.634
DIG						1	.32	.20	.51**	.21	.502
PCO							1	.21	.41*	.43*	.618
SPA								1	.49**	.51**	.684
PCA									1	.36*	.694
OBJ										1	.765

Note: Variables are as follows:
INF: Information
COM: Comprehension
ARI: Arithmetic
SIM: Similarities
VOC: Vocabulary
DIG: Digit Symbol
PCO: Picture Completion
SPA: Spatial
PCA: Picture Arrangement
OBJ: Object Assembly
*$p \leq .05$; **$p \leq .01$; ***$p \leq .001$; ****$p \leq .0001$.

TABLE 9
Intercorrelations of Reaction Time latency (in ms) to Target Stimulus between Reaction Time Tasks

Test	SRT	CRT	SD2	CAT	DIG	SA2	Loadings on First Principal FACTOR
SRT	1	.79****	.60***	.39*	.45**	.36*	.665
CRT		1	.83****	.65****	.73****	.69****	.896
SD2			1	.79****	.87****	.79****	.947
CAT				1	.77****	.89****	.877
DIG					1	.83****	.905
SA2						1	.890

Note: Tasks are represented as follows:
SRT: Simple Reaction Time
CRT: Choice Reaction Time
SD2: Physical Similarity
CAT: Category Matching
DIG: Sternberg Digit
SA2: Semantic Similarity
*$p \leq .05$; **$p \leq .01$; ***$p \leq .001$; ****$p \leq .0001$.

TABLE 10
Intercorrelations of Intraindividual Variability in Reaction Time (SDRT in ms) to Target Stimulus Between Reaction Time Tasks

Test	SRT	CRT	SD2	CAT	DIG	SA2	Loadings on First Principal FACTOR
SRT	1	.65	.65	.71	.67	.61*	.978
CRT		1	.94	.87	.82	.75	.971
SD2			1	.91	.89	.81	.986
CAT				1	.89	.88	.968
DIG					1	.91	.985
SA2						1	.975

Note: Tasks are represented as follows:
SRT: Simple Reaction Time
CRT: Choice Reaction Time
SD2: Physical Similarity
CAT: Category Matching
DIG: Sternberg Digit
SA2: Semantic Similarity
All significant at $p \leq .0001$ except * $p \leq .001$.

TABLE 11
Intercorrelations of Movement Time latency (in ms)
to Target Stimulus between Reaction Time Tasks

Test	SRT	CRT	SD2	CAT	DIG	SA2	Loadings on First Principal FACTOR
SRT	1	.93	.97	.94	.97	.93	.771
CRT		1	.97	.92	.93	.94	.921
SD2			1	.93	.97	.95	.952
CAT				1	.95	.94	.964
DIG					1	.96	.950
SA2						1	.910

Note: Tasks are represented as follows:
SRT: Simple Reaction Time
CRT: Choice Reaction Time
SD2: Physical Similarity
CAT: Category Matching
DIG: Sternberg Digit
SA2: Semantic Similarity
All significant at ****$p \leq .0001$.

TABLE 12
Intercorrelations of P300 Latency (in ms) to Target Stimulus Between Reaction Time Tasks

Test	SRT	CRT	SD2	CAT	DIG	SA2	Loadings on First Principal FACTOR
SRT	1	.52**	.09	.32	.24	.09	.552
CRT		1	.42*	.41*	.24	.21	.767
SD2			1	.31	.29	.63***	.745
CAT				1	.33	-.04	.593
DIG					1	.21	.586
SA2						1	.543

Note: Tasks are represented as follows:
SRT: Simple Reaction Time
CRT: Choice Reaction Time
SD2: Physical Similarity
CAT: Category Matching
DIG: Sternberg Digit
SA2: Semantic Similarity
*$p \leq .05$; **$p \leq .01$; ***$p \leq .001$.

TABLE 13
Intercorrelations of P300 Amplitude (in uV)
to Target Stimulus between Reaction Time Tasks

Test	SRT	CRT	SD2	CAT	DIG	SA2	Loadings on First Principal FACTOR
SRT	1	.78***	.27	.19	.20	.12	.388
CRT		1	.15	.05	.13	.10	.288
SD2			1	.76***	.76***	.66***	.879
CAT				1	.80***	.77***	.903
DIG					1	.75***	.908
SA2						1	.855

Note: Tasks are represented as follows:
SRT: Simple Reaction Time
CRT: Choice Reaction Time
SD2: Physical Similarity
CAT: Category Matching
DIG: Sternberg Digit
SA2: Semantic Similarity
***$p \leq .0001$.

TABLE 14
Intercorrelations of First Factor Scores
between IQ (IQg), Reaction Time (RTg), Movement Time (MTg)
Intraindividual Variability in Reaction Time (SDRTg)
P300 Latency (P300Lg) and P300 Amplitude (P300Ag)

Variables	IQg	RTg	MTg	SDRTg	P300Lg	P300Ag
IQg	1	-.27	-.14	-.18	-.36**	-.30*
RTg		1	-.18	.20	.07	-.31*
MTg			1	.76****	.02	.07
SDRTg				1	.07	-.14
P300Lg					1	.13
P300Ag						1

Note: *$p \leq .10$; **$p \leq .05$; ****$p \leq .0001$

APPENDIX A

EXPLANATION OF RESEARCH PROJECT

From:
Patricia McGarry
School Of Psychology
Room 417 Monpetit Hall
Ottawa University
Ottawa, K1N 6N5
1988

Thanks again for your participation in my Ph.D. thesis research. I wanted to take this opportunity to provide you with some feedback with regards to your contribution.

Intelligence tests and measures of intellectual ability are encountered by most people at one time or another during education and/or career life. Students are judged on knowledge of specific course material from spelling to biology, and job interviews can involve examination of various skills at work. Most everyone can recall a day when a peculiar stranger entered the classroom and took a whole morning to administer ability and aptitude questions to each student, usually resulting in everyone missing recess! However, few people recall receiving meaningful results, and most of us wonder whether we really should give MENSA a call after all. Unfortunately, the concept of intelligence is unclear to many individuals and measures and scores are misinterpreted. Here's a brief summary of how researchers view intelligence, as well as some information about your contribution to a study which will further advance knowledge in this field.

Intelligence testing dates back to 1905, when A. Binet and T. Simon reported their findings on school children in France. Substantial research followed, and in 1958 David Wechsler defined the hypothetical construct of intelligence in these terms:

> "aggregate or global capacity of the individual to act purposefully, to think rationally and to deal effectively with his or her environment. It is aggregate or global because it is composed of elements or abilities, which though not entirely independent, are qualitatively differentiable".

In other words:
a) intelligence involves separate abilities organized together
b) intelligent behaviour and intelligence are distinguishable
c) intelligent behaviour is influenced by more than just abilities
d) high ability in one specific area does not necessarily result in intelligent behaviour in others.

In 1984 Douglas N. Jackson pointed out that intelligence is a hypothetical construct inferred from observational, psychometric and laboratory measures. He also mentions that intelligence measures are context dependent and socially defined, and that intelligent behaviour is manifested in social-environmental abilities as well as abilities reflected in traditional cognitive performances.

There is also a physiological substrate to intelligence. Intellectual ability shows a developmental trend and researchers have found neuro-electrical correlates as well. Intelligent behaviour has been linked to reaction times, information processing speed and electrical activity of the brain. It is this last aspect that this research project addresses. This is why, as is explained during the experiment, we measure brain waves of subjects while they performed simple verbal, digital and reaction time tests. We are trying to learn more about the relationship between electrical activity of the brain and various levels of ability.

These levels of ability, as you recall, are measured using a group IQ test designed by Dr. Douglas N. Jackson called the Multidimensional Aptitude Battery. This test provides a "convenient objectively scorable measure of general aptitude or intelligence in the form of a profile containing five verbal and five performance subtest scores". It is comparable to the widely used Wechsler Adult Intelligence Scale (WAIS) and is valid and reliable. All subjects for this study are tested under similar timed conditions. Once completed, and after accurate scoring procedures, a total score is compiled for each individual based on the combined results of the verbal test and the performance test. The results are interpreted by consulting corresponding age appropriate tables. This information remains strictly confidential. It does not enter academic records in any fashion, and only the principal researchers have access to it. The purpose of the individual IQ is for averaging and grouped statistical computations. If at any time you are interested in the evoked potential aspects of the study, which also remain confidential, feel free to call me at the department of Psychology.

I am very happy and grateful to you for your help. Thank you for giving me the chance to explain the research to you, and let me wish you much success in your studies. *See you in the lab!*

Yours very truly,

Patricia McGarry
564 8238

APPENDIX B

CONSENT FORM

RESEARCH PARTICIPATION CONSENT

I, ______________________________, the undersigned, agree to participate in the research study consisting of intellectual assessment, the monitoring of EEG, eye movements, autonomic and muscle activity during various reaction time tasks.

The procedure involved has been carefully explained to me and I understand that the results will be treated with utmost confidentiality.

I understand that at any time I am free to withdraw and that any withdrawl will not affect any current or subsequent activity, program or academic course at the University of Ottawa or elsewhere.

Signed:

Date:

Witness:

Address to forward results of experiment if interested:

Street and number:

City, Province:

Postal Code:

APPENDIX C

SUBJECT QUESTIONNAIRE

QUESTIONNAIRE

NAME:

Are you right-handed?:

Do you have any hearing difficulties? Yes____ No____
If yes please specify:

Do you have any visual difficulties? Yes____ No____
If yes please specify:

Do you wear glasses or contacts? Yes____ No____

Do you have any physical or motor difficulties?
Yes____ No____
If yes please specify:

Are you on any medication? Yes____ No____

Rate your present health: Excellent___ Good___ Fair___

Use of alcohol today:

Intake of coffee or tea today:

Do you smoke?

All information gathered is strictly confidential and is required to ensure that all individuals involved in this research have similar characteristics when we collect our data.

Thank you

APPENDIX D

RECEIPT FOR PAYMENT

UNIVERSITÉ D'OTTAWA UNIVERSITY OF OTTAWA
OTTAWA ONTARIO
CANADA

RECEIPT FOR PAYMENT FOR INVOLVEMENT AS SUBJECT FOR RESEARCH

Name:

has received from Dr. Robert Stelmack a sum of $20.00

--------------Twenty------------------------xx dollars

for participation in an IQ - Reaction Time - Evoked Potential research study.

Date:

Signature of subject

Signature of principal investigator: Patricia Roberts (McGarry)

École de psychologie
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APPENDIX E

STIMULUS LISTS

File: B:SRT.TES

No. of Trials: 10
No. of Stimuli Type: 1

1=rt response
simple rt test
when see x

Trial No.	Stim type	Stim#1	Stim#2
1	1		X
2	1		X
3	1		X
4	1		X
5	1		X
6	1		X
7	1		X
8	1		X
9	1		X
10	1		X

File: B:SRT.EXP

No. of Trials: 70
No. of Stimuli Type: 1

1=rt response
simple rt exp
when see x

Trial No.	Stim type	Stim#1	Stim#2
1	1		X
2	1		X
3	1		X
4	1		X
5	1		X
6	1		X
7	1		X
8	1		X
9	1		X
10	1		X
11	1		X
12	1		X
13	1		X
14	1		X
15	1		X
16	1		X
17	1		X
18	1		X
19	1		X
20	1		X
21	1		X
22	1		X
23	1		X
24	1		X
25	1		X
26	1		X
27	1		X
28	1		X
29	1		X
30	1		X
31	1		X
32	1		X
33	1		X
34	1		X
35	1		X
36	1		X
37	1		X
38	1		X
39	1		X
40	1		X
41	1		X
42	1		X

43	1	X
44	1	X
45	1	X
46	1	X
47	1	X
48	1	X
49	1	X
50	1	X
51	1	X
52	1	X
53	1	X
54	1	X
55	1	X
56	1	X
57	1	X
58	1	X
59	1	X
60	1	X
61	1	X
62	1	X
63	1	X
64	1	X
65	1	X
66	1	X
67	1	X
68	1	X
69	1	X
70	1	X

File: B:CRT.TES

No. of Trials: 10
No. of Stimuli Type: 2

1is X
2is O
crt test seed 5

Trial No.	Stim type	Stim#1	Stim#2
1	1		X
2	2		O
3	2		O
4	1		X
5	1		X
6	2		O
7	2		O
8	2		O
9	1		X
10	1		X

File: B:CRT.EXP

No. of Trials: 140
No. of Stimuli Type: 2

1is X
2is O
choice rt exp seed 143

Trial No.	Stim type	Stim#1	Stim#2
1	1		X
2	2		O
3	1		X
4	2		O
5	1		X
6	1		X
7	2		O
8	2		O
9	1		X
10	2		O
11	2		O
12	1		X
13	1		X
14	2		O
15	1		X
16	2		O
17	1		X
18	1		X
19	1		X
20	2		O
21	1		X
22	1		X
23	1		X
24	1		X
25	1		X
26	2		O
27	2		O
28	1		X
29	1		X
30	1		X
31	2		O
32	1		X
33	1		X
34	2		O
35	2		O
36	2		O
37	1		X
38	2		O
39	2		O
40	2		O
41	1		O
42	1		X
			X

43	2	O
44	1	X
45	1	X
46	1	X
47	2	O
48	1	X
49	2	O
50	1	X
51	2	O
52	2	O
53	2	O
54	2	O
55	1	X
56	2	O
57	1	X
58	1	X
59	2	O
60	1	X
61	2	O
62	1	X
63	1	X
64	2	O
65	1	X
66	1	X
67	2	O
68	2	O
69	1	X
70	1	X
71	1	X
72	2	O
73	1	X
74	1	X
75	2	O
76	2	O
77	1	X
78	2	O
79	2	O
80	2	O
81	1	X
82	1	X
83	1	X
84	1	X
85	2	O
86	1	X
87	1	X
88	2	O
89	1	X
90	2	O
91	1	X
92	1	X
93	1	X
94	2	O
95	2	O

96	2	O
97	1	X
98	2	O
99	2	O
100	2	O
101	2	O
102	2	O
103	2	O
104	2	O
105	2	O
106	1	X
107	1	X
108	2	O
109	1	X
110	2	O
111	2	O
112	2	O
113	2	O
114	1	X
115	1	X
116	2	O
117	1	X
118	2	O
119	2	O
120	1	X
121	2	O
122	1	X
123	2	O
124	2	O
125	1	X
126	2	O
127	2	O
128	2	O
129	2	O
130	1	X
131	2	O
132	1	X
133	1	X
134	1	X
135	2	O
136	1	X
137	2	O
138	1	X
139	1	X
140	2	O

File: B:CATMATCH.TES

No. of Trials: 10
No. of Stimuli Type: 2

1=same category
2=diff.category
seed no.5

Trial No.	Stim type	Stim#1	Stim#2
1	1	colour	red
2	2	weapon	ruby
3	2	gem	blue
4	1	weapon	knife
5	1	gem	diamond
6	2	colour	gun
7	2	colour	spear
8	2	gem	pink
9	1	weapon	bomb
10	1	gem	jade

File: B:CATMATCH.EXP

No. of Trials: 140
No. of Stimuli Type: 2

1=same category
2=diff. category
seed=21

Trial No.	Stim type	Stim#1	Stim#2
1	1	clothing	pants
2	2	animal	table
3	2	clothing	tennis
4	1	clothing	coat
5	2	fruit	dresser
6	1	furniture	bed
7	1	sports	football
8	2	furniture	grape
9	1	sports	basketball
10	2	sports	lamp
11	1	fruit	pear
12	2	fruit	dress
13	1	animal	elephant
14	2	furniture	shoes
15	1	fruit	cherry
16	2	clothing	cat
17	2	sport	plum
18	1	sport	swimming
19	1	animal	house
20	2	sport	skirt
21	2	furniture	hockey
22	1	sport	golf
23	1	fruit	peach
24	2	animal	socks
25	1	animal	dog
26	1	fruit	apple
27	2	sport	pig
28	2	furniture	tiger
29	2	fruit	soccer
30	1	furniture	desk
31	1	animal	lion
32	1	clothing	skirt
33	1	furniture	couch
34	1	clothing	blouse
35	1	furniture	chair
36	1	clothing	shorts
37	2	clothing	sofa
38	1	clothing	vest
39	2	animal	baseball
40	2	clothing	banana
41	2	fruit	cow
42	1	furniture	nightstand

43	1	sports	canoeing
44	1	sports	fishing
45	1	fruit	grapefruit
46	2	animal	orange
47	2	furniture	lime
48	2	clothing	ringuette
49	2	furniture	sweater
50	2	clothing	eagle
51	2	animal	stool
52	2	furniture	diving
53	1	animal	sheep
54	1	fruit	lemon
55	1	sports	raquetball
56	2	fruit	cabinet
57	1	animal	bird
58	2	animal	tie
59	2	fruit	boots
60	2	sports	fridge
61	2	animals	skiing
62	2	sports	coconut
63	1	sports	bowling
64	1	fruit	kiwi
65	2	fruit	waterpolo
66	2	animal	pineapple
67	2	fruit	zebra
68	1	animal	rabbit
69	1	fruit	avocado
70	2	sports	gloves
71	2	sports	raccoon
72	2	furniture	camel
73	1	furniture	stove
74	2	clothing	shelf
75	1	animal	bear
76	1	clothing	raincoat
77	2	clothing	blueberries
78	2	furniture	otter
79	2	clothing	goat
80	1	furniture	chandelier
81	2	furniture	honeydew
82	1	clothing	scarf
83	2	clothing	nectarine
84	2	animal	snowsuit
85	1	furniture	recliner
86	1	clothing	jacket
87	1	clothing	underwear
88	1	animal	cheetah
89	1	sports	squash
90	2	furniture	whale
91	1	sports	waterskiing
92	1	fruit	raisins
93	2	fruit	crocodile
94	2	animal	parka
95	2	fruit	barstool

96	1	animal	bear
97	2	sports	crabapple
98	1	fruit	blackberries
99	2	animal	longjohns
100	1	sports	camping
101	2	sports	snake
102	2	fruit	pantyhose
103	1	animal	antelope
104	1	sports	surfing
105	2	animal	pincherry
106	1	fruit	raspberries
107	1	animal	groundhog
108	1	fruit	strawberries
109	1	furniture	microwave
110	2	fruit	crinoline
111	2	sports	bookshelf
112	2	sports	caribou
113	2	furniture	cricket
114	2	clothing	rhinocerous
115	2	clothing	wallunit
116	2	furniture	fox
117	1	animal	seal
118	1	clothing	belt
119	1	furniture	toaster
120	2	clothing	hippopotamus
121	1	clothing	kilt
122	1	furniture	loveseat
123	1	clothing	cape
124	1	clothing	hat
125	2	furniture	sweatpants
126	1	furniture	stereo
127	2	clothing	skating
128	2	animal	melon
129	2	furniture	bathingsuit
130	1	sports	curling
131	2	fruit	muskrat
132	1	sport	shotput
133	1	fruit	dates
134	2	animal	commode
135	1	animals	donkey
136	1	fruit	gooseberry
137	1	sports	boxing
138	1	animal	gazelle
139	2	fruit	gliding
140	2	sport	moose

File: B:SA2.TES

No. of Trials: 10
No. of Stimuli Type: 2

1=synonym
2=antonym

Trial No.	Stim type	Stim#1	Stim#2
1	1	eat	consume
2	2	prove	disprove
3	2	bright	dull
4	1	tire	fatigue
5	1	cold	frigid
6	2	gain	lose
7	2	polite	rude
8	2	naked	dressed
9	1	gape	stare
10	1	bind	tie

File: B:SA2.EXP

No. of Trials: 140
No. of Stimuli Type: 2

1= synonyms
2= antonyms
seed= 143

Trial No.	Stim type	Stim#1	Stim#2
1	1	simple	easy
2	2	up	down
3	1	quick	fast
4	2	near	far
5	1	cost	price
6	1	idea	thought
7	2	shut	open
8	2	fast	slow
9	1	sure	certain
10	2	hot	cold
11	2	pull	push
12	1	bad	evil
13	1	little	small
14	2	poor	rich
15	1	attempt	try
16	2	wrong	right
17	1	order	command
18	1	noisy	loud
19	1	end	finish
20	2	deep	shallow
21	1	sorrow	grief
22	1	ill	sick
23	1	big	large
24	1	choice	option
25	1	possess	own
26	2	early	late
27	2	narrow	wide
28	1	mend	fix
29	1	listen	hear
30	1	feel	sense
31	2	above	below
32	1	love	care
33	1	hate	despise
34	2	after	before
35	2	heavy	light
36	2	die	live
37	1	touch	feel
38	2	short	tall
39	2	happy	sad
40	2	spend	save
41	1	lift	raise
42	1	get	retrieve

43	2	peak	crest
44	1	switch	change
45	1	wash	clean
46	1	earth	ground
47	2	man	woman
48	1	up	skyward
49	2	private	public
50	1	under	below
51	2	take	give
52	2	harvest	sow
53	2	play	work
54	2	fat	skinny
55	1	pants	trousers
56	2	smile	frown
57	1	blanket	cover
58	1	hat	cap
59	2	buy	sell
60	1	mute	silent
61	2	help	hinder
62	1	paradise	heaven
63	1	maternal	mother
64	2	hire	fire
65	1	pebble	stone
66	1	penalty	punishment
67	2	rent	own
68	2	round	square
69	1	treat	reward
70	1	peace	quiet
71	1	take	receive
72	2	confuse	explain
73	1	poach	steal
74	1	poke	prod
75	2	hide	expose
76	2	expand	contract
77	1	cut	tear
78	2	life	death
79	2	increase	decrease
80	2	east	west
81	1	stream	brook
82	1	murder	kill
83	1	paternal	father
84	1	help	aid
85	2	north	south
86	1	pound	hit
87	1	expensive	costly
88	2	dig	fill
89	1	press	push
90	2	marry	divorce
91	1	siren	horn
92	1	slip	fall
93	1	smile	grin
94	2	domestic	wild
95	2	enter	exit

96	2	cow	bull
97	1	speak	talk
98	2	canine	feline
99	2	top	bottom
100	2	accuse	quit
101	2	low	high
102	2	agree	differ
103	2	age	youth
104	2	carry	drop
105	2	sprout	wither
106	1	pull	tow
107	1	call	shout
108	2	stay	go
109	1	throw	toss
110	2	noisy	calm
111	2	border	center
112	2	catch	release
113	2	clean	dirty
114	1	cart	wagon
115	1	casual	liesurely
116	2	height	depth
117	1	frugal	thrifty
118	2	cloudy	clear
119	2	light	dark
120	1	charter	rent
121	2	console	harass
122	1	windy	breezy
123	2	cool	warm
124	2	copy	original
125	1	decipher	explain
126	2	danger	safety
127	2	curse	bless
128	2	deep	shallow
129	2	hide	display
130	1	ditch	trench
131	2	doubt	faith
132	1	home	domain
133	1	dwell	live
134	1	dynasty	empire
135	2	comfort	discomfort
136	1	take	steal
137	2	vigour	laziness
138	1	ashes	embers
139	1	embrace	hold
140	2	always	never

File: B:SD2.TES

No. of Trials: 10
No. of Stimuli Type: 2

1= same
2= diff
seed=5

Trial No.	Stim type	Stim#1	Stim#2
1	1	image	image
2	2	yes	yet
3	2	unusual	unlucky
4	1	let	let
5	1	as	as
6	2	myself	cheese
7	2	cross	great
8	2	my	me
9	1	penny	penny
10	1	far	far

File: B:SD2.EXP

No. of Trials: 140
No. of Stimuli Type: 2

1= same
2= diff
seed=146

Trial No.	Stim type	Stim#1	Stim#2
1	1	no	no
2	1	once	once
3	2	or	go
4	1	novel	novel
5	2	ill	pot
6	2	twine	world
7	1	yes	yes
8	1	inflict	inflict
9	1	saucer	saucer
10	2	hover	rover
11	2	cast	mast
12	1	pin	pin
13	2	bow	mow
14	2	mile	tile
15	2	overall	quality
16	1	faulter	faulter
17	1	ache	ache
18	2	hi	he
19	2	in	an
20	1	rest	rest
21	2	breezes	parched
22	2	ten	den
23	1	enter	enter
24	2	art	sew
25	1	sister	sister
26	1	initial	initial
27	2	smooth	window
28	2	boat	moat
29	1	berries	berries
30	1	sheet	sheet
31	2	mine	yarn
32	1	in	in
33	2	complain	compound
34	2	piece	glass
35	1	jelly	jelly
36	1	mean	mean
37	1	sit	sit
38	2	relation	mutation
39	2	arches	basket
40	1	banana	banana
41	2	do	he
42	1	boating	boating

43	2	planters	addition
44	1	swim	swim
45	1	immerse	immerse
46	1	cat	cat
47	2	cannot	wicker
48	1	knotted	knotted
49	1	prolong	prolong
50	1	toes	toes
51	1	at	at
52	2	to	so
53	2	animal	farmer
54	1	hers	hers
55	1	leave	leave
56	2	sour	tour
57	2	supple	starch
58	1	mustard	mustard
59	2	cheerful	hangings
60	2	bay	law
61	1	be	be
62	1	lustrous	lustrous
63	1	kite	kite
64	1	refrains	refrains
65	2	fragrant	specials
66	1	toils	toils
67	1	reach	reach
68	2	rote	tote
69	1	any	any
70	2	mount	cover
71	1	pecans	pecans
72	1	probable	probable
73	2	sure	lure
74	1	we	we
75	2	burning	turning
76	1	cereal	cereal
77	1	building	building
78	2	as	at
79	2	cracker	tackles
80	2	job	sob
81	2	try	fry
82	2	be	is
83	1	procure	procure
84	1	boggle	boggle
85	1	proctor	proctor
86	2	western	stretch
87	2	belt	yawn
88	2	melt	heat
89	1	mammalia	mammalia
90	1	if	if
91	2	coloured	fabulous
92	1	lie	lie
93	1	deliver	deliver
94	2	shelves	biscuit
95	1	maintain	maintain

96	1	so	so
97	2	moisture	shimmers
98	2	make	mite
99	2	perfect	special
100	2	wink	mink
101	1	bingo	bingo
102	1	majesty	majesty
103	2	rider	cheat
104	2	juice	rough
105	1	golfer	golfer
106	1	cups	cups
107	2	genuine	holding
108	2	flowers	pencils
109	1	locked	locked
110	1	key	key
111	2	she	the
112	1	knight	knight
113	2	out	wig
114	2	my	by
115	2	bride	drink
116	2	to	it
117	2	trustful	truthful
118	2	idle	fire
119	2	contain	refrain
120	1	book	book
121	1	magnolia	magnolia
122	1	house	house
123	2	twinkle	mingles
124	2	clapping	bathtubs
125	1	lullaby	lullaby
126	1	see	see
127	1	knives	knives
128	2	beauties	gorgeous
129	2	earrings	necklace
130	2	dancing	talking
131	2	list	done
132	2	lavender	discover
133	1	quiver	quiver
134	2	see	tee
135	1	an	an
136	1	may	may
137	2	us	on
138	1	on	on
139	2	eye	buy
140	1	four	four

File: B:DIGITS.TES

No. of Trials: 10
No. of Stimuli Type: 2

1=digit seen
2=digit not see
seed=5

Trial No.	Stim type	Stim#1	Stim#2
1	1	8	8
2	2	91	2
3	2	132	9
4	1	957	5
5	1	864523	8
6	2	37681	9
7	2	82365	7
8	2	7	2
9	1	23678	6
10	1	18	1

File: B:DIGITS.EXP

No. of Trials: 140
No. of Stimuli Type: 2

1=digit seen
2=digit not seen
seed=21

Trial No.	Stim type	Stim#1	Stim#2
1	1	9	9
2	2	25	6
3	2	5271	9
4	1	1782	1
5	2	4	2
6	1	5342	2
7	1	7328694	8
8	2	97215	6
9	1	362	6
10	2	584	1
11	1	49	9
12	2	8	3
13	1	6	6
14	2	43	7
15	1	251	2
16	2	769431	5
17	2	8735	2
18	1	2693	6
19	1	7591	5
20	2	58	3
21	2	46952	3
22	1	83	8
23	1	542736	2
24	2	571984	2
25	1	9734	3
26	1	7	7
27	2	176	8
28	2	541987	3
29	2	243981	7
30	1	713294	1
31	1	64	6
32	1	23897	2
33	1	3	3
34	1	95	5
35	1	42	2
36	1	4136	4
37	2	9852	7
38	1	821	1
39	2	51378	4
40	2	6198437	5
41	2	65983	2
42	1	54721	4

43	1	587	7
44	1	2741695	6
45	1	16	6
46	2	769254	8
47	2	852	4
48	2	9	5
49	2	71	9
50	2	68	9
51	2	523978	4
52	2	2431	9
53	1	537	3
54	1	2	2
55	1	6149	6
56	2	9425	7
57	1	27	7
58	2	2871	6
59	2	5	1
60	2	438	5
61	2	9534281	6
62	2	5369	8
63	1	285371	3
64	1	356819	6
65	2	632184	5
66	2	32657	8
67	2	1	8
68	1	7452368	5
69	1	8257	7
70	2	2143	6
71	2	92	6
72	2	984762	1
73	1	85362	6
74	2	5198	2
75	1	27583	5
76	1	3247958	2
77	2	94862	5
78	2	6931245	8
79	2	3724	5
80	1	8	8
81	2	523781	6
82	1	31	1
83	2	569712	4
84	2	27	5
85	1	8961	1
86	1	18	8
87	1	73	7
88	1	825	5
89	1	92413	3
90	2	512	3
91	1	5	5
92	1	38291	1
93	2	732189	6
94	2	7368	5
95	2	14	3

96	1	8123496	8
97	2	2431576	8
98	1	936185	5
99	2	714538	9
100	1	823	8
101	2	7	6
102	2	23897	1
103	1	8947613	1
104	1	38	3
105	2	32	7
106	1	6348	3
107	1	9864712	7
108	1	37981	7
109	1	1	1
110	2	2	5
111	2	489	5
112	2	314825	7
113	2	579624	8
114	2	9631	4
115	2	3	4
116	2	7583169	4
117	1	1367845	5
118	1	82731	8
119	1	651	6
120	2	1754863	2
121	1	9381	8
122	1	6751483	3
123	1	6394587	6
124	1	9251	9
125	2	8752	1
126	1	897	9
127	2	54	1
128	2	8562197	3
129	2	376	2
130	1	853124	4
131	2	3479825	6
132	1	5627	7
133	1	6	6
134	2	1532476	9
135	1	459173	7
136	1	6472139	4
137	1	2	2
138	1	4217395	2
139	2	318	1
140	2	6	1

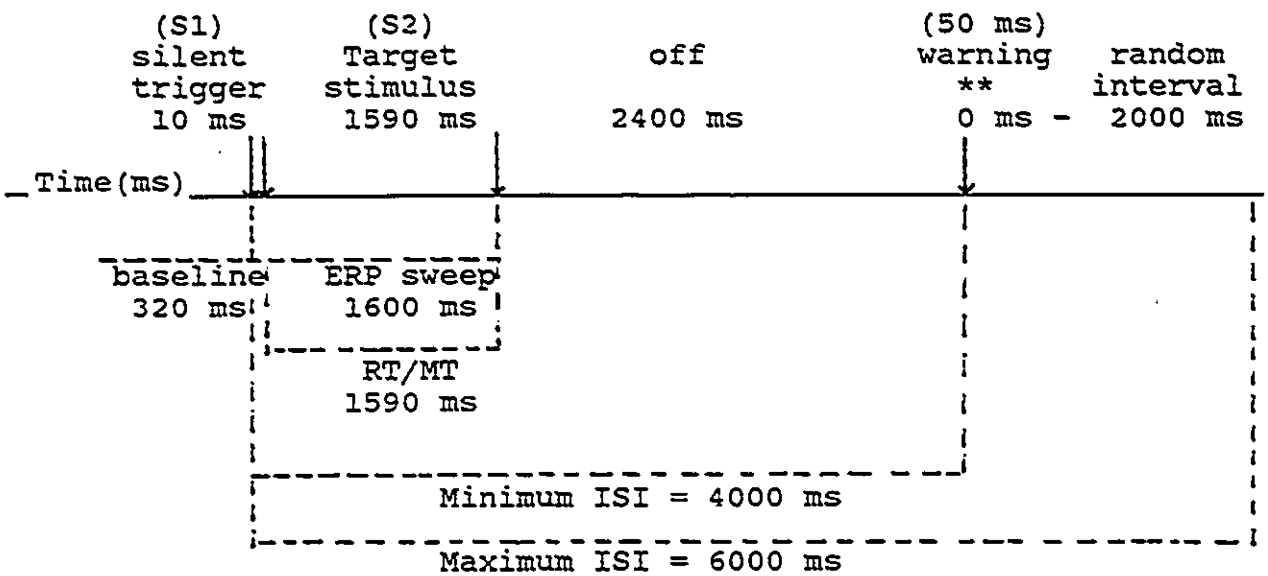
APPENDIX F

STIMULUS PRESENTATION/DATA COLLECTION TIMING

FOR SRT AND CRT TASKS

STIMULUS PRESENTATION/DATA COLLECTION TIMING

FOR SRT AND CRT TASKS



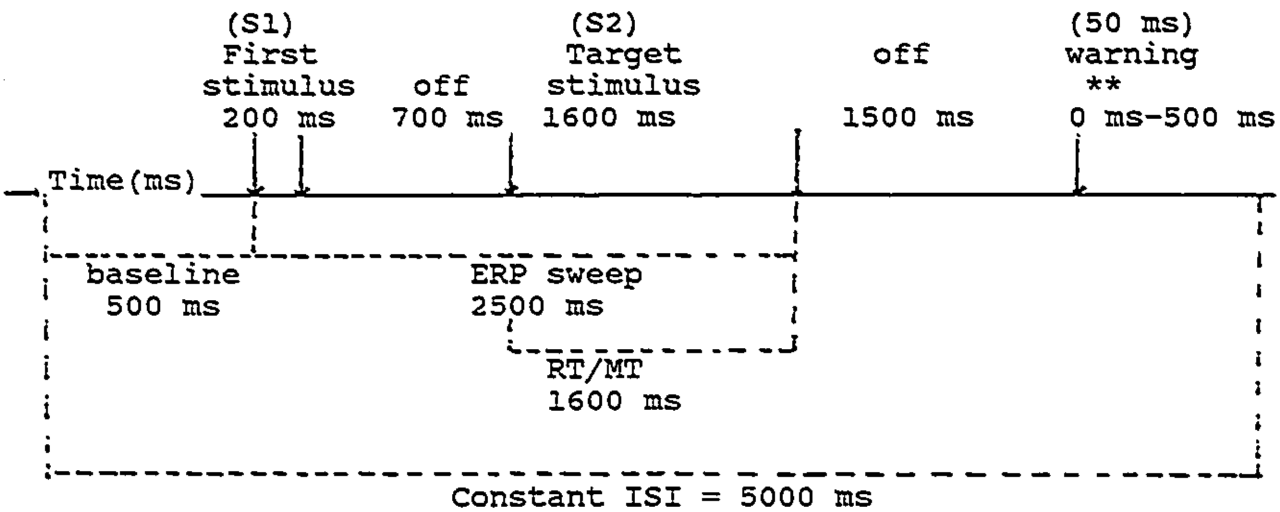
APPENDIX G

STIMULUS PRESENTATION/DATA COLLECTION TIMING

FOR PAIRED STIMULI TASKS

STIMULUS PRESENTATION/DATA COLLECTION TIMING

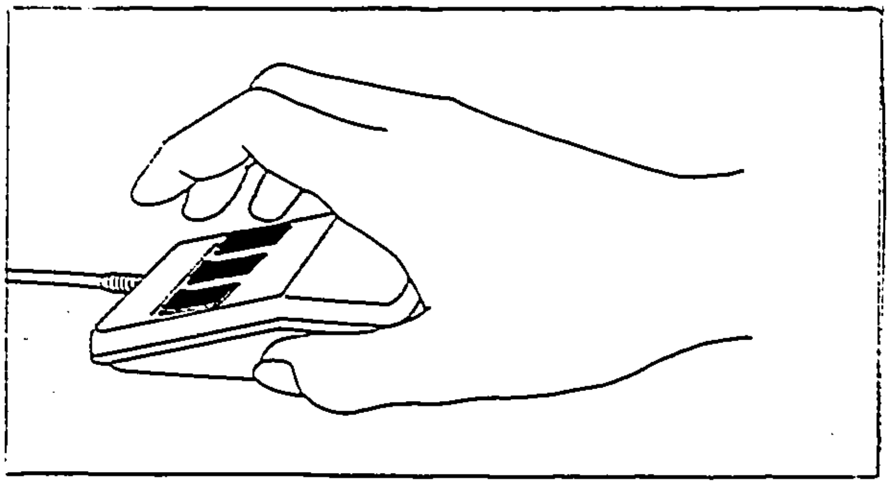
FOR PAIRED STIMULI TASKS



APPENDIX H

LOGITECH MOUSE

RT/MT Recording Apparatus



LOGITECH MOUSE

APPENDIX I

ELECTRODE PLACEMENT

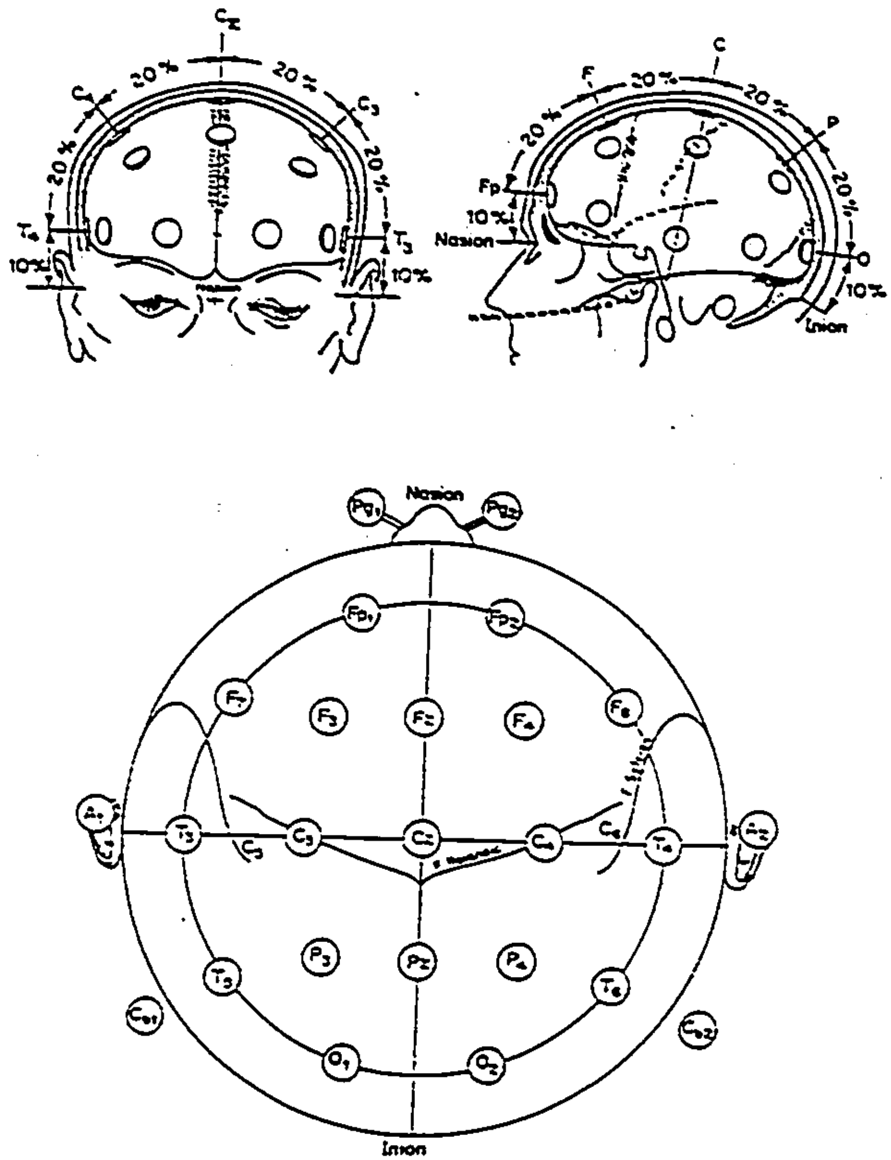
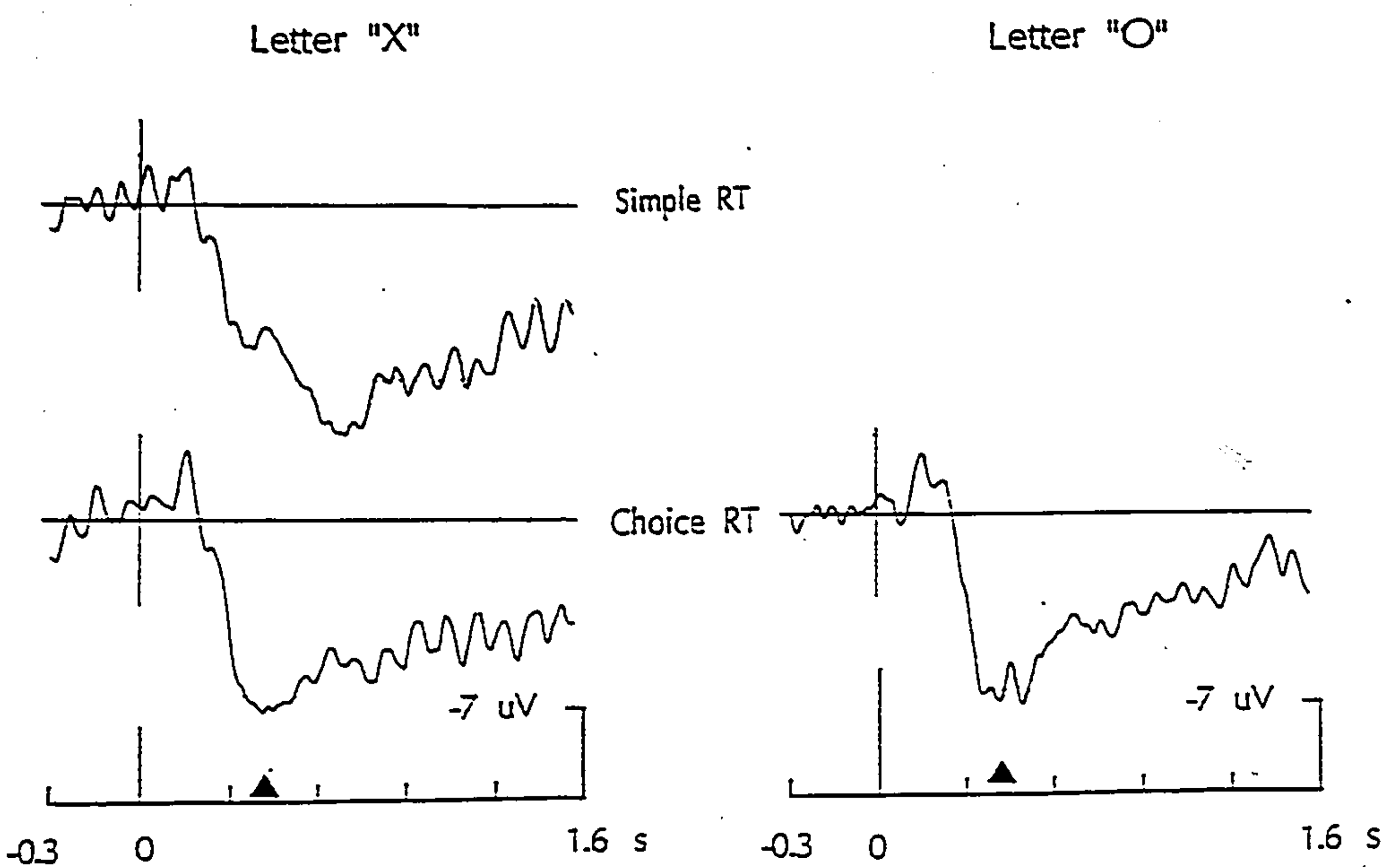


FIGURE 2. The 'ten–twenty' system of electrode placement. (From Jasper, 1958)

APPENDIX J1

ERP WAVEFORMS AT PZ FOR AVERAGE ABILITY SUBJECT

FOR SRT AND CRT TASKS



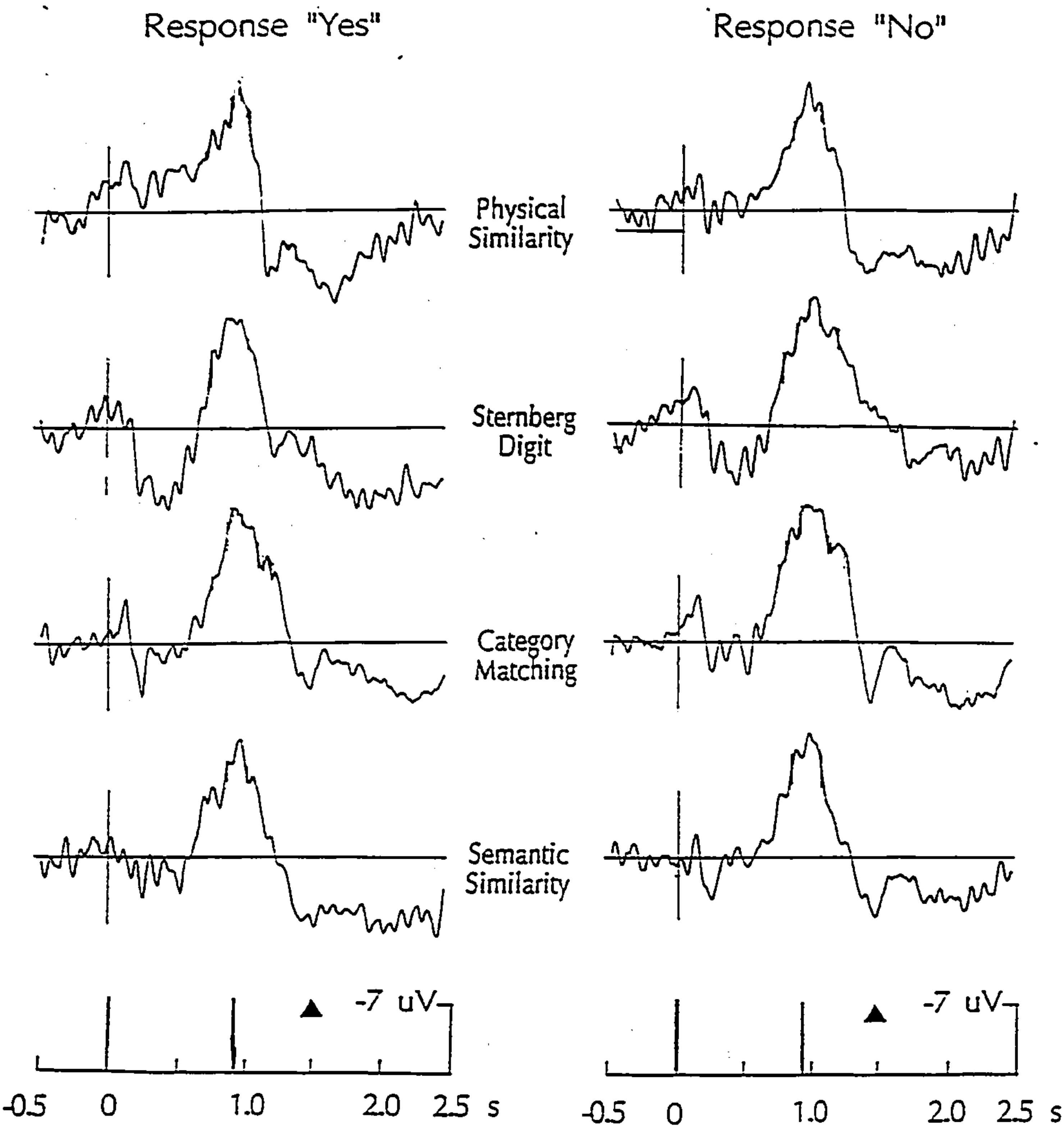
AVERAGE ABILITY

SUB: 36 jan 17 1989 F=4 S=2 (Neg Up)

APPENDIX J2

ERP WAVEFORMS AT PZ FOR AVERAGE ABILITY SUBJECT

FOR PAIRED STIMULI TASKS

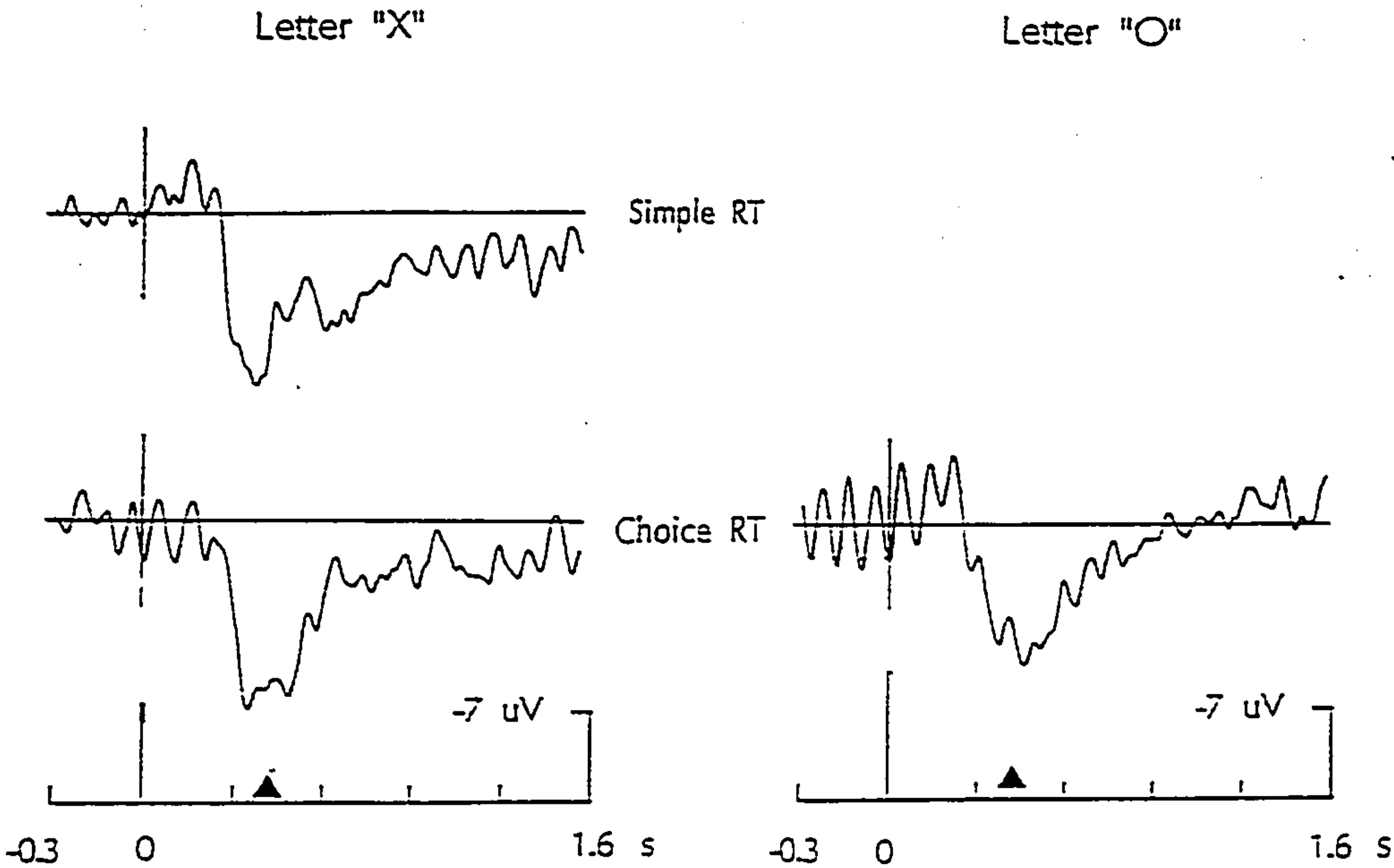


AVERAGE ABILITY

SUB: 36 jan 17 1989 F=4 S=2 (Neg Up)

APPENDIX K1

ERP WAVEFORMS AT PZ FOR ABOVE AVERAGE ABILITY SUBJECT FOR SRT AND CRT TASKS

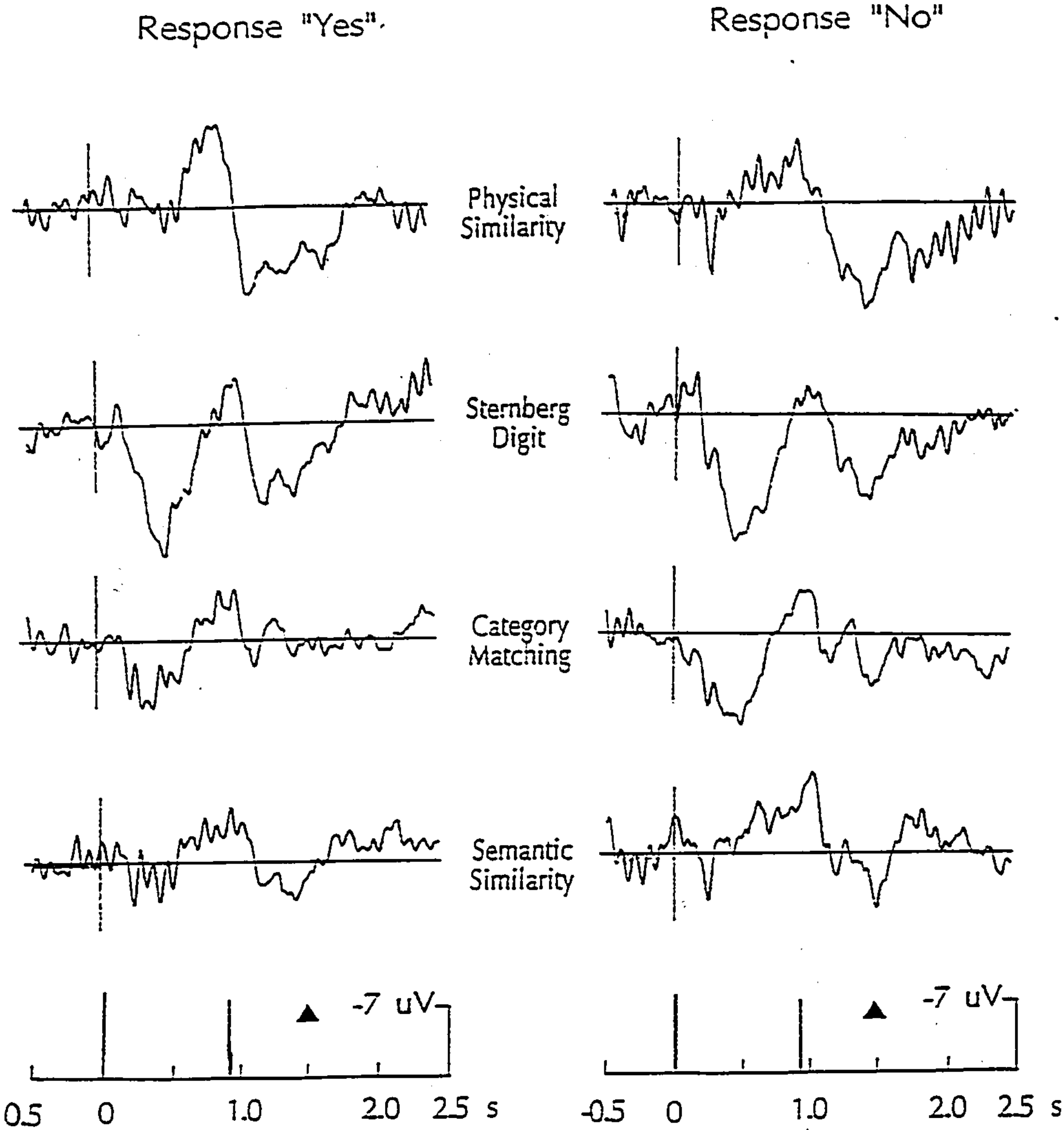


ABOVE AVERAGE ABILITY

SUB: 01 nov 1 1988 F=4 S=2 (Neg Up)

APPENDIX K2

ERP WAVEFORMS AT PZ FOR ABOVE AVERAGE ABILITY SUBJECT FOR PAIRED STIMULI TASKS



ABOVE AVERAGE ABILITY

SUB: 01 nov 1 1988 F=4 S=2 (Neg Up)

APPENDIX L

ANOVA TABLE FOR MEAN RT IN SRT AND CRT

Two way ANOVA for Mean RT in SRT and CRT

Sources of Variance	SS	df	F	p
Between groups	559.37	1	0.10	.75
Error	160033.73	28		
Between tasks	213749.88	1	333.24	.00
Task x group	2227.71	1	3.47	.07
Error	17960.08	28		

APPENDIX M

ANOVA TABLE FOR MEAN RT IN PAIRED STIMULI TASKS

Three way ANOVA for Mean RT in paired stimuli tasks

Sources of Variance	SS	df	F	p
Between groups	252967.26	1	4.00	.05
Error	1771580.61	28		
Between tasks	1568223.81	3	120.49	.00
Task x group	25420.21	3	1.95	.13
Error	364422.13	84		
Response	163386.00	1	99.79	.00
Response x group	5829.23	1	3.56	.07
Error	45844.27	28		
Task x response	26810.64	3	13.70	.00
Task x response x group	7605.54	3	3.89	.01
Error	54784.91	84		

APPENDIX N

ANOVA TABLE FOR MEAN P300 AMPLITUDE TO TARGET STIMULUS IN SRT AND CRT TASKS

Two way ANOVA for Mean P300 amplitude to target stimulus in SRT and CRT

Sources of Variance	SS	df	F	p
Between groups	57.35	1	0.17	.68
Error	9484.32	28		
Between tasks	689.93	1	21.50	.00
Task x group	0.12	1	0.00	.95
Error	898.51	28		

APPENDIX O

ANOVA TABLE FOR MEAN P300 LATENCY TO TARGET STIMULUS IN SRT AND CRT TASKS

Two way ANOVA for Mean P300 latency to target stimulus in SRT and CRT

Sources of Variance	SS	df	F	p
Between groups	2728.21	1	1.35	.25
Error	56378.22	28		
Between tasks	18827.50	1	24.05	.00
Task x group	2201.61	1	2.81	.10
Error	21923.20	28		

APPENDIX P

ANOVA TABLE FOR MEAN P300 AMPLITUDE TO FIRST STIMULUS IN PAIRED STIMULI TASKS

Three way ANOVA for Mean P300 amplitude to first stimulus in paired stimuli tasks

Sources of Variance	SS	df	F	p
Between groups	960.52	1	3.64	.06
Error	7392.04	28		
Between tasks	8577.38	3	57.47	.00
Task x group	83.64	3	0.56	.64
Error	4179.20	84		
Response	4.39	1	0.41	.53
Response x group	2.76	1	0.26	.61
Error	298.29	28		
Task x response	4.77	3	0.11	.95
Task x response x group	45.02	3	1.06	.37
Error	1191.93	84		

APPENDIX Q

ANOVA TABLE FOR MEAN P300 LATENCY TO FIRST STIMULUS IN PAIRED STIMULI TASKS

Three way ANOVA for Mean P300 latency to first stimulus in paired stimuli tasks

Sources of Variance	SS	df	F	p
Between groups	4316.66	1	.90	.35
Error	134857.29	28		
Between tasks	27562.73	3	4.68	.00
Task x group	11469.06	3	1.95	.13
Error	165052.77	84		
Response	210.86	1	0.21	.65
Response x group	4.29	1	0.00	.95
Error	27923.70	28		
Task x response	475.97	3	0.15	.93
Task x response x group	1249.04	3	0.39	.76
Error	88890.29	84		

APPENDIX R

ANOVA TABLE FOR MEAN P300 AMPLITUDE TO SECOND STIMULUS IN PAIRED STIMULI TASKS

Three way ANOVA for Mean P300 amplitude to target stimulus in paired stimuli tasks

Sources of Variance	SS	df	F	p
Between groups	939.94	1	.89	.35
Error	29688.13	28		
Between tasks	6534.20	3	27.38	.00
Task x group	118.75	3	0.50	.68
Error	6681.80	84		
Response	116.37	1	3.68	.06
Response x group	31.86	1	1.01	.32
Error	884.41	28		
Task x response	152.70	3	2.35	.08
Task x response x group	110.04	3	1.70	.17
Error	1816.17	84		

APPENDIX S

ANOVA TABLE FOR MEAN P300 LATENCY TO SECOND STIMULUS IN PAIRED STIMULI TASKS

Three way ANOVA for Mean P300 latency to target stimulus in paired stimuli tasks

Sources of Variance	SS	df	F	p
Between groups	26414.86	1	3.38	.07
Error	219081.45	28		
Between tasks	1653427.20	3	172.27	.00
Task x group	1409.67	3	0.15	.93
Error	268738.05	84		
Response	95563.32	1	41.62	.00
Response x group	0.48	1	0.00	.99
Error	64292.23	28		
Task x response	94850.36	3	14.22	.00
Task x response x group	/535.17	3	1.13	.34
Error	186764.72	84		