Analysis of methodological variables underlying correlations between elementary cognitive tasks and IQ

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Abstract

A series of experiments is reported in which the relationships are measured between, on the one hand, IQ, measured by the Wechsler Adult Intelligence Scale Revised (WAIS-R) and the Raven Advanced Progressive Matrices (APM) and, on the other, three commonly employed elementary cognitive tasks (ECTs), Inspection Time (IT), Hick Reaction Time (RT) and Averaged Evoked Potentials (AEPs). The dissertation examines the effects of several methodological variables on the relationship between IT, RT, AEPs and IQ.

Eight chapters are presented. Chapter 1 serves as an introduction to the work presented in the subsequent chapters. In this Chapter, it is argued that although a purely psychometric approach has provided significant information on the nature of intelligence, future information requires a theoretical framework. One such framework has been described by Eysenck (1988) and his model of intelligence is described.

Chapter 2 investigates a methodological issue relating to the measurement of decision time (DT) and movement time (MT) from the Jensen-Hick paradigm. The possibility that subjects have employed a cognitive strategy in previous Hick RT-IQ experiments is examined by comparing RTs to masked and unmasked stimuli, on the assumption that the former condition removes or at least substantially reduces opportunities for developing strategies. Results suggested that in the unmasked RT condition, subjects employed a strategy in which additional decision time is gained during the movement component of RT. In order to address whether this strategy determined the negative DT-IQ correlation reported in previous experiments by Jensen, Vernon and others, the relationship between IQ and both DT and MT variables under masked and unmasked conditions was assessed. As significant negative correlations were obtained between DT and MT variables with IQ variables, under both masked and unmasked conditions, it is concluded that the use of this type of strategy did not determine the correlation between DT and IQ. There was some evidence that suggested the correlation between DT and IQ was reduced in the masked condition compared to the unmasked condition. Means and SDs for DT and MT were generally reliable after 12 months. The effects of trial size and order effects on the relationship between RT and IQ are also discussed. MT-IQ correlations were not significantly different from DT-IQ correlations and DT slope-IQ correlations were nonsignificant, suggesting that the Jensen information processing model of intelligence should be revised or abandoned.

Chapter 3 describes previous experiments that have been concerned with the relationship between parameters of the AEP and IQ, focusing on research that has attempted to link the complexity of the AEP waveform (Hendrickson paradigm) with IQ test performance. Despite previous inconclusive results, Experiment 2 provides significant and substantial correlations between the string length measure and IQ variables. Nonsignificant correlations were obtained between the variance measure and IQ measures, suggesting that previous explanations of the string length-IQ relationship in terms of errors in cortical processing were untenable. The significant correlations between string length and IQ are interpreted within an attentional framework which offers the most plausible attempt at reconciling previous research on this relationship. It is also argued that the Hendrickson methodology is inadequate to provide reliable AEP measures before 100 msecs has elapsed from the presentation of the stimulus. Preliminary reliability data are presented for the string length measure of AEP complexity.

Experiment 3 addresses the attentional model proposed in Chapter 3. The Bates and Eysenck (1983) hypothesis that the focus of attention may reverse the sign of the correlation between the string length measure of AEP waveform complexity and IQ is examined. Recording AEPs to a task requiring focussed attention demonstrated that subjects with high IQ recorded significantly longer string lengths than low IQ subjects. Because Bates and Eysenck employed a PEST procedure, differences in parameters of the AEP may be attributable to differences in stimulus intensity (low IQ subjects were administered trials of longer duration than high IQ subjects). It is concluded that the results of Experiment 2 and 3 are both consistent with the hypothesis that high IQ subjects allocate more attentional resources to the task than low IQ subjects.

Experiment 4 was designed to investigate whether high IQ subjects allocate more attentional resources to information processing tasks than low IQ subjects, employing a classical Picton and Hillyard "selective attention" AEP procedure in which the relationship between the amplitude of the N1 component of the AEP waveform to attended and unattended competing auditory tones was measured. This experiment also tests the Hunt (1980) and Macintosh (1986) hypothesis that differences in IQ are determined by attentional resource allocation. Results did not suport the allocation of attention model proposed in Chapter 3. High IQ subjects did not allocate more attentional resources than low IQ subjects, but performed significantly better on the information processing task. Therefore, this result is not consistent with the Hunt or Macintosh hypothesis.

Chapter 5 investigates the relationship between IT and IQ variables. Experiment 5 examines Howe's (1989) hypothesis that IT and IQ are meaningfully correlated only in samples with intellectually disabled subjects and in samples of less than 40 subjects. Correlations of the order of -.5 were observed, consistent with both Nettelbeck's (1987) and Kranzler and Jensen's (1989) meta-analysis of this relation, and therefore inconsistent with Howe's (1989) hypothesis. In a large sample (N=67), verbal IQ (VIQ)-IT correlations were not significantly different to performance IQ (PIQ)-IT correlations. Chapter 5 also examines two other methodological issues relating to the measurement of IT and to the relationship between It and IQ. Pilot study 1 examines the difference between IT estimates derived from tachistoscope and Hercules graphics monitor administration. This study specifically examined whether previous inconsistent results could be explained in terms of the apparatus to administer the IT task. Similar IT-IQ correlations were observed in both tachistoscope and monochrome computer monitor conditions, with ITs from both administrations correlating at a moderate level. Experiment 6 evaluates the apparent motion effect reported by Mackenzie and Bingham (1985). Three different backward visual masks were examined in relation to their effect on performance and to their effect on IT-IQ correlations. Results suggested that the standard mask used in nearly all previous IT experiments allows substantial use of apparent motion compared to a lines and lightning mask. The new lines mask prevents nearly all use of apparent motion. Nonetheless, there was no evidence to suggest that the magnitude of the correlation between IT and IQ were different in any of the masking conditions. The latter result was consistent with the view that the use of apparent motion cues in the IT procedure does not determine the correlation between IT and IQ.

Chapter 6 describes experiments examining the relationship between personality and temperament variables and IT, RT, AEPs, and IQ. Experiment 7 examines the relationship between personality and temperament variables with IT, RT, AEPs, and IQ, and on the correlation between the ECTs and IQ; and tests the hypothesis that correlations between IT, RT, AEPs and IQ are mediated or determined by personality and temperament variables. Thus

Chapter 6, is primarily concerned with the suggestions by Howe (1989) and by Brody (1985), that correlations between IQ test performance and ECTs may only reflect characteristics of personality and temperament rather than biological characteristics constraining the development of knowledge. On the whole, personality and temperament variables did not mediate correlations between the ECTs and IQ. The Robinson (1989) hypothesis that ambiverts may have an advantage for IQ test performance and for speed of information processing is assessed. Results were consistent with this hypothesis although other possibilities are discussed.

Chapter 7 examines the inter-relationship among IT, RT, AEPs and IQ. Correlations reflected the independent measurement of each variable and not concurrent measurement. Factor analysis, stepwise regression and correlation indicated that a substantial part of the WAIS-R IQ variance could be accounted for by the IT, RT and AEP tasks. This result suggests that the Juhel (1991) view, that the relationship between IT, RT, AEPs and IQ may be too small to be of practical significance, could not be supported. The result was difficult to dismiss in terms of subject strategies inherent in all tasks.

Chapter 8 summarises the results of the preceding chapters, highlighting some problems with the experimental work presented, and outlines some implications of the results for a theory of intelligence. Flynn's (1987) view that validating new measures of intelligence (e.g., ECTs) with IQ may be problematical given that there have been large increases in IQ scores over the last two generations is discussed. In Chapter 1 it is noted that IQ tests have been validated as a measure of intelligence in terms of predicting scholastic and organizational success or qualities which are normally regarded or accepted to relate to "intelligence". Experiment 8 addresses whether one of the ECTs employed in this dissertation (IT) possesses high criterion validity by correlating scholastic performance, IQ and IT scores. Results indicated that IT significantly predicted both final year secondary school exam performance and IQ. The result was consistent with the hypothesis that individual differences in ITs relate to basic differences in the ability to acquire information. Future research is outlined.

Statement

This thesis contains no material which has been accepted for the award of any other degree or diploma in any University and to my best knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text.

I consent to this thesis being made available for photocopying and loan if accepted for the award of the degree.

Con Kerry Kenneth Stough

November, 1994

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Publications Arising From Thesis

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CHAPTER 1

1.1 Introduction

The suggestion that indices of biological functioning determine differences in intelligence is not new, dating back to both Galton (1883) and MacKeen Cattell (1886a). Early attempts to provide empirical support for this position were generally unsuccessful (e.g., Beck, 1933; Wissler, 1901). However, with the development of more adequate procedures to measure basic physiological and psychophysical processes, a resurgence of interest in this area has occurred, and three main experimental tasks have emerged: Inspection Time (IT), Reaction Time (RT) and Averaged Evoked Potentials (AEPs). Significant correlations between performance on these laboratory tasks and on intelligence tests have been explained by several authors as reflecting the biological mechanisms influencing the development of intelligence (Brand & Deary, 1982; Eysenck, 1986, 1987, 1988; A. E. Hendrickson, 1982; D. E. Hendrickson, 1982; Jensen, 1982, 1987a, 1987b) and it is these which may be regarded as a biological explanation for individual differences in IQ. This is referred to as the "biological explanation".

This dissertation is concerned with the evaluation of methodological parameters underlying the biological explanation. To this end several experiments are reported which examine whether the biological explanation is justified in terms of the experimental methodologies employed in previous studies correlating IT, RT and AEPs with IQ. In addition, several other hypotheses are examined which relate to the validity and nature of the biological explanation for IQ and intelligence.

1.2 Preamble

The history of research in intelligence has been described by Eysenck (1988) as following two different lines. One school has tested the hypothesis that intelligence may be best understood in terms of one's physiology, that intelligence is largely a genetic property that can be measured using elementary physiological tasks. This approach is often referred to as the Galtonian school because Sir Francis Galton (1874, 1875, 1883) advocated investigating intelligence by way of elementary sensations. Spearman (1904) was an advocate of this school, proposing that intelligence was a single entity. The other approach, usually referred to as the Binet school, after the inventor of the first IQ test, has taken a more practical view of intelligence, advocating tests that sample higher order cognitive abilities (eg., comprehension and reasoning) in order to identify individual differences in the abilities of children to respond to education.

Historically, the Binet line, from which the IQ test has developed, has dominated research on intelligence and popular conceptions of intelligence. Although IQ tests have gained universal use within psychological domains, they have evolved basically from a common sense view of intelligence, without recourse to any clearly formulated scientific theory. Most IQ tests were devised to address a practical problem- the prediction of individual differences in scholastic ability. Thus the development of the majority of IQ tests has been based on empirical rather than theoretical notions of intelligence. In fact, those theories of intelligence that have been proposed have been inferences based on IQ test data (see Vernon, 1979 for a review of theories of intelligence based on IQ data). As Jensen (1987b) has remarked, the literature on intelligence measurement far outweighs the literature on theories of intelligence.

In most paradigms, tests and measures are developed out of theory. However, as Maloney and Ward (1973, pp. 585) highlight, intelligence tests have developed independently from intelligence theory:

> **"In terms of scientific validity, the tests do seem to be inadequate. They bear little or no relationship to the theories we have examined and thus lack an adequate theoretical foundation or superstructure. Never-the-less, the items of intelligence tests have proven their theoretical value, such as the prediction of school achievement. Thus, while not conforming to any theoretical notions per se, the tests do relate to the types of performances that almost everyone agrees reflect the operations of intelligence, that is, school achievement."**

1.3 IQ as a predictor of intelligence

Although IQ tests may correlate highly with scholastic success and moderately with occupational success (eg., Brody, 1985; Lanvin, 1965; Ree & Earles, 1992), the fact that IQ measures have been constructed without little theoretical basis[1] may suggest that they measure only particular unknown aspects of the construct intelligence. As Boring (1950) commented: **"Intelligence is what the tests test"**. Thus, this enterprise has assumed that whatever IQ tests measure is a worthwhile entity (in terms of external validity). That IQ is correlated with school and occupational success and that IQ tests have proved useful in clinical settings serves to reassure psychologists that IQ tests do measure something important. Moreover, the fact that when IQ tests are inter-correlated a large positive factor emerges (general intelligence), despite the employment of a wide variety of different tests, suggests that not only do the tests measure something important but also something robust. However, the scientific understanding of why IQ tests predict real-life qualities requires a theoretical framework. As Eysenck (1982) points out, science seeks to understand concepts by systematically investigating relationships and reducing complex associations into their constituent parts. If IQ tests do measure something important for intelligence, then it is crucial to understand the underlying physiological and cognitive processes.

1.4 Towards a scientific understanding of intelligence

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[1] There are some exceptions (eg. Raven Matrices tests, Alice Heim tests) that have been constructed within a theoretical framework, although these are rarely used outside of research settings.

On the whole, theories of intelligence to date have been based on investigations involving factor analysis of IQ test data. Although this approach has yielded much information, it is now clear that additional levels of analysis are required for further refinement of theories of intelligence. As Eysenck (1988) has argued, theories based solely on IQ measurement have reached a theoretical cul-de-sac, and the use of IQ data will not, by itself, be sufficient for the development of an adequate scientific explanation of intelligence. In partial recognition of this fact, some investigators have advocated an approach involving adaptive intelligence (e.g., Guilford, 1959, 1965, 1967, 1977, 1985; Sternberg, 1985). This view may include many variables (eg. personality, motivation and adaptive behaviours) that may be thought of as influences on personality rather than on intelligence. As Eysenck and Barrett (1985) comment, the study of intelligence does not necessitate the study of the whole of human personality. Other investigators have measured the association between elementary cognitive tasks (ECTs) designed within the confines of experimental psychology, and performance on IQ tests. It is their hope, that, by employing tasks that are amenable to scientific analysis, they may uncover new information, mainly cognitive and/or physiological, about the nature of intelligence, Along these lines, recent evidence from studies employing laboratory measures with apparently very low knowledge requirements have suggested that both Galtonian and Binet measures may be reconciled within a theoretical framework.

1.5 New Measures of Intelligence? Introducing IT, RT, and AEPs.

> **"The notion of elementary processing stages as the unit of intelligence is an attractive notion. It offers an alternative to the psychometric factor as the unit of analysis, a unit which seems to be afflicted with its own methodological problems."**
>
> **Longstreth (1984, p. 158).**

Over the last two decades a relatively new[2] approach has evolved in the study of human intelligence. Investigators following this paradigm have employed elementary tasks requiring very low levels of knowledge in order to perform them (e.g., AEP, IT and RT), to measure individual differences in how subjects receive, process and reach decisions about simple sensory stimuli. The aim has been to observe the correlation between performance on these measures and performance on IQ tests. Usually, by correlation, researchers infer that processes required to perform the IT, RT, and AEP tasks are identical to processes implicated in performance on an IQ test. As Jensen (1987b, p. 394), has speculated, this approach may unlock the door to a new approach in intelligence research that may not have the same theoretical problems as a purely psychometric approach.

> **".... But an even more basic reason that RT tasks with very little resemblance to psychometric tests interests me is the very fact of their little resemblance. This allows the correlation they have with psychometric factors to extend the meaning of those factors beyond the confines of psychometric tests. To find that the common factor of a number of simple chronometric tasks that bear no surface resemblance to IQ is correlated with the g of IQ is, at least to me, a much more pregnant phenomenon, scientifically, than a demonstration that chronometrically derived components of IQ test items are correlated with the g factor derived from the very same or highly similar tests. "**

Eysenck (1982) has proposed that all ECTs may measure a common process termed R (see Chapter 3 for a description) which may be the major process mediating performance on IQ tests. This possibility is addressed in Chapter 7 and serves as one of the discussion points of this dissertation.

1.6 Different Conceptions of Intelligence and the Development of a Theoretical Framework

Hebb (1949) suggested that intelligence is too vague a concept to be meaningful. After many years of investigating the effects of environmental

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[2] Studies relating elementary measures of reaction time to intelligence date back to the late 19th century. "New" in the current context refers to a resurgence of interest due to advances in computer technology.

deficiencies in developing young animals, he concluded that intelligence was best conceptualised in two forms; Intelligence A and Intelligence B. Intelligence A was defined as the basic physiological potential of the individual to behave intelligently, which is determined by the genes. The degree to which this potential is realised depends upon the quality of one's education and childhood nurturance. Because of the interaction between our inherited biology and life experiences, Hebb believed Intelligence A to be essentially unmeasurable, although arguably it could be estimated on the basis of certain assumptions, by measuring elementary processes of the brain and its nervous system. On the other hand, Intelligence B is the intelligence one displays in everyday life, due to the genes but also due to the subtle interplay of genes and environmental factors. According to Hebb, Intelligence A and B are not co-existent, but are two different expressions of the same concept. Thus an estimate of, for example, an intelligence test score would be more related to intelligence B rather than intelligence A. Vernon (1979) extended this model by adding a third construct, Intelligence C, which is the IQ measure in effect, a sample of Intelligence B. Because intelligence tests are imperfect measures of intelligence B, it is impossible to measure Intelligence B with total accuracy. Thus, different IQ tests may reveal different Intelligence Cs because each test samples only a reduced range of the possible cognitive abilities an individual may possess.

Eysenck (1988) has recently developed these ideas to indicate how measures like ECTs might be used to estimate biological potential underpinning developed intelligent behaviour. His conception of intelligence is represented in Figure 1. This includes biological intelligence (measured by the AEP, IT, and RT tasks) which is causally linked to subsequent intellectual development, psychometric intelligence (IQ) which is assumed to sample both potential and subsequent development, and social intelligence (a composite quality, built on biological potential but influenced by personality, motivation, environmental experience etc.).

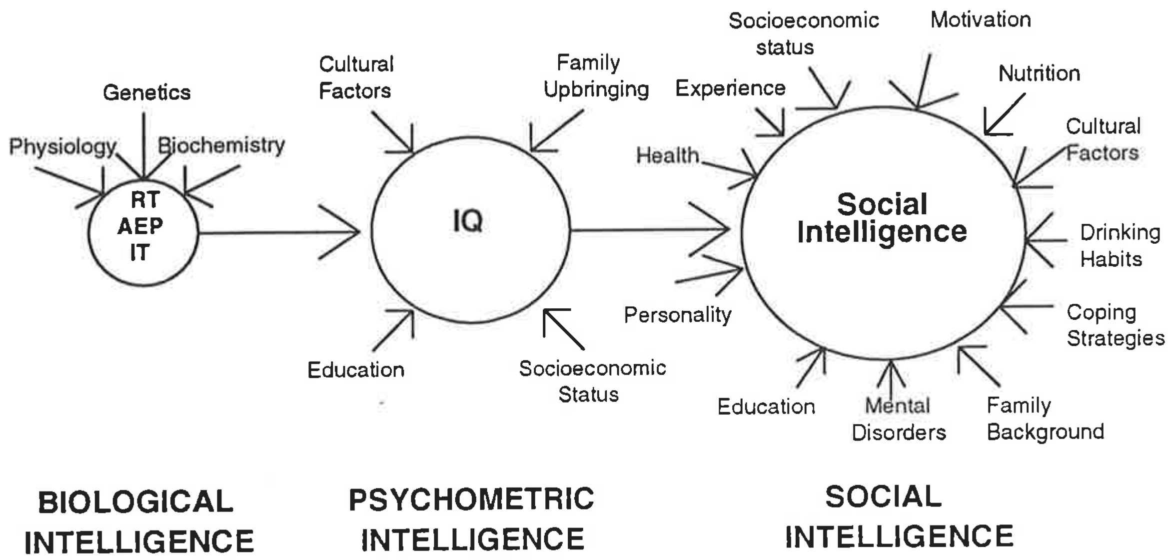


Figure 1: Three concepts of intelligence.
(Adapted with permission from Eysenck, H.J., 1988. The concept of intelligence: Useful or Useless?, Intelligence, 12, p.4.)

According to Eysenck (1988), this model can account for the lack of consensus on the nature of intelligence. He has concluded that there has been no agreement on a definition of intelligence because different investigators have widely disparate views (although not necessarily disconfirmatory) on the meaning of the word intelligence. It may be the case that the construct is sufficiently large to enable a variety of research to be undertaken on different aspects of intelligence. As Eysenck proposes, different researchers have addressed different notions of intelligence. He has argued that Intelligence A is the most fundamental of all intelligences, representing a genetic quality that is uninfluenced by the environment. However, insofar as Eysenck proposes that biological intelligence can be measured by IT, RT or AEP tasks, then this view is not equivalent to Hebb's Intelligence A, because Hebb postulated that one's genetic predisposition to intelligence could not be measured. Whether biological intelligence can be adequately measured by the IT, RT or AEP is a matter for further research. Nevertheless, Eysenck's model is useful because it raises questions about conceptions of intelligence that may be addressed scientifically; that is, it provides operational definitions for different conceptions of intelligence. For example, it would be expected from the Eysenck model that the AEP, IT and RT measures would have very high heritabilities, although at present there is little information on this issue. In addition, the model also predicts that the ECTs, because of their high association with biological intelligence, will correlate highly with IQ and less highly with other aspects of social intelligence (e.g., personality measures). This prediction is examined in Chapter 6.

A number of studies have attempted to investigate the degree to which psychometric intelligence is inherited or biologically determined. In a recent study investigating the similarity of monozygotic and dizygotic twins reared apart and together, Bouchard, Lykken, McGue, Segal, and Tellegen (1991) have concluded that about 70% of the variance in IQ in their sample was from genetic sources. Similarly, Bouchard and McGue (1981) from their meta-analytic review of the results from 140 studies investigating the causality of IQ, suggested that high average correlations of IQ between monozygotic twins reared together (.85) and reared apart (.72) were consistent with a polygenic model of inheritance. In a more recent experiment investigating the genetic factors underlying measures of RT, IQ, and *g*, Ho, Baker, and Decker (1988) have reported a heritability of .78 for g and .50 for RT. From these studies, it would appear that somewhere between 50% and 80% of the IQ variance is due to genetic sources. However, whether ECTs measure a genetic or other quality is still to be adequately resolved.

As outlined above, under this model, social intelligence represents the application of one's biological intelligence to everyday life. It is difficult to know precisely the relative importance of psychometric intelligence to social intelligence, because there are a number of non-cognitive factors that are held to contribute to social intelligence e.g., nutrition, personality and so on. Nonetheless, it is accepted that social intelligence is related to occupational success, on the basis of studies showing that IQ scores correlate significantly with this variable (Lanvin, 1965). An example of a theory pertaining to social intelligence is Sternberg's Triarchic theory of intelligence. Sternberg (1985, p. 55) admits that his view;

> **"is certainly highly inclusive in the sense that it includes within the realm of intelligence characteristics that typically might be placed in the realms of personality or motivation ... for example, motivational phenomena relevant to purpose of adaptive behaviour-such as motivation to perform well in one's career-would be considered part of one's intelligence broadly defined."**

According to Eysenck (1988), this view is unacceptable for any science intending to investigate the concept of intelligence systematically. He suggests that although IQ may provide a reasonable practical definition for intelligence (because of its close association with biological intelligence), social intelligence does not. On the other hand, the AEP, IT and RT procedures may be relatively free from cultural influences and therefore more amenable to scientific analysis.

Sternberg (1985) and Flynn (1987a) have both raised the issue of whether researchers are justified in using IQ as a criterion of intelligence while trying to perfect a better measure. Essentially this amounts to concern that if IQ tests lack high construct validity, then designing new tasks to correlate with such tests may be futile. This is not a problem specific to research in intelligence of course and, as Eysenck (1987) has pointed out, such a strategy is commonly adopted in most scientific disciplines. Moreover, there are two points to be made in support of this strategy. Firstly, although IQ tests are imperfect (e.g., Flynn, 1987b), there is good evidence that they predict not only general cognitive ability to a reasonable extent (Eysenck, 1987), but also real life qualities, such as scholastic and occupational success (Lanvin, 1965; Ree & Earles, 1992). Secondly, Eysenck's model clearly differentiates different conceptions of intelligence, hypothesising a relative independence of ECTs (biological intelligence) from psychometric intelligence. Within this theoretical model it is therefore possible to explain why psychometric intelligence may be an imperfect measure of intelligence and why biological intelligence may be a better measure. A preliminary examination of this prediction is provided in Chapter 8, by examining the criterion validity of IT as a measure of intelligence.

1.7 Alternative explanations for the correlation between Elementary Cognitive Tasks and IQ.

Howe (1990) has provided an alternative view to that of Eysenck regarding correlations between ECTs and psychometric intelligence. According to Howe, intelligence is a term which has never been satisfactorily defined. He argues that simply because intelligence tests measure some quantity does not imply that there is an underlying quality or ability; the term "intelligence" is merely a description of behaviours rather than a representation of any quality that can be observed between individuals. Indeed, he warns that by departing from labels of how people behave implies that we understand differences in intelligence test performance. Instead of intelligence test performance reflecting differences in intellectual capacity between individuals, Howe argues that differences in IQ may simply be due to differences in other attributes of personality or temperament, that similarly affect performance on, for example, ECTs (e.g., IT, RT and AEPs) and intelligence tests. This hypothesis is further discussed and tested in Chapter 6 where relationships between personality, temperament, RT, AEPs, IT and IQ are measured.

Howe (1990) does concede that research into the relationship between basic cognitive tasks or physiological functions and intelligence test scores may substantiate the belief that intelligence is a valid scientific construct. As he comments;

> **"Potentially, such information could be of great value. Imagine that three achievements have been made. First, it has proved possible to identify certain primitive mental "building-block" processes that can be shown to be essential components of the more complex tasks used in intelligence tests. Second, it has been shown that scores at tests which measure them vary considerably between individuals. Third, it is found that differences in people in their levels of performance at the tasks which make up intelligence tests are systematically related to individual differences in the efficiency with which these primitive processes function.**
>
> **If these three steps were to be achieved, progress would have thereby been made towards identifying causes of (or, at least, the simpler mental components of) variability in performance of the task that enters into tests of ability. And if one could be certain that intelligence test scores directly depend upon measurable parameters of physiological functioning that reflect inherent differences between people in (say) the power or speed of the physical operations underlying mental processes, there would be justification for saying that measures of tested intelligence are useful indicators of physical parameters that are basic causes of mental functioning. (p. 492)."**

Although Howe admits to the potential that such variables may have for the construct intelligence, he argues that the above mentioned steps have not been met, and that specific measurable processes related to more complex intelligence test behaviours have been difficult to find. On this point, Howe (1989) has criticised Anderson's (1989) position and Nettelbeck's (1987) review that IT and IQ are correlated at around -.5, suggesting that if those studies with either sample sizes of less than 40 or those which have tested subjects with an intellectual disability are omitted from calculation, then the mean correlation between IT and IQ drops to a minuscule -.15 for adults and -.14 for children. There are also similar criticisms by Mackintosh on the relationship between both IT and AEPs and IQ (see Macintosh, 1981, 1986) and by Longstreth (1984, 1986) on the relationship between RT and IQ. Eysenck and Barrett (1985) have suggested that it is impossible to gauge the relationship between the string length measure of AEP waveform complexity and IQ until studies are conducted which employ the same methodology as described in the initial string length study. Smith and Carew (1987) have highlighted the possibility that the significant negative RT-IQ correlations reported by Jensen, Vernon and others are determined by strategy use rather than by biological factors constraining information processing. Similalrly, Mackenzie & Bingham (1985) have suggested that apparent motion use in the IT paradigm might invalidate the mental speed hypothesis, and, as noted briefly before, Howe (1990) has suggested that significant ECT-IQ correlations may only be a function of personality and/or temperament variables.

1.8 Specific hypotheses relating to the validity of the biological explannation

In order to address the points made by Howe (1989, 1990), Mackenzie and Bingham (1985), Eysenck and Barrett (1985), and Smith and Carew (1987) and, therefore, whether correlations between RT, IT and the string length measure of AEP complexity and IQ reflect biological processes or simply strategy use (i.e., are "valid" biological measure of intelligence) the following empirical questions are addressed:

1. Smith and Carew's (1987) finding that some subjects in the Hick RT paradigm are able to use a strategy to shorten their decision time (DT) independent of their mental speed. This raises two main questions which are addressed in Chapter 2. Firstly, whether strategy use in the Hick RT procedure produces a significant change in DT and movement time (MT), and, secondly, whether this change in MT and DT invalidates previous research relating Hick RT to IQ.

2. The relationship between the string length measure of AEP waveform complexity and IQ is examined, using a near-identical methodology to that

described by D. E Hendrickson (1982). The possibility that poor reliability may account for disparate results from previous studies is also investigated. The role of attention in the string length/AEP procedure is also examined in two other EEG experiments.

3. Howe's (1989) contention that IT and IQ are only moderately correlated in studies with small sample sizes or in studies testing subjects with intellectual disabilities is examined. The possibility that display mode may account for inconsistent results from previous studies is also examined.

4. Mackenzie and Bingham's (1985) suggestion that apparent motion in the IT procedure may invalidate the mental speed hypothesis is examined by investigating the IT-IQ correlation and apparent motion phenomenon across three different visual masks.

5. The Howe (1990) hypothesis that personality and/or temperament variables may account for significant ECT-IQ correlations is examined.

Juhel: magnitude of the correlations between Elementary Cognitive Tasks and IQ.

More recently Juhel (1991, pp. 97-98) has suggested that correlations between IT, RT and AEPS and IQ may be too small to be of importance for our practical and theoretical understanding of intelligence.

> **"In summary, we suggest that, in terms of percentage of explained variance, mean contribution of each of these various elementary cognitive measurements to general intelligence does not reasonably exceed 15 or 20%. Though certain investigators think that this contribution could be about 25% of explained variance, this threshold would need to be validated by replications conducted on large samples with standardized and non-ambiguous interpretable paradigms. One must therefore question the functional significance of the relationship between IQ and EPs, RT and IT."**

Experiments described in this dissertation have attempted to address the issue of the extent to which IT, RT and AEPs may account for the IQ variance by employing procedures which may reduce strategy use (and which therefore might be considered 'purer' measures of information processing) and by measuring the three tasks independently in the same subject pool. The latter procedure raises the possibility that the three tasks may contribute independently to the IQ variance and therefore account for more than the 15 to 20% of the variance described by Juhel (1991).

Arrangement of Chapters

Chapters 2, 3, and 5 describe the effects of methodological factors (e.g., atention, strategy, use of apparent motion cues, stimulus display) on the association between IQ and RT (Chapter 2), the string length measure of AEP waveform complexity (Chapters 3) and IT (Chapter 5). Chapter 4 examines whether the deployment of attentional resources during an elementary cognitive task determines differences in IQ. Chapter 6 addresses the relationship between personality and temperament, and RT, AEPs, and IT; and on the correlation between RT, IT, AEPs and IQ. Chapter 7 examines the relationship between all main experimental tasks and the extent to which the RT, AEPs and IT measures can account or predict the IQ measures. Chapter 8 provides a summary of the main experimental results and discusses their implications. Chapter 8 also examines Flynn's (1987) position that validating ECTs against IQ measures may be problematical and assesses the criterion or external validity of IT.

CHAPTER 2

Reaction Time and IQ

"The RT experiment completely refutes the notion that individual differences in g are largely the result of individual differences in learned strategies, in any acceptable sense of that term."

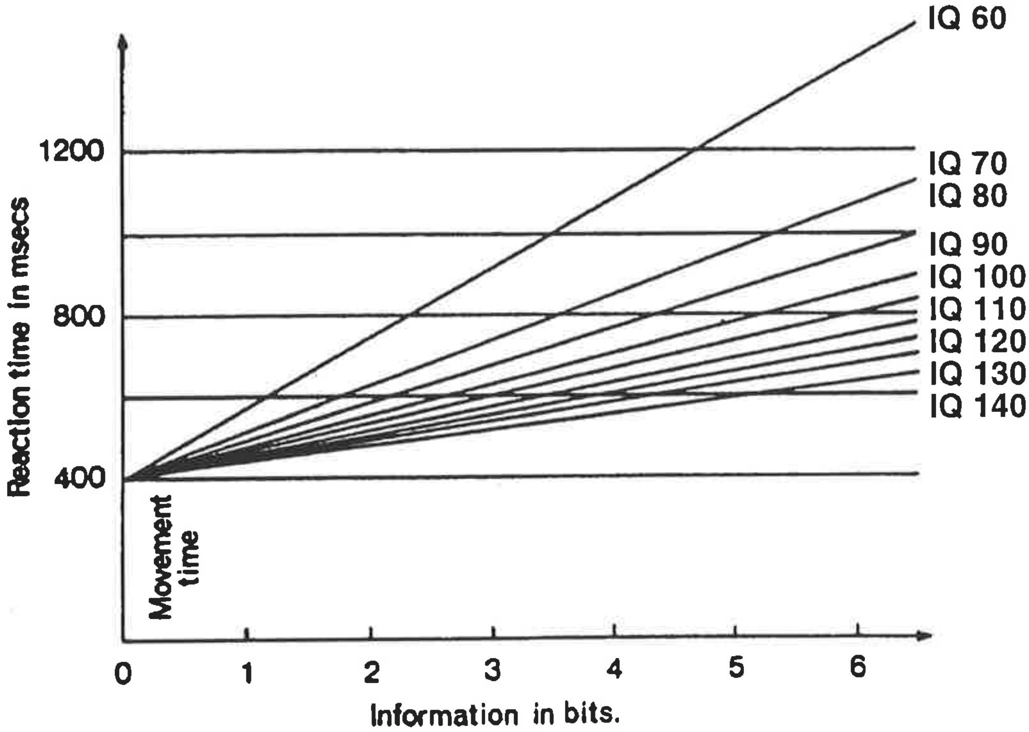
Jensen (1979, p. 23)

2.1 Introduction

The above statement by Jensen sets the context for much of the empirical work reported in this chapter. An experiment is reported in which the effect of strategy use and other methodological variables on the putative correlation between DT and IQ is investigated. The alternative hypothesis, that correlations between RT and IQ derived from the Jensen procedure, are a function of cognitive strategy and other methodological problems is discussed.

2.2 The Hick Paradigm

Hick (1952) first showed that the time taken to respond to a stimulus increases linearly with the logarithm of the number of stimulus alternatives, or information in the stimulus array, when information is measured in binary digits (bits). The term "bit" was first introduced by Shannon and Weaver (1949) to refer to the amount of information that reduces uncertainty by half [i.e., the logarithm (base 2) of the number of equally probable stimulus alternatives or choices]. According to Eysenck (1987), the slope of this function may be assumed to estimate the rate of mental processing of stimulus alternatives, per bit of information, so that longer RTs are derived from conditions in which stimulus complexity (that is, number of alternatives) is higher. This procedure is known as the choice RT or Hick paradigm and has been employed successfully in intelligence research by the German Erlangen school. Much of the early work from this school was influential in the development of the methodological and theoretical positions subsequently developed by Jensen, Vernon and others in several studies on RT and IQ. The initial study was by Roth (1964) who first correlated the slope of the Hick function with IQ scores, and reported that higher IQ scores were negatively associated with the rate of increase in RT with increasing bits of information. Figure 2 from Lehrl (1983) illustrates the rate of increase in DT with increasing stimulus complexity for subjects with different IQs (simulated data).



<u>Figure 2:</u> **Slope of DT across stimulus complexity for subjects with different IQ scores. Reproduced with permission from S. Lehrl (1983) Intelligenz: Informationpsychologische Grundlagen. <u>Enzyklopadie der Naturwissenschraft und Technik</u>. Landsberg, Germany: Moderne Industrie.**

From testing 58 subjects on the Amathauer (1955) IQ test, Roth reported that the correlation between the angle of the Hick function and IQ was -.39. Bieger (1968) replicated this finding in 50 subjects, reporting a correlation of -.33, corrected for restriction in range. Although published in an obscure journal, Roth's experiment was drawn to the wider attention by Eysenck (1967a); its importance lay in the fact that it enabled researchers (eg., Jensen, 1982) to define intelligence operationally in terms of rate of information processing. Jensen has subsequently defined the rate of information processing in the Hick paradigm as the reciprocal of the slope (1/*b*) across choice. According to Jensen (1982), Roth's result represented a difference in information processing abilities that is causally associated with the development of intelligence;

> **"Individuals with greater speed of information processing acquire more cognitively integrated knowledge and skill per unit of time that they interact with the environment. Seemingly small individual differences in speed of information processes amounting to only a few milliseconds per bit of information, when multiplied by months or years of interaction with the environment can account in part for the relatively large differences observed between individuals in vocabulary, general information and the other developed cognitive skills assessed by IQ tests."**
>
> **Jensen (1982, pp. 98-99).**

The belief, vividly described in the above quotation, that faster processing of environmental stimuli leads to a greater awareness of the world and the development of better cognitive skills, has been the impetus for the voluminous and significant work by Arthur Jensen on the relationship between DT and IQ. Although there are other RT paradigms (eg. Posner, Sternberg), this thesis will concentrate on the relationship between Hick RT (here designated as the Hick paradigm) and IQ.

2.3 Jensen's Apparatus

In order to investigate Hick's RT parameters and their relationship to intelligence, Jensen has adapted an apparatus that enables the separation of decision and movement times from total reaction time. Figure 3 displays Jensen's apparatus, in which eight lights are arranged in a semi-circular configuration. A response button is located adjacent to each light . A "home" button is situated in the centre of the panel. Subjects are required to depress the home button key until they see a target light and then to release the home button as quickly as possible and to depress the response button adjacent to the stimulus light. Decision time (DT) is defined as the time from stimulus onset to the release of the home button, and movement time (MT) as the time from release of the home button to the depression of the stimulus button. Choice is manipulated by varying the number of stimulus alternatives, from 0 bits (i.e., one light at one possible location) to 3 bits of information (i.e., the stimulus may appear in any one of the eight light positions).

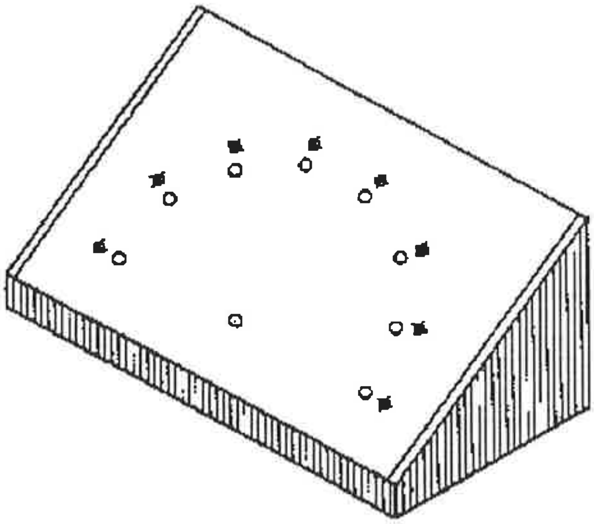


Figure 3: **Jensen's Reaction Time Apparatus. Reproduced with permission from A.R. Jensen, (1987). Individual differences in the Hick paradigm. In P.A. Vernon, (Ed.), Speed of Information Processing and Intelligence, (pp. 101-175). Norwood, N.J.: Ablex.**

In all of Jensen's Hick-RT experiments to date, subjects are given a few practice trials in the eight stimulus (i.e., eight lights) condition so that they can familiarise themselves with the task. Most studies have employed only 16 trials at each choice (i.e., 16 trials at each of one, two, four and eight stimulus conditions), although some have employed up to 32 trials. All experiments have started with one stimulus light and progressed to two, and then four and finally to eight stimulus alternatives. DTs of less than 150 msecs are discarded as outliers, because Jensen argues that a physiological limit prevents shorter

DTs. DTs over 999 msecs are also discarded and replaced with an additional trial. In addition, all DTs exceeding three SDs above the subject's mean DT are discarded (Jensen, 1987). Jensen derives a number of statistical measures from this procedure; the median, mean and intraindividual variability (σ_i-average standard deviation) of both DT and MT for all choice, intercept of the DT function across choice and the slope of this function. These measures are referred to as Hick variables.

2.4 Summary of Jensen's results

The relationship between Hick variables and IQ.

Jensen (1987) has summarised the results of 33 studies investigating the relationship between Hick variables and IQ scores. In all studies in which comparisons between groups differing in IQ test scores was possible, slope of the DT function was significantly different in the predicted direction, with groups with lower mean IQs showing steeper slopes than groups with higher mean IQs. Due to the low reliability of slope, these differences, if corrected for unreliability, are of a moderate magnitude. Correlations between IQ test scores and Hick parameters are also provided for 26 studies. Table 1 summarises the correlations for the Jensen meta-analysis (corrected and uncorrected for restriction in range of IQ).

<u>Table 1</u>

Uncorrected and corrected (restriction in range of intelligence test scores) correlations between Hick parameters and IQ (Jensen, 1987, p. 159).

	Mean median DT	Intercept DT	Slope DT	SD DT	Mean median MT	SD MT
Uncorrected	-.201	-.117	-.117	-.208	-.189	-.011
Corrected	-.279	-.165	-.165	-.288	-.263	-.016

Jensen argues that the majority of these studies report substantial restriction in range of IQ scores, so that a better estimate of the magnitude of the correlation may be found in an experiment by Nettelbeck and Kirby (1983a), in which they employed three groups of subjects- above average, average, and a retarded sample. The magnitudes of the correlations were larger in this study than the mean correlation from the meta-analysis reported by Jensen. Of special note was the correlation of .71 between $DT\sigma_i$ and IQ. Bearing in mind that $DT\sigma_i$ has very low reliability and that the magnitude of this correlation is significantly greater than that reported by the majority of other studies, this result must be treated with caution. Generally the correlations between IQ and Hick RT variables hover around the -.20 to -.30 mark, this being a consistent finding across studies. Although important, the magnitude of this correlation may suggest that Hick RT parameters are not sufficient to explain performance adequately on IQ tests, even though most studies report restriction in range of IQ test scores. One of the reasons why the meta-analysis reveals very low correlations between Hick RT parameters and IQ may be that the meta-analysis summarises correlations based on studies using different "intelligence" measures. The Jensen (1987) meta-analysis included several different tests of intelligence, together with Scholastic Aptitude Test scores (SAT) and reading comprehension tests. Given the fact that many IQ tests may only share about 25% of the common reliable variance (e.g., APM and WAIS-R), a meta-analysis based on all of these tests may only serve to cloud the relationship between Hick RT parameters and *g*, VIQ, PIQ and other measures such as reading ability and scholastic aptitude.

A re-analysis of Jensen's meta-analysis was done to examine the correlation between Hick RT parameters and the different IQ tests used in previous studies. Two different tests were predominantly used in the 26 samples analysed by Jensen, a Raven's Progressive Matrices test (either the Advanced or Standard) and the WAIS-R. Correlations were larger for the WAIS-R full-scale than the Raven's test (Table 2). The uncorrected correlations between mean median DT, and DTσ_i and IQ accounted for between 4 and 10% of the reliable variance, which, although not impressive, from a practical viewpoint may nevertheless be important for a theory of intelligence, particularly if the magnitude of these correlations may be depressed because of unreliability, restriction in range of IQ scores, or other methodological problems associated with the measurement of DT and MT. The next section discusses some of the criticisms of the Jensen RT procedure. Suffice to note here that the possibility exists that the magnitude of the correlations between Hick RT parameters and IQ (as reported in Table 2) may be increased if various methodological shortcomings are addressed and corrected, this being discussed in more detail later in the chapter.

Table 2:
Mean correlations from reanalysis of Jensen' (1987) meta-analysis of the relationship between Hick RT variables and IQ.

IQ Test	Number of studies	Mean median DT	Intercept DT	Slope DT	SD DT	Mean median MT	SD MT
Ravens	**18**	**-.25**	**-.08**	**-.10**	**-.25**	**-.26**	**-.16**
WAIS-R	**3**	**-.31**	**-.29**	**-.15**	**-.32**	**-.30**	**.14**

It is apparent from Table 2 that mean median MT correlates with WAIS-R IQ and Raven IQ to the same extent as mean median DT does and statistically significantly better than DT slope across choice. This result is difficult to reconcile with Jensen's theoretical position linking IQ and central decision making processes.

The importance of Jensen's theory is that it predicts that differences in IQ are a function of information processing speed and that differences in information processing speed lead to the development of differences in acquired information and problem solving skills. This theory does not describe a mechanism which accounts for MT-IQ correlations. Another problem highlighted by Table 2 is the correlation between slope and WAIS-R IQ and Raven IQ. The magnitudes of these correlations does not indicate that the slope is of theoretical or empirical interest for intelligence research. Both of these variables are examined in Experiment 1.

Correlations between Hick variables and IQ as a function of set size and slope.

Jensen has argued that if speed of information processing is an important process determining performance on IQ tests, increasing correlations should be found between IQ and DT as choice increases. In a meta-analysis of 15 independent samples, correlations between DT and IQ were; -.19, -.21, -.24 and -.26 for 0 to 3 bits respectively, demonstrating that the increase in the correlation coefficient across choice is almost perfectly linear. A departure from this finding is that the correlation between DTσ_i and IQ does not increase as a function of stimulus uncertainty. As Jensen (1987) admits, this finding is counter to predictions made from his oscillation model (Jensen 1982) and other error type models of information processing (e.g., A.E. Hendrickson 1982).

2.5 Problems with Jensen's studies

There have been a number of criticisms of Jensen's claim that correlations between DT and IQ reflect biological parameters constraining information processing. Longstreth (1984, 1986) has suggested three major methodological flaws in Jensen's experiments: order effects, visual attention effects and response bias effects, although it is unclear whether such methodological problems negate Jensen's conclusion. It is not the intention of this dissertation to review these areas, but suffice to note that at present there is little evidence suggesting that DT-IQ correlations can be accounted for by these methodological problems.

Slope-IQ correlation

Longstreth (1984) has also re-examined Jensen's claim that the slope of the Hick function is negatively related to IQ test performance, and found no evidence to support such a claim. Comparing groups that differ markedly in IQ, no statistical difference was found in slope. In some groups, slope and IQ were positively correlated, and in others the negative association is small and not statistically significant unless corrected for restriction in IQ range.

The slope of the DT function across bits is assumed by Jensen to include time taken to program the response. Longstreth has argued that this is probably not the case, pointing to similar DT slopes from conditions requiring and not requiring an MT component. Similarly, Nettelbeck and Kirby (1983b) suggested that shorter DTs may reflect delayed response organization until after the subject releases the home key, which therefore translates into slower MTs. This finding is consistent with Smith and Carew's (1987) study in which they provided evidence that subjects can decrease their DTs by adopting a strategy which delays response programming. Having observed that some subjects appeared to release the home key before fully locating the stimulus, they decided to use a backward masking procedure to define exposure duration so as to prevent corruption of RT measures. This procedure involved synchronising the onset of the lights in all stimulus positions when the subject released the home key (backward masking), thus ensuring that the subject could not continue to sample information about the position of the target after releasing the home key. Their analysis confirmed significantly longer DTs in the masked RT condition than in the unmasked condition. It would appear, then, that this new procedure may have important implications for experiments which relate choice RT to intelligence and information processing.

However, a number of important issues were not addressed by their methodology. Firstly, they employed only a single 6-choice procedure, and so did not address the possibility that the relationship between DT and task complexity, as defined by degree of choice, might differ across the masked and unmasked conditions. Secondly, and more importantly, they did not investigate the relationship between their new procedure and IQ. Experiment 1, which compares DT and MT in masked and unmasked conditions across four levels of choice addresses these shortcomings. Differences in mean DTs and slope across bits of information between these two conditions would support Smith and Carew's (1987) suggestion that strategy use may confound previous results in the Hick-RT paradigm. Experiment 1 also examines the correlation between IQ measures and DT and MT measures from both the masked and unmasked conditions. If strategy use has been responsible for the significant negative DT-IQ correlation reported in several experiments by Jensen, Vernon and others, then it can be predicted that in the masked RT condition the correlation between DT and IQ will be significantly reduced below levels normally found. As this is the first experiment correlating masked RT and IQ, Experiment 1 describes test re-test data for masked RTs.

Experiment 1

2.6 Strategy use in the Jensen paradigm? Effects of mask.

2.6.1 Method

Subjects

Fifty-two first year psychology students whose mean age was 20.1 years (SD= 2.5) volunteered to take part in the experiment.

Apparatus

The stimulus display was the apparatus described by Jensen (1982; 1987a). Briefly, the console is a flat black board measuring 33 cms deep x 43 cms wide in size and angled at a 30 degree tilt. A home button is situated in the centre of the panel, 15 cms from each of the remaining 8 buttons, which are arranged in a semi-circle around the home key. A stimulus light is situated immediately adjacent to each response button. A computer was connected to the apparatus to drive the task and to collect data.

Procedure

All 52 subjects participated in both the masked and unmasked RT measures. The order of the masked and unmasked RT sessions were balanced. In addition, the 1, 2, 4 and 8 stimuli trials were presented in separate blocks. The order of blocks was balanced (Latin square). Sixty-four trials were presented for each choice RT block. Therefore, in total each subject responded to 512 trials-i.e., 64 x 4 (1, 2, 4 and 8 stimuli) x 2 (masked and unmasked) trials.

In both the unmasked and masked conditions, the subject held down the home key for a pseudo-random period which defined an inter-trial interval, ranging from 1-8 seconds before the onset of the stimulus light. In the masked condition, all lights for that choice were turned on as soon as the subject released the home key, thereby masking the stimulus. In both conditions, the onset of the stimulus did not occur without the depression of the home key. Stimuli (and mask) remained on until the subject pressed a response key. The next trial could occur only when the subject pressed the home key, at which time the onset of the inter-trial interval started. All subjects were given 10 practice trials before each block of trials to enable them to become familiar with the task. Responses which were made after a period exceeding twice the standard deviation from the mean response were subsequently discarded from analyses.

The full version of the WAIS-R and the APM were administered to each subject. The order for administrating the IQ tests and completing the RT tasks was balanced.

2.6.2 Results and Discussion

Decision Time

A repeated measures analysis of variance was conducted to test whether the mean DTs in the masked 1, 2, 4 and 8 stimulus conditions were significantly longer than the mean DTs obtained in the unmasked conditions. The outcome was highly significant ($F_{(1,51)}$=15.0, p<.001). In addition, the main effect for the number of choices was also highly significant ($F_{(3,153)}$ =123.7, p<.001), confirming the relationship between mean DT and increasing task complexity. Means and SDs for DTs derived under 1, 2, 4 and 8 stimulus conditions are provided in Table 3.

Table 3:
Means (and SDs) for DTs (msec) from 1, 2, 4 and 8 choice masked and unmasked conditions (N=52; Experiment 1).

	1 stimulus	2 stimuli	4 stimuli	8 stimuli
UNMASKED	294 (53)	325 (58)	336 (50)	361 (50)
MASKED	312 (54)	347 (57)	354 (49)	384 (60)

The regression of DT on the number of stimuli (choice), for both masked and unmasked conditions, is shown in Figure 4. Of interest was the finding that masked DT was slower than unmasked DT in the single stimulus condition, and to about the same extent as in the multiple choice conditions. This was unexpected, since, with only a single stimulus involved, masking cannot occur. Presumably, masking in the choice situations produced a response set which applied under all circumstances.

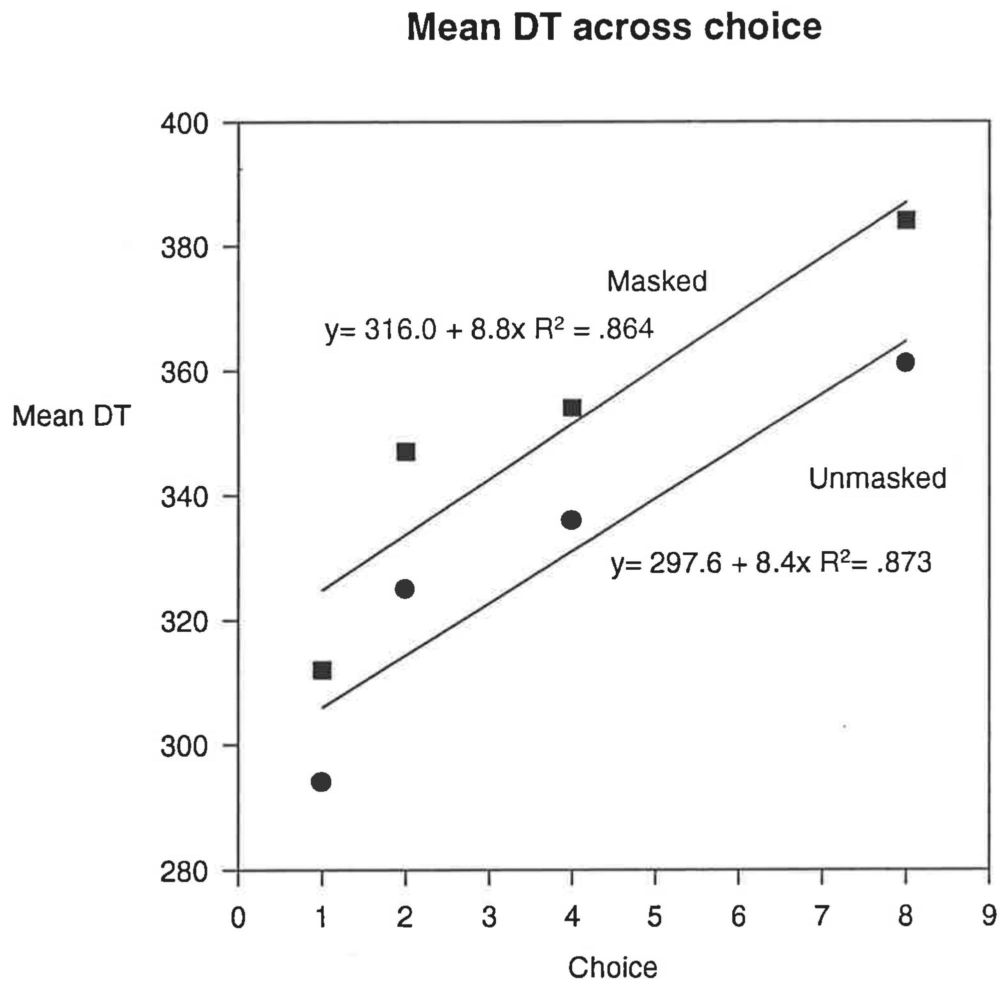


Figure 4: Mean DT across different levels of choice for masked and unmasked conditions. Slope, intercept and R^2 statistics are provided for both masked and unmasked conditions (N=52; Experiment 1).

These results confirmed the finding of Smith and Carew (1987) that subjects significantly decrease their DTs by employing a strategy in the unmasked condition. It should be noted that it is the unmasked condition that Jensen and colleagues have employed to date in all of their experiments on RT and IQ. Although there was a significant increase in DT at all stimulus levels, there was no evidence to suggest that the slope of DT across choice was different for masked and unmasked conditions. The equations for the relationship between mean DT across choice for both conditions were very similar and the linear function accounted for nearly identical variance. Thus, it may be concluded that the masked procedures only served to increase mean DTs by a constant amount across bits of information. Thus, strategy use in the unmasked procedure does not appear to produce a qualitative difference in the slope of mean DT across choice. In view of this, it seems unlikely that the results of past experiments which have used an unmasked RT procedure have been systematically affected unless IQ scores are related to the part of the DT variance that is due to this strategy effect. If this was the case then it would be expected that either no correlation or a significantly reduced correlation with IQ would be observed in the masked condition when this strategy use is eliminated.

Pearson correlations between Verbal IQ (VIQ), Performance IQ (PIQ) and Full Scale IQ (FSIQ) scores from the WAIS-R, APM scores and DTs to 1, 2, 4 and 8 stimuli, for unmasked and masked conditions, are reported in Table 4. Correlations between IQ test variables and mean DT at different levels of choice ranged from -.24 to -.57 for the unmasked condition and from -.19 to -.51 for the masked condition. Importantly, all 32 correlations were negative in sign and 31 out of the 32 correlations were significantly different from zero (22 out of 32 at the .01 level of probability). All correlations between IQ scores and unmasked mean DTs at different stimulus levels were greater in magnitude than the respective unmasked correlations, suggesting that the addition of the mask has served to decrease the DT-IQ correlation reported in previous experiments by Jensen and others.

Table 4:
Correlations between mean masked and unmasked DTs (msec) and VIQ, PIQ, FSIQ and APM scores at 1, 2, 4, and 8 choice conditions (N=52: Experiment 1).

UNMASKED	1 stimulus	2 stimuli	4 stimuli	8 stimuli
VIQ	-.43**	-.42**	-.52**	-.55**
PIQ	-.33**	-.24*	-.37**	-.40**
FSIQ	-.44**	-.38**	-.51**	-.55**
APM	-.56**	-.44**	-.57**	-.49**
MASKED				
VIQ	-.27*	-.26*	-.32**	-.30*
PIQ	-.23*	-.19	-.26*	-.36**
FSIQ	-.28*	-.26*	-.32**	-.36**
APM	-.41**	-.43**	-.51**	-.31*

****p<.05, ** p<.01 (1 tailed).***

In order to test the difference between the size of the Pearson correlations between DT and IQ obtained under masked and unmasked conditions, the correlations were first transformed into Fischer z scores. The z scores were then compared using a related samples t-test. This comparison indicated that the magnitude of the correlations between DT and IQ derived under masked and unmasked conditions were significantly different from each other (t=7.7, p < .01). This result suggests the following conclusions. Firstly, that strategy use has significantly lowered the correlation between DT and IQ. Secondly, that correlations between DT and IQ derived under the masked condition are larger than those reported by Jensen in his meta-analysis of these variables. Thus, although correlations between DT and IQ variables were smaller in magnitude in the masked compared to the unmasked condition, in no sense can the significant negative correlation between mean DT and IQ variables, reported by Jensen, Vernon and others, be attributable to the type of strategy use investigated here and by Smith and Carew (1987). The magnitude of the correlations between mean DT and IQ reported here are larger than those reported by Jensen (1987) in his meta-analysis of this relationship. This discrepency is suggestive of procedural factors which were not the same across the two comparisons. Apart from the addition of the mask the present study differed from Jensen's previous studies in two main ways; order of choice blocks was balanced across subjects and more trials were collected at each choice condition in order to increase the reliability of Hick variables.

Correlations were moderate in magnitude and have not been corrected for restriction in the range of IQ scores (Table 5), although, because they represent a restricted range compared to the population, the reported correlations are likely to underestimate the best estimate of the correlation between mean DTs and IQ.

Table 5:
Means and SDs for VIQ, PIQ, FSIQ and APM scores (N=52; Experiment 1).

IQ Test	Mean	SD
VIQ	110.0	13.0
PIQ	111.4	11.9
FSIQ	111.5	12.5
APM	25.0	5.4

Movement Time

Means (and SDs) for MT are reported in Table 6. A repeated measures ANOVA was performed to examine the relationship between mean MTs obtained under masked and unmasked condition and the relationship between mean MT and increasing choice. The effect of mask on mean MT was not significant ($F_{(1, 51)}$= 2.2, NS). However, the effect of choice on mean MT was significant ($F_{(3, 153)}$=7.4, $p < .01$). This result indicates that the mask did not significantly change Mean MT, a surprising result given that the addition of the mask significantly increased mean DT. It might be expected that if subjects are using a strategy to shorten their DTs in the unmasked condition, then this decrease in DT might be reflected in a commensurate increase in MT when subjects are lifting their fingers off the home key before reaching a decision in the unmasked compared to masked condition. Thus it is concluded that the mask effectively prevents this type of strategy use. It may be argued that in the masked condition, subjects use a more stringent criterion before responding. Whereas in the unmasked condition subjects delay reaching a decision until lifting their finger off the home key, in the masked condition subjects needed to reach a decision about the correct stimulus before they lifted their finger off the home key. This explanation accounts for the significant increase in mean DT and the non-significant change in mean MT across the two conditions.

Table 6:
Means (and SDs for MTs (msec) at 1, 2, 4 and 8 choice for masked and unmasked conditions. (N=52; Experiment 1).

	1 stimulus	2 stimuli	4 stimuli	8 stimuli
UNMASKED	219 (39)	228 (45)	231 (48)	244 (60)
MASKED	224 (50)	238 (57)	238 (55)	248 (59)

Table 7 reports Pearson correlations between IQ variables and mean MT derived under masked and unmasked conditions. All correlations were negative, 29 out of 32 correlations being significantly different from zero at the .05 level of probability or lower, suggesting that mean MT is a statistically significant predictor of IQ test performance. Correlations ranged from -.22 to -.58 for the unmasked condition, and from -.15 to -.48 for the masked condition. The Pearson correlations were transformed into z scores and then used in a related samples T-test to examine whether the magnitude of the MT-IQ correlations were significantly different across masking conditions. The result

(t_{16}=.16, NS) suggested that the magnitude of the correlations between mean MT and IQ variables were not significantly different for the masked compared to the unmaksed conditions. The fact that the magnitude of MT-IQ and DT-IQ correlations obtained in Experiment one are clearly indistinguishable does not support Jensen's theoretical model of RT in which DT rather than MT is posited to be the most important correlate of IQ. In addition, Jensen's view that DT-IQ correlations reflect individual differences in information processing speed, as measured by the slope of the Hick function, was not supported in the present experiment. The correlation between the slope of DT and VIQ, PIQ, FSIQ and APM scores was; -.13, -.14, -.15 and -.12 for unmasked; and .01, -.13, -.06 and .13 for unmasked respectively.

Table 7:
Correlations between mean masked and unmasked MTs (msec) and VIQ, PIQ, FSIQ and APM scores for 1, 2. 4, and 8 stimuli (N=52; Experiment 1).

UNMASKED	1 stimuli	2 stimuli	4 stimuli	8 stimuli
VIQ	-.38**	-.28*	-.31*	-.22
PIQ	-.31*	-.28*	-.24*	-.28*
FSIQ	-.38**	-.31*	-.31*	-.27*
APM	-.53**	-.46**	-.58**	-.38**
MASKED				
VIQ	-.45**	-.30*	-.40**	-.34**
PIQ	-.33**	-.15	-.28*	-.20*
FSIQ	-.44**	-.27*	-.39**	-.31*
APM	-.48**	-.35**	-.45**	-.41**

p <.05, ** p <.01 (1 tailed).

On the basis of these findings concerning correlations between DT and MT with IQ, it is suggested that a new theoretical model for RT-IQ correlations is required. One possibility stems from a relatively new line of research centering on the relationship between nerve conduction velocity and intelligence. To date, two types of nerve conduction velocities have been used in intelligence research: peripheral nerve concuction velocity (peripheral NCV) and brain nerve conduction velocity (brain NCV). Concerning peripheral NCV, Vernon and Mori (1989) reported a significant correlation of -.42 with Multidimensional Aptitude Battery (MAB) IQ. The theortical exposition of this relationship is not clear. However, it appears that the rationale for most of this work follows Reed's (1984) hypothesis that NCV and intelligence might be correlated as a result of individual differences in the proteins involved in transmitting electrical impulses down synapses (Vernon, 1991). Clearly, the implication is that faster peripheral NCV may be one of the causal mechanisms for RT-IQ correlations. Although peripheral NCV, DT and MAB IQ were all inter-correlated, peripheral NCV was not able to account for the correlation between DT and IQ.

While the results of Vernon and Mori's (1989) study was not confirmed by two subsequent studies (Barrett, Daum, & Eysenck, 1990; Reed & Jensen, 1991). Vernon and Mori (1992) replicated their previous finding in 88 undergraduate students. Again, RT, IQ and peripheral NCV were inter-correlated. Vernon and Mori interpreted their results within the umbrella of an efficiency model of brain functioning and accounted for the failure of the two other studies to replicate their findings in terms of methodological parameters. A very recent study (Wickett & Vernon, 1994) replicated the NCV-IQ correlation but only in males. At this early stage of research future studies are required to describe this relationship more fully.

The second type of NCV has been reported by Reed and Jensen (1992) in which they estimate brain NCV by means of measuring the latency of two EEG components to visually presented stimuli and dividing these latencies by the subject's head size. Correlations with IQ were .184 for N70 NCV and .256 for P100 NCV, accounting for approximately 3.3% and 6.6% of the IQ variance respectively. It is suggested that if the NCV-IQ relationship can be adequately replicated, then this paradigm might be able to explain both DT-IQ and MT-IQ correlations. Obviously, both DT and MT reflect, to some degree, the influence of speed of transmission across neuronal synapses and axons.

Also of interest here is the Larson and Sacuzzo (1989) view that the RT-IQ correlation should increase as stimulus complexity increases. The magnitude of the DT-IQ correlations were not significantly different across choice. To be fair, an experiment requiring several hundred subjects would be required to show small differences in correlation coefficients. Suffice to point out here, however, that the average correlation between IQ measures and mean DT at the four different levels of stimulus complexity were -.37, -.33, -.44 and -.42 for 1, 2, 4 and 8 stimulus conditions respectively. This pattern of correlation is not consistent with the prediction that an increase in the magnitude of the correlation coefficient should parrallel increase in stimulus complexity.

2.7 Reliability of masked RTs

The smaller magnitude of the correlations between IQ and masked mean DT, compared to unmasked mean DT, may be explained in terms of unreliability, if, for instance, the addition of the mask leads to DTs which are less reliable than the unmasked DTs. In order to assess this possibility, preliminary data are offered in the following section.

2.7.1 Introduction

Three types of reliability estimates have been reported in Jensen's Hick studies thus far (four split-half, one Cronbach's alpha and test-retest). Generally, most of the Hick parameters show moderate to high reliabilities, with two exceptions. Firstly, $DT\sigma_i$ shows variable reliability ranging from .07 test-retest to .72 split half; weighted split-half was .66 and test-retest only .40. Secondly, DT slope, although showing adequate split-half reliability (.80), showed very low test-retest reliability (.39). Cronbach's alpha has only been reported in one study with only two Hick variables. MT variables demonstrated adequate reliabilities. In order to provide preliminary evidence on the reliability of masked RTs (both DT and MT), and to compare the reliability of both masked and unmasked DT and MT variables for this sample, test re-test correlations were computed for means and SDs for DT and MT variables at 4 and 8 choice conditions (both masked and unmasked conditions).

2.7.2 Method

Subjects

Twenty subjects who had participated in Experiment 1 agreed to participate in a further RT session, 12 months after their initial RT testing session in which they completed sixty-four RT trials in both th4 four and eight stimulus conditions in both masked and unmasked conditions. Due to time constraints 1 and 2 stimulus conditions were not administered.

Apparatus and Procedure.

Apart from those variations noted below, an identical apparatus and procedure was used to that described for Experiment 1. All subjects were given 10 practice trials before each block of trials to enable them to re-familiarise themselves with the task. The 4 and 8 choice RT blocks were presented in a balanced order as was the order of the masked and unmasked condition.

2.7.3 Results and Discussion

Table 8 provides means and SDs for the masked and unmasked RT measures recorded 12 months since first administration. Table 9 provides test re-test correlations between mean and SD for DT and MT variables. Generally, correlations from Table 9 were high in magnitude and statistically significant, providing evidence for good masked and unmasked RT reliability. Thus, it is unlikely that the lower correlations between DT and IQ in masked compared to unmasked conditions can be attributable to the unreliability of masked RTs.

Table 8:
Mean and SDs for masked and unmasked RT variables at 4 and 8 stimulus conditions, 12 months after first administration. (N=20; Experiment 1).

Masked	Mean	SD	Unmasked	Mean	SD
Mean DT 4 stimulus	348.7	40.5	**Mean DT 4 stimulus**	328.2	26.5
Mean DT 8 stimulus	362.3	68.4	**Mean DT 8 stimulus**	339.3	41.9
SD DT 4 stimulus	50.0	18.2	**SD DT 4 stimulus**	48.0	19.8
SD DT 8 stimulus	57.4	26.2	**SD DT 8 stimulus**	60.4	23.9
Mean MT 4 stimulus	198.2	40.0	**Mean MT 4 stimulus**	190.8	35.1
Mean MT 8 stimulus	216.9	37.4	**Mean MT 8 stimulus**	210.7	33.8
SD MT 4 stimulus	47.0	18.7	**SD MT 4 stimulus**	45.5	11.2
SD MT 8 stimulus	54.7	12.5	**SD MT 8 stimulus**	57.8	14.8

Table 9:
Test re-test correlations for masked and unmasked mean and SDs of DT and MT variables, 12 months after first administration. (N=20; Experiment 1).

Masked	Correlation	Unmasked	Correlation
Mean DT 4 stimulus	.89*	**Mean DT 4 stimulus**	.79*
Mean DT 8 stimulus	.56*	**Mean DT 8 stimulus**	.63*
SD DT 4 stimulus	.75**	**SD DT 4 stimulus**	.78**
SD DT 8 stimulus	.71**	**SD DT 8 stimulus**	.70**
Mean MT 4 stimulus	.89**	**Mean MT 4 stimulus**	.91**
Mean MT 8 stimulus	.97**	**Mean MT 8 stimulus**	.88**
SD MT 4 stimulus	.57*	**SD MT 4 stimulus**	.49*
SD MT 8 stimulus	.29	**SD MT 8 stimulus**	.37

** p < .05 ** p < .01*

2.8 General Discussion and Implications

The empirical work presented in Chapter 2 was concerned with the question of whether the significant negative correlations reported in previous experiments by Jensen, Vernon and others would still hold in a condition which prevented the use of a strategy based on gaining additional decision time during the movement component of the RT. The results of Experiment 1 suggested that there was a reasonably large cognitive strategy use effect in the Jensen paradigm, and that this effect was approximately 20 msecs. This difference was statistically significant and consistent across choice, suggesting that in previous experiments employing the Jensen apparatus, DT has been confounded by strategy use. Interestingly, mean MT was not significantly different across masked and unmasked conditions, suggesting that subjects alter their criterion for responding in the masked condition. The possibility therefore existed for correlations between DT and IQ to be merely a function of cognitive strategy use rather than of the relationship between basic processing speed per se and intelligence. However, as significant negative correlations were obtained between DT and IQ in both the masked and unmasked conditions, it is clear that the type of strategy use studied in Experiment 1 does not *determine* the previosuly reported relationship between DT and IQ.

The present study also addresses one of the criticisms made of Jensen's mental chronometry work by Longstreth (1984), who suggested contamination of choice DTs due to practice effects- Jensen employs a procedure in which RTs are recorded at the 1 stimulus condition followed by the 2 stimulus condition followed by the 4 and 8 stimulus conditions. In the present study the order of presentation of choice DTs was balanced to control for this potential problem. Furthermore, larger numbers of trials were administered to each subject, to increase the reliability of mean RT used in analyses, compared to most previous studies which have employed only 8 or 16 trials per choice condition. Significant negative correlations were still observed despite the correction of these two methodological 'problems', suggesting that past negative correlations between mean DT and IQ are not due to order or reliability effects. Indeed, despite restriction in range, correlations reported here were larger in magnitide than in the Jensen (1987) meta-analysis (most correlations were about -.2) suggesting that order effects and unreliability may have served to decrease or mask the "true" relationship between DT, MT and IQ that has been reported in previous experiments employing this procedure.

The results of Experiment 1 also raised some interesting problems for the Jensen speed of information processing model in which the slope appears to be the cornerstone. Correlations between slope and IQ were not significant suggesting that the slope may not be of theoretical importance in explaining the significant negative association between mean DT and IQ. Furthermore, the mean MT-IQ correlations obtained consistently across choice and masking condition are difficult to explain under the Jensen model. Further basic research is required to determine the physiological processes underlying DT and MT. The pattern of correlations with IQ (both DT and MT) is consistent with an error model of synaptic processing in which transmission speed is determined by the accuracy of information processing across neuronal synapses (Eysenck, 1987). Alternatively, it may by hypothesised that high-IQ subjects possess more direct neuronal circuits for information processing than low-IQ subjects, so that information is only propagated through a fraction of the number of neurons. There is a many other possibilities, including intra-individual differences in strategy and motivation; and these are discussed in the concluding chapter.

Having examined this type of strategy use in the Hick RT paradigm the focus now shifts to examine methodological variables in two other elementary cognitive correlates of IQ: the string length measure of AEP waveform complexity and IT.

CHAPTER 3

String length and IQ

3.1 Introduction

In attempting to develop IQ tests uncontaminated by culture, education and socioeconomic status, the Averaged Evoked Potential (AEP) procedure has been explored to test whether more objective measures of intelligence could be developed. However, as Callaway (1973) explained, the possibility that the AEP procedure can be developed to measure intelligence adequately depends on a number of empirical and theoretical problems. For instance, do AEP parameters measure cognitive processes that reflect only the subject's attitude to the stimulus? Alternatively, does the AEP waveform reflect genuine neurophysiological processes that are causally related to performance on a paper and pencil test of intelligence? Although intelligence must have a biological basis, it is by no means clear that available AEP measures effectively represent this quality. Alternatively an "AEP measure of intelligence" may be just a more complicated and less precise procedure to measure intelligence than standard IQ tests. Although these questions are yet to be resolved through empirical investigation, considerable research has been reported on the nature of the relationship between measures of the AEP and IQ. The purpose of this chapter is to review this body of work, to draw inferences about various relationships concerned with the AEP measurement of IQ, and to propose hypotheses and present the results of two empirical studies designed to clarify some aspects of the relationship between AEP measures and IQ.

3.2 EEG Measures and Intelligence

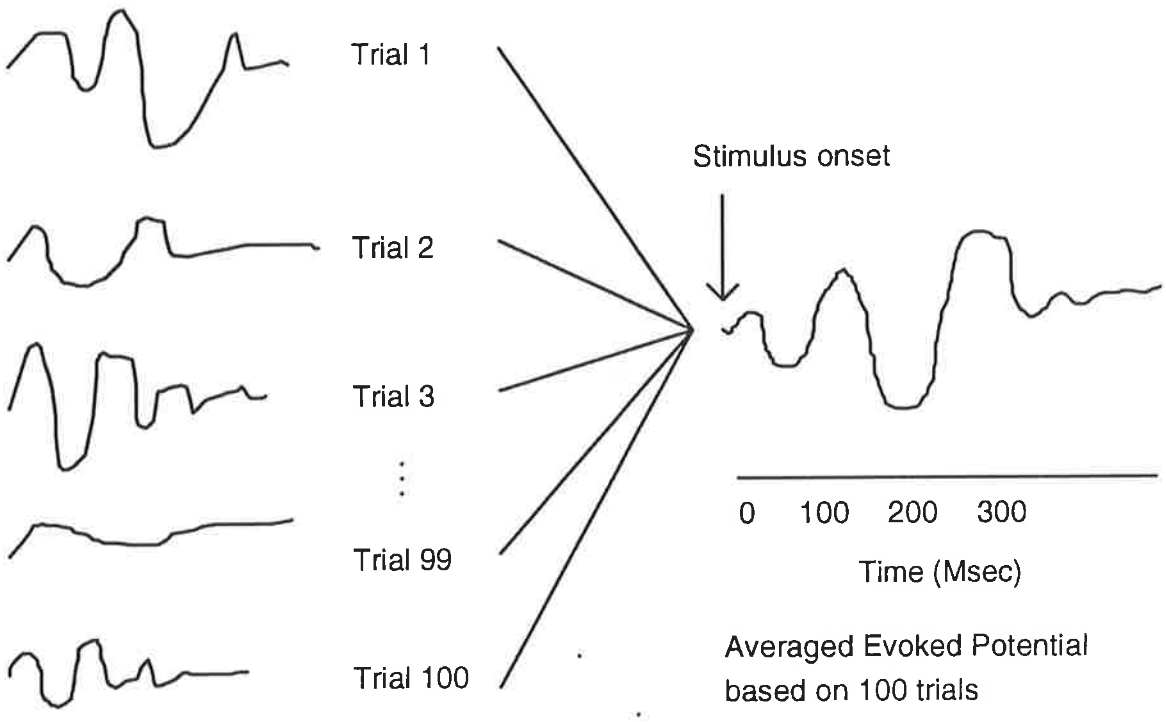
Before Berger's (1929) report of the first scalp-recorded electroencephalogram (EEG), researchers investigating individual differences in ability and intellect limited themselves largely to the study of non-physiological variables (e.g., vocabulary, memory and problem solving skills). The focus was not on physiological processes but on the cognitive processes underlying learning, memory and the effects of differential environmental experiences. This approach ignored the possibility that the central nervous system (CNS) played an important role in influencing individual differences in intellect. Since the invention of the EEG, some researchers have postulated that measurable differences in electrical or chemical processes of the brain may mediate observable differences in intellect.

Early experiments using raw spontaneous electrical activity failed to find significant relationships between the EEG and IQ, and prompted Lindsay (1944) to discount the possibility that the EEG could elucidate any properties of intelligence. Others (Ellingson, 1966; Ostow, 1950) also discounted the possibility of a relationship between EEG parameters (e.g., alpha rhythm) and IQ, although as Vogel and Broverman (1964) indicated in their review of the literature, at least as many confirmatory as disconfirmatory studies had been reported. The results of their meta-analysis suggested that there was indeed a reliable relationship between the EEG and IQ, but that the strongest evidence for that relationship was found in samples of children, institutionalised geriatric patients, individuals with intellectual disabilities and brain injured persons. Ellingson (1966) has provided a more sceptical view of the relationship between EEG and IQ measures but has nevertheless admitted that intellectual impairment is associated with abnormal EEG recordings.

3.3 The AEP Procedure

The evoked response, the precursor to the AEP, heralded an improvement in previous techniques, controlling the presentation of the stimulus, and thereby permitting a more quantifiable measurement of the response (Dustman, Schenkenberg, & Beck 1976). The evoked response procedure measures the electrical response of the brain to short stimuli (e.g., tone pips, light flashes, or a brief shock) and can be observed via a cathode ray oscilloscope. With advances in computer technology, the capacity emerged for storage of a large number of evoked response trials which could then be averaged, all time locked to the onset of the stimulus. This advancement (termed the AEP) enabled the brain's electrical response to a stimulus to be "averaged-out" from the underlying background noise, this providing researchers with new information on the waveform and its underlying component structure under different stimulus conditions.

The AEP procedure usually involves both the presentation of a large number of repetitive stimuli, usually between 50 and 300, and the concurrent recording of electrical potentials on the surface of the scalp. EEG sampling is time locked to the presentation of the stimulus. Evoked responses from single trials are usually noisy in nature (i.e., the electrical activity in response to the signal may not be clearly separated from the ongoing neural background activity) so that the average across many trials is usually regarded as a more reliable measure. Because the evoked responses are time locked from the stimulus onset, they can be averaged across all stimulus presentations, 'averaging-out' the background noise from the system. The averaged signal remains "hypothetically" free from the underlying neural noise, and may represent the 'pure' response of the brain to the stimulus. This procedure is illustrated in Figure 5.



<u>Figure 5:</u> **Diagram illustrating an hypothetical AEP based on 100 evoked potentials trials. Individual trials (left) are regarded as "noisy" and do not allow adequate resolution of evoked potential components. The AEP is normally based on 50 to 300 evoked potentials (right).**

A consistent finding in past AEP studies is that this waveform contains distinctive peaks and troughs which are referred to as components. Although there are variations in the waveform (depending upon the stimulus conditions), the components remain consistent and reliable parameters of the AEP, even given different sensory modalities and methodologies. Figure 6 displays a visual AEP waveform and the characteristic components labelled as P1, N1, P2, N2, P3 and N3. P1 usually refers to a positive component occurring about 100 msec post stimulus, and N1 to a negative component occurring at approximately 140 msec post stimulus. P2 usually occurs around 200 msec post stimulus; N2 around 250 msec post stimulus, and P3 between 300 and 400 msec post stimulus (Donchin, 1984). It should be pointed out, however, that the latencies of these components vary according to the sensory modality and electrode site. P refers to a positive wave and N to a negative wave.

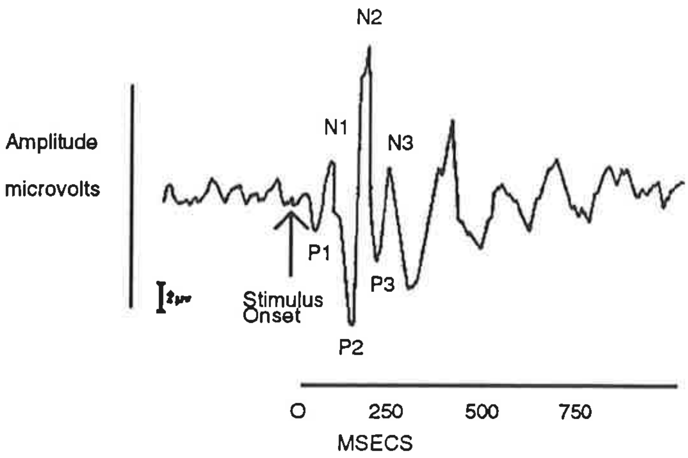


Figure 6: **Diagrammatic representation of the visual AEP (Adapted with permission from H.J. Eysenck (1976). The Cognitive Dimension, p. 167.)**

3.4 AEPs and Intelligence

The first systematic attempt to relate AEP parameters to IQ was by Ertl and his co-investigators (i.e., Barry & Ertl, 1966; Chalke & Ertl, 1965; Ertl, 1971; 1973; Ertl & Schafer, 1969). Employing crude estimation techniques in the identification of visual AEP components, Barry and Ertl (1966) reported correlations of -.88 and -.76 between component latency and IQ in college students. Chalke and Ertl (1965) confirmed that shorter latencies were associated with higher intelligence in a more representative sample of IQ scores. Ertl (1966) reported correlations of -.70 between latency of the third negative peak and IQ in 100 subjects with IQs ranging from 77 to 136. A subsequent replication (Ertl, 1969) obtained a correlation of -.51 between the latency of the third negative peak and IQ in 300 children. In the largest study to date, Ertl and Schafer (1969) tested 573 primary school children (317 males, 256 females; Grades 2 through 8) with the Wechsler Intelligence Scale for Children (WISC), the Primary Mental Abilities test (PMA) and the OTIS test of mental abilities, as well as a visual AEP task in which the subject was required to attend but not to respond to brief photic stimuli. Highest correlations were obtained between the latency of the third and fourth peak and the WISC, PMA, and OTIS scores respectively (-.35 and -.33; -.34 and -.32; -.35 and -.35). Although these three tests of intelligence each pose very different problems for the subject, their correlations with the latency of the third and fourth peaks were nearly identical, indicating that the latency of the third and fourth components may tap some general process common to all tests. Ertl and Schafer (1969) claimed that this finding reflects the role of speed of information processing within the brain, a concept further developed by Hendrickson and Hendrickson (1980) in their biological model of intelligence. Other researchers have made similar suggestions when attempting to explain the processes underlying IT and RT and their relationship to IQ (Brand & Deary, 1982; Eysenck, 1987; Eysenck & Barrett, 1985).

Other studies have provided evidence for an AEP latency-IQ relationship. In a notable experiment, Schucard and Horn (1972) reported correlations between latency measures of the AEP and a battery of psychological tests designed to measure crystallised and fluid abilities, as well as factors relating to speed and level measurements of fluid ability (see Furneaux 1952, 1961). One hundred and eight subjects (60 males, 48 females, with ages ranging from 16 to 68) attended three AEP conditions in which the level of attention and arousal was systematically manipulated from a requirement to respond (high arousal) not to respond but to count (medium arousal) and, finally, not to respond or count but to attend (low arousal). Nearly all the correlations between the IQ tests and latency were negative, ranging from -.15 to -.32, with shorter latency associated with higher IQs. Most significant correlations with IQ were obtained with latencies of the later AEP components in the low arousal condition, a finding consistent with the results from similar methodologies employed by Ertl and his co-workers. In fact, some researchers have warned that significant correlations can only be obtained between AEP measures and IQ if the attentional/arousal level of subjects is held at a relatively low level (Eysenck & Barrett, 1985; Schucard & Horn, 1972). Callaway (1973) has also reported significant negative correlations between P3 latency and IQ in 191 Naval recruits (although much of the detail concerning this experiment was not specified).

Rhodes, Dustman and Beck (1969) examined the relationship between AEP measures (latency and amplitude) and IQ. From a sample of 800 children, two groups of 10 and 11-year-old children were selected, a high IQ group (with WISC scores ranging from 120 to 140) and the second with WAIS IQ scores in the borderline to normal range (70-90). One hundred visual evoked potentials (VEPs) were elicited on two occasions (separated by 1 month) at different light intensities (three levels of intensity). Only one of the latency measures (peak delay), recorded at the occipital site, showed significant differences between the two groups, with the N4 component occurring later in the low IQ group. Importantly, consistent differences were found between the two groups with respect to amplitude, the high IQ group displaying greater responses from both occipital and centrally elicited VEPs at all intensities. A subsequent manipulation of the ages of the subjects into two groups, reported by Dustman et al. (1976), so that each group contained children varying in ages from 4 to 15 years (Group 1: mean IQ = 110; Group 2: mean IQ = 88) resulted in few significant correlations between IQ and these AEP parameters. The authors concluded that intelligence is only weakly correlated with visual AEP amplitude, and only observable when age-related amplitude changes are controlled. Alternatively, differences in amplitude between low and high subjects may merely reflect different levels of attention. A subsequent experiment, reported by the same authors, showed that greater focussed attention was associated with increases in the amplitude of visual AEPs, indicating that amplitude-IQ differences may reflect attentional differences, with high IQ subjects generally more alert than low IQ subjects. This finding was therefore consistent with more recent work by Haier, Robinson, Braden, and Williams (1983), in which larger N1-P2 peak amplitude excursion was related to higher IQ.

Overall, the results of these studies reviewed in this section suggest that both AEP latency and amplitude are related to IQ under different stimulus conditions, and that the attentional demands and arousability of the stimulus has played some part in most of those studies reporting a significant AEP-IQ correlation.

3.5 The string length measure

Hendrickson and Hendrickson (1980) have more recently reinterpreted Ertl's results and developed a model of neural functioning that relates to individual differences in intelligence. As a rationale for their physiological measure of intelligence, A.E. Hendrickson (1982) suggested that at present the IQ test, because of its cultural and environmental biases, is not the best measure of biological intelligence; instead, he suggests that the EEG, or more specifically the AEP, may be a better measure. As evidence, Hendrickson cites studies concerned with the relationship between sensory stimulation, neuronal firing and the AEP waveform. Fox and O'Brien (1965) recorded the activity of single neurones in the cat cortex to large numbers of repetitive visual stimuli (4000 in total). Immediately after the presentation of the stimulus, the pulse train activity of the neuron was measured. The time from stimulus onset to pulse activity at the single neuron was recorded and a histogram of the number of pulse occurrences determined. The close approximation between the histogram reported by Fox and O'Brien and their AEP waveforms was interpreted by A.E. Hendrickson to correspond to the summation of the individual pulses (assuming that the pulses are the same).

The AEP waveform which represents electrical activity measured on the scalp was regarded by A.E. Hendrickson as reflecting the initial pulse activity and its subsequent propagation through the cortex. Thus, the AEP waveform was regarded as a description of the individual pulse trains that are set off by the stimulus. Pulse trains are transmitted from one neuron to the next through synaptic transmission, with errors in propagation of the initial activity resulting in the AEP waveform showing degradation, from one of complexity to simplicity. A.E. Hendrickson (1982, p. 195) proposes that

> **" If high IQ people have high levels of R[3], it may be because their axonal-pulse train transmission has less error in it. If axonal pulse trains give rise to the AEP waveform, then we should be able to see differences between the AEP records of high-IQ people and low-IQ people."**

According to the Hendricksons, it is possible to obtain a measure of the complexity of the AEP which reflects the accuracy of sensory transmission through the cortex by measuring the length of the AEP's contour, which they termed the string-length. It is this measure that they have related to IQ test performance. Those subjects with complicated AEP waveforms are held to have the ability to process information within the brain more accurately (and quickly) and propagate information within the brain with less error, than those subjects exhibiting less complicated AEP waveforms. Eysenck (1982) has elaborated upon this point, suggesting that the important process here is accuracy, with speed of performance therefore a secondary consideration, because inaccurate transfer of information will slow the process.

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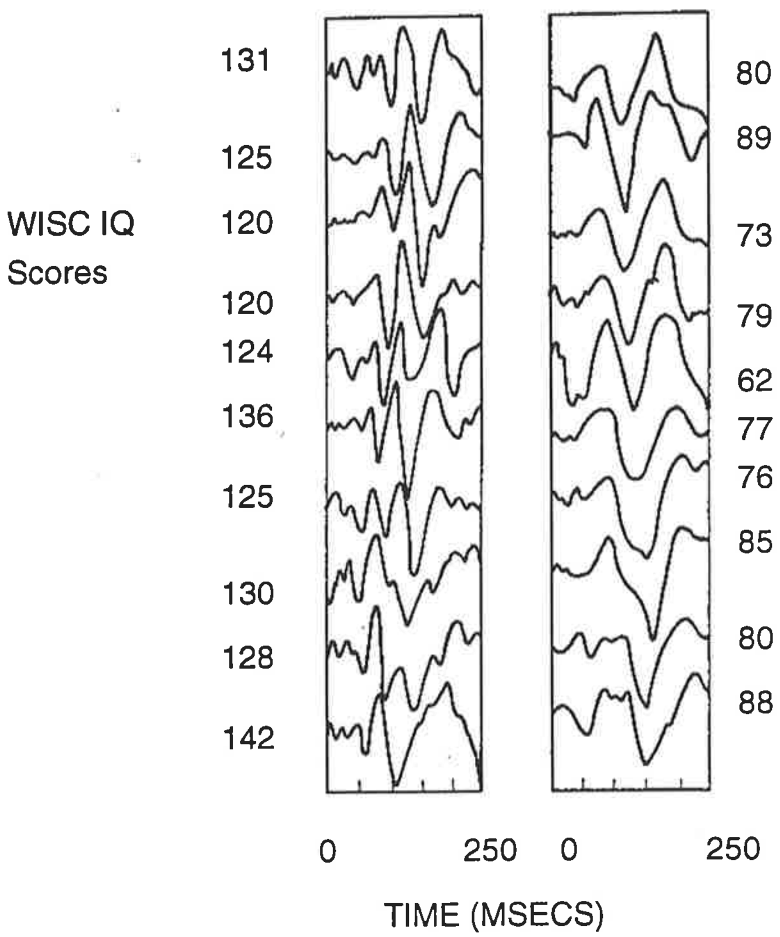
3 According to A.E. Hendrickson (1982), R represents the probability that one synaptic recognition will succeed, i.e., that the message will be accurately propagated from one synapse to the next. This probability will be very high, although because it is assumed that the same information or activity will be propagated through millions of synapses, relatively small differences in R may result in large differences in terms of AEP measurement.

To examine the relationship between the string length and IQ, D. E. Hendrickson (1982) re-analysed data presented by Ertl and Schafer (1969). Results are shown in Figure 7. Among 20 children (10 high WISC IQ and 10 low WISC IQ) the string length measure correlated +.77 with IQ, accounting for more than half the IQ variance.



<u>Figure 7:</u> AEPs for 10 high and 10 low WISC IQ subjects illustrating more complex AEPs for high compared to low WISC-IQ subjects.
[Adapted with permission from Ertl, J.P., and Schafer, E.W.P. (1969). Brain response correlates of psychometric intelligence. <u>Nature</u>, <u>223</u>, 421-422].

Blinkhorn and Hendrickson (1982) also reported significant correlations between string length and scores on the APM among students. AEPs from 100 tones (1-8 second pseudo-random inter-stimulus interval (ISI), 85 dB auditory tone pips) were elicited, although only 90, 64, and 32 trials were used for later analyses. Correlations between the APM and the string length measured +.50, +.36, and +.45 for 90, 64 and 32 trials (averaged) respectively. Other verbal tests (Verbal Concepts and Verbal Critical Reasoning and various divergent thinking tests) were also administered, but did not significantly correlate with the string length. Correcting the correlations for restriction in attenuation of APM scores increased the string length-IQ correlations to a level (.7 to .85) that is characteristic of the internal reliabilities of many IQ tests (Eysenck & Barrett, 1985). This result provided preliminary support for Hendrickson and Hendrickson's (1980) post-hoc re-analysis of Ertl's work, although it should be treated with caution due to the large increase in the magnitude of the correlation coefficients after correction for restriction in range of IQ scores. Nevertheless, this result prompted Blinkhorn and Hendrickson to hypothesise that;

> **"These results, and comparable results reported elsewhere using similar techniques..... suggest the possibility of identifying sources of individual differences in measured intelligence distinct from the quality of cognitive strategies and processes involved in intelligent performance, which might ultimately resolve several of the outstanding issues in differential psychology."**
>
> **Blinkhorn and Hendrickson (1982, pg 597)**

Whether the AEP measure is devoid of the "environmental" variables and the problems associated with the psychometric measurement of intelligence, however, awaits further experimental confirmation.

D. E. Hendrickson (1982) has reported the most convincing support for the string length measure to date. In a sample of 219 school children (Mean age= 15.6 years, SD= 1.13; FSIQ Mean = 108, no SD published) she reported a Pearson correlation between the string length and WISC FSIQ of +.72. Two other AEP measures were also used- a variance measure (a measure of the electrophysiological variability of each trial) and a composite measure (variance minus the string length). These measures correlated -.72 and -.83 with FSIQ respectively. Interestingly, the string length and variance measures may be measuring different aspects of the same process, so that one would predict that the composite measure would correlate more highly (and more reliably) than either one of the measures by itself (Haier et al., 1983).

The WISC subtests correlated between .3 and .8 with the AEP measures, with the overall result providing further support for the preliminary study reported by Blinkhorn and Hendrickson (1982). However, the string length correlated more highly with the verbal subtests of the Wechsler test than with the performance subtests, a finding which was not consistent with the Blinkhorn and Hendrickson result, although different tests were used to assess performance IQ and verbal IQ in the two studies. In both these experiments, the methodology was carefully described to allow future replication. In fact, the Hendrickson methodology may be seen as a careful attempt to extract the important methodological features from past AEP-IQ experiments (especially those by Ertl and his collaborators) and preliminary work by the same authors (see D.E. Hendrickson, 1982 for a detailed description of their methods and apparatus).

Since the Hendrickson (1982) and Blinkhorn and Hendrickson (1982) studies, there have been only a few studies attempting to replicate and extend the string length-IQ relationship. This is surprising, given the potential importance of the string length measure for intelligence theory. Shagass, Roemer, Straumanis and Josiassen (1981) found no significant relationship between auditory, visual and somatosensory string length measures and IQ (Raven's Progressive Matrices) in 20 subjects ranging in age from 18 to 49. However, a large number of positive correlations were obtained between amplitude of both visual and auditory evoked AEPs and IQ (r=.60 for auditory and r=.73 for visual; n=14[4]), a finding consistent with results reported by Haier et al. (1983) and Robinson, Haier, Braden and Krengel (1984), as well as by a number of other studies reporting amplitude-IQ differences. Although Shagass et al. reported non-significant string length-IQ correlations, this may be attributable to the different stimuli and methodologies they employed compared to other investigators (Eysenck & Barrett, 1985; Haier et al., 1983). For instance, the auditory stimuli employed by Shagass et al (auditory clicks for 1 msec at 50 dB SPL over white noise at 75 dB) were not equivalent to the Hendrickson's 1000 Hz tones played for 30 msec at 85 dB. As Haier et al. point out, Bloch's Law would suggest that the stimulus intensities used by Shagass et al. (1981) were much less than those employed by the Hendricksons. In addition, no two identical types of stimuli (i.e., either both auditory, both visual or both somatosensory) were presented consecutively; Shagass et al. employed a different "pseudo' random ISI of between 1.5 and 2.0 seconds, a range which is too narrow to prevent subjects from accurately estimating when the stimulus would occur. Moreover, Shagass et al. also partialed out chronological age from the relationship before any correlations were computed between the PM (Standard Progressive Matrices) and the AEP variables. Following Schucard and Horn (1972), this transformation may have served to lower the correlation between the string length and IQ, as an ageing central nervous system (CNS) would hypothetically result in less complex AEP waveforms, and therefore shorter string lengths. Finally, because the PM was used instead of the APM as the measure of intelligence in the high IQ group, a ceiling effect occurred, this again reducing the possibility of identifying a positive relationship between the string length and IQ. Subsequent correlations were based on only 14 subjects from the original sample of 20 subjects, and no correlations were

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4 No reason was reported for the smaller sample size.

reported between the amplitude and IQ measures for the original set of subjects. Nevertheless, Shagass et al. did obtain high correlations between their amplitude measure and IQ in 14 subjects, suggesting that AEP amplitude is an important correlate of IQ, a point further elaborated by two consequent studies by Richard Haier and David Robinson.

In their first study, Haier et al. (1983) set out to examine the relationship between amplitude measures and IQ (a subject investigated in a number of studies, e.g., Dustman et al., 1975; Rhodes et al., 1969; Shagass, 1972, Shagass et al., 1981) and the string length and IQ. In addition, Haier et al. (1983) argued that the intensity of the stimulus may play an important role in determining amplitude differences, so that at low stimulus intensities, amplitude differences may be less evident because of poor signal-to-noise ratios. They also argued that at high intensities, saturation of some evoked potential components occurs, which may reduce the observed amplitudes (Clynes, Kow, & Liftshitz, 1964; Van der Tweel, & Ver duyn Lunel, 1965). To examine this possibility, 23 students (22 females) were tested with the APM, together with a visual AEP task. These subjects viewed in total 256 light flashes (64 at each of four intensities), of 500 msec duration, separated by 1 second. The same procedure was followed in an identical session, so that the reported measures (string length, P1 amplitude, P2 amplitude, and peak N1-P2 amplitude excursion (also known as N140-P200 elsewhere) were an average of the two sessions. Although significant correlations were obtained between the string length measure and APM scores, the authors reported larger associations between APM and amplitude measures, especially the peak N1-P2 amplitude excursion (up to .69; $p<.0005$). They argued that the highest IQ-amplitude correlations are seen at optimal stimulus intensities. Although the N1-P2 peak amplitude excursion measure was highly correlated with the string measure, ranging from .74 to .80 for different string epochs, when the N140-P200 measure was partialled out of the string length-IQ correlations, this association became small and negligible. This finding would then suggest that the string length parameter is only an "epiphenomenon" of the N140-P200 amplitude excursion differences.

Apart from the main finding, that stimulus intensity is important in determining the strength of the relationship between AEP measures and IQ, the results of Haier et al, (1983) may have clarified an unresolved inconsistency found in the literature. Past studies that have failed to find statistically significant amplitude-IQ correlations may have used stimulus intensities at lower levels. Another finding relates to the model of brain functioning proposed by the Hendricksons. If the reported amplitude-IQ correlations are determined by stimulus intensity, then the activity of the central nervous system (measured by AEPs) relates to intensity in a more direct manner than the proposed biological model hypothesised by the Hendricksons (Haier et al., 1983). Whether this is demonstrated or not awaits future empirical work, but, as Eysenck and Barrett (1985) point out, direct comparisons between the Haier et al. results and previously published material on the string length cannot be objectively made, due to the employment of completely different experimental conditions in the different studies.

In a similar study, Robinson et al. (1984) replicated the results of the Haier et al. (1983) study, but only when 12 subjects (out of 27) were excluded from the analysis because of age, sex and measurement error. Importantly, significant correlations between the string length and IQ were only obtained for female subjects. It should be pointed out that 22 of the 23 subjects tested by Haier et al. (1983) were also females. Caryl and Fraser (1985) have obtained a correlation of .8 between the string length and APM in 10 subjects (IQs ranging from 105 to 140) using stimulus parameters and procedures faithful to the

Hendricksons' experiments. However, in view of the small sample, and the fact that these investigators report rejecting about 70% of the original sample because of unacceptably high inter-electrode resistances, this result should also be interpreted with caution.

To date, it has been difficult to evaluate the Hendricksons' string length measure, since only a few studies have been published that have attempted to replicate faithfully their experimental protocol. Although these other studies (Shagass et al., 1981; Haier et al., 1983; Robinson et al., 1984; Caryl & Fraser, 1985) have been valuable, the important task of empirically testing the established theory and/or experimental results presented by the Hendricksons has been forgotten. As Eysenck and Barrett (1985) comment in their review of AEP-IQ research;

> **" In concluding the examination of the Hendrickson paradigm, it must be said that, to date, their EEG results have not yet met the rigorous challenge that is demanded by initial results of such import and clarity. Rather, it appears that a somewhat sporadic nonchalant approach has been adopted by the Shagass et al. and Haier et al. studies."**
>
> **Eysenck and Barrett (1985, p26.).**

Although this opinion is now nearly 10 years old, it is still relevant. Since 1985 there has been only a handful of experiments investigating the relationship between the string length and IQ. Barrett and Eysenck (1992) have recently reported correlations between string length and IQ ranging from -.20 to -.44 at various electrode sites in 40 subjects. Importantly, the correlation between the sting length and IQ was <u>negative</u> rather than the <u>positive</u> correlation reported in most previous studies. Bates and Eysenck (1993) interpreted this result as reflecting the role of attention in string length-IQ correlations. In their view, the procedural conditions were such that subjects were asked to attend actively to the tones. In all other respects the Barrett and Eysenck (1992) study was a faithful replication of the A. E. Hendrickson (1982) study.

Widaman, Carlson, Saetermore and Galbraith (1993) have also reported negative correlations between the string length measured at Cz, T3 and T4 electrode sites at three different stimulus intensities, and fluid and crystallized IQ measures obtained from WAIS-R sub-tests (derived from Horn, 1985) in 48 students. Correlations between string length, variance, and latency and amplitude of AEP components (P1, N1, P2 and N2) were generally not significantly different from zero at Cz, T3 or T4 at any stimulus intensity. There was a small (although significant) negative correlation between AEP amplitude and string length with a crystallized intelligence factor from the WAIS-R at Cz at the highest stimulus intensity (85 dB SPL). It should be noted that the experimental conditions were quite different from those described by A.E Hendrickson (1982) which, again, makes comparison across studies difficult. Widaman et al employed a stimulus duration which was more than three times longer than that used in the Hendrickson studies, did not employ a pseudo-random ISI, and used tones of different stimulus intensities in the same stimulus sequence. Also it is difficult to interpret the role of attention in this experiment because it is unclear whether subjects were required to respond, attend but not respond, or simply attend or not attend. These requirements, following the review presented earlier in this chapter, appear to be important. Thus, even recent experiments are difficult to interpret because of the different methodologies employed.

Experiment 2

3.7 The Relationship between Parameters of the AEP and IQ[5].

3.7.1. Rationale

Experiment 2 was designed to investigate the string length-IQ relationship using a near identical methodology to that described by D.E. Hendrickson (1982). The few studies that have attempted to replicate the string length-IQ relationship (Haier et. al., 1983; Haier et. al., 1984; Shagass et. al., 1981) have used different methodologies and therefore have not been able to assess the replicability of the Hendricksons' results.

The only change in the methodology of Experiment 2 relative to that described by the Hendricksons was to decrease the tone intensity to 70[6] dB Sound Pressure Level (SPL). To investigate the relationship between the string length and IQ more adequately the AEP epoch was partialled into more discrete temporal units than previously reported in past experiments. This tested therefore whether the string length-IQ relationship can be localised to a specific temporal epoch or applies to a general temporal period. Two "mainstream" IQ tests, measuring both verbal IQ, performance IQ and general IQ were included to resolve a past inconsistency in the literature regarding the relationship between the string length and VIQ and PIQ and between the string length and

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5 An analysis of the first 20 subjects was published as Stough, C.K.K., Nettelbeck, T., & Cooper, C. (1990). Evoked Brain Potentials, String Length and Intelligence. Personality and Individual Differences, 11, 401-406.

6 During initial piloting of this experiment, some subjects became startled with the tones administered to them at 85 dB SPL (Hendrickson tone intensity). It was therefore decided that for Experiment 2 a tone of 70 dB SPL would be used. As Haier et al (1983) have argued that larger string length-IQ correlations are obtained employing strong rather than weak or moderate stimulus intensities, the moderate stimulus intensity used in this experiment may allow the possibility that the string length derived at 70 dB SPL would not correlate with IQ. If no significant string length-IQ association could be demonstrated at 70 dB SPL, then a within subjects design would have been employed using both tone intensities.

gf and gc. The APM and WAIS-R have been the two tests used in nearly all previous experiments concerned with the string length, although both have never been used together.

3.7.2 Methodology

Subjects

Seventy first-year Psychology students (49 females and 21 males) with a mean age of 18.2 years (SD= 1.1) ranging from 17 to 21 years were tested .

Procedure

Subjects participated on a voluntary basis, attending, in total, one EEG session and one or two additional sessions for the administration of the WAIS-R test. All students had earlier participated in a group testing session at which time the APM was administered. The order between the WAIS-R IQ and the EEG session was varied but approximately balanced. Instructions for the EEG measurement emphasised that each subject should close his/her eyes and attend to a series of tones to be played through headphones, but that no other response would be required.

EEG Measurement

Subjects were seated, with high quality stereophonic headphones (SONY MDR-M55) and electrodes attached, in a darkened, lead-lined room. After a brief period to permit the subject's adjustment to the EEG testing room and to the attached electrodes, 100 tone pips each of 30 msec duration (with negligible rise and fall times) and a frequency of 1000 Hz and intensity of 70 dB SPL were presented in a sequence with random ISI, ranging between 1 and 8 seconds. The EEG was recorded from the vertex (Cz) position in the 10-20 international electrode placement system and referred to the left mastoid electrode.

Electrodes were silver/silver-chloride, 9 mm in diameter; inter-electrode resistance was below 10 kilohms and usually below 5 kilohms. The electrical signals were amplified through a Neomedix "Neotrace 800 ZF" physiological recorder, with the -3 dB band pass limits of the EEG preamplifiers set to 2 and 125 Hz and amplified 10,000 times. A ground electrode was connected to the right mastoid. The EEG record was sampled for 1 sec per trial (from 300 msec prior to stimulus onset and 700 msec after stimulus onset) at a sampling rate of 4 msec, i.e., 250 times/sec. Output data were subsequently transferred to a computer for averaging and analysis.

3.7.3 Results and Discussion

IQ scores

Mean (and SD) for VIQ from WAIS-R was 112.0 (11.0); for PIQ, 112.5 (13.6); and for FSIQ, 113.6 (11.6), and 25.9 (4.8) for the APM. The ranges of scores were 89-132; 86-134; 92-135; and 11-33 for VIQ, PIQ, FSIQ, and APM raw scores, respectively. Table 10 presents the correlations between scores of the subtests of the WAIS-R and the APM. The inter-correlations between VIQ, PIQ, FSIQ and APM scores were generally similar to those reported by Wechsler (1981) and Anastasi (1982), although smaller in magnitude, probably reflecting the restriction in range of IQ scores in this sample. The corrected correlation between VIQ and PIQ was .65, compared to the .74 cited by Anastasi (1982).

Table 10:
Uncorrected Pearson correlations between IQ scores on the WAIS-R and raw APM scores (N=70; Experiment 2)

	PIQ	FSIQ	APM
VIQ	.48**	.88**	.50**
PIQ		.79**	.53**
FSIQ			.60**

** p<.05; ** p<.01*

String lengths at 70 dB SPL

String length was calculated using the following equation

$$\frac{\sum_{i=m}^{n} (avpot_{i-1} - avpot_i)^2}{(m-n+1)}$$

where m= string start; n= string end; and *avpot*= the average potential per point over the trials.

Unlike other investigations of the string length parameter, separate string lengths were calculated over several different temporal epochs following stimulus onset (0-100, 0-200, 0-250 100-200 and 100-300 msec). Table 11 summarises the magnitudes and significance of the Pearson correlations between the string length (measured over different temporal epochs) and the subscales of the WAIS-R and APM scores. The figures in parentheses represent Pearson correlations, corrected for restriction in range and IQ test reliability. On the whole the results were similar to those reported by Stough, Nettelbeck, and Cooper (1990), which were based on an analysis of the first 20 subjects of the present sample. However, a significant difference between the previous result and the result based on the larger sample reported in Table 11 was that in the earlier version the string length did not correlate significantly with the APM at any temporal epoch. This result is plausibly attributable to the restriction in attenuation of APM scores among the first 20 subjects, and increasing subject numbers which increased the range of APM scores. Nonetheless, correlations between the various string lengths and the APM were still smaller in magnitude than those between string lengths and WAIS-R IQ variables.

Table 11:
Uncorrected correlations (top rows) between string length at different epochs, IQ scores and raw APM[7] scores together with correlations corrected for restriction in range and test reliability (bottom rows). (N=70; Experiment 2)

Epochs	VIQ	PIQ	FSIQ	APM
000 - 100	.28 *	.23	.29 *	.24
	.37**	.25	.36**	
000 - 200	.61 ***	.42 *	.51 **	.31 *
	.72 ***	.45 **	.60 **	
000 - 250	.61 ***	.50 **	.61 ***	.39 **
	.72 ***	.54 ***	.73 ***	
100 - 200	.65 ***	.47 ***	.64 ***	.33 *
	.76***	.51 ***	.77 ***	
100 - 300	.60 ***	.43 *	.55 ***	.29 *
	.71 ***	.46 **	.65 ***	

** p< .05, ** p< .01, *** p< .001*

The results reported here are consistent with those reported by A.E. Hendrickson (1982), Blinkhorn and Hendrickson (1982), and Haier et al. (1983), in that they provide further evidence for the significance of the string length-IQ relationship. The magnitudes of the correlations between these two

[7] No correlations corrected for restriction in range, between string length and APM scores, have been calculated due to the poor norms of the APM test.

variables tend to suggest that, although the materials and nature of the IQ test and EEG measurement are different, they both tap some common process. Whether this common process is related to personality or temperament variables, as suggested by Howe (1990), is empirically tested in Chapter 6. The uncorrected correlations are likely to underestimate significantly the magnitude of the correlation between the string length and IQ in a normal distribution because of the relatively narrow range of IQ scores obtained in this study. The "true" correlation may lie somewhere between the corrected and uncorrected correlations found in Table 10, and it is for this reason that both the corrected and uncorrected coefficients are provided. Nevertheless, even in an average to above average IQ group, the finding that electrical brain activity is related to abilities normally considered to be important, in a practical sense, in everyday life, and with processes of learning, is obviously an important first step in the formulation of a biological model of intelligence or even towards the reconstruction of intelligence as a scientific construct.

The highest correlations between the various string lengths and IQ (particularly VIQ) occurred after 100 msec post-stimulus. A significant difference was obtained between the VIQ-string length correlation measured from 100-200 msec post stimulus and the VIQ-string length correlation measured from stimulus onset to 100 msec post stimulus epoch (t_{69}= 2.14; $p<.05$). This suggests that physiological processes that correspond to achievement on an IQ test may be more pronounced in terms of measurement after 100 msec, although it should be noted that significant correlations with IQ, albeit small in magnitude, were still observed between IQ and string length in the period 0 to 100 msec post stimulus. Therefore, it should not be concluded that processes occurring during the first 100 msec are unimportant in terms of AEP-IQ correlations. The correlation obtained between the string length and IQ scores in this epoch were of the same magnitude often found in IT-IQ studies in which the first 100 msec reflects the time required to discriminate adequately the IT stimulus. Thus if it is assumed that the first 100 msec post stimulus of the AEP record reflects stimulus input processes then the present result suggests that AEP-IQ correlations are more than merely a reflection of input speed processes. Indeed it may be hypothesised that the higher correlations between IQ and the string length, measured after 100 msec, may reflect input speed differences as well as stimulus processing differences. It should be interesting to correlate IT and string length in different temporal epochs to test if perceptual speed, as indexed by IT, is one aspect of the correlation between the string length and IQ, and if so, at what epoch of the AEP. Thus, it would appear that differences in input speed are an important but not adequate explanation for string length-IQ correlations.

The fact that nearly all SL-IQ correlations were statistically significant, together with the fact that the magnitude of the correlations ranged from .3 to .7, suggests that the string length measure of AEP complexity is a robust and important correlate of IQ over all temporal epochs (at least to 250 msec post stimulus).

VIQ-PIQ Differences

The correlations between the string length and VIQ were significantly greater than those between the string length and PIQ except over the first 100 msec post stimulus (see Table 12). This result is in agreement with the D.E. Hendrickson (1982) study, in which she tested schoolchildren on the WISC-R and reported that VIQ correlated more significantly with string length scores than did PIQ. Although significant differences were obtained for correlations between both VIQ and PIQ with the string length, correlations between PIQ and the string length were nevertheless on the whole significantly larger than correlations between the string length and PIQ. Here, the possibility is raised that IT, RT and AEPs may not correlate with IQ because of the same underlying physiological process. If so, then some ECTs may provide better correlations with verbal IQ measures while others provide more substantial correlations with performance measures. The somewhat lower correlations between the string length and the APM, which is normally regarded as a good measure of general intelligence, may suggest that the string length correlates less well with general intelligence than with verbal intelligence measures.

Table 12:
Comparison of the difference between SL-PIQ correlations and SL-VIQ correlations (N=70, Experiment 2).

Epoch	t	N	Significance
000 - 100	1.00	70	N.S.
000 - 200	2.59	70	$p < .05$
000 - 250	1.84	70	$p < .05$
100 - 200	2.32	70	$p < .05$
100 - 300	2.78	70	$p < .05$

Table 13 displays the correlations between string length measures and two factors of the WAIS-R which Horn (1985) has described as reflecting fluid and crystallised abilities. Although both fluid and crystallised IQ correlated significantly with the string length, the magnitude of these correlations were smaller than those reported in Table 11 between VIQ and the various string length epochs. Correlations were slightly higher in magnitude for crystallised compared to fluid IQ, which is consistent, and indeed, inevitable, because of the larger correlation between string length and VIQ, compared to PIQ[8]. This result is important because it addresses the Eysenck (1982) suggestion that AEP parameters are more closely associated with fluid than crystallized

[8] This is inevitable as the crystallized and fluid IQ subscales are derived from similar sub-tests of the WAIS-R as VIQ and PIQ respectively.

measures of intelligence which, he has argued, provides a closer approximation to Intelligence A or Biological Intelligence. A related samples t-test conducted on transformed Fischer z scores revealed a significant difference between correlations between string length epochs and crystallized and fluid IQ measures reported in Table 13 (t_4= 5.0, $p < .01$).

Vernon (1983) has also discussed whether correlations between AEP parameters and IQ reflect Intelligence B and suggests that it is plausible that the development of intelligence produces neurophysiological changes which may change the EEG pattern. The present results suggest that the string length is a better correlate of intelligence measures thought to reflect the attainment of knowledge and education (i.e. VIQ) than fluid measures, although, as Brody (1985) has explained, it is difficult to explain differences in knowledge without differences in ability to learn and assimilate knowledge.

Table 13:
Correlations between fluid, and crystallised IQ measures obtained from Horn's (1985) formula using WAIS-R sub-tests, and various string length epochs (N=70, Experiment 2)

Epoch	gf	gc
000-100	.10	.23
000-200	.21	.37*
000-250	.35*	.48**
100-200	.41*	.49**
100-300	.20	.46**

** p < .05 ** p < .01*

Sex Differences

Previously, two studies by Haier et al. (1983) and by Robinson et al. (1984) have demonstrated significantly larger string length-IQ correlations in samples of female subjects compared to male subjects. Therefore it was expected, on the basis of previous results, that string length-IQ correlations would be sensitive to sex differences. Statistical analysis did not confirm this hypothesis. No significant differences were found between male and female subjects on any of the string length measures, except for the string length epoch 0-200 msec post stimulus (Table 14).

Table 14:
t-Tests investigating differences in string length scores between males and females in the sample
(N=70; Experiment 2)

Epochs	t	df	p (two tailed)
000-100	**1.38**	**68**	**N.S.**
000-200	**2.05**	**68**	**P < .05**
000-250	**.17**	**68**	**N.S.**
100-200	**.80**	**68**	**N.S.**
100-300	**1.01**	**68**	**N.S.**

These results should be treated with caution, because of the small number of males (N=12) involved in the study. Because the string length measured from 000-200 msec post stimulus was significantly different for males and females, Pearson correlations were computed between string length and IQ, with sex partialled out of the correlation. The results are reported in Table 15.

Table 15:
Correlations between string length, VIQ, PIQ, FSIQ, and APM scores with sex partialed out.

Epoch	VIQ	PIQ	FSIQ	APM
000 - 100	.38*	.22	.30*	.25
000 - 200	.60***	.38*	.49**	.32*
000 - 250	.64***	.45**	.59***	.39**
100 - 200	.67***	.49**	.61***	.32*
100 - 300	.55***	.34*	.47**	.27*

** p< .05; ** p< .01; *** p< .001*

These correlations should be compared to the uncorrected correlations reported in Table 11. Results do not support the notion that sex differences determine correlations between string length and IQ, as reported by Haier et al. (1983) and Robinson et al. (1984).

Inter-trial variability at 70 dB SPL.

Inter-trial variability (variance) within each epoch was also correlated with IQ variables. These correlations are reported in Table 16. Correlations were on the whole non-significant with all IQ measures (24 out of 25 were non-significant), suggesting that the string length and variability measure do not both correlate with IQ. The Hendrickson (1982) suggestion that correlations between the string length and IQ are a consequence of individual differences in trial variability was therefore not supported, which suggests that the correlation must be explained by processes other than between-trial variability.

Table 16:
Correlations between various "Variance" measures and IQ variables from the WAIS-R (N=70; Experiment 2).

Epoch	VIQ	PIQ	FSIQ	Gf	Gc
000-100	.02	.17	.09	.06	-.11
000-200	.14	.15	.16	.11	-.02
000-250	-.07	.15	-.03	.06	-.15
100-200	.05	.14	.09	.04	-.06
100-300	-.21	-.21	-.06	-.17	-.12

Correlations between string length and variance measures.

Correlations between string length and variance were only significant for epochs that did not include the measurement of the first 100 msecs post stimulus (100-200 msec $r= .44$, $p < .01$; 100-300, $r= .61$. $p < .01$). Inter-trial variability (variance) correlated positively with string length, suggesting that, contrary to the Hendrickson and Hendrickson (1980) proposal, greater variability does not lead to smaller but to longer string lengths. The rationale for the string length, therefore, must be revised to account for these results.

Component analysis

In addition to the string length and variability measures, other AEP parameters were recorded and scored. This was done to examine the relationship between the string length, variance, IQ and amplitude and latency of AEP components. Amplitude and latency of the P1, N1, and P2 components were computed for each subject and related to IQ scores. The results are presented in Table 17.

Table 17:
Uncorrected correlations between amplitude and latency of AEP compoents and VIQ, PIQ, FSIQ, and APM scores (N=70; Experiment 2).

Component	VIQ	PIQ	FSIQ	APM
P1 Latency	-.30*	-.33*	-.32*	-.41**
P1 Amplitude	-.09	.02	-.06	-.03
N1 Latency	-.23	-.29*	-.28*	-.48***
N1 Amplitude	.39**	.16	.24*	.09
P2 Latency	-.36*	-.36*	-.43**	-.55***
P2 Amplitude	.36*	.12	.21	.20

* $p < .05$; ** $p < .01$; *** $p < .001$

Generally, shorter latencies, and, to a lesser degree, longer amplitudes were associated with higher IQ scores. This finding is consistent with previous studies, mainly by Ertl and his colleagues, who have demonstrated a relationship between latency, amplitude and IQ in large samples. It remains to be seen if latency and amplitude of AEP components may also relate to differences in speed of information processing, specifically IT and RT measures. Faster information processing may lead to the resolution of earlier components, or to larger amplitudes, if it is assumed that subjects with, for example, shorter ITs, reflect the resolution of more stimulus information per unit time than subjects with longer ITs. Recently, increased EEG sampling as reflected in 40 HZ activity has been reported to be related to perceptual processes (Crick, 1991) so it is plauisble that the latency of the AEP components may also be influenced by perceptual processes.

Interestingly, the highest correlations were obtained between the APM and component latency. The pattern of correlations between the two IQ tests and various AEP parameters is a curious one: string length is more highly correlated with WAIS-R IQ but latency is more highly correlated with APM.

Thus it may be proposed that general intelligence (APM) is more related to latency of AEP components while string length is more related to specific abilities, particularly verbal ones.

Table 18 reports the Pearson correlations between various string lengths and latency and amplitude scores from the P1, N1, and P2 components. High to moderate correlations were obtained between the amplitude of the N1 and P2 and all string length epochs except that from 0-100 msecs post stimulus. As amplitude and IQ were only weakly correlated in this sample then it is unlikely that the most important aspect of the relationship between the string-length and IQ is amplitude, as suggested by Haier et al. (1983). In order to examine whether amplitude determines the correlation between string length and IQ, partial correlations were calculated iin which the effects of N1 and P2 amplitude were removed from the correlation (Table 18)

Table 18
Correlations between VIQ and string length (various epochs) with N1 amplitude and P2 amplitude partialled out (N=70, Experiment 2)

Epoch	VIQ-string length Unpartialled	VIQ-string length N1 Amp Partialled out	VIQ-string length P1 Amp Partialled out
000-100	.28**	.21*	.24*
000-200	.61***	.50***	.43**
000-250	.61***	.55***	.52***
100-200	.65***	.57***	.55***
100-300	.60***	.50***	.43**

** p < .05, ** p < .01, *** p < .001*

Results reported in Table 18 suggest that N1 and P2 amplitude differences account for a small part of the correlation between the string length and IQ but that the majority of this relationship must be explained in other terms. The fact that the string length-IQ correlations could only partially be explained by amplitude differences (at 70 dB SPL) may suggest that the Haier et al. hypothesis is incorrect in studies employing the Hendrickson methodology in which tones are presented at the weaker intensity (70dB SPL). However, the possibility remains that although the string length, independent of amplitude, is strongly correlated with IQ at 70 db SPL amplitude independent of the string length may be strongly correlated with IQ at *higher* stimulus intensities. As Haier did not employ the Hendrickson methodology, the failure of the string length at moderate to weak stimulus intensities to correlate with IQ cannot be directly compared to findings following the Hendrickson methodology.

Table 19:

Correlations between various string lengths and amplitude and latency of the P1, N1, and P2 components. (N=70; Experiment 2).

Epoch	P1 Latency	P1 Amplitude	N1 Latency	N1 Amplitude	P2 Latency	P2 Amplitude
100 -200	.35*	-.14	-.15	.61***	-.25	.72***
000 -250	-.20	.00	-.11	.44**	-.19	.52**
000 -100	.00	.21	.00	.02	-.04	-.03
000 -200	.31*	.03	-.37*	.49**	-.35*	.63***
100 -300	.22	-.24	-.18	.41**	-.25	.61***

* p< .05; ** p< .01; *** p< .001

Inspection of Table 19 also provides evidence on the processes underlying the string length measure of AEP waveform complexity, and for the importance of amplitude in string lengths after 100 msec. Although amplitude of the N1 and P2 components post 100 msec accounted for large and significant amount of the string length variance, other factors, which have yet to be identified are also important. Nevertheless, both N1 and P2 amplitude appear to be very important variables for studies wishing to examine AEP-IQ relationships. The N1 component occurs typically somewhere from about 70 to 150 msec post stimulus, and has been the subject of much cognitive AEP research which has addressed attentional processes underlying N1 amplitude and this will be further examined and discussed in Chapter 4. P1 amplitude and latency are poor and inconsistent correlates of string length, which is consistent with the correlations between IQ and the string length derived from 0-100 msec post stimulus reported earlier in this chapter. One possible explanation is the poor reliability of parameters of the AEP waveform in the first 100 msec when only 100 trials are averaged. It is well known that the earlier components of the AEP are much smaller than the later components. For instance, the components originating from the brainstem are in the single microvolt range, so that thousands of trials may be required for their accurate estimation. Components later than these, e.g., the N1, may require several hundred evoked potential trials compared to later components, e.g., P3, which may only require 30 EP trials for their reliable resolution. An AEP is dependent on the signal-to-noise ratio, so that more trials are required if the signal is noisy. Generally it is accepted that a signal-to-noise ratio of approximately 2 is required for reliable estimation of the AEP (Clarke, 1993). The signal to noise ratio may decrease in proportion to the square root of the number of trials. If the noise is assumed to be constant across an EP trial, the number of trials required for correct estimation of the component is dependent on the frequency of the component. Thus correct estimation of earlier components requires significantly more trials than the latter components. These issues have been discussed at length by Coppola, Tabor and Buchsbaum (1978) and more recently by Turetsky, Raz and Fein (1988). Future research may wish to administer larger numbers of trials. That only 100 trials are averaged may be a serious methodological problem in the Hendrickson paradigm if researchers are interested in the first 100 msec post stimulus. Particularly relevant are the low correlations between the string length measures from 0-100 msec and IQ. This problem, which may also account for some of the inconsistent results of other experiments reported to date, is examined in the next section in which preliminary test re-test reliabilities are reported. If 100 trials are insufficient for the reliable average of EEG processes in the first 100 msec then it is predicted that test re-test reliability for the string length measured over the 100 msec will be low compared to the reliability of the string length measured after 100 msec.

3.8 Preliminary test re-test reliabilities for the string length measure.

3.8.1 Rationale and Introduction

The results of Experiment 2 suggested that the string length measure of AEP waveform complexity is a significant predictor of individual differences in IQ. However, correlations between string length and IQ measured in the first 100 msec were generally lower than correlations between the string length measured after 100 msec and IQ. One explanation offered for this was that 100 trials are not sufficient to reliably resolve AEP components in the first 100 msecs. This experiment reports preliminary reliability data for the string length measure (70 dB) over a 12 month period. The result should be regarded as preliminary because of the small sample size.

3.8.2 Method

Subjects

Twenty subjects who had participated in Experiment 2, chosen at random agreed to be tested 1 year after their first string length measurement.

Procedure and Equipment

In all respects, the procedure and equipment was identical to that reported in Experiment 2.

3.8.2 Results and Discussion

Table 20 reports the Pearson test re-test reliabilities for string lengths measured over different epochs. Given the large error associated with Pearson correlation coefficients calculated on such a small sample as the present one,it was deemed prudent to accept correlations of the order of .5 as reflecting reasonable test re-test reliabilities. Results suggested that the string length showed reasonable reliability after 100 msec post stimulus. Reliability for string length measured between 0 and the first 100 msec was poor. Generally, the reliabilities reported in Table 20 are consistent with the earlier suggestion that the string length derived from the Hendrickson methodology may not be able to reliably resolve EEG processes occurring in the first 100 msec post stimulus. This explanation, as stated before, may account for the relatively better correlation obtained between string lengths and IQ measured after 100 msec compared to correlations obtained in the first 100 msec.

Future research may wish to systematically vary the number of trials to investigate issues of reliability and correlation with IQ. These results raise the possibility that increasing the number of trials may produce similar correlations between IQ and string lengths measured before and after the first 100 msec post stimulus.

Table 20:
Test re-test reliabilities for the string length measure at different epochs.(N=20; Experiment 2)

Epoch	Correlation
100-200	.52*
000-250	.26
000-100	-.21
000-200	.15
100-300	.54*

* $p < .05$

3.9 General Discussion

The results of Experiment 2 provided further evidence for a significant and strong relationship between the string length parameter of the AEP and IQ. The study also provided some support for other studies, particularly by Ertl and his collaborators, linking shorter AEP latencies with higher IQ. One possible explanation for this may be that shorter latencies reflect faster processing of stimuli within the brain. Quicker processing, as the Hendricksons have suggested, may be a secondary measure of the primary process efficiency. If mistakes are made, then longer time is required to correct for those mistakes. Along these lines, it may also be possible that, after mistakes are made, the system samples the information for longer periods of time, in order to correct inefficiencies in the nervous system. One may speculate that faster perceptual systems will exhibit shorter ITs, shorter DTs and commensurate shorter AEP latencies and larger AEP amplitudes. Variance was a poor correlate of IQ, raising the possibility that string length-IQ correlations are not related to error/ variability processes as suggested by Hendrickson and Hendrickson (1980), but to other processes which at least to a small degree reflect amplitude differences. The fact that the variance measure did not significantly correlate with IQ disputes the Mackintosh (1986) assertion that string length-IQ correlations reflect differences in concentration or sustained attention. The rationale here is that high IQ subjects are better able to concentrate for all the 100 trials, concentration leading to less variable EPs. Thus, the string length-IQ correlation requires a different explanation.

Contrary to the findings of Haier et al. (1983), Robinson et al. (1984), and Shagass et al. (1981), this experiment found limited support for the reported amplitude-IQ association, although amplitude was highly and significantly correlated to string length scores and weakly correlated with IQ. A possible explanation for this finding is that this relationship may not be observed in studies using low to moderate stimulus intensities. The arousability of stimulus conditions (e.g., Gale, 1983) appears to be important in AEP studies. It was noted earlier in this chapter that levels of arousal and focussed attention were important factors in many of the previous studies which showed a significant AEP-IQ relationship. Another possibility is that the relationship does not hold in the auditory modality as well as in the visual modality. Empirical validation for the amplitude-IQ-stimulus intensity relationship is yet to be satisfactorily provided, the different methodologies employed in the two studies preventing a definitive conclusion. The correlation between latency of N1 and P2 and IQ was large enough to be the focus of continued research. Shorter N1 and P2 latency was significantly related to higher IQ scores, particulalrly on the APM, which suggests that the latency of N1 and P2 may reflect differences in general intelligence.

The experimental work discussed in this Chapter also provided some evidence for the lower reliability of the AEP from 0 to 100 msec post stimulus when the AEP is based on 100 EP trials. This explannation accounts for the lower correlations between IQ and the string length measured from 0 to 100 msec post-stimulus compared to later epochs, and for the lower correlation between

P1 amplitude and IQ compared to correlations between IQ and the amplitude of N1 and P2.

String length was a significantly better predictor of VIQ than PIQ, which supports the Vernon (1983) suggestion that the AEP may reflect biological processes which have become adapted to learning and which reflect individual differences in vocabulary, arithmetic and such skills normally associated with learning. A re-analysis of this relationship, employing the Horn (1985) WAIS-R formula for obtaining fluid and crystallized IQ suggested that crystallized IQ was a better predictor of the various string lengths than fluid IQ.

An attentional model in which high IQ subjects allocate more attention to the processing of the stimulus may be consistent with the present results, although there are other possibilities. If longer string lengths reflect increased attentional deployment then it may be argued that the correlation between the string length and IQ is determined by differences in attentional deployment between high and low IQ subjects. However, the results of a recent experiment by Bates and Eysenck (1993), in which high IQ subjects recorded shorter string lengths than low IQ subjects does not support the attention model. Thus, the next section addresses this experiment and its implications for the relationship between string length and IQ.

3.10 Recent String length-IQ studies

More recent studies on the relationship between the string length and IQ have indicated that the positive correlation between string length and IQ reported by D.E. Hendrickson (1982), Blinkhorn and Hendrickson (1982), Haier et al. (1983), Robinson et al. (1984), Caryl and Fraser (1985) and Experiment 2, may be reversed in certain situations. Barrett and Eysenck (1992) have recently reported negative correlations between the string length and IQ, ranging from -

.20 to -.44 at various electrode sites, in 40 subjects. Bates and Eysenck (1993) interpreted this reversal in sign as reflecting the role of attention on the correlation between string length and IQ. In their view, the procedural conditions were such, that subjects were asked to actively attend to the tones. while all other respects the Barrett and Eysenck (1992) study faithfuly replicated the A. E. Hendrickson (1982) methodology. In a further study in which attention to the stimuli was explicitly demanded from subjects, Bates and Eysenck reported a large negative correlation between string length and WAIS-R FSIQ at fronto-central sites, ranging from -.37 to -.61, as well as positive correlations between the string length and information processing speed, as measured, by DT and IT. In their study, string length was measured concurrently with an IT task. This protocol, which required significant focussed attention, can be contrasted to the attentional requirements invoked by the original Hendrickson protocol. The method, meticulously described by A.E. Hendrickson, required subjects to listen but not to respond to the 100 auditory tones, so that no discrimination was required or implied. Thus, this instruction may be interpreted as presenting a protocol in which subjects were not required to attend to the stimulus and which, therefore, did not invoke focussed attention. The positive string length-IQ correlation under this experimental set was explained by the Hendricksons in terms of reduced error rates during neural transmission of stimulus characteristics, leading to AEPs which preserved the complexity of single trials. This model, however, cannot explain the negative correlation under attended conditions.

An alternative explanation for the negative string length-IQ correlation was given by Bates and Eysenck (1993). They suggested that the positive correlation under no attention conditions and the negative correlation under attended conditions may be explained in terms of an efficiency/capacity model. Citing work by Haier, Siegal, Nuechterlein, Hazlett, Wi, Paek, Browning, and

Buchsbum (1988) on Positron Emission Topography (PET) glucose metabolism measures, they suggested that in attend conditions, higher IQ subjects are more efficient at processing stimuli, and therefore consume less metabolic effort, while retaining spare capacity to devote to other stimuli which are not explicitly attended to. This theory predicts that high IQ subjects in attended conditions will generate shorter string lengths relative to lower IQ subjects.

To explain the positive correlations between string length and IQ in unattended conditions, Bates and Eysenck (1993) suggest that string lengths of high IQ subjects reflect the "open-nature" of these stimuli. Unlike the stimuli in tasks requiring a response, there is no 'solution' to the unattended stimuli, and a large quantity of processing resources may be devoted to them. Bates and Eysenck (1993, p. 373) have explained their post-hoc theory in the following terms;

> **"High string length following the destabilisation provided by the stimulus input in the non-attend (non damped) condition may be thought to reflect a greater freedom to take on high frequency states, i.e., capacity or bandwidth, while attention to the stimulus will cause a dampening of oscillation as the brain settles into the low-energy equilibrium 'well' representing a consistent solution with a consequent short string length in a brain which can rapidly reach a solution."**

There are two problems with the Bates & Eysenck (1993) post-hoc theory. First of all, their explannation of the positive correlation between the string length and IQ under no-attention conditions does not fit our existing understanding of neuroscience very well (e.g., see Donchin, 1984) because it posits two completely different neuronal processes that underly the processing of the auditory tone under no-attention condition and the IT visual stimulus under attention condition. Why would two completely different brain mechanisms underly string length in the two different studies? As this suggestion was a post-hoc explannation it should be accorded that status. Secondly, AEPs in the Bates and Eysenck study were derived from trials with different stimulus durations for high and low IQ subjects. Because lower IQ subjects recorded longer ITs than high IQ subjects (correlation between IT and IQ was -.6), and because a PEST procedure was used to administer the IT trials, lower IQ subjects performed IT trials with considerably longer stimulus durations than the higher IQ subjects. Thus, as Bloch's law dictates, lower IQ subjects received IT stimuli of greater stimulus intensity than higher IQ subjects. The negative correlation between the string length and IQ reported by Bates and Eysenck, therefore, may be a function of the fact that lower IQ subjects received more intense stimuli and that the amplitude of the AEP waveform is sensitive to increased stimulus intensity (e.g., Gale, 1983; Haier et al., 1983).

Thus, in order to examine the relationship between IQ and string lengths derived from the IT task, Experiment 3 employs the procedure known as the Method of Constant Stimulus Durations (MCSD) in which all subjects receive the same IT trials. If, as suggested by Bates and Eysenck (1993), string length and IQ are negatively correlated in conditions requiring focussed attention, then it is predicted that the high IQ group will record significantly shorter string lengths than the low IQ group and that this difference will be a consequence of processing efficiency. If, however, the Bates and Eysenck result is a consequence of differences in stimulus intensity, then it is predicted that the high IQ group will record significantly longer string lengths than the low IQ group.

Experiment 3

3.11 String length,concurrent IT measurement and IQ. Is the string length reversed under focussed attention?

3.11.1 Method

Subjects

Sixteen first-year Psychology students (10 females and 6 males) with a mean age of 19.3 years (SD= 1.4) and an age range from 18 to 23 years were tested.

Procedure

Subjects participated on a voluntary basis, attending one session in which 160 IT trials were administered, concurrently with EEG measurement. All students had earlier participated in a group testing session in which the APM had been administered, and one or two additional sessions for the administration of the WAIS-R test. Subjects were selected on the basis of their WAIS-R FSIQ score: 8 high FSIQ subjects and 8 low FSIQ subjects. The low FSIQ group had the following FSIQ scores; 87, 92, 94, 95, 95, 98, 100, and 100. The high FSIQ group had the following scores; 132, 132,133, 133, 135, 135, 137, and 138. All subjects had participated in two IT sessions prior to testing (Chapter 6) and were therefore familiar with the procedure.

IT Procedure

In total, 140 IT trials were presented to each subject (20 trials at the following stimulus durations: 20, 40, 60, 80, 100, 120 and 140 msecs). A monochrome monitor was used to present the IT stimuli and flash mask. The stimulus was composed of two vertical lines, one, 29mm, the other, 21mm in length, positioned 16 mm apart. A pair of vertical lightning rod shaped lines 29mm in length representing the mask ("flash"), was presented immediately after the stimulus for 500 ms. The response-stimulus interval was set at 2000 ms. Subjects indicated which was the shorter of the two lines by pressing the appropriate response button, (left button for left line and vice versa). Ten practice trials with a set exposure duration of 500 ms were given. IT scores were calculated at the 75 % accuracy level (using probit analysis, in which the data are fitted to the inverse of the cumulative standard normal distribution function).

EEG Measurement

Subjects were seated, with high quality stereophonic headphones (SONY MDR-M55) and electrodes attached, in a darkened lead-lined room. Following adjustment to their EEG testing room and to the attached electrodes, the IT practice trials were followed by the main IT trials. The EEG was recorded from the vertex (Cz) position in the 10-20 international electrode placement system and referred to the left mastoid electrode. Electrodes were silver/silver-chloride, 9 mm in diameter; inter-electrode resistance was below 10 kilohms and usually below 5 kilohms. The electrical signals were amplified through a Neomedix "Neotrace 800 ZF" physiological recorder, with the -3 dB band pass limits of the EEG preamplifiers set to 2 and 125 Hz and amplified 10,000 times. A ground electrode was connected to the right mastoid. The EEG record was sampled for 1 sec per trial (300 msec prior to stimulus onset and 700 msec after stimulus onset) at a sampling rate of 1 msec, i.e., 1000 times/sec. Output data were subsequently transferred to a computer for averaging and analysis. String lengths were calculated with the same formula as that described in Chapter 3.

3.11.2 Results and Discussion

String length was calculated for the periods 0-100, 100 to 200 and from 200 to 300 msec post stimulus. Table 21 reports means and SDs for string lengths calculated from 0-100, 100-200 and 200-300 msec post stimulus for high and low FSIQ groups. An unrelated samples t-test approached significance (t= 1.9, df=14, p < .10) for the temporal epoch measured from 0 to 100 msec post stimulus, was significant from 100 to 200 msec post stimulus (t= 2.5, df= 14, p < .05) and approached significance from 200 to 300 msec post stimulus (t= 1.9, df=14, p < .10) suggesting that string length in the high FSIQ group was longer than in the low FSIQ group.

Table 21
Means and SDs of string lengths for low and high FSIQ groups
(N=16; Experiment 3)

String Length	High FSIQ	Low FSIQ
000-100	1732 (981)	1568 (722)
100-200	1978 (1102)	1409 (501)
200-300	1687 (1020)	1350 (480)

Thus, the present result does not confirm the Bates and Eysenck (1983) result suggesting that the negative correlation between the string length and IQ, reported in their study, reflects stimulus intensity differences. This result also casts doubt over the efficiency model proposed by Bates and Eysenck (1993) as the present results suggest that there is a positive association between the string length and FSIQ, so that high IQ subjects expend more energy or expend energy less efficiently, if, as Bates and Eysenck have proposed, the string length measure is a reflection of the efficiency or energy of neronal propogation. Obviously, the finding of this experiment must be regarded as preliminary until replication is achieved with a larger sample. However, the present results are important because they indicate that the positive relationship between the string length and IQ does not reverse for tasks which require increased "focussed" attention. Thus, the results of Experiments 2 and

3 are suggestive of a robust relationship between string length and IQ, across attention conditions, type of task and modalities.

Earlier in this Chapter it was concluded that the error model proposed by the Hendricksons to account for positive correlations between the string length and IQ and negative correalations between the variance and IQ should be replaced. It was suggested that the results are consistent with an attentional model in which high IQ subjects are able to allocate or sustain their attention for the duration of the task. This explanation was first suggested by Stough, Nettelbeck and Cooper (1991) and more recently by Barrett and Eysenck (1994) to account for the relationship between string length and IQ. Both the Stough et al and the Barrett and Eysenck (1992) studies employed this hypothesis as a post-hoc explanation and subsequently tested N100 amplitude differences between low and high IQ groups. The rationale behind this hypothesis is described in more detail in Chapter 4, but suffice to point out here that Hillyard, Picton and colleagues have provided substantial evidence that the amplitude of the N1 component of the human auditory AEP indexes the amount of attentional resources that subjects allocate to the processing of an auditory stimulus. In both the Stough et al and the Barrett and Eysenck post-hoc analysis, N100 amplitude was not significantly related to IQ. However, several studies have demonstrated that unless a specific methodology to that described by Picton, Hillyard and colleagues is employed (described in the next Chapter) then the amplitude of the N100 component may index other processes (see Naatanen, 1992 for a review). Thus Experiment 4 provides the first adequate investigation of the relationship between attentional resource allocation in an auditory information processing task, and intelligence.

CHAPTER 4

Attention, AEPs and IQ.

4. 1 Introduction

Selective attention may be defined as the ability of the human listener to hone his/her attention to a single source or "channel" of auditory information and to ignore concurrent, competing, background information from other channels. Typically, selective attention tasks have involved a high sensory information load (i.e., a high level of auditory information per unit time), thereby consistent with the experimental paradigm first introduced by Hillyard, Hink, Schwent & Picton (1973). This paradigm involved delivering randomised trains of tone pips concurrently to different input channels (i.e. binaurally) at extremely rapid rates to two or more (multiple) channels with the same equiprobability. Therefore, this type of task involves two levels of stimulus selection (Okita, 1979). Firstly, there is a between-channel selection which forces participants to restrict their attention to only one channel at a time, and secondly, there is a within-channel selection that involves the discrimination of infrequently occurring target stimuli (which differ slightly in pitch) from standard stimuli. Under such conditions, where participants are forced to restrict their attention to a single channel, a substantially negatively enhanced event related brain potential (ERP) is produced in response to the attended source of tonal stimuli relative to the ERP evoked to the unattended source. This occurs over and above any influences of non selective-attention or non-specific arousal.

This negatively enhanced human auditory ERP has been termed the "N1 effect" or "Nd" wave. It may be elicited with an onset latency as early as 50 msec following stimulus onset. Importantly, the amplitude of the N1 peak recorded to attended tones is increased relative to AEPs recorded to unattended tones. This N1 amplitude enhancement provides a physiological index of selective attention, or an index of the differential distribution of attentional capacity among competing input channels (e.g., Hillyard et al., 1973; Hillyard, Squires, & Squires, 1984; Picton & Hillyard, 1974; Schwent & Hillyard, 1975). Therefore, a more demanding task will result in a greater difference in the amplitude between the attended and unattended channels. Hillyard. Picton and others, interpreted this early attention effect in the context of a 'stimulus set' or 'filter' mode of attention (see Broadbent, 1970, 1971; Treisman, 1977). The stimulus set indexes a preferential selection mechanism of one sensory input channel over another on the basis of simple physical attributes such as pitch and spatial location while simultaneously rejecting inputs from the other.

Experiment 4

4.2 The Schwent and Hillyard Selective Attention Paradigm

This paradigm is of interest for research in intelligence because it allows the experimenter to operationally define attentional processes within a larger theoretical model. The Schwent and Hillyard (1975) procedure was used to examine the relationship between the allocation of selective attentional resources to auditory stimuli and IQ. Two hypotheses were addressed. The firstly is the Hunt (1980) and the Macintosh (1986) hypothesis that individual differences in IQ are a function of the allocation of attentional resources. Consistent with this prediction, it is expected that the difference between the amplitude of the N1 component of attended versus unattended (ignored) stimuli will be positively correlated to IQ performance. The second hypothesis predicts that correlations between the string length and IQ are determined by the allocation of attentional resources (Barrett & Eysenck, 1994; Stough et al., 1990). Consistent with this hypothesis, it is expected that the N100 amplitude difference will be significantly correlated with string length.

4.2.1 Methodology

Subjects

Twenty first year Psychology students with ages ranging from 18-23 (mean= 19.8, SD= 2.4) agreed to participate in the experiment .

Procedure

The full version of the WAIS-R was administered to all subjects. The order of EEG and IQ measurement was balanced. Four blocks of 2000 auditory tones (8000 in total) of different frequencies were administered via high quality headphones across four spatially separated auditory channels. A 5 minute rest break occurred after each block. The four equidistant auditory channels, which are shown in Figure 8 were left ear, left of centre, right of centre and right ear respectively. Two types of tones occurred in each channel, a common non-target tone and an infrequent rare target tone. The non-target tone occurred 90% of the time and the target tone 10% of the time. Tones of specific frequencies occurred in each channel so that in the left ear non-target tones of 1000 Hz and target tones of 1060 Hz were administered. Similarly tones of 500 and 530, 2000 and 2120 and 4000 and 4240 were played in the right of centre, right ear and left of centre channels respectively. The tone of higher frequency in any given auditory channel was always the infrequent target tone. Tones were presented pseudo-randomly with a mean ISI of 250 msecs, ranging from 100 to 800 msec, and derived from an approximate exponential distribution so that most tones occurred between 190 and 240 msec ISI. Mean ISI for tones in attended channel was 4 times 250 msec (1000 msecs). Only tones with ISIs greater than 200 msecs were used in the AEP. Subjects were instructed to attend to one specified auditory channel per block and to press a button when the target tone in this attended channel was perceived. Attended channel and blocks were balanced across subjects.

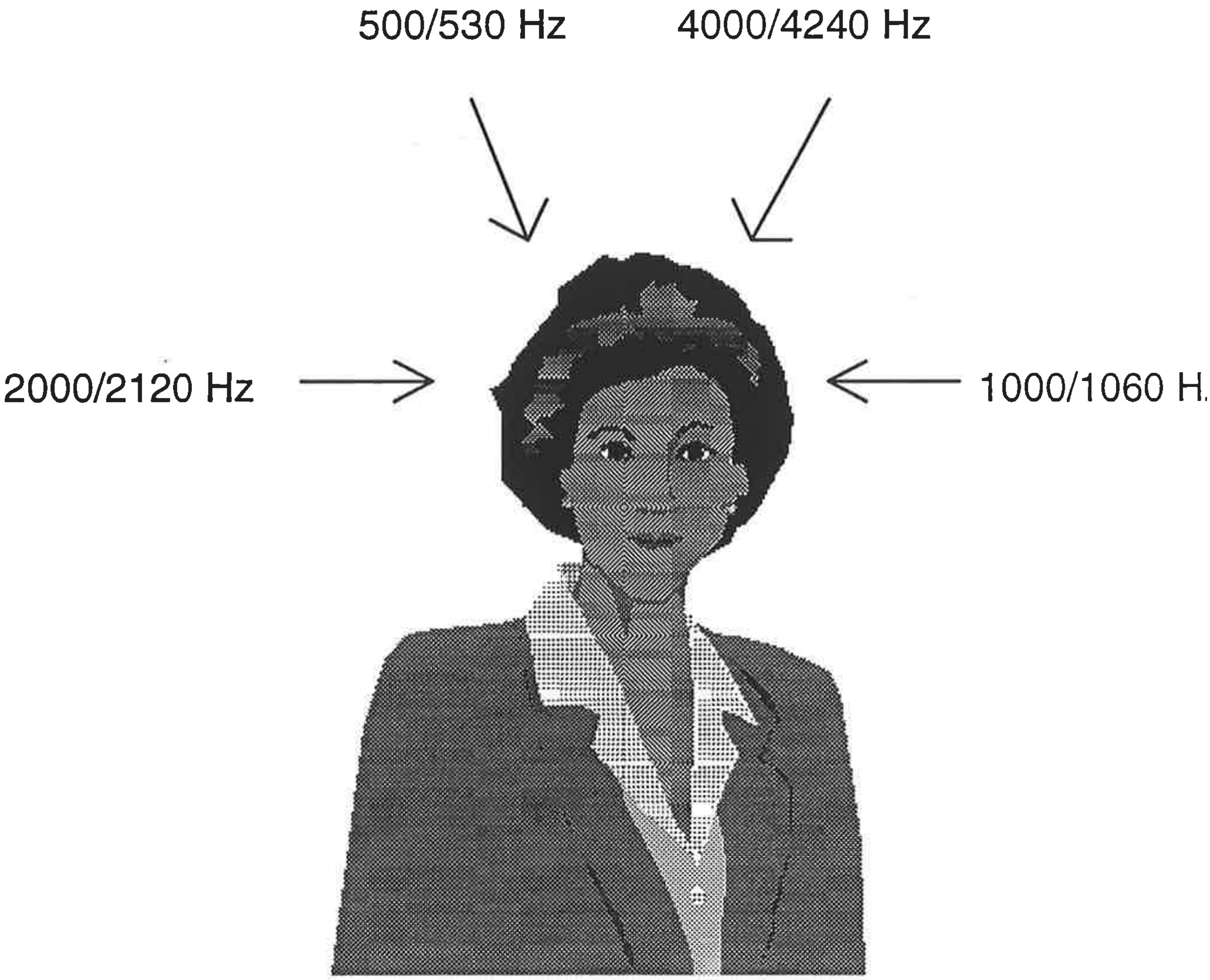


Figure 8: Location of auditory channels and tones of different frequencies.

EEG Measurement

EEG was recorded from the vertex (Cz) position of the 10-20 international electrode position, using an ECI electrode cap. The common electrode was referenced to linked ears. The EEG machine was a Nicolet IA98 EEG machine which sampled the EEG at 512 Hz by a Macintosh IIx computer utilising two National Instruments 16 channel-2 bit analog to digital converter boards. The EEG was collected using a .5 to 70 Hz Butterworth filter. Target and non-target tones were collected and averaged according to spatial location. String length was measured using the same formula as described in Chapter 3.

4.2.2 Results and Discussion

Table 22 presents correlations between the difference between N1 amplitude of attended and the average of the unattended tones for each spatial location. Correlations were generally moderate in magnitude and indicate that higher IQ subjects use significantly less attentional resources (difference in N1 amplitude for target minus non-target tones) than subjects with lower IQ.

Table 22:
Correlations between the difference in N1 amplitude between attended and unattended tones for different spatial locations and VIQ, PIQ and FSIQ (N=20).

Attended Location	VIQ	PIQ	FSIQ
Left Ear	-.51*	-.31	-.50
Right of Centre	-.62**	-.57**	-.67**
Left of Centre	-.48*	-.58**	-.53*
Right Ear	-.55*	-.39*	-.49*

*** p < .05 ** p < .01**

This result clearly indicates that the allocation of attention in this information processing task cannot explain individual differences in IQ. This result is in the direction opposite to that predicted by both Hunt (1980) and by Mackintosh (1986), who have suggested that individual differences in intelligence are a function of attentional resources. The correlations between FSIQ and the number of correct detections of the target tone was .62 ($p < .05$) indicating that higher IQ subjects performed significantly better at this task than low IQ subjects, despite employing less attentional resources than low IQ subjects. Thus not only do high IQ subjects allocate less of their attention to the target stimuli than low IQ subjects, but this lower allocation of attentional resources is indicative of superior information processing. How does one explain this counter-intuitive finding?

The conclusion here is that the allocation of attentional resources cannot explain differences in IQ, at least in the paradigm tested here. The obvious conclusion is that these differences are differences in other factors relating to the processing of the stimuli which are independent of attention. If high IQ subjects use fewer attentional resources than low IQ subjects, but performed the task better than low IQ subjects, then there must be other factors relating to the processing of the stimulus which can differentiate the two IQ groups. These factors may involve auditory perceptual speed, faster and/or more efficient decision processes, more efficient neural processing, amongst other possibilities.

String lengths to attended tones

In order to assess the relationship between the string length and IQ employing this protocol, mean string lengths across all the attended tones (four conditions), for the epoch 70-180 msec post stimulus, were calculated for each subject. Mean string length for the high IQ group was 2217 (SD= 894) and for the low IQ group was 1638 (SD=748). The string length epoch 70-180 msec was chosen because it represents the period in the AEP waveform in which all subjects recorded the N100 component. The difference between the high and low IQ groups was highly significant ($F_{(1,19)}= 9.2$, $p < .05$), again indicating a significant relationship between the string length and IQ across different methodologies. If attention was mediating the relationship between the string length and IQ, then it would be predicted that the difference in N100 amplitude to target versus non-target tones would positively correlate with the string length. This correlation was not significant ($r=-.11$, NS), indicating that the allocation of attentional resources [contrary to that hypothesised by Barrett and Eysenck (1994) and by Stough et al (1990)] cannot account for the positive relationship between the string length and IQ.

4.3 Summary and Conclusions

The present experiment examined the hypothesis that the deployment of attentional resources may provide an explanation for individual differences in IQ (Hunt, 1980; Macintosh, 1986), and for the positive association between the string length and IQ (Barrett & Eysenck, 1994; Stough et al., 1990). Employing the procedure described by Picton, Hillyard and colleagues, which is a well-grounded procedure in cognitive psychology, neither hypothesis could be supported.

Having examined attentional deployment in the string length-IQ paradigm, the next chapter examines other variables which may contribute to, or determine the relationship between IT and IQ.

CHAPTER 5

Inspection Time and IQ

5.1 Introduction

A measure of mental speed which has emerged in the intelligence literature in the last two decades is termed "inspection time" (IT). According to Vickers, Nettelbeck and Willson (1972) who coined the term, IT refers to the minimum amount of time needed to make near error-free decisions about a simple sensory stimulus. The procedure for measuring IT involves the presentation of a simple stimulus figure followed by a backward mask which prevents continued sensory sampling from the stimulus. IT resulted from the attempt to develop a measure of mental speed that was relatively elementary in nature and immune from the influence of higher order cognitive abilities, motivation and other environmental factors (Vickers & Smith, 1985, 1986). IT is based upon the accumulator model of discriminative judgement described in detail by Vickers et al. The model holds that subjects make a number of independent samplings of the sensory information (each sample taking a small and constant amount of time) in order to gain the necessary information, until a critical amount is collected for either of the response alternatives. Although the IT procedure has been used in several different areas of research, the most frequent has been in the field of intelligence, where it has been examined to test the possibility that individual differences in IQ may relate to individual differences in mental speed. The following section contains a brief and selective review of past IT-IQ work. The remaining section of Chapter 5 is concerned with the results of three empirical studies which investigate the whether methodological variables may account for the relationship between IT and IQ.

5.2 Inspection Time procedure.

A variety of stimulus parameters (stimuli, masks, number of trials, modes of presentation etc.) have been employed in previous studies measuring IT. The procedure described here is the same visual IT procedure used in nearly all the studies by Nettelbeck and co-investigators at the University of Adelaide. Following the onset of a cue, two lines that usually differ by about .8 to 1.6 degrees of visual angle are presented for short durations (see Figure 9). Subjects are required to determine on which side the shorter stimulus line is presented. The time between the onset of the stimulus and the onset of the mask is varied until near-perfect performance is reached by the subject (97.5% for earlier experiments and between 85% and 95% for more recent experiments). The stimulus duration at which the subject achieves near-perfect responding is referred to as the IT for that subject. There are two methods used in the presentation of trials. Firstly, the method of constant stimuli (MCS) presents a set number of trials at a range of pre-determined stimulus durations. The second method is controlled by PEST (Parameter Estimation by Sequential Testing), in which the stimulus durations are either increased or decreased in response to subject response accuracy until a pre-set criterion level of accuracy and number of reversals is reached (Taylor & Creelman, 1967).

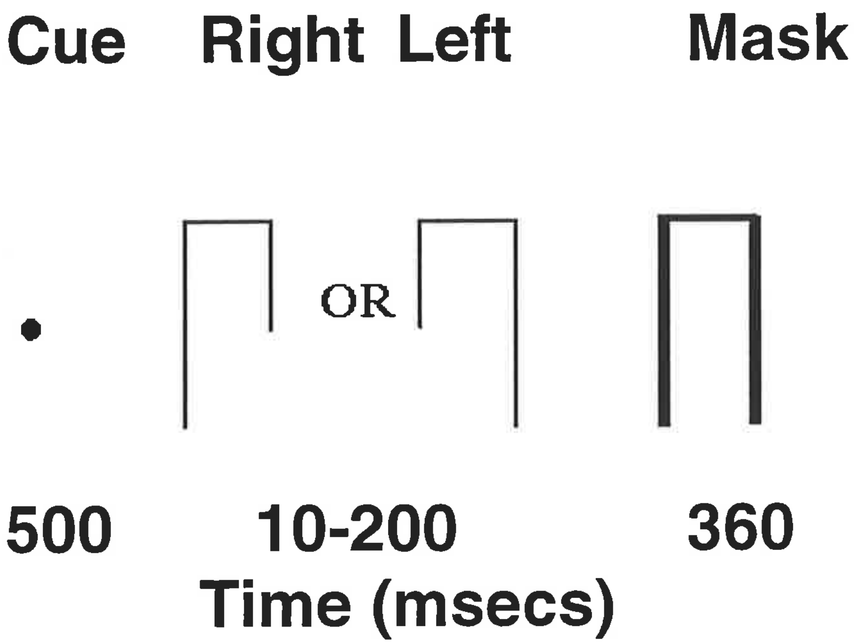


Figure 9: **<u>Inspection time procedure.</u> A cue is presented for 500 msec (far left) followed by either one of two stimulus alternatives (centre) followed by a mask (right).**

5.3 IT as a measure of intelligence?

Although Vickers et al. (1972) first defined IT, it was Nettelbeck and Lally (1976) who first attempted to explore the possibility that IT measures correlate with IQ scores, although, as Deary's (1986) review of the history of inspection time-type research reveals, Cattell (1886a; 1886b) anticipated the notion that a backward masking procedure would provide reliable differences in performance between two people with different measured intellects. This history notwithstanding, the most important contributions to the IT-IQ debate which have occurred in the last decade have centred on the possibility that IT may be used as a measure or a correlate of IQ.

5.3.1 IT and IQ

Nettelbeck and Lally (1976) reported large correlations between WAIS performance subtests and two sets of inspection time scores (r_{IT1}-PIQ= -.92; r_{IT2}-PIQ= -.89), in a sample of 10 intellectually able and disabled adults (WAIS

FSIQ, range: 47-119). They interpreted their results to suggest that the intellectually disabled subjects reached a decision that was based on less evidence than that required by normal subjects, and thus implicated some basic limitation in perceptual sampling of stimuli. An interesting finding was that the correlations with verbal subtests were small and statistically nonsignificant, suggesting that IT may serve as a better correlate of PIQ than VIQ or FSIQ. However, as will be seen, the results from about half of the published studies examining the relationship between IT and IQ suggest that verbal IQ measures are more highly correlated with IT than are performance IQ measures, although many studies do not report whether these observed differences were statistically significant.

The results of Nettelbeck and Lally (1976), however, should be treated with caution. The small sample (10 subjects), which was not randomly selected and contained subjects with a wide range of IQ, including intellectually disabled subjects, together with subjects of above average intellects, would have artificially inflated the magnitude of the reported correlations between PIQ and IT (Howe, 1989; Nettelbeck, 1987). An additional problem arises from the calculation of IT. Although the longest stimulus duration presented in the experiment was 300 msec, long IT estimates of 554 msec and 804 msec were made. Extrapolations of this magnitude, made by estimating near-perfect levels of responding, may have been unsound. Lally and Nettelbeck (1977) obtained similar results using 47 subjects, 16 retarded (PIQ = 57 to 81), 16 normal (PIQ = 90 to 115) and 16 above average (PIQ = 116 to 130). Pearson correlations between PIQ and IT reached -.80 ($p<.001$), with the retarded sample exhibiting markedly longer ITs than either the average or above-average groups. These results, taken together with the results from part 2 of their experiment (a choice RT experiment), suggested that differences in mean ITs between the two groups related to differences in the decision factors responsible for the integration of visual information. Within group correlations of PIQ and IT were significant for the retarded sample (r=-.45, p<.05) and for the normal sample (r=-.54, p<.05) but not for the above-average group. An explanation for the smaller correlations found within groups might be the relatively narrow spread of IQ scores (i.e., SD = 6-7).

Other studies have reported significant correlations between VIQ and IT, but small and statistically nonsignificant correlations between PIQ and IT. Nettelbeck (1982) reported a correlation of -.34 (p<.05), between IT and verbal IQ in a sample of 45 university students using an Australian verbal reasoning test. Nettelbeck (1985) has also reported moderate correlations between IT and VIQ from the WAIS-R in two samples of University students using different IT procedures (r=-.34 and -.38; p<.05). In this study, significant correlations were also reported with PIQ (r=-.49 and r=-.55; p<.05).

Following the initial experiments by Nettelbeck and others, a series of experiments were conducted on the relationship between IT and IQ at the University of Edinburgh and Dublin by Brand, Deary, Egan and colleagues. According to Brand and Deary (1982), by 1979 accumulated evidence suggested that IT was more related to general intelligence and measures of vocabulary than to performance IQ. Citing Hosie (1979) who reported Pearson correlations of -.78 between the Colour Progressive Matrices (CPM) and IT among 12 four-year-olds, they suggested that IT is highly correlated with general intelligence even in young children. As will be described later, their claim is supported by some but not all of the reported studies investigating the association between IT and IQ. Deary (1980) described the results of two experiments using visual inspection time (VIT) and auditory inspection time (AIT). Correlations between VIT and AIT and the Mill Hill Vocabulary scores were -.69 and -.66 respectively, and with the APM, -.72 and -.70, although

Deary, Caryl, Egan and Wight (1989) point out that these correlations were inflated by the inclusion of subjects with an intellectual disability.

Other studies have investigated the notion that general intelligence scores are more highly correlated with IT than are verbal or performance IQ scores. These studies have generally administered either the full-scale version of an age-appropriate Wechsler test, a Raven's Matrices test [i.e., colour (CPM), standard (PM), or advanced (APM)], or the Cattell Culture Fair Test of intelligence. Comparing studies listed in Table 3 of Nettelbeck (1987) reveals that different conclusions can be drawn about the nature of the relationship between IT and IQ. About half of the listed studies report high to moderately significant correlations between IQ and IT (i.e., Anderson, 1977; Deary, 1980; Grieve, 1979; Hosie, 1979; Mackenzie & Bingham, 1985) and the remainder small and nonsignificant relationships (Edwards, 1984; Hulme & Turnbull, 1983; Irwin, 1984; Mackenzie & Bingham, 1985; Nettelbeck, 1973; Nettelbeck, 1982; Nettelbeck, Chesire & Lally, 1979; Nettelbeck & Kirby, 1983a; Smith & Stanley, 1983; Vernon, 1983). Many of the studies reporting small and/or nonsignificant correlations may be criticised on methodological grounds (i.e., small sample sizes, non-standard IT tasks, confusing instructions to subjects, small range of IQ scores etc.). Other criticisms may also be directed at studies reporting higher IT-IQ correlations (e.g., the practice of including severely intellectually disabled subjects in statistical analyses and small sample sizes).

Inspection time and IQ in non retarded samples.

Previous research on the relationship between IT and IQ in children has also been empirically equivocal. Hartnoll (1978), reported in Brand and Deary (1982), correlated IT with a vocabulary measure amongst two groups of 18 children aged 11-12 years. The IT task consisted of animal pictures instead of the "normal" pi figure. Spearman correlations between IT and IQ, although both negative, were not both statistically significant (r=-.54, p<.05 and r=-.20, NS.) although this may be due to the small samples. Correlations between the Thurstone Spatial Ability scores and IT in two other groups of 11 and 12-year-olds were not significant. Hulme and Turnbull (1983) reported the opposite finding. Employing a different but conventional IT procedure and a different IQ test (WISC-R), correlations were -.08 (NS.) for VIQ-IT and -.29 (p<.05) for PIQ-IT. These correlations are small, with the PIQ-IT correlation accounting for less than 10% of the variance, and may even overestimate the association due to the larger than normally found distribution of IQ scores in their sample (SD= 18 compared to SD=15 which is the population figure). They also reported high correlations in a sample of intellectually disabled subjects (N=8), concluding that IT is only related to IQ in intellectually disabled populations and not in normal samples.

Irwin (1984) reports the results of two experiments using 47 children (aged 11-13 years). In the first experiment, the Mill-Hill Vocabulary scales and Raven's Matrices scores were correlated with a visual-alphabet task, and in the second the same tests were correlated with a 2-tone AIT task. Correlations were moderate to low between all variables (-.43 and -.24 between AIT and the Mill-Hill and Raven's tests; -.25 and -.34 between VIT and the same two tests respectively). Results did not support Deary's (1980) suggestion that VIT and AIT were strongly correlated ($r_{VIT-AIT}$= .17, N.S.). However, as Seashore pitch scores were significantly correlated with the Mill-Hill Test of Verbal Abilities (.37), Irwin concluded that the relationship between AIT and IQ was due to AIT being related to pitch discrimination ability. Irwin concluded that a small negative relation exists between IT (both VIT and AIT) and intelligence, suggesting that the larger correlations reported earlier have been due to methodological errors associated with samples which were small and showed excessively large ranges of IQ scores, and incorrect extrapolation of IT.

However, as Nettelbeck (1987) suggests, the results from the Irwin paper must be treated with some caution as the very large IT distributions reported there may be due to the fact that the subjects did not understand the requirements of the task.

Deary et al. (1989) have also reported results that have addressed in part Irwin's criticisms. They used a battery of different IT measures (both visual and auditory), together with the Mill-Hill Vocabulary (MHV) the Advanced Progressive Matrices (APM) and the Alice Heim 5 (AH5) tests in an adult sample. All tests showed restricted range in scores, which would tend to reduce the magnitude of the correlations between IT and the various IQ tests. The uncorrected correlations (restriction in range) between the various IT measures and IQ varied from .05 to -.40; because 24 out of the 25 correlations between IT and different IQ tests were negative the authors concluded that a substantial proportion of the IQ variance is located in individual differences in perceptual intake speed. It should be pointed out, however, that only 8 of the 24 correlations were significantly different than zero at the .05 probability level. In any case, the Deary et al. study was different to the Irwin (1984) study because Deary et al. tested adult subjects, rather than the children used by Irwin (1984). It may be the case, therefore, that IT and IQ are not correlated at all or to the same extent in samples of children as in adults. This idea has some empirical support (Hulme & Turnbull, 1983; Irwin, 1984; Smith & Stanley, 1983). Conversely, Ridgers (1986) reported a correlation of -.42 in thirty-eight 12-year-olds but a correlation of only -.28 in thirty-eight 8-year-olds. Garnett (1986), using 122 Hawaiian students (ages 8-11) reported a high correlation of -.79 between IQ and IT. Sen and Goswami (1983) report significant correlations between IT and Peabody Picture Vocabulary Test (PPVT) scores of -.56 and -.48, for the two versions respectively, in a cross-cultural experiment among 48 Indian children aged 6 to 11 years. However, they did not employ a backward mask as part of their procedure, so caution must be exercised when comparing their result with other IT experiments.

It was not until recently that reliable evidence has been put forward for a significant negative relationship between IT and IQ in the developing child (Nettelbeck & Young, 1989; Nettelbeck & Young, 1990; Wilson, 1984). These studies provide evidence that IT decreases with age, but that the IT-IQ correlation is stable at around -.5 across different ages. Overall, this result is consistent with Brand and Deary's (1982) view that differences in mental speed capabilities reflect differences in fluid or biological intelligence which influence the development of crystallised intelligence. These studies reported higher correlations between VIQ and IT than PIQ and IT and it may be the case that VIQ scores serve as better measures of fluid intelligence until adulthood, when PIQ scores may serve as more valid markers for fluid intelligence. A stable relationship between IT and IQ, demonstrated in both young age and old age groups, indicates that IT is an important influence on the development of intelligence.

The view from the top.

The interest in IT as a correlate of IQ has ranged from those investigators who claim that IT might replace IQ tests, to those who propose it as an adjunct to IQ, to those who suggest that IT may only be of theoretical but of no practical interest. There are some investigators who have denied that IT is correlated with IQ sufficiently to make it of theoretical or practical importance. There have been a number of commentaries as to the magnitude of the association between IT and IQ. Nettelbeck (1987, p. 341), from a review of 29 direct IT-IQ investigations, concluded that there was evidence of a correlation between IT and IQ of -.34 (corrected for restriction in range to approximately -.5). Kranzler and Jensen (1989) have also conducted a meta-analysis, concluding that a correlation (corrected for restriction in range of IQ scores) of about -.5 exists between IT and IQ in normal adults. Uncorrected correlations between IT and Performance and Verbal IQs were -0.45 and -0.18, respectively. However, Howe (1989), after reviewing the 29 IT-IQ investigations listed in Nettelbeck (1987) has argued that if one only includes studies in which there are more than 40 subjects without intellectual disability, then the correlation between IT and IQ drops to a minuscule and unimportant -.14 for children and -.15 for adults. More recently, Juhel (1991), who, although noting procedural inadequacies in the IT parameter as a measure of perceptual speed, has indicated that there is some evidence for a modest association between IT and IQ, with IT probably not accounting for more than between 10 and 20% of the IQ variance. Thus, estimates for an uncorrected correlation between IT and IQ vary from -.14 to -.45.

Following the review of previous research on the nature of the relationship between IT and IQ, there are two conclusions that can be drawn. Firstly, there appears to be a modest relationship between IT and IQ, although, as Howe (1989) has pointed out in studies with large numbers of subjects, correlations between IT and IQ are very small in magnitude. More studies with larger sample sizes are obviously required. Secondly it is unclear whether IT is more related to PIQ, VIQ, fluid, crystallized or to general IQ. Few studies have administered more than one IQ test to examine the relationship between various IQ measures and IT.

The experiment reported below examines the magnitude of the correlation between IT and IQ in a sample of more than 40 normal adults without intellectual disability (Howe's criterion). The methodology described by Nettelbeck (1987), which has been employed in most previous IT-IQ studies has been followed.

Two other studies are reported in which possible confounding influences on the IT-IQ correlation are investigated. These are methodological variables such as display mode, strategy use, apparent motion and mask typeas suggested by Howe (1989, 1990), Mackenzie and Bingham, (1985), Mackintosh (1981, 1986),

Experiment 5

The relationship between IT, WAIS-R and APM scores

5.7.1 Methodology

Subjects.

Sixty-eight first year Psychology students (50 females and 18 males) with a mean age of 18.1 years (SD = 2.0) and a range of ages of 17 to 28 years participated in the experiment.

Procedure.

Subjects participated on a voluntary basis, attending in total one IT session and one or two additional sessions for the administration of the WAIS-R. Sixty-four of the total number of students had previously participated in a group testing session in which the APM had been administered. The order between the IT and IQ sessions was approximately balanced. Subjects were tested for visual acuity with the Schnell eye chart. No subjects were excluded from participating in the experiment because of poor visual acuity. Instructions for the IT task emphasised that the procedure involved accurate but not rapid responding. Subjects were told that the task involved simple visual discriminations in which they were required to judge which one of two lines was the shorter. They were instructed that if during the task they became tired, they should take a break and then resume. A cue was presented for 500 msec prior to stimulus onset. Subjects were given 10 practice trials at 100 and 200 msec stimulus duration. Following the presentation of the cue, a stimulus was presented for varying duration before a mask was onset. The inter-stimulus interval (ISI) was 2 seconds.

A PEST procedure (Taylor & Creelman, 1967) was used to determine each subject's IT at the 90% level of accuracy. The initial stimulus duration was 100 msec for all subjects. Eight reversals were required before an IT estimate could be made. The stimuli and mask were presented via a four field tachistoscope driven by an IBM compatible computer (AT).

5.7.2 Results and Discussion

Table 23 reports the distribution of VIQ, PIQ, FSIQ, raw APM, and IT scores. Mean IQs from the WAIS-R were approximately 1 SD above the population average and were also moderately restricted in range, with VIQ recording the greatest restriction in range.

Table 23:
Means, SDs and range of VIQ, PIQ, FSIQ, raw APM, and IT (N=67; Experiment 5).

	MEAN	SD	RANGE
VIQ	113	10.8	88-137
PIQ	114	13.5	86-133
FSIQ	115	11.6	87-138
APM	26	3.7	18-35
IT	61	25.7	21-136

Table 24 shows the magnitude of the Pearson correlations between IT and raw APM scores, VIQ, PIQ, FSIQ, and fluid and crystallised IQ scores derived from the WAIS-R. When corrected for restriction in range, IT accounts for about 25% of FSIQ and PIQ variance. This is the figure Nettelbeck (1987) proposed as the 'bench mark' estimate of the association between IT and IQ. IT accounted for less than 25% of the VIQ and APM raw score variance. Generally, the pattern of correlations are indicative of a moderate association between IT and various IQ measures, particularly PIQ and FSIQ. Thus the present results do not support Howe's (1989) position that IT and IQ are very weakly correlated in large samples.

Table 24:
Inter-correlations between IT, VIQ, PIQ, FSIQ and APM scores (bottom figures denote correlations corrected for restriction in range). (N=67; Experiment 5)

	VIQ	PIQ	FSIQ	APM
IT	-.25**	-.40***	-.39***	-.27*
	-.34**	-.44***	-.48***	N/A
VIQ		.45***	.87***	.41***
		.57***	.92***	.56***
PIQ			.80***	.38**
			.83***	.42**
FSIQ				.47***
				.57***

* p<.05; ** p<.01; *** p <.001.

VIQ-IT Vs. PIQ-IT correlations

Nettelbeck (1987), in reviewing the literature on whether IT is a better correlate of verbal or performance intelligence, has concluded that although the evidence suggests that IT is more highly correlated with performance than verbal measures, there is at present no unequivocal conclusion that can be made. Deary (1993) has recently addressed whether IT is a correlate of performance or verbal processes. Employing confirmatory factor analyses, he demonstrated moderate loadings for IT on a performance factor, and near zero loadings on both a general factor (principal components) and on a Varimax rotated verbal factor. Testing the difference between PIQ-IT and VIQ-IT correlations (corrected and uncorrected) revealed significant differences; t= 3.8, p < .01 for uncorrected; and t= 2.2, p < .05 for corrected. The present results therefore support Deary's analyses and indicate that the correlation between PIQ and IT is statistically stronger than the correlation between VIQ and IT.

Sex differences

Partial correlations controlling for sex were computed for correlations between IT and the IQ variables; VIQ, PIQ, FSIQ, and APM. Partial correlations were; -.20, -.40, -.35 and -.27 for comparisons between IT and VIQ, PIQ, FSIQ and APM respectively. These results suggest that sex is not an important or contributing factor in IT-IQ correlations.

5.7.3 Summary

This experiment addressed the Howe (1989) contention that in studies employing more than 40 subjects, IT and IQ are only weakly associated. The results suggested that IT accounts for approximately 25% of the PIQ and FSIQ variance, and that sex differences did not account for this relationship. How then does one account for the discrepant results of previous experiments? A number of explanations may be suggested which address the past pattern of inconsistent results. Firstly, correlations based on small sample sizes are unreliable. The standard error of measurement for Pearson correlations has typically ranged from .2 to .5 in previous experiments. Given a small sample, chance fluctuations may realise correlations between IT and IQ which range from being significant to being small and non-significant. Secondly, different studies have used different IQ tests. Correlations between different tests of intelligence are usually in the range .5 to .8 accounting for only 25% to 50% of the shared variance between different tests. The magnitude of correlations between different IQ tests may make comparisons between different studies tenuous. Future studies should, wherever possible, employ samples large enough to reduce standard error of measurement to sufficiently low levels and employ a battery of psychometric tests. Thirdly, different studies have employed different display modes to present the IT procedure to subjects. The physical characteristics of these displays are known to be quite different (e.g., the monochrome phosphor decay is more appreciable than the decay of a tachistoscope bulb).

In order to examine whether such methodological variables effect the correlation between IT and IQ variables a pilot study was conducted in which the IT procedure was administered via a Gerbrands tachistoscope display and a Hercules monochrome video monitor. This experiment also served to test the reliability of the IT measure across different forms of presentations (see Barrett & Kranzler, 1994 for a discussion of some issues relevant to ITs derived from a computer screen).

Pilot study 1

Effect of stimulus display on the correlation between IT and IQ.

5.8.1 Methodology

Subjects.

Thirty eight subjects (27 females and 11 males), with a mean age of 19.2 (SD= 2.4) participated.

Procedure and Apparatus.

Subjects were administered the IT task twice (computer monitor and tachistoscope) using a PEST procedure. Subjects were given the same instructions as in Experiment 5. The computer used in this study was an IBM-PC with a monochrome monitor. The refresher rate for the monitor was 16 seconds. It should be noted that there was significant stimulus persistence from the relatively slow phosphor decay of the monochrome monitor. Apart from this difference, all other conditions were the same as that reported in Experiment 5. The two IT procedures were administered in a balanced order.

5.8.3 Results and Discussion

Mean ITs for both IT procedures [tachistoscope mean = 58.3 (SD= 24.2); computer monitor mean = 53.1 (SD= 17.0)] were not significantly different (t= 1.4, NS). Table 25 displays the Pearson correlations between the two IT estimates, VIQ, PIQ, FSIQ and raw APM scores.

Table 25:
Pearson correlations between IT_1 (tachistoscope), IT_2 (computer monitor), VIQ, PIQ, FSIQ, and APM scores
(N=38; pilot study 1)

	IT_1	VIQ	PIQ	FSIQ	APM
IT_2 (Computer)	.47**	-.12	-.37*	-.31	-.25

** p<.05; ** p<.01.*

Despite the relatively low correlations between the two IT estimates (.47) the correlations between IQ and IT derived under the two conditions were nearly identical, providing evidence for the robustness of the correlation between IT and IQ across different display modes. This result suggests that display mode does not explain previous inconsistent results. This experiment also demonstrated that the computer monitor version of the IT task may be as valid, as the more chronometrically precise tachistoscopic version of the task. If the IT task is to be used as either an adjunct to IQ tests, or as a measure of information processing ability in applied settings, then the computer monitor has a number of economic and administrative disadvantages over the tachistoscope (i.e., the tachistoscope is less portable and considerably more expensive than the computer monitor version). Thus the computer monitor version of the IT procedure may be advantageous in a practical sense.

The next experiment investigates the effect of another methodological variable on the correlation between IT and IQ, specifically examining the effects of apparent motion and mask type on correlations between IT and IQ.

Experiment 6

The effects of apparent motion on IT and on the correlation between IT and IQ.

5.9 Rationale

The present experiment investigates another methodological issue specific to experiments in which a visual stimulus and mask are presented in short temporal sequence- apparent motion. The experiment examines the frequency and effect of apparent motion on IT and on the correlation between IT and IQ in three different mask conditions; the standard (traditional), a new mask proposed by Evans and Nettelbeck (1993) and a new mask designed for use in this study. This experiment also directly tests the Brebner and Cooper (1986) finding that in the traditional masking condition, extraverts are more likely to use apparent motion cues to bias their ITs.

5.9.1 Introduction

Mackenzie and Bingham (1985) have reported that apparent motion influenced the association between IT and Wechsler IQ. In a group of subjects who perceived apparent motion, a non-significant correlation between IT and IQ was reported, whereas for subjects who were not able to use apparent motion, the relationship between IT and IQ was negative and significant (-.71 with FSIQ). A lower mean IT was reported for the apparent motion group, but the two groups did not differ significantly on IQ scores, suggesting that for subjects who were able to employ apparent motion cues, their ITs were not a true indication of their mental speed per se. Mackenzie and Bingham also found that the employment of apparent motion cues could not be effectively learnt by subjects who did not spontaneously use them, suggesting that the ability to use apparent motion cues may not be a cognitive strategy so much as a natural perceptual ability. Mackenzie and Cumming (1986) replicated this result with the APM. The results of these two studies suggest that strategy use may invalidate some ITs as an index of perceptual speed, because those subjects who are able to employ apparent motion cues are able to artificially shorten their ITs.

Along these lines, Brebner and Cooper (1986) found that the ability to use strategies to shorten ITs related to personality type. Specifically, they found that extraverts were more likely to use cues than introverts. In a more recent study, Deary et al. (1989) reported significant negative correlations between IT (auditory and visual) and a wide range of IQ tests, and suggested that there is no specific strategy that subjects can use across different modalities (i.e., both auditory and visual). The possibility remains, however, that subjects who perceive apparent motion in VIT studies may also be able to adopt other strategies that may artificially decrease AIT. In their study, VIT and AIT only correlated weakly, suggesting that these tasks may be more different than similar. Deary et al did not record whether subjects were using apparent motion cues or any other strategies, so it is difficult to determine from their results whether strategy use influenced ITs.

Egan (1986) has suggested that apparent motion effects occur in all visual backward masking methodologies and that the influence of strategies has not been systematically documented. Egan argues that further research is required before it would be sensible to suggest that strategy use may confound IT as a measure of perceptual speed. This opinion is supported by the work of Sharp (1984) who reported a significant negative relationship (-.49) between Critical Stimulus Duration (CSD) and Raven's Progressive Matrices scores. CSD is similar to IT, except that no mask follows the presentation of the stimulus. Sharp's result indicates then that a backward mask may be unimportant in the IT procedure and, if CSD and IT measure the same process, then strategy use would be irrelevant. Whether the IT parameter is an accurate measure of perceptual speed or not, therefore, is an empirical question still to be resolved.

Evans and Nettelbeck (1993) have attempted to design a flash mask to reduce apparent motion use in the IT paradigm, suggesting that apparent motion use may be significantly eliminated if two features of the masking procedure could be changed. Firstly, if both lines of the mask were to be extended downwards, then both the long and short lines of the stimulus may appear to move, thus not allowing subjects to use downwards apparent motion to identify the shorter line. Secondly, if an apparent flash was seen in the middle of the display then this might interfere in some way with the flash reported by some subjects when the masking lines covered the shortest line of the stimulus.

Recently Knibb (1992) has also designed a new mask for the IT procedure, utilising a dynamic approach. In his task, the subject's perception is swamped by rapidly changing (dynamic) masks (with frame durations ranging from 20 to 60 msecs) after the presentation of the stimulus, creating additional irrelevant apparent motion, peripheral to the target area. Knibb concludes that the employment of these rapidly changing dynamic frames produces apparent motion that is uninterpretable for stimulus discrimination This procedure has been criticised by Evans and Nettelbeck (1993), because Knibb employed a methodology in which the stimulus parameters were changed, (i.e., the difference between the two target lines were shorter at shorter SOAs than at longer SOAs) and differed from the procedure used in the traditional mask condition. Obviously then, it is difficult to evaluate whether the dynamic mask is a better mask than the traditional mask if the discrimination has changed. Longer ITs reported by Knibb may merely indicate that the discrimination has increased in difficulty. On this point, recent evidence reported by Frank (1992) suggests that the dynamic mask produces shorter rather than longer ITs when compared to the traditional mask if the level of discrimination is held constant across the two masking conditions. The slower this rate the less precise the IT estimates.

Knibb (1992) and Evans and Nettelbeck (1993) have both reported significant negative correlations between their new masks and IQ in small samples (N=22 and N=17 respectively). However, because of the small sample sizes employed in these studies, it is difficult to compare correlations between IT and IQ across different mask conditions, and, therefore, whether the use of apparent motion cues determines the correlation between IT and IQ

Experiment 6 addresses three issues. Firstly, it investigates the Mackenzie and Bingham (1985) and Mackenzie and Cumming (1986) findings that apparent motion influences IT and the IT-IQ association. Secondly, it attempts to replicate the Brebner and Cooper (1986) finding that personality may be related to subjects' ability to use apparent motion cues or strategies. Thirdly, it tests the effectiveness of the standard IT mask against two other masks (flash and lines) developed to reduce apparent motion cues, and compares the IT-IQ correlation for each mask condition in a large sample of subjects. The aim here is to design masks which significantly reduce the use of apparent motion cues. By comparing the traditional mask (high cue use) with other masks (low cue use) it may be possible to examine the effects of apparent motion on the correlation between IT and IQ.

An important aim of this experiment was to develop and test the effectiveness of backward masks, without changing the stimulus parameters of the IT procedure. Towards this goal a comparison was made between the flash mask (first reported by Evans & Nettelbeck, 1993), the standard mask employed in the majority of IT experiments (traditional) and a lines pattern mask designed after extensive experimentation with a wide variety of masks. Chaiken and Young (1993) have recently employed a mask which consisted of unfilled bar shaped boxes closely surrounding the areas where each of the vertical lines of the test stimulus had previously been exposed. The design of this mask followed experimental work linking metacontrast masks with the apparent motion phenomenon (Banta & Britmeyer, 1985; Fiscaro, Bernstein, & Narkiewica, 1977). Unfortunately this mask did not reduce apparent motion use in their sample, suggesting that metacontrast may not operate at the same level as the apparent motion process. Therefore, the present study employed a pattern mask instead of a metacontrast mask, together with the lightning and traditional masks.

5.9.2 Method

Subjects.

Fifty psychology students (42 females and 8 males), with ages ranging from 19-34 years (Mean = 21.8; SD= 3.3) participated.

Apparatus.

A Macintosh LC with a frame rate of 16.6 msecs (60 Hz) was used to present the stimuli.

Procedure.

The IT procedure and IQ tests were both administered in the same session. Three masks (flash, lines and traditional) were used in the IT procedure in a balanced order across subjects. The AH5 (verbal and figural) Test and APM Test were administered to all 50 subjects. Due to time constraints, a short version of the APM, which included the practice set, but omitted the first 12 questions from set II, was used. Stough, Nettelbeck, and Cooper (1993), have reported that in a large sample of psychology students (N=450), scores from the first 12 questions of the APM do not differentiate high and low scoring subjects. This was undertaken so that another group IQ test could be administered in the same testing session. Subjects were also given the Eysenck Personality Questionnaire Revised (EPQ-R) at the end of the testing session, although this was not mandatory. Subjects always completed the IT session before the IQ session.

IT

The three masks used in this experiment are shown in Figure 10. Each subject completed 10 trials with each mask at each of the following stimulus durations; 16.6, 33.3, 49.9, 66.6, and 83.3 msecs. In addition, all subjects completed 20 practice trials for each mask (10 at 165 msec and 10 at 150 msec). In total, all subjects completed 210 IT trials across three different masks. The total correct was recorded and later used to estimate IT at 75% responding accuracy (using probit analysis, in which the data are fitted to the inverse of the cumulative standard normal distribution function). Subjects were also required at the completion of the IT procedures to rank the three masks in terms of difficulty, and to describe the process used to discriminate the two stimulus alternatives in each condition.

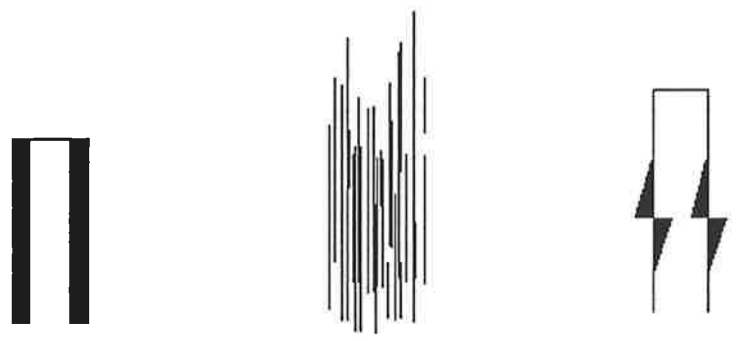


Figure 10: IT masks; traditional, lines, and flash.

The IT procedure is similar to that described by Nettelbeck (1987). Briefly, a cue was presented for 500 msec prior to each stimulus which consisted of two parallel vertical lines 24 mm and 34 mm long, separated by 10 mm and joined by a horizontal bar across the top. Subjects were required to respond by pressing a left button if the shorter line was on the left side and a right button if it was on the right side. The shorter line was located with equal probability of occurrence to the left or right side. Following the stimulus duration, a mask was presented for 500 msec. The inter-trial interval was varied by each subject because the next trial proceeded only after the subject pressed a button. Subjects were instructed to respond as accurately as possible.

5.9.3 Results and Discussion

Strategy use and IT across different masks

Table 26 presents the mean ITs calculated at 75% accuracy for each mask.

Table 26:
Mean IT (75%) in each mask condition
(N=50; Experiment 6)

	Flash	Lines	Traditional
Mean IT	**49.2**	**53.2**	**33.5**
SD IT	**13.9**	**12.2**	**16.3**

Subjects in the flash and lines conditions required significantly longer ITs in order to discriminate the stimulus than in the traditional mask condition. t-tests of the differences between ITs obtained from the flash and traditional masks and between the lines and the traditional masks were both significant ($t_{(1,49)}$ =5.5, p< .01 and $t_{(1,49)}$ =7.5, p<.01, respectively). ITs for the flash and lines masks were not significantly different ($t_{(1,49)}$ =1, N.S.). In order to test the possibility that some subjects were able to use a strategy to shorten their ITs, subjects were asked to describe the process used to discriminate between the stimuli at the completion of the IT session. The percentages of subjects reporting the use of apparent motion cues were; Traditional 35.6, Flash 20.4 and Lines 10.2. Results, therefore, suggested that the traditional mask allowed more subjects to use apparent motion cues to shorten their ITs than did the other masks. The mean ITs for subjects reporting and not reporting the use of apparent motion cues in the three mask conditions are reported in Table 27. Subjects who reported using apparent motion cues had significantly lower ITs than subjects who did not in the traditional IT mask condition ($F_{(1, 46)}$= 6.7, p=

.01). If IT has been regarded as a relatively pure measure of perceptual speed then these results would suggest that for subjects who report the use of apparent motion cues, this may not be a valid assumption. The comparison between subjects who use apparent motion cues in the other two mask conditions is difficult because, in both the flash and lines mask, relatively few subjects reported using apparent motion cues. Only 10 % of the subjects reported observing apparent motion in the lines mask condition, suggesting that in terms of providing a measure of perceptual speed that is relatively free from the perception of apparent motion, the lines masks is superior to the traditional mask. The results demonstrate that apparent motion was significantly reduced in the lines condition. Subjects also rated the lines mask the most difficult (73% vs 27% in the flash condition and 0% in the traditional condition). Mean IT for the apparent motion group (N=5) was greater than in the non-apparent motion group, indicating that the ability to perceive apparent motion in this mask condition did not reduce IT. In the flash mask condition the ability to use apparent motion cues was not significantly related to smaller ITs, although this effect approached significance. However, only 10 subjects reported apparent using motion cues in this condition, so that comparison with other conditions is difficult.

Table 27:
Mean and SD (parentheses) ITs for Apparent Motion and Non-Apparent Motion Groups. (N=50; Experiment 6)

	Apparent Motion	No Apparent Motion
Flash	**45.9 (14.7)**	**54.6 (11.5)**
Lines	**57.5 (5.9)**	**53.9 (12.1)**
Traditional	**23.4 (12.6)**	**36.8 (16.9)**

In the lines mask condition, mean IT was longer for subjects who reported using apparent motion cues than for those who did not, indicating that subjects who perceived apparent motion were unable to use this ability to shorten their ITs. These results then suggest that mean IT is significantly shorter in conditions which allow the use of apparent motion cues.

There are two possibilities to account for this finding, and its implications for the relationship between IT and IQ. Firstly, the use of apparent motion cues significantly reduces ITs independently of their mental speed. In this case, if it could be shown that high IQ subjects used this strategy more than low IQ subjects, then the correlation between IT and IQ would at least to some extent be explained by use of this macro level strategy (e.g., Cecci, 1990), by contrast with the currently held view that assumes a relationship between mental speed and intelligence. If this is true, then it is predicted that a significant negative correlation between IT and IQ will be observed in the traditional mask condition (because it allows the use of apparent motion cues) but a non-significant and small correlation between IT and IQ in the lines and flash mask (because they do not allow the use of apparent motion cues). The second possibility is one repeatedly made by Deary and Egan (Deary et al., 1989; Egan, 1986), who regard apparent motion use as an "epiphenomenon" of short ITs. That is, there is no causal link between apparent motion use and IT, it is simply the case that subjects who record short ITs often report that they see apparent motion more than subjects with longer ITs. Egan (in press) has recently suggested that when subjects are taught to use apparent motion cues; this strategy does not shorten their ITs, a view which is consistent with the Mackenzie and Cumming finding that they were unable to teach subjects how to use apparent motion strategies. This view would be supported by the demonstration of significant negative correlations between ITs and IQ scores across all three mask conditions.

Ability to use apparent motion cues in the traditional mask was significantly related to AH5 figural scores ($F_{(1, 49)}$= 6.46, p= .01) and to AH5 total scores ($F_{(1, 49)}$= 4.63, p < .05). AH5 verbal and APM scores were not significantly related to subject's ability to use apparent motion cues. The AH5 figural test may be regarded as an intelligence test that taps mental imagery, rotation and other perceptual processes. Mean and SDs of AH5 figural scores for apparent motion users were; Mean = 20.1, SD= 4.3 and Mean =16.7; SD= 4.3 for non-apparent motion users. Subjects reporting apparent motion cues in the traditional mask were also more likely to report the use of apparent motion cues in the flash mask condition than in the lines mask condition (r=.75, p<.01 vs r=.35, p<.05).

ITs derived from the three mask conditions correlated negatively and significantly with performance on the IQ tests (Table 28).

Table 28:
Pearson correlations between IT and IQ, uncorrected for restriction in range or test reliability (N=48; Experiment 6).

	AH5 verbal	AH5 figural	AH5 Total	APM
Flash	-.33**	-.34**	-.39**	-.47**
Lines	-.38**	-.24*	-.34**	-.24*
Traditional	-.31*	-.26*	-.28*	-.20

* p< .05 ** p< .01

The Egan and Deary view, that apparent motion is an epiphenomenon of short ITs, and which predicts that all correlations between IT and IQ should be significant and negative, was supported. The hypothesis that apparent motion use accounts for the correlations between IT and IQ cannot be supported. For this hypothesis to be supported, then the correlation between IT and IQ in masks that do not allow apparent motion should not be significantly different from zero. This is obviously not the case.

In addition, the Mackenzie and Bingham (1985) finding that apparent motion use reduces the true correlation between IT and IQ was examined by computing correlations between IT and IQ in the traditional mask condition for subjects reporting the use of apparent motion cues and those who did not. This analysis could not be done for the lines and lightning conditions because of the small number of subjects who reported using apparent motion cues (N=5 and 11 respectively). Table 29 reports the correlations between IT and IQ for these two groups.

Table 29:
Pearson correlations between IT and IQ scores uncorrected for restriction in range and test reliability for apparent motion and non apparent motion groups in the traditional mask condition (N=50; Experiment 6).

	AH5 verbal	AH5 figural	AH5 Total	APM
Apparent Motion	-.07	-.17	-.12	-.23
No Apparent Motion	-.46**	.14	-.19	-.31*

*** p<.05, **p< .01**

Results provied some support for Mackenzie and Bingham's (1985) result in which correlations between IT and IQ were significant and negative for subjects who did not use apparent motion cues and non-significant for subjects who do.

Relationship between masks and personality

All correlations between reported ability to use apparent motion cues and EPQ-R personality dimensions were small and statistically non-significant. This finding does not support the Brebner & Cooper (1986) study.

5.9.4 Summary

Experiment 6 investigated the effectiveness of different backward visual masks in the IT paradigm. The ability of subjects to use apparent motion was investigated in three backward masking conditions (traditional IT mask and two new masks). Apparent motion was most frequently reported by subjects under the traditional masking condition. The results generally support the conclusion that the significant negative correlation between IT and IQ, which has been reported in previous studies employing the traditional mask, may not be due to the ability of high IQ subjects to use apparent motion cues. There was no difference between the magnitude of the correlations between IT and IQ under mask conditions which differed in the extent to which subjects reported using apparent motion cues. This result is supportive of the view of Egan and Deary in which they regard the ability to use apparent motion cues as an epiphenomenon of short ITs.

5.10 Chapter summary.

Chapter 4 has investigated a number of methodological issues relating to the IT procedure. Firstly, the hypothesis proposed by some critics (e.g., Howe and Macintosh) that IT and IQ correlate only because of sample bias (both the inclusion of intellectually disabled subjects and the fact that many previous studies report correlations based on small samples) was examined. Significant negative correlations of the order estimated by Nettelbeck (1987) and employed by Anderson (1993) in his model of cognitive development were reported in Experiment 6. Notably, this experiment did not include any subjects who could be classified as intellectually disabled on either the WAIS-R or the APM. A pilot study examined the effects of different stimulus display modes on IT and on the relationship between IT and IQ. Previous experiments have employed several different display modes, although nearly all have used either a computer screen or a multi-channel tachistoscope. The hypothesis that inconsistencies in reported IT-IQ correlations from previous studies are due to the employment of different display modes was examined. Results suggested that in both the tachistoscope and computer monitor (monochrome video) conditions, significant negative correlations between IT and IQ were reported.

Experiment 6 compared the use of apparent motion cues under three masking conditions; the traditional mask employed in nearly all previous experiments, the lightning mask (a new mask developed by Evans & Nettelbeck, 1993) and a lines mask (a new mask selected out of 50 or so masks piloted as part of this study). Results suggested that both the lightning and lines mask significantly decreased apparent motion use in the IT paradigm. Experiment 6 also examined the Brebner and Cooper (1986) finding that extraversion was related to the ability to use apparent motion cues. Results did not confirm this prediction. Thus the result of the two experiments and one pilot study have indicated that at least in terms of the variables examined, the relationship between IT and IQ cannot be accounted for by strategies or methodological variables in which higher IQ subjects are more apt to employ than lower IQ subjects.

The focus now moves on to examine whether personality and temperamental variables can account for the relationship between ECT and IQ reported earlier in this thesis; Chapter 2 (DT, MT and IQ), Chapter 3 (AEP and IQ) and Chapter 5 (IT and IQ).

CHAPTER 6

Personality and Temperament

6.1 Introduction

Two specific hypotheses are tested in this chapter. Firstly, that personality and temperament variables are related to WAIS-R IQ, APM raw scores, IT, RT and the string length and secondly, the Howe (1990) hypothesis that correlations between IQ and IT, RT, and the string length are mediated by personality and/or temperament dimensions.

6.2 Rationale

Chapters 2, 3, and 5 have provided evidence that RT, the string length, and IT are correlated with various IQ measures. However, although ECTs may correlate with IQ, correlation does not imply causation. There may be other variables mediating correlations between IQ and IT, RT, and the string length. Along this line, Howe (1990, p. 492) has raised an alternative explanation for correlations between speed of information processing and intelligence:

> **"There will be additional reasons for a person's scores at different tasks being correlated whenever, as often happens, a person exhibits attributes of personality or temperament that similarly affect that individual's performance on each of a number of different tasks......As a result, a person's scores at the different tasks will tend to be correlated, a fact which may be mistakenly taken to be evidence of the presence of general ability or intelligence."**

The link between IQ and IT, RT and the string length may reflect the efficiency or speed of biological processes, or, on the other hand, may be mediated via cognitive strategies. In either case personality or temperament may be imvolved. Howe's view is similar to one expressed in a recent review of personality-intelligence studies by Zneider (1994) who suggests that;

> **" Individuals who do poorly on intelligence tests because of the debilitating effects of certain personality factors (e.g., high test anxiety, low motivation) would most likely do poorly on the criterion performance and for much of the same reasons."**

Brody (1985) has also suggested that the relationship between the string length and IQ may be mediated by aspects of one's temperament that similarly affect both measures. However, neither Brody (1985) nor Howe (1990) defines "personality" or "temperament" in such a way that testable hypotheses relating personality, temperament, ECTs and intelligence can be formulated. Therefore, a commonly used test of personality has been employed in this dissertation- the Eysenck, Personality Questionnaire (EPQ) and of temperament- the Strelau Temperament Inventory (STI) to test this hypothesis. The EPQ was chosen as the personality test because of its substantial research base and ease of administration. Other possible tests included the Cattell 16 Primary Factor Questionnaire (16PF), the Minnesota Multi Phasic Inventory (MMPI) and the NEO-PI. There is some evidence that both the second-order factors of the 16PF and the five factors of the NEO-PI measure similar dimensions to the EPQ. For this reason, together with the ease of use of the EPQ and extensive research base led to its choice over the former two tests. The MMPI, although a trait test, is difficult to administer (over 550 items), difficult to interpret, and measures psychodynamic traits which would appear to have low face validity at least in terms of their relation with intelligence. In addition there have been several criticisms of the MMPI in terms of reliability and generalizability to normal subjects (Anastasi, 1988).

The inclusion of the STI as the test of temperament was more straightforward than the selection of the EPQ. The STI is the only available test, in English form, that attempts to measure basic CNS temperamental properties as defined by Pavlov. The STI has also been researched extensively and has a strong theoretical basis. The theoretical basis for both the EPQ and STI will be briefly outlined in the next section. Some detail on arousal theory is described in order to set the scene for a discussion of Robinson's position that ambiverts (moderate arousability), because of CNS properties directly related to arousal, are at an advantage both on IQ tests, and also on speed tests such as RT and IT. This hypothesis is empirically examined later in this chapter.

6.3 Intelligence and Personality

The review of this area is not intended to be exhaustive as there are many personality variables within the domain of personality (both traits and states). This section will concentrate on the relationship between IQ, IT, RT and the string length and the personality dimensions measured by the EPQ and STI.

6.3.1 The EPQ personality dimensions

Eysenck has in several papers described his three main personality dimensions; extraversion/introversion (E), neuroticism (N) and psychoticism (P). Figure 11 displays Eysenck's two most fundamental dimensions of personality: extraversion-introversion and neuroticism or emotional stability and personality traits associated with these two super-factors. Eysenck has argued that these two super-factors are consistently found in large studies on trait personality, usually from factor analyses of questionnaire data. A third factor termed Psychoticism (P) was later introduced by Eysenck to form the third super factor derived from the Eysenck Personality Questionnaire [Eysenck & Eysenck, 1976]. It may be noted, however, that the existence of the third factor, P, has been the focus of continued and considerable debate (i.e., see Costa & McRae, 1992).

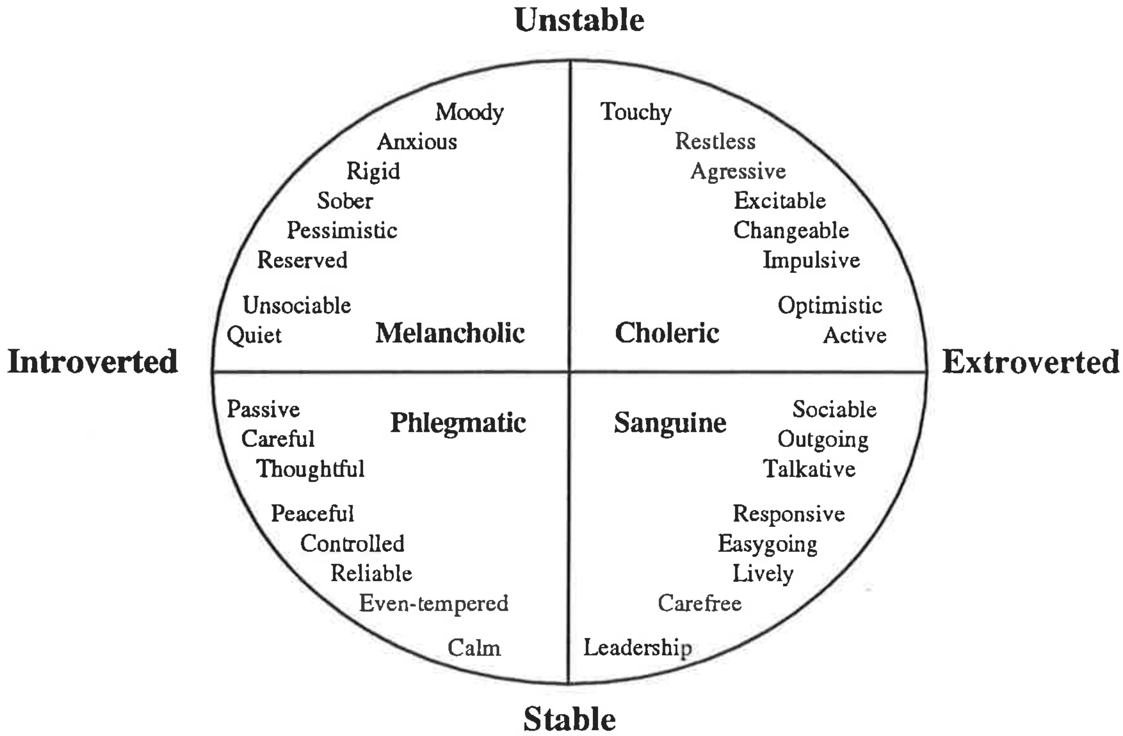


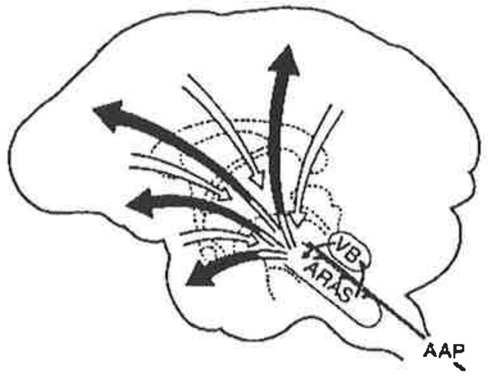
Figure 11: **Diagrammatic representation of two dimensions of personality: extraversion versus introversion, and emotional instability versus stability (neuroticism). [Reproduced with permission, from Eysenck (1983a). Is there a paradigm in personality research? Journal of Research in Personality, 17, 369-397].**

6.3.2 The STI temperament dimensions

The STI (Strelau, 1987) contains four dimensions, strength of excitation (Ex), strength of inhibition (In), balance (B) and mobility (M), which are all aimed at identifying temperament dimensions based on Pavlovian principles. Strength of Excitation refers to the level of excitation created by stimuli of given intensity, with greater excitatory strength indicating the nervous system's greater capacity to withstand strong and/or prolonged excitation (Strelau, 1987). Strength of Inhibition describes the processes involved in the ability to maintain a state of conditioned inhibition of which extinction and delay are examples. Balance refers to the ratio between strength of excitation and strength of inhibition, representing the ability of the nervous system to adapt to changes in the environment. Mobility is the capacity to switch between excitatory and inhibitory states (Strelau, 1987).

6.4 Relationship between personality and IQ

Eysenck has described the physiological basis of E in several reports. Figure 12 illustrates the proposed physiological basis of extraversion and neuroticism. According to Eysenck's model, extraversion-introversion differences are largely determined by activity in the reticular formation-cortex arousal loop. Introverts are hypothesised to have greater resting cortical arousal than extraverts so that they show greater arousability than extraverts to stimuli of weak intensity. As Brebner and Stough (1994) have pointed out, the biological mechanism postulated by Eysenck to underly both extraversion (arousal) and intelligence (cortical error propagation) are regarded as independent processes. Extraverts are usually regarded as sociable, outgoing, and impulsive, whereas introverts tend to be introspective, less sociable and less impulsive, are more reliable and moralistic. Eysenck and Eysenck (1976) have argued that E, N, P, and IQ are all independent orthogonal trait dimensions. Several studies have examined whether differences in IQ can be observed between introverts and extraverts.



VB Visceral Brain
AAP Ascending Afferent Pathways
ARAS Ascending Reticular Activating System

Figure 12: **Diagram illustrating the hypothetical physiological basis of extraversion (reticular formation-cortical arousal) and neuroticism (limbic system or visceral brain). Reproduced with permission from H.J. Eysenck (1983b). Psychophysiology and Personality: Extraversion, Neuroticism and Psychoticism. In Gale, A. and Edwards, J. A. Physiological Correlates of Human Behaviour. Vol. III: Individual Differences and Psychopathy. Academic Press: Sydney.**

In one of the largest studies to date, Eysenck (1971) has reported that in 398 male nurses, E, N and P did not significantly correlate with either the Raven's Progressive Matrices (RPM) or the Mill Hill Vocabulary Test. However, it should be noted that one of the problems in searching for correlations between personality and intelligence measures is the fact that even within intelligence testing, many tests may only share 30-40% common variance, when correlated. For example, the correlation between the WAIS-R and the APM is usually only around the .5 mark, so that even if a personality dimension does not correlate with one particular test of intelligence, it may still significantly correlate with another test (Brebner & Stough, 1994). Obviously the best approach, where practical, is to inter-correlate a range of tests. Both the WAIS-R and APM have been used in this study for this reason.

In earlier work Eysenck and Cookson (1969) proposed that a positive association exists between extraversion and IQ in primary school children. This association, however, reverses during development, so that at secondary school a negative correlation exists. Presumably in adulthood this relationship has disappeared. As pointed out by Zneider (1994), there are several alternative explanations for this finding. For instance, it may be the case that with increasing education more intelligent students become more introverted, while less intelligent students become more extraverted. Anthony (1973) has provided some confirmation for this view. Another suggestion by Anthony (1973) is that introverts and extraverts develop at different rates around a mean peak of about 14 years of age, but there are several other possibilities.

Saklofske (1985) has provided support for Eysenck's position that personality and IQ are unrelated. Employing the Kaufman Assessment Battery for Children, the Woodcock-Johnson Brief Scale and the Junior version of the Eysenck Personality Questionnaire (JEPQ) in 105 eight to ten year-olds, he reported no significant differences between any of the JEPQ dimensions and IQ tests. Against these findings are studies by Lynn, Hampson, and Magee (1982) and by Crookes, Pearson, Francis, and Carter (1981). In the first study, Lynn et al. correlated extraversion and IQ amongst 711 adolescents in Northern Ireland. Correlations ranged from +.19 for girls and +.21 for boys, accounting for small but significant parts of the IQ variance. Crookes et al. also reported a positive correlation between IQ and extraversion in 15-16 year old boys and girls.

Robinson (1982a, 1982b, 1983, 1985, 1986) has discussed differences in extraversion in relation to performance on IQ tests, and has proposed that introverts may perform better on tasks requiring verbal IQ whereas extraverts may perform better on tasks requiring performance IQ. In his model, he adopts Eysenck's view that introverts inherit a nervous system which facilitates the formation of learned connections between stimulus and response. Eysenck also suggested that introverts are more conditionable than extraverts (Eysenck & Levy, 1972). For introverts, any stimulus is associated with greater numbers of learned connections. In addition, Robinson proposes that, in introverts, these learned connections are more quickly accessed, which leads to the development of greater verbal skills than in extraverts. This advantage however comes at some cost, because the introvert nervous system, because of greater tonic arousal, shows weaker inhibition of the brain stem system. The brain stem is hypothesised to be involved in motor sequence processes, so that, over time, introverts will also develop decrements in motor performance skills relative to extraverts. This was shown by Eysenck (1967b) and termed reactive inhibition. Thus Robinson has proposed that extraverts will be superior to introverts on IQ tests measuring performance ability and inferior to introverts on IQ tests measuring verbal ability. Robinson (1985) in partial support of this theory, has provided evidence that differences in E are associated with different intellectual styles but not to absolute levels on intelligence tests, so that differences were not observed in overall IQ, but in terms of test profile. Saklofske and Kostura (1990) have tested Robinson's predictions in a sample of 84 children who were divided into three groups; extraverts, ambiverts and introverts. All children completed the JEPQ and the WISC-R. Analysis of variance revealed no significant differences on any sub-test of the WISC-R IQ (including VIQ and PIQ) for the three groups, a finding which Saklofske and Kostura interpreted as supporting Eysenck's position that personality and intelligence are unrelated.

More recently, Robinson (1989) has proposed a novel model of the neurophysiological basis of intelligence in which previous linear models are replaced with a curvilinear model, linking EEG parameters to intelligence at different levels of arousal. Linking behavioural data on the relationship between performance on cognitive tests and different levels of arousal (e.g., Corcoran, 1972), he has suggested that the neurophysiological processes underlying the development of intelligence work best when operating at a moderate level of arousal. Robinson equates arousal level directly with Eysenck's conception of extraversion, extraverts being less aroused than introverts at resting level. He has concluded that an intermediate level of arousal is optimal for neural transmission of information. Correlations between measures of mental speed (specifically IT and RT) and IQ test performance do not reflect a simple serial information processing-IQ relationship, but instead a trade-off between the time taken to access internally stored information and the time taken to extract information from the stimulus that is not previously stored. Robinson's theory offers a clear hypothesis to test; ambiverts (intermediate resting arousal levels) will record significantly higher IQs than either extraverts or introverts. Until now, however, this hypothesis has remained basically untested.

It has long been known (e.g., Eysenck, 1967b) that differences in task strategies exist between extraverts and introverts for most speeded experimental tasks. For instance, extraverts are usually more impulsive responders and record more errors whilst introverts usually require more time but record fewer errors and are more accurate. These differences in task strategies have also been explored in terms of the Furneaux tests in which performance on intelligence tests are divided into their constituent parts; speed, accuracy and persistence. Investigations along these lines usually demonstrate that extraverts are faster, less accurate and less persistent than introverts. Jensen (1964) for instance has reported that extraverts are quicker to find a solution in the Raven's Progressive Matrices (PM), but make more errors.

In a recent unpublished study Brebner et al. (1993) have correlated factor B (general intelligence) from the 16 PF with several measures of personality including the EPQ. No consistent pattern of results was observed although there was weak evidence for measures of emotionality (i.e., N from the EPQ) to be negatively correlated with IQ. This analysis, however, assumes a linear relationship, which may hide the inverted U function proposed by Robinson.

The pattern of results reviewed in this section suggests that there may be small relationships between E from the EPQ and IQ test measures, although the pattern of results from previous experiments does not provide any definitive answer to this question. As Zneider (1994) suggests, at best, there is inconclusive evidence to support a relationship between personality and intelligence. Part of the problem is the lack of studies on this topic, especially studies investigating the relationship between personality and IT, RT and the string length, this being a topic for further discussion in this chapter.

6.5 Relationship between personality and String length

At present, there are very few studies examining the relationship between AEPs, personality and IQ, although there are several studies concerned with any two of these variables (see Brebner & Stough, 1994 for a review). Examining whether string length is related to personality variables, D.E. Hendrickson (1982) has reported negligible correlations between EPQ and string length scores; -.03 for extraversion, -.01 for neuroticism, and -.13 for psychoticism. Only the correlation between string length and P was significant but accounted for less than 2 percent of the variance. These results suggest that the EPQ dimensions and AEPs, at least in terms of the string length measure, are not associated in any meaningful way. More recently, Bates and Eysenck (1993) reported a correlation of -.31 between psychoticism and string length measured at the T5 electrode site from a warning tone, and -.3 and -.34 between string length and psychoticism at the P4 and O1 electrode sites from an IT stimulus. They interpreted these correlations as supporting a role for attention in the string length measure. String lengths in the latter experiment were evoked from an IT task requiring a response, and which therefore differed from the D.E. Hendrickson (1982) study in which string lengths were derived from a tone, requiring no response. Because of the different experimental conditions of the D.E. Hendrickson (1982) and the Bates and Eysenck (1993) study, the larger correlations in the latter experiment may have been due to increased attentional demands, as psychoticism and attention have previously been shown to be correlated (Baruch, Hemsley, & Gray, 1988).

The most important problem in reviewing past work in this area is that no studies have specifically been concerned with assessing the influence of personality on the string length-IQ correlation. Neither D.E. Hendrickson nor Bates and Eysenck provided any evidence as to whether personality mediates the correlation between string length and IQ.

6.6 Relationship between personality and Inspection Time

Presently, there have only been two studies that have examined whether IT or IT-IQ correlations are related to personality. Brebner and Cooper (1986) provided evidence that extraverts were more likely to use apparent motion cues to artificially decrease their ITs independent of their 'true' information processing speed. Because of this ability, the mean ITs of extraverts were significantly shorter than those of introverts. It is unclear, however, whether extraverts consciously used a cognitive strategy. In any case, this result suggested that some subjects, on the basis of their personality attributes, were able to improve their ITs. Unfortunately, this study did not measure IQ, so the effects on the IT-IQ correlation could not be observed. The other study, which was reported in Chapter 5, suggested that apparent motion effects were unrelated to personality, at least when the traditional mask was employed. This study also tested two additional masks in which apparent motion was significantly reduced. Even in these conditions, subjects who reported using apparent motion cues did not significantly differ from those who did not on any of Eysenck, Eyenck and Barrett's (1985) EPQ-R dimensions.

6.7 Relationship between personality and Reaction Time

Few studies have examined personality effects in the Hick paradigm, employing the Jensen procedure. The main problem with the Jensen procedure is that it does not allow errors to be measured. Subjects are instructed to respond as quickly as possible, and, because the task is very elementary (even at the highest stimulus complexity level) and because the response keys are spatially separated, errors occur very occasionally. Welford (1986) has commented that it is difficult to assess strategy use in this paradigm because of this problem, the main strategy being the speed-accuracy trade-off.

A recent study by Stough, Mangan, Bates and Pellett (submitted) has provided evidence for a significantly lower mean DT in introverts than in extraverts. Introverts recorded some 30 msec advantage over extraverts in mean DT scores. This study also examined whether personality dimensions from the EPQ-R were related to strategy use (the same type as described in detail in experiment one of this dissertaion, in which masked and unmasked RT conditions were compared). Stough et al. concluded that personality was unrelated to the use of this strategy. Importantly, however, correlations between Hick parameters and IQ were only significantly negative in the introverted group. It is possible that introverts may show a greater degree of caution in this task than extraverts, and which may account for their slower DTs. Subjects in many RT paradigms employ differential strategies so it is not implausible that personality dimensions influence RT responses in the Hick paradigm.

There have also been other RT paradigms in which personality has been related to RT performance. For instance, Brebner and Cooper in a series of experiments have reported differences in mean RTs between extraverts and introverts (Brebner & Cooper, 1978, 1985; 1986). In their theory, introverts gain arousal from stimulus analysis, so that tasks which involve increasing stimulus complexity show progressive RT improvements for introverts compared to extraverts. On the other hand, extraverts are hypothesized to gain arousal from response organization, with more complex responses translating into progressive advantages for extraverts compared to introverts.

Experiment 7

The Relationship between personality, tempeament and IQ, IT, RT and AEPS.

6.8 Method and Procedure

In order to assess the relationship between the main variables employed in this study and personality and temperament, the Eysenck Personality Questionnaire (EPQ) and the Strelau temperament Inventory (STI) was administered to 70 first-year university students. These were the same subjectss who had participated in the IT, AEP and RT tasks reported in Chapters 2, 3 and 5.

6.9 Results and Discussion

EPQ, STI and IQ Variables

Table 30 presents mean (and SDs) for personality and temperament variables. All scores fall within the normal range of scores for these tests.

Table 30:
Means (and SDs) for personality (EPQ) and temperament (STI) dimensions (N=70; Experiment 8).

	Mean	SD	Range
Personality			
Extraversion	14.4	4.9	2-21
Neuroticism	12.1	5.1	1-23
Psychoticism	4.1	3.2	0-16
Lie	6.9	3.9	1-19
Temperament			
Excitation	53.8	10.3	26-78
Inhibition	60.5	11.3	32-82
Mobility	56.8	9.7	29-82
Balance	.94	.27	.52-1.8

Table 31 shows Pearson correlations between VIQ, PIQ, and FSIQ from the WAIS-R, APM raw scores and the personality and temperament dimensions of the STI and EPQ. There were three main sets of significant correlations between variables in Table 31. Firstly, VIQ and APM raw scores are significantly negatively correlated with social desirability (L scores) from the EPQ, indicating that subjects with lower VIQ and APM scores are more likely to fake EPQ responses. This finding is consistent with previous research (e.g., Eysenck & Eysenck, 1991). Secondly, strength of excitation from the STI was significantly correlated with IQ (positively). Although a small effect, this is an important finding because it suggests that a more specific analysis of the relationship between different levels of arousal and IQ test performance should be undertaken. Thirdly, there was a small positive correlation between mobility from the STI and the IQ measures. As Brebner and Stough (1994) have explained, Mobility scores are positively related to timed IQ test scores which supports Strelau's (1977) view that temperament traits may be expressed in the dynamics pf intellectual processes, referring to the importance of speed of mental processes, and the dynamics of mental activation. In his model, both the efficiency and quality of thought processes influence intellectual abilities. Along these lines, Kozcielak (1979) has compared inventors and non-inventors on tests of intellectual ability and creativity and STI dimensions, and has shown that the inventor group scored significantly higher than the non-inventor group on both inhibition and mobility dimensions from the STI, and on the intellectual ability and flexibility tests. Results from Table 31 provide some support for this finding, linking intellectual ability and quickness of mental activation. Apart from these correlations, it appears, then, that there is little relationship between different measures of IQ, IT and the personality and temperament dimensions.

Table 31:
Correlations between VIQ, PIQ, FSIQ, and raw APM scores and personality and temperament dimensions. (N=67; Experiment 8).

	E	N	P	L	Ex	In	M	B
VIQ	-.03	-.20	-.03	-.29*	-.17	-.01	.21*	.12
PIQ	.08	-.12	-.02	-.01	.27*	.09	.27*	.11
FSIQ	.00	.04	.00	-.20	.26*	.03	.30**	.15
APM	.04	.02	-.05	-.26*	.22*	.01	.22*	.11
IT	.09	.11	-.10	-.13	-.23*	-.05	-.09	-.12

** p < .05, ** p < .01*

Robinson's Hypothesis

As mentioned above, Robinson (1989) has hypothesised that an inverted U function exists between IQ and E, so that an IQ advantage exists for ambiverts compared to either introverts or extraverts. In order to examine whether such a relationship exists, subjects were divided into three groups on the basis of extraversion; Extraverts with scores ranging from 17-21 (N=27); Ambiverts with scores ranging from 12-16 (N=20); and Introverts, with scores ranging from 2-11 (N=20). Planned comparisons revealed a significant IQ score advantage for ambiverts compared to the extravert and introvert groups; VIQ ($t= 1.8$, $p < .05$); PIQ ($t= 1.9$, $p < .05$); FSIQ ($t= 2.3$, $p < .01$); and APM ($t= 1.7$, $p < .05$). Mean scores, which are reported in Table 32, suggest that ambiverts may demonstrate modest IQ score superiority over both extraverts and introverts. According to Robinson (1989) this superiority is due to differences in arousal, with ambiverts possessing an optimal level of arousal for performance on intellectual tasks. Assuming that this difference is related to CNS arousal level then the educational significance of this finding is clear. It suggests that there may be an optimal level of CNS arousal for learning and performance in tasks requiring intelligence, and that this optimal level may be measured by the extraversion dimension. Intellectual performance may be enhanced if arousal levels are manipulated to some optimal level.

Table 32:
Scores on VIQ, PIQ, FSIQ and raw APM scores for introverts, ambiverts and extraverts (N=67; Experiment 8).

IQ Test	Introverts	Ambiverts	Extraverts
VIQ	110	117	111
PIQ	108	119	113
FSIQ	109	120	112
APM	25	27	25

RT Measures

Correlations between DT variables and personality and temperament variables were generally small and statistically non-significant (Table 33), although small and significant correlations were obtained between mobility and some DT variables. According to Strelau's (1987) view of Mobility, the negative correlation between these two variables suggests that subjects who record faster DTs possess nervous systems that are more mobile than subjects with slower DTs.

Table 33:
Pearson correlations between mean masked DT and dimensions from the EPQ and STI. (N=70; Experiment 8)

	E	N	P	L	Ex	In	M	B
1 stimulus	-.02	.18	.02	.02	-.12	-.20	-.23*	.11
2 stimuli	-.01	.01	-.04	.05	.13	-.01	-.11	.09
4 stimuli	-.01	-.02	-.16	.01	.03	-.09	-.25*	.11
8 stimuli	-.11	.06	-.21	.06	-.02	.03	-.24*	-.05
Slope	-.07	.00	-.32*	.01	-.01	.14	-.10	-.15
Intercept	-.06	.07	.18	-.02	-.11	-.22	-.18	.15

** p<.05;*

Table 34 presents the correlations between MT variables and personality and temperament dimensions from the EPQ and STI. All correlations were low in magnitude (31/32 were non-significant), indicating that personality and temperament, at least measured by the present tests, do not relate to MT variables.

Table 34:
Pearson correlations between mean masked MT scores and dimensions from the EPQ and STI dimensions. (N=70; Experiment 8)

	E	N	P	L	Ex	In	M	B
1 stimulus	.13	.14	.03	.06	-.16	-.06	-.15	-.03
2 stimuli	.03	.00	-.03	.06	-.02	-.07	-.16	.02
4 stimuli	.01	.00	-.06	.05	-.11	-.09	-.28*	.01
8 stimuli	-.04	.06	-.24	.12	.08	-.15	-.07	.16

** p<.05 ** p<.01*

Robinson's hypothesis was examined for masked mean DT and MT. Planned comparisons indicated that Ambiverts were not significantly different to introverts or extraverts on mean DT or MT variables at any level of choice. Overall, MT and DT measures from the Hick paradigm are not related to any of the personality and temperament variables examined in this study except for mobility.

IT

Contrary to the hypothesis linking mobility with measures of speed of information processing, IT did not correlate with any of the EPQ or STI dimensions (Table 35).

Table 35:
Pearson correlations between mean IT scores and EPQ and STI dimensions.(N=67; Experiment 8)

	E	N	P	L	Ex	In	M	B
IT	.11	.10	-.11	-.12	-.22	-.05	-.08	-.11

** p < .05 ** p < .01*

In addition, Robinson's view that ambiverts should demonstrate a superiority for IT over both extraverts and introverts was not supported. Planned comparison indicated that the IT of ambiverts were not significantly different than the IT of extraverts or introverts ($T_{,67}$= .3, NS). The finding that ambiverts relative to extraverts and introverts demonstrated an advantage for IQ test performance but not for IT performance is surprising given the correlation between IT and IQ in this sample. This result may be explained in terms of Gale's (1983) position that one should measure arousal levels in the context of the arousing conditions of the task. He has suggested that both extraverts and introverts will attempt to increase and decrease their arousal levels to a level in which performance is optimal. According to the theory, it might be hypothesised that for the IT task, extraverts and introverts are able to efficiently modulate their arousal level so that all subjects perform at a moderate level of arousal. Whether or not this explanation can be empirically verified will await the results of an experiment that measures arousal level across tasks differing in complexity for introverts, extraverts and ambiverts.

Although Table 35 shows little or no relationship between personality and temperament on IT performance, the possibility remains that personality and temperament variables may influence the relationship between IT and IQ. In order to explore this possibility, partial correlations were calculated between IT and IQ in which the effects of personality and temperament dimensions had been removed (Table 36). The results indicate that the significant negative correlation between IT and IQ, and which was reported in Chapter 4, is not in any sensible way different after the effects of personality and temperament have been removed. Table 36 clearly establishes that insofar as the EPQ and STI dimensions are concerned personality and temperament do not determine the association between IT and IQ.

Table 36:
Partial correlations between IT and VIQ, PIQ, FSIQ, raw APM scores and fluid and crystallized measures obtained from the WAIS-R with personality and temperament patialed individually (N=67; Experiment 8).

	E	N	P	L	Ex	In	M	B
IT-VIQ	-.16	-.19	-.16	-.21*	-.13	-.16	-.15	-.15
IT-PIQ	-.40**	-.38**	-.39**	-.39**	-.35**	-.38**	-.38**	-.38**
IT-FSIQ	-.33**	-.33**	-.33**	-.36**	-.29*	-.33**	-.32**	-.32**
IT-gf	-.38**	-.36**	-.36**	-.39**	-.33**	-.36**	-.36**	-.37**
IT-gc	-.16	-.18	-.18	-.20	-.14	-.17	-.16	-.16
IT-APM	-.25*	-.25*	-.25*	-.28*	-.19	-.24*	-.23*	-.23*

** p<.05, ** p<.01*

A further check of this relationship was performed in the form of stepwise multiple linear regression analyses. Employing IQ variables as dependent variables in each regression equation and all the personality, temperament and IQ variables as independent variables, the results of the analyses were consistent with those from the partial correlations. The only significant variable in the VIQ regression was the social desirability dimension (L scale) from the EPQ. IT was not significantly related to VIQ scores. In the PIQ regression, IT was the only significant variable ($T=-3.1$, $p < .05$). In the FSIQ regression, both IT ($T=-2.7$, $p < .05$) and Mobility ($T=2.2$, $p < .05$) were significant predictors. In the APM regression, mobility was the only significant predictor of performance. This pattern of results suggest that for both PIQ and FSIQ, IT was a significant predictor independent of the effects of the personality and temperament variables. The Mobility dimension of the STI was a significant predictor of both FSIQ and APM scores, linking Strelau's concepts of mental dynamics with performance on these two tests, presumably because of processes involved in spatial intelligence.

AEPs

Table 37 reports the correlations between personality dimensions and string length scores measured at different epochs.

Table 37:
Pearson correlations between string length and personality dimensions from the EPQ and STI (N=70; Experiment 8).

EPOCH	E	N	P	L	Ex	In	M	B
100-200	-.30*	.08	-.34*	-.06	.25	.08	-.02	.08
0-250	-.27*	-.02	-.28*	-.08	.36**	.23	.06	.05
0-100	-.22	-.16	-.20	-.02	.37**	.30*	.12	.00
0-200	-.11	.32*	-.33*	-.07	-.01	.13	-.10	-.11
100-300	-.09	.26	-.21	-.20	.12	.09	.01	.02

***p* < .05, ** *p* < .01**

The pattern of correlations is difficult to interpret but there is some evidence for a significant relationship between the string length and extraversion, psychoticism and strength of excitation. Seven (out of 15) of the correlations between these variables were significant at the .05 level or less, although the effect was small, accounting for approximately 10% of the reliable variance. This pattern of correlation is consistent with previous work which has demonstrated a reliable association between E and Ex (Mangan, 1982). Correlations between neuroticism and string length measured from 0-200 msec post stimulus and between inhibition and string length measured from 0 to 100 msec post stimulus were also significant. These results therefore do not support Hendrickson's (1982) finding that the string length measure does not correlate with personality dimensions, which poses a problem for their theory explaining the string length-IQ correlation. According to Hendrickson and Hendrickson (1980), the string length is a measure of cortical information processing. Theories of personality dimensions, on the other hand, specifically extraversion, neuroticism, psychoticism and strength of the nervous system do not describe processes relating to the accuracy of cortical information processing.

How do we explain these results? Consistent with recent experiments we may hypothesise that performance on laboratory tasks relates to arousal level. In a previous section evidence was provided for an IQ superiority (both WAIS-R and APM) in ambiverts compared to either introverts or extraverts. This result was explained in terms of the optimal level of arousal to perform the IQ test. Within the context of the IQ testing environment, introverts may be over-aroused, extraverts under-aroused and ambiverts optimally aroused. According to Eysenck (1982), extraverts at resting levels have low CNS arousal levels whilst introverts posses high CNS arousal level. In the current experiment, subjects were required to listen but not respond to auditory tones in a darkened room. This procedure may be considered to be very under arousing, so that the arousal level of introverts and extraverts may remain relatively high and low respectively. If the string length, to some extent, measures CNS arousal, which is plausible in terms of the pattern of correlations between the string length and extraversion and strength of excitation variables, then it might be expected that introverts will show significantly greater string lengths than extraverts. In order to test this possibility, subjects were divided into two groups based on their extraversion score. Introverts were defined as those scoring less than 14 and extraverts as those scoring greater than 14 on this scale. An unrelated samples t-test revealed significant differences between extraverts and introverts for string lengths measured from 100-200 and from 0-250 msec post stimulus (both $t=1.8$, $p < .05$). Differences between extraverts and introverts were not significant for the other string length epochs, although for all epochs introverts recorded higher mean string lengths than extraverts (Table 38). This result suggests then that in conditions which may be regarded as under-arousing, the string length measure of AEP waveform complexity is larger in introverts than extraverts which is consistent with the hypothesis that greater arousal leads to larger string lengths.

Table 38:
Means and (SDs) of string lengths measured at different temporal epochs for extraverts and introverts (N=70; Experiment 8).

Epoch	100-200	0-250	0-100	0-200	100-300
Introverts	1495 (703)	1187 (537)	948 (914)	1002 (373)	1055 (480)
Extraverts	1164(51)	931 (419)	656 (401)	872 (409)	1020 (421)

This result, taken together with the significant correlations between IQ and the string length, leads to two suggestions which may explain the string length-IQ-personality interactions. Firstly, it is possible that the significant string length-IQ correlations reported in Chapter 3 and in other experiments, are at least, in part, mediated by personality variables. Secondly, it may be that the string length measure of AEP waveform complexity correlates with both IQ and personality measures independently, and thus IQ and personality share independent parts of the reliable string length variance. The following section examines this possibility. At present there is little evidence to support one over the other possibility.

String length-IQ and personality/temperament

Stepwise multiple linear regression analyses were performed to investigate the relationship between the string length, IQ and all personality variables. Employing either VIQ, PIQ, FSIQ or APM variables as the dependent variable in each regression equation and all the personality, temperament and string length variables as the independent variables, suggested that for VIQ, PIQ, and APM, the string length measure was the only significant predictor ($p < .01$) of

IQ. For FSIQ, both the string length and mobility from the STI were significant predictors (T=2.6, $p < .05$ and T=2.4, $P < .05$ respectively). Thus these analyses suggested that the string length is an important predictor of IQ variables independent of personality and temperament variables

Another method of investigating the effects of personality on string length-IQ correlations is the partial correlation statistic. If personality mediates the string length-IQ correlation then the correlation between string length and IQ will decrease after personality dimensions have been partialed out. In fact, partialing out personality dimensions from the string length-IQ correlations only decreased correlations to a small degree. For example the correlation between VIQ and string length measured from 100-200 msec post stimulus decreased from .63 to .59 when extraversion was partialed out of the correlation. A similar result was found for the other personality variables. Psychoticism was associated with the greatest reduction in the string length-IQ correlation, although even this effect was weak (about 5% of the string-IQ variance). Tables 39 and 40 report partial correlations between string length measured at different temporal epochs and VIQ and PIQ, with personality and temperament dimensions partialed out of the correlations.

Table 39:
Correlation between string length and VIQ and PIQ before and after partialing out EPQ personality dimensions.
(N=67; Experiment 8)

Epoch	VIQ	PIQ	VIQ	PIQ	VIQ	PIQ	VIQ	PIQ	VIQ	PIQ
	Unpartialed		*E Partialed*		*N Partialed*		*P Partialed*		*L Partialed*	
0-100	.29*	.24*	.24*	.29*	.30*	.20	.24*	.27*	.39**	.16
0-200	.58**	.37**	.57**	.39**	.59**	.42**	.52**	.64**	.62**	.35**
0-250	.56**	.45**	.52**	.52**	.56**	.44**	.51**	.58**	.69**	.47**
100-200	.62**	.48**	.59**	.53**	.62**	.44**	.57**	.43**	.69**	.47**
100-300	.54**	.35**	.55**	.54**	.54**	.38**	.50**	.55**	.60**	.39**

** p<.05 ** p<.01*

Table 40:
Correlation between string length and VIQ and PIQ before and after partialing out STI personality dimensions. (N=67; Experiment 8)

Epoch	VIQ	PIQ	VIQ	PIQ	VIQ	PIQ	VIQ	PIQ	VIQ	PIQ
	Unpartialed		*Ex Partialed*		*In Partialed*		*M Partialed*		*B Partialed*	
0-100	.29*	.24*	.39**	.16	.38**	.16	.38**	.19	.40**	.22
0-200	.58**	.37**	.67**	.37**	.65**	.34*	.65**	.38**	.66**	.38**
0-250	.56**	.45*	.71**	.44**	.71**	.48**	.71**	.52**	.72**	.49**
100-200	.62**	.48*	.68**	.47**	.69**	.50**	.69**	.54**	.69**	.50**
100-300	.54**	.35**	.62**	.40**	.62**	.40**	.63**	.42**	.62**	.41**

** p<.05 ** p<.01*

In order to examine Robinson's hypothesis concerning the string length measure of AEP waveform complexity planned comparisons were performed at each string length epoch. None of the comparisons waw significant, indicating that ambiverts do not possess longer string lengths than either extraverts or introverts.

These results suggest that the string length-IQ correlations are largely independent of the personality and temperament dimensions of the EPQ and STI, although there was some evidence suggesting that psychoticism could account for some of the string length-IQ variance. The string length measure, therefore, may be a useful index of extraversion and strength of the nervous system independent of IQ; it is not a single entity, but in fact measures at least two processes which underly both IQ and extraversion, psychoticism and strength of the nervous system.

This conclusion may support the Haier et al (1983) finding that the string-IQ correlation was strongest at moderate stimulus intensities and the widely held view that extraversion is related to CNS arousal levels. Introverts recorded significantly longer string lengths than extraverts which may suggest that the relationship between the arousability of experimental tasks and personality dimensions is important and should be further studied. The fact that psychoticism and string length correlated in both the Bates and Eysenck (1993) and the present study suggests that further research should investigate the relationship between psychoticism, string length and IQ in more detail. Brebner and Stough (1994) have discussed this possibility in terms of impulsivity, arousal and adherence to the task requirements although there are obviously other possibilities, including attention.

The pattern of intercorrelations between string length and personality dimensions suggests that temporal changes in the string length measure may be sensitive to different biological processes underlying different personality and temperament variables. For example, a significant correlation was obtained between string length measured from 0 to 200 msec post stimulus and neuroticism but at no other temporal epochs, suggesting that 0 to 200 msec might be an informative period in which to study individual differences in neuroticism with this biological parameter.

Finally, future research may wish to further elaborate the physiological processes that underly both the string length and personality. As Barrett and Eysenck (1992) explain, despite the Hendricksons' attempts to anchor the string length measure to a biochemical and neurophysiological model of brain functioning and therefore to an error model, there is no persuasive reason why string length should be considered to be a measure of information processing accuracy. Despite the lack of an adequate scientific explanation for the string length measure the correlation between the string length and IQ is compelling reason for further experimental work. It should be pointed out too, that despite nearly 100 years of research in intelligence tests there is still no adequate scientific model of IQ.

6.11 Summary and Conclusions

Chapter 6 has been primarily concerned with testing the Howe (1990) hypothesis that ECTs and IQ are only correlated because of personality and temperament variables. In examining this possibility, the relationships between personality and temperament variables and IT, RT, the string length, and IQ were examined. Results suggested that although there was some evidence that personality dimensions are related to IQ, personality and temperament did not mediate or account in any statistical sense of the word for correlations between the ECTs and IQ as reported in chapters 2, 3, and 5.

The results of chapter 6 are important because they disconfirm a possible mediating variable of ECT-IQ correlations reported earlier in this dissertation. The most striking result was the examination of Robinson's hypothesis linking ambiversion with higher IQs than extraverts and introverts. Ambiverts scored significantly better on all IQ variables, suggesting that there may be an optimal level of extraversion for performance on IQ tests. Surprisingly, this inverted U effect of E was not recorded for performance on IT, RT, or the string length, particularly as IT, RT and the string length have been demonstrated to significantly correlate with IQ in this sample of subjects. However, introverts demonstrated significantly larger string lengths than extraverts and this difference was ascribed to the arousability of the stimulus conditions of the Hendrickson procedure.

CHAPTER 7

Inter-correlations between IT, RT, AEPs and IQ

7.1 Introduction

The purpose of this chapter is to further examine the nature of the correlation between ECTs and IQ. Specifically this chapter addresses whether IT, RT and AEPs are correlated, whether IT, RT and AEPs share the same or different parts of the IQ variance and the extent to which the IQ variance can be accounted for by these three measures.

7.2 Inter-correlations[9] between IT, RT and AEPs.

Table 41 summarises the correlations between ECTs and IQ reported in previous chapters. It should be noted that the correlations reflect independent measurement of each variable rather than the concurrent measurement of different variables (e.g., IT with concurrent AEP reported by Bates & Eysenck, 1993). Correlations reported between Hick RT variables and the other variables (IQ, IT, String length) are based on N=70 rather than the N=52 reported in Experiment 1. Eighteen additional subjects to those tested in Experiment 1 were administered the masked RT procedure in order to allow comparisons between all ECTs with similar sample size.

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[9] Significance of correlations throughout this section reflect one tailed probability levels.

Table 41:
Correlations between ECTs and IQ reported in Chapters 2, 3 and 5.

ECT	N	Chapter	Experiment	Correlation with		
				VIQ	PIQ	APM
Mean DT[10] 1 stimulus	52	Two	One	-.27*	-.23*	-.41**
Mean DT 2 stimuli				-.26*	-.19	-.43**
Mean DT 4 stimuli				-.32**	-.26*	-.51**
Mean DT 8 stimuli				-.30**	-.43**	-.31*
Mean MT 1 stimulus				-.45**	-.33*	-.48**
Mean MT 2 stimuli				-.30*	-.15	-.35**
Mean MT 4 stimuli				-.40**	-.28*	-.45**
Mean MT 8 stimuli				-.34**	-.20*	-.41**
String 000-100	70	Three	Two	.28**	.23*	.24*
String 000-200				.61***	.42***	.31**
String 000-250				.61***	.50***	.39***
String 100-200				.65***	.47***	.33**
String 100-300				.60***	.43***	.29**
IT	67	Five	Five	-.25*	-.40**	-.27*

** p < .05, ** p < .01, p < .001*

[10] Masked RT condition.

Speed Measures: IT and RT

Table 42 a and b report the interelationship between IT and RT. IT showed stronger relationships to MT than to DT variables, with shorter ITs associated with faster mean MTs and with greater MT variability. The latter result, consistent across the 2, 4, & 8 stimulus conditions, was surprising. There is no obvious reason why variability in MT should be related to IT, particularly given the direction of this correlation. Eysenck (1987) has suggested that speed of information processing tasks are correlated with IQ because of the relationship between variable nervous systems and the development of knowledge. Similarly, Jensen (1987) has suggested that correlations between DT and IQ reflect the relationship between information processing speed and the acquisition of knowledge. Both of these hypotheses are difficult to sustain given that IT and MT measures have both been shown to correlate with IQ in this sample. The fact that shorter ITs were related to greater MT variability and to faster mean MTs, and that IT and DT were not related, suggests that there are at least two types of mental speed. This is particularly important given the fact that both DT and IT have been shown to correlate with IQ in this sample..

Tables 42 (a) and (b):
Correlation between IT and DT and MT (mean and SD)
(N=67)

DT variable	IT
Mean DT 1 stimulus	.02
Mean DT 2 stimuli	.28*
Mean DT 4 stimuli	.01
Mean DT 8 stimuli	.07
SD DT 1 stimulus	-.05
SD DT 2 stimuli	-.13
SD DT 4 stimuli	-.13
SD DT 8 stimuli	-.01

MT variable	IT
Mean MT 1 stimulus	.34*
Mean MT 2 stimuli	.10
Mean MT 4 stimuli	.24*
Mean MT 8 stimuli	.17
SD MT 1 stimulus	-.05
SD MT 2 stimuli	-.37**
SD MT 4 stimuli	-.27*
SD MT 8 stimuli	-.24*

** p < .05 ** p < .01 (one tailed)*

IT and AEPs

(i) String length and variability

If the string length and variance index neuronal transmission accuracy, and if IT is a measure of perceptual speed, then IT may only correlate with the Hendrickson measures if, as Eysenck has suggested, speed is a measure secondary to efficiency. In this model a nervous system, which makes many errors, is also a slow nervous system, as the correct processing of incoming information will be impeded because of errors in transmission through the cortex. In support of Eysenck's (1982) view that individual differences in intelligence are related to R (described in Chapter 3), it is expected that measures of timed performance (such as IT) may be negatively correlated with the Hendrickson measures. An hypothesis linking IT and the Hendrickson measures may be justified, if it is assumed that the sampling of the stimulus or the sensory registration of the stimulus is also related to neural transmission accuracy.

Table 43 reports the correlations between IT and the Hendrickson measures. Significant negative correlations were calculated for correlations between string length (measured at different temporal epochs) and IT, the highest magnitude at around the -.5 mark. Given the reliabilities of both the string length and IT the magnitude of this correlation is substantial both from an empirical and theoretical viewpoint. No significant correlations were obtained between variance and IT. This, together with the finding that the string length and variance were not correlated in this sample (reported in Chapter 3), suggests that there are at least two independent processes underlying the two Hendrickson measures. These results force a revision of the Hendrickson's view that the string length and variance index the same process, R, thought to underlie individual differences in IQ.

Table 43:
Correlations between IT, string length and variance (N=67) at five temporal epochs

Hendrickson Measure	IT
String 000-100	-.20*
String 000-200	-.28**
String 000-250	-.46***
String 100-200	-.46***
String 100-300	-.27*
Variance 000-100	-.03
Variance 000-200	-.14
Variance 000-250	.04
Variance 100-100	-.06
Variance 100-300	.14

* $p < .05$, ** $p < .01$, $p < .001$

(ii) AEP components and IT

Table 44 presents the correlations between AEP amplitude and latency measures of P1, N1 and P2 and IT scores. If the latency of AEP components reflects information processing speed, and if subjects with short ITs sample the stimulus significantly more often than subjects with long ITs, then it is predicted that the components of short IT subjects may be located earlier in the AEP waveform than those for subjects with long IT. This was clearly not the case, with no significant correlations between amplitude or latency of any of the components computed with IT.

Table 44:
Correlations between amplitude and latency of P1, N1 and P2 and IT (N=67).

AEP Component Measure	IT
P1 Amplitude	-.11
P1 Latency	-.13
N1 Amplitude	-.15
N2 Latency	-.03
P2 Amplitude	-.11
N2 Latency	.02

RT and AEPs

(i) Decision Time

Table 45 presents correlations between string length, variance and mean and SD for DT at different stimulus conditions. There was a small negative relationship between string length (0-200 and 100-300 msecs) and mean DT for the 1 and 2 stimulus conditions, indicating that faster DTs are associated with longer string lengths. This result might be predicted by a model linking faster information processing speed with either an error or attention model of the string length. Both of these models of AEP functioning may also support the small negative correlations between string length (100-300) and SD of DT at the 1 and 2 stimulus conditions. There was also a small positive correlation between string length (0-250 and 0-100) and SD of DT under the two stimuli condition, which may suggest that correlations between the string length and SD may be sensitive to temporal processes occurring in the AEP. In general the results suggested that there is some evidence for an association between AEP and DT variables at low levels of stimulus complexity, because 6 out of 8 of the significant correlations between string length (5 epochs) and mean and SD of DT at 1, 2, 4 and 8 stimulus conditions (i.e. 20 correlations) were between string length and DT measures at either the one or two stimulus conditions. The information processing load of the AEP experiment approximates the 1 stimulus condition (i.e. a single stimulus). It may be interesting to measure the correlation between these variables if stimulus complexity is varied in the AEP task. In general there was little relationship between the string length and mean and SD of DT (32 out of 40 correlations were not significant).

The pattern of correlations between AEP variance and mean and SD of DT variables suggested that evoked potential variability (trial to trial variability) and DT variability, as reflected in the SD of DT, are related, although only at the 1 stimulus condition, which may again reflect the informational load of the AEP task. However only 3 out of the 20 possible correlations were significantly different from zero. Lower mean DT was also related to lower variance although only at the 8 stimulus condition.

Table 46 describes the correlations between amplitude and latencies for P1, N1 and P2 AEP components and measures of DT. Few correlations were significant and no pattern of results are easily discernible, although there was limited evidence suggesting that N1 amplitude may be related to both mean DT and SD of DT.

Table 45:
Correlations between string length, variance measures and DT measures (N=70)

Hendrickson Measure	Mean 1 stimulus	Mean 2 stimuli	Mean 4 stimuli	Mean 8 stimuli	SD 1 stimulus	SD 2 stimuli	SD 4 stimului	SD 8 stimuli
String 000-100	-.10	.15	-.16	.00	-.04	.20	.36**	.04
String 000-200	-.34**	-.23*	-.20	-.07	-.20	-.16	-.06	.00
String 000-250	-.17	-.05	-.04	.08	-.13	.04	.35**	.14
String 100-200	-.04	.00	.15	.12	-.10	.02	.16	.12
String 100-300	-.32**	-.33**	-.06	-.09	-.29**	-.42**	-.05	-.16
Variance 000-100	-.08	.02	-.03	-.30**	.39**	.03	.02	-.10
Variance 000-200	-.09	-.05	-.16	-.08	.18	.04	-.09	.07
Variance 000-250	-.09	.09	-.07	-.37**	.49**	.10	-.02	-.19
Variance 100-200	-.14	-.02	.07	-.22*	.32**	.01	-.05	-.06
Variance 100-300	.36**	.28**	.30**	.08	.21	.00	.15	-.11

$* p < .05$ $** p < .01$

Table 46:
Correlations between amplitude and latencies of P1, N1 and P2 with DT measures (N=70)

AEP Measure	Mean 1 stimulus	Mean 2 stimuli	Mean 4 stimuli	Mean 8 stimuli	SD 1 stimulus	SD 2 stimuli	SD 4 stimului	SD 8 stimuli
P1 Amplitude	.11	.15	-.03	-.08	.08	.08	-.09	-.01
P1 Latency	.03	-.13	-.09	-.15	-.05	-.02	-.10	-.11
N1 Amplitude	.16	.12	.34**	.38**	.17	.07	.26*	.39**
N1 Latency	-.05	-.07	.00	-.15	-.03	-.04	-.23*	-.08
P2 Amplitude	-.16	-.16	.16	.33**	-.13	-.10	.06	.26*
P2 Latency	.24*	.12	.18	.10	.25*	-.04	-.08	.22*

* $p < .05$ ** $p < .01$

Movement Time

Table 47 reports correlations between mean and SD of MT for 1, 2, 4 and 8 stimulus conditions and the string length and variance. Mean MT was negatively related to string length (correlations ranged from -.07 to -.65) across all stimulus conditions and string length epochs. Particularly for the 1 and 2 stumulus conditions, SD of MT was positively correlated with string length, indicating that while longer string lengths translated into lower mean MT, variability in MT increased. Increased evoked potential variability was again related to larger mean and SD of MT, although the correlations were substantially smaller in magnitude than between the string length and mean and SD of MT.

Table 48 presents correlations between amplitude and latency of the P1, N1 and P2 components of the AEP and MT measures. In general the correlations were indicative of the fact that longer component latency was related to increased mean and SD of MT. This result is consistent with the assumption that AEP components index rate of information processing, so that longer latencies reflect slower information processing.

Table 47:
Correlations between string length and variance, and mean and SD of MT
(N=70)

Hendrickson Measure	Mean 1 stimulus	Mean 2 stimuli	Mean 4 stimulu	Mean 8 stimuli	SD 1 stimulus	SD 2 stimuli	SD 4 stimuli	SD 8 stimuli
String 000-100	-.41**	-.38**	-.65**	-.20*	.38**	.33**	-.10	.16
String 000-200	-.42**	-.20*	-.48**	-.07	.25*	-.09	-.17	-.19
String 000-250	-.39**	-.32*	-.61**	-.31*	.36**	.51**	.05	.09
String 100-200	-.19	-.21*	-.28**	-.33*	.22*	.50**	.15	.07
String 100-300	-.27*	-.13	-.24*	-.12	.30**	.09	.09	-.05
Variance 000-100	-.19	.29**	.21*	.23*	.24*	.27*	.23*	.13
Variance 000-200	.35**	.37**	.20*	.22*	.12	.12	-.06	-.03
Variance 000-250	-.26*	.24*	.15	.19	.06	.13	.22*	.13
Variance 100-200	-.14	.25*	.20*	.21*	.30**	.29**	.18	.10
Variance 100-300	-.15	-.01	-.01	-.07	-.18	.00	.00	-.15

** p < .05 ** p < .01*

Table 48:
Correlations between amplitude and latencies of P1, N1 and P2 and MT (mean and SD) (N=70)

AEP Component	Mean 1 stimulus	Mean 2 stimuli	Mean 4 stimulu	Mean 8 stimuli	SD 1 stimulus	SD 2 stimuli	SD 4 stimuli	SD 8 stimuli
P1 Amplitude	-.13	.14	-.06	.16	-.21*	-.02	-.03	.06
P1 Latency	.09	.40**	.13	.13	.44**	-.07	.00	.18
N1 Amplitude	-.10	.13	.24*	.21*	-.22	.04	-.08	-.11
N1 Latency	.01	.15	-.29**	-.37**	.32**	.28*	.11	.04
P2 Amplitude	-.36**	-.09	-.05	-.02	-.09	-.09	-.27*	-.15
P2 Latency	.29**	.29**	-.02	-.11	.06	.17	-.08	.17

* $p < .05$ ** $p < .01$

7.3 IT, RT, and AEPs, and general intelligence.

(i) Extraction of WAIS-R factors

This section examines the correlation between IT, RT, and AEPs and factors obtained from factor analysing WAIS-R sub-tests. Table 49 describes the factors obtained from the principal components analysis. Only factors with eigen values greater than 1 were extracted. Due to listwise deletion of missing data, all factor analyses and regression analyses are based on a sample of 60 subjects.

Table 49:
Principal components analysis of WAIS-R sub-tests
(N=60)

Factor	Eigen value	% of variance	Cum % of variance
1	3.71	33.7	33.7
2	1.55	14.1	47.8
3	1.08	9.8	57.6

Table 50 displays the factor loadings of the WAIS-R factor analysis for the three factors extracted. Factor 1 is a general factor because it accounts for the largest percentage of the variance, and all factors (except digit symbol) substantial loadings on it. Factors 2 and 3 are difficult to interpret in any meaningful psychological sense and in this context, with both verbal and performance sub-tests loading strongly on both factors. Factor 2 positively loaded performance sub-tests and negatively verbal sub-tests. Conversely, Factor 3 positively loaded verbal sub-tests and negatively performance sub-tests.

Table 50:
Factor loadings for WAIS-R sub-tests (N=60).

Sub-test	General	Factor 2	Factor 3
Arithmetic	.64	.21	.15
Block Design	.57	.62	-.08
Comprehension	.71	-.35	.15
Digit Span	.63	-.09	-.29
Digit Symbol	-.06	.62	.64
Information	.69	-.43	.20
Object Assembly	.47	.54	-.23
Picture Arrangement	.52	.15	-.39
Picture Completion	.56	.02	-.29
Similarities	.52	.05	.35
Vocabulary	.73	-.31	.30

(ii) Correlations between factors and IT, RT, and AEPs

Correlations between IT, RT and AEP variables and the three extracted factors are reported in Table 51. Correlations between IT, string length from most temporal epochs and mean MT and DT (at all stimulus conditions) correlated significantly with Factor 1 (general factor). Correlations between string length, mean DT and MT and IT were not significantly greater than correlations reported in Chapters 2, 3 and 5 when they were correlated with VIQ or PIQ from the WAIS-R, suggesting that these variables tap specific abilities in addition to a general intelligence factor.

Table 51:
Correlations between ECTs and 3 factors obtained from principal components analysis

ECT	Factor 1	Factor 2	Factor 3
DT 1 stimulus	-.31**	-.05	.13
DT 2 stimuli	.24*	.10	.07
DT 4 stimuli	-.27*	-.11	.02
DT 8 stimuli	-.29*	-.12	.03
MT 1 stimulus	-.49***	.07	-.05
MT 2 stimuli	-.41***	-.02	.07
MT 4 stimuli	-.39***	-.14	.01
MT 8 stimuli	-.47***	-.11	.15
IT	-.34**	-.19	.07
String 100-200	.53***	.04	.01
String 000-250	.47***	.14	.22*
String 000-100	.17	.12	.29*
String 000-200	.36**	.15	.23*
String 100-300	.46***	.03	.15

** $p < .05$, ** $p < .01$, ***$p < .001$*

Rotation of factors

A Varimax rotation employing the Kaiser normalisation technique (Norussis, 1993) was employed in order to define more clearly the underlying factor structure. The Varimax (orthogonal) rotation utilised the principal components extraction. According to Spruill (1984), three factors are normally identified in factor analytic studies of the WAIS-R; a verbal comprehension factor, a perceptual organization factor and a memory/freedom from distractibility factor. Generally the verbal sub-tests load on the verbal comprehension factor, the performance sub-tests load on the perceptual organization factor and Digit Span, Arithmetic and Digit Symbol load on the memory/freedom for distractibility factor, although for the first two factors there is some overlap.

Correlations between WAIS-R sub-tests on the 3 Varimax factors is displayed in Table 52.

Table 52:
WAIS-R sub-test loadings on factors obtained from Principal Components analysis (Varimax rotation)
(N=60)

Sub-test	Verbal Comprehension	Perceptual Organization	Memory/ Freedom
Arithmetic	.46	.46	.22
Block Design	.13	.78	.31
Comprehension	.78	.17	-.15
Digit Span	.39	.48	-.31
Digit Symbol	-.05	.03	.89
Information	.89	.08	-.17
Object Assembly	.01	.74	.16
Picture Arrangement	.16	.60	-.22
Picture Completion	.29	.51	-.23
Similarities	.53	.19	.27
Vocabulary	.84	.13	-.02

The factor loadings reported in Table 52 are in closer agreement with previous studies examining the factor structure of both the WAIS and WAIS-R in large samples of subjects. The first factor is best described as a verbal comprehension factor, the second a perceptual organization-performance factor and the third a factor which digit symbol loaded highly and thus may be regarded as a speed/memory factor. Although the third factor is not precisely the same as the memory/freedom from distractibility factor described by Spruill (1984), the factor loadings of the third factor are more consistent with this result after rotation. Table 53 displays the correlations between IT, RT, and AEPs and the orthogonally rotated principal components factors from the WAIS-R. Mean DT correlated weakly with the verbal comprehension factor and non-significantly with both the perceptual organization and memory factors. Mean MT correlated significantly with both the perceptual organization factor and the verbal comprehension factor but not with the memory factor. IT significantly correlated with the perceptual organization factor. String length, however, was more related to verbal comprehension than to the other factors, although significant (albeit smaller) correlations were also obtained at some temporal epochs with the perceptual organization and memory factors. Apart from the string length variable, no significant correlations were obtained between any of the main variables and the memory factor. This result may be due to the discrepancy of the memory loadings to that described by Spruill (1984) or to the fact that the main variables do not load on that particular part of the WAIS-R factor variance.

Table 53:
Correlations between ECTs and orthogonal rotated principle component factors from the WAIS-R (N=60)

Variable	Factor 1	Factor 2	Factor 3
DT[11] 0 bit	-.25*	-.15	.07
DT 1 bit	-.21	-.04	.12
DT 2 bit	-.20	-.13	-.05
DT 3 bit	-.27*	-.09	-.04
MT 0 bit	-.39***	-.35**	-.05
MT 1 bit	-.29*	-.31**	.06
MT 2 bit	-.25*	-.35**	-.06
MT 3 bit	-.28*	-.44***	.06
IT	-.15	-.36**	-.06
String 100-200	.39***	.35**	.00
String 000-250	.41***	.26*	.24*
String 000-100	.23*	.03	.29*
String 000-200	.34**	.17	.25*
String 100-300	.41**	.22*	.12

** p < .05, p < .01*

In general the results of the principal component and factor rotations indicate the following:

(i) Principal components analysis reveals a large general factor on which all main variables significantly correlate. The magnitudes of these correlations are approximately the same as those between the main variables and VIQ or PIQ reported in Chapters 2, 3 and 5 and summarised in Table 41.

(ii) Orthogonal (Varimax) rotations of the three principal components yielded

[11] Mean Masked RT variables are reported in this Table

a verbal comprehension factor, in which many of the verbal sub-tests of the WAIS-R load highly, a perceptual organization factor on which many of the performance sub-tests of the WAIS-R moderately load, and a third factor which is more difficult to define. Mean DT was a weak predictor of the verbal comprehension factor. Mean MT at all stimulus conditions correlated with both the verbal and perceptual factors but not with the memory factor. IT correlated with the perceptual factor and the string length correlated, to some degree, with all three factors, although correlations with the verbal comprehension factor were the largest.

7. 4 Stepwise Regression

In order to examine the extent to which IT, Mean MT and DT at 1, 2 4, and 8 stimulus condtions and the string length (various epochs) variables predicted IQ variance stepwise mulitple regression were performed for each of VIQ, PIQ, FSIQ, APM and the general factor extracted from the WAIS-R. At each step the independent variable not in the equation which had the smallest probability of F was entered, if that probability was sufficiently small. Variables in the regression equation were removed if their probability of F became sufficiently large. The method terminates when no more variables are eligible for inclusion or removal (Norussis, 1993). This procedure is important because it allows for the examination of particular variables which account for specific parts of the IQ variance. Tables 54a-e describe the stepwise regression[12] equations for VIQ, PIQ, FSIQ, APM and g respectively.

The multiple correlations were all larger than any correlation between a single ECT and any IQ variable reported earlier in this dissertation suggesting that IT, Mean DT and MT, and the string length, if used together, account for more of

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[12] Some correlations are slightly different to those reported earlier because of the employment of listwise deletion of missing data for several variables.

the reliable IQ variance than any single variable. It should be noted that just because a variable significantly correlates with the dependent variable does not mean that it will be included in the regression equation. Only variables that add significantly to the equation are entered. The values have not been corrected for restriction in range or test reliability.

VIQ

The stepwise regression of the ECTs on VIQ accounted for 57% of the reliable variance (Table 54a). Variables which contributed unique variance were the string length (measured 100-200 and 000-200 msec post-stimulus), DT at 4 and 8 stimulus conditions and variance (measured from 100-200 msec post stimulus). Other variables which significantly correlated with VIQ as reported in earlier chapters, did not uniquely explain the VIQ variance in addition to these variables, indicating that they do not contribute uniquely to the VIQ variance.

Table 54a:
Stepwise linear regression with VIQ as dependent variable. Variables entered if F value has $p < .10$
(N=60)

Variable entered	Multiple R	R^2	F
String 100-200	.61	37%	27.0
DT 8 stimuli	.66	44%	17.0
Variability 100-200	.70	49%	14.0
String 000-200	.72	52%	11.8
DT 4 stimuli	.75	57%	11.0

PIQ

Independent contributors to PIQ variance were the string length at 100-250 and 0-100 msec post stimulus, IT and mean DT at 1, 2 and 8 stimulus conditions. Interestingly, although mean MT correlated with PIQ, it did not contribute any unique variance above the contributions of other variables reported in Table 54b.

Table 54b:
Stepwise linear regression with PIQ as dependent variable. Variables entered if F value has p < .10
(N=60)

Variable entered	Multiple R	R2	F
String 000-250	.48	22%	13.5
IT	.52	27%	8.2
DT 2 stimuli	.55	31%	6.5
DT 8 stimuli	.59	35%	5.8
String 000-100	.64	41%	5.7
DT 1 stimulus	.66	44%	5.4

FSIQ

The main variables accounted for nearly 70% of the FSIQ variance which, if corrected for restriction in range, may approximate total variance (Table 54c). Important contributors to the multiple correlation were string length, mean DT and variance measure of the AEP waveform.

Table 54c:
Stepwise linear regression with FSIQ as dependent variable. Variables entered if F value has p < .10

Variable entered	Multiple R	R2	F
String 100-200	.61	37%	26.7
DT 8 stimuli	.66	44%	17.6
MT 8 stimuli	.70	49%	13.9
DT 2 stimuli	.72	52%	11.5
String 100-300	.74	55%	10.3
IT	.76	58%	9.6
MT 4 stimuli	.78	61%	8.8
Variance 100-200	.80	64%	8.5
Variance 000-250	.82	68%	9.0

APM

Only 19% of the APM variance was accounted for, suggesting that the main variables were not very successful at predicting performance on this test (Table 54d). The two significant predictors were parameters of the AEP.

Table 54d:
Stepwise linear regression with APM as dependent variable. Variables entered if F value has p < .10
(N=60)

Variable entered	Multiple R	R2	F
String 00-250	.37	14%	7.3
Variance 100-200	.43	19%	5.2

General intelligence factor

Sixty percent of the general factor (*g*) was accounted for by the main variables (Table 54e). IT, mean DT and MT and the AEP measures significantly predicted the *g* variance.

Table 54e:
Stepwise linear regression with g as dependent variable. Variables entered if F value has p < .10 (N=60)

Variable entered	Multiple R	R2	F
String 100-200	.47	22%	13.3
DT 8 stimuli	.60	36%	12.8
MT 8 stimuli	.67	44%	11.7
IT	.69	47%	9.6
DT 2 stimuli	.71	50%	8.9
Variability 100-200	.73	53%	7.8
MT 4 stimuli	.75	58%	7.5
DT 1 stimulus	.78	60%	7.4

7.5 Conclusions

Chapter 7 has been concerned with the inter-relationship between the main variables employed in this dissertation and the extent to which they predict performance on the IQ variables. The stepwise regression analyses have indicated that a large part of the WAIS-R IQ variance can be accounted for by the IT, RT and AEP tasks. The finding that ECTs significantly correlate with IQ is not that surprising; however, the finding that they add or contribute additionaly to the IQ variance is important. Rarely has a study correlated more than one ECT with IQ, and never before have regression analyses been applied to assess the contribution of IT, string length, DT and MT on IQ variance. The important finding here is that employing IT, RT and AEPs tasks in the same sample allows the experimenter to infer more (both from a cognitive and physiological stand point) about performance on the relatively complex IQ test. Although no attempt was made to construct a model of IQ in terms of the IT, RT and AEP processes, mainly because of the limitations of such a model given the relatively small sample size used in the regressions (N=60), such a model may be constructed if this result is replicable in larger samples. For instance, it may be possible to construct an information processing model of IQ in which IT and MT are independent processes and which uniquely add to the IQ variance.

The pattern of results is difficult to dismiss in terms of subject strategies inherent in both the laboratory tasks and the IQ tests, as has been suggested by Howe (1990). It would be difficult to imagine task strategies that, for instance, high IQ subjects could employ in all three laboratory tasks and which, therefore, might determine the correlation between ECTs and IQ. Such subject characteristics (e.g., cognitive strategies, personality dimensions), have been examined in some detail in this dissertation and for the most part rejected. The basis of the association is still to be adequately resolved although the results are suggestive of biological characteristics and processes.

A surprising result was the regression analysis for the APM. Flynn (1987) has raised doubts over the validity of Raven's tests to predict intelligence after describing their large generational gains over the last 30-40 years. Although other IQ tests showed these gains, the Raven tests showed significantly greater increases over time. Because such generational increases have not been paralleled by a corresponding increase in the number of geniuses and level of intelligence in the community, Flynn has argued that the Raven tests no longer measure intelligence but a weak correlate. Flynn has reported this outcome for only the Raven Progressive Matrices (RPM) and not for the APM so it remains to be seen whether such an increase may also be shown in the APM version of the test.

The discrepancy between the results of the regression analyses for the WAIS-R and for the APM is difficult to explain. The Raven tests are generally regarded as good measures of general intelligence and it would be predicted if this was the case then the regression analysis of the ECTs on the APM would be similar to the regression of the ECTs on the general factor extracted from the WAIS-R. This was not the case. Obviously the ECTs are better predictors of the "intelligence" measured by the WAIS-R than the APM. It is not the case that ECTs dod not correlate with the APM- high correlations were reported between the APM and AEP component amplitude.

The importance of these data is that they demonstrate that the string length, mean RT and MT (derived from the Hick procedure) and IT predict IQ variance to a greater extent when employed together than when used separately. Part of this effect, may of course, be due to the effects of test reliability- correlations may be more reliable if many variables which attempt to measure the same process are used or the fact that variables obtained from the same measurement may contain the same error terms. This is not true of correlations between variables derived from independent measurement. The increase in the amount of IQ variance accounted for by the various ECTs is suggestive of the conclusion that individual ECTs may contribute uniquely to the IQ variance. Thus the possibility exists, in a larger sample, for the specific amount of IQ variance that each ECT determines to be reliably mapped out. The advantage of such a technique lies in the fact that if the biological basis of intelligence is to be understood then it may be best understood in terms of several biological processes.

CHAPTER 8

Concluding Chapter

> **"It seems most probable that it is from this sphere of research at the interface of brain and behaviour that a scientifically adequate theory of individual differences in intelligence will eventually take shape"**
>
> **Jensen (1987, p. 173).**

8.1 Summary

This dissertation has reported a series of experiments investigating the relationship between IQ and elementary cognitive tasks specifically examining whether correlations between IT, RT, and AEPs, and IQ could be accounted for or determined by other variables, e.g., personality, strategy, apparent motion use etc. Large to moderate correlations were found between measures of VIQ, PIQ, FSIQ and g and IT, RT and AEPs. The magnitude of the correlations suggested that processes underlying performance on IQ tests also underlie performance on IT, RT and AEPs, closely linking Eysenck's Psychometric Intelligence with notions of biological intelligence. Employing multiple linear regression revealed that IT, RT and AEPs share both common and distinct parts of the VIQ, PIQ, FSIQ and *g* variance. Importantly, the ECTs, in combination, accounted for the majority of the reliable variance in WAIS-R IQ. Specifically the experiments reported in this dissertation allow the following conclusions;

1. That the Jensen-Hick RT apparatus allows strategy use which confounds DT and MT processes. When this strategy is removed, MT and DT variables provided consistent negative correlations with IQ. Future research should use a mask that prevents strategy use of this type. Results also suggested that future work should investigate in more detail the relationship

between masked MT and IQ and that a new theory is required to explain MT-IQ correlations.

2. That the string length measure of AEP waveform complexity is highly correlated with WAIS-R IQ, particularly VIQ. Contrary to that predicted, the Hendrickson variance measure was only weakly correlated with WAIS-R IQ. It was suggested that the string length and variance do not index the same processes Some evidence was presented which indicated that for certain epochs, string length and variance were positively correlated which is contrary to that proposed by D. E. Hendrickson (1982). Future work employing the string length measure should administer greater than 100 trials as this number is not sufficient for the reliable resolution of early AEP components. The later parts of the AEP components were generally reliable and provided significantly higher correlation with IQ variables than the earlier ones.

3. The negative correlation between string length and IQ recently reported by Bates and Eysenck (1993) was examined. It was pointed out that they employed a procedure in which high IQ subjects were administered stimuli of lower intensity than those administered to the lower IQ subjects. Thus, the negative correlation between string length and IQ may reflect differences in stimulus intensity rather than the effects of focussed attention. Employing a MCSD procedure in which stimulus duration and intensity were controlled, string length was significantly longer in the high IQ group. Results suggested that the efficiency model of string length could not be supported. An alternative hypothesis was suggested, in which the longer string lengths of high IQ subjects, was determined by the allocation of attentional resources to stimuli.

4. The hypothesis of Hunt (1980) and of Macintosh (1986), that IQ is a function of that allocation of attention or "attentional resources" was examined

employing an AEP methodology first described by Picton and Hillyard (1973). The amplitude of the N1 component derived from tones in attended minus unattended channels was used as the operational definition of attentional resources following two decades of research by Picton, Hillyard and colleagues. The hypothesis that differences in IQ can be explained in terms of the allocation of attention was not supported. High IQ subjects oscillated their attentional resources significantly less than average IQ subjects to attended compared to unattended tones.

5. IT and IQ were moderately correlated and this correlation could not be explained in terms of small sample sizes, the inclusion of subjects with intellectual disabilities, presentation characteristics, or apparent motion strategies. A new IT mask ("Lines") was designed and evaluated by comparing ITs and apparent motion use in the "Traditional" mask and a new "Flash" mask. It was concluded that future research should utilise the "Lines" or "Flash" mask.

6. The effect of personality and temperament variables on IT, RT and AEPs and on their correlation with IQ variables was examined. Although some personality/temperament characteristics were related to some of the main variables, in no meaningful sense did personality/temperament account or explain the significant correlations between IT, RT, AEPs and IQ variables. The Howe (1990) hypothesis was therefore rejected. Notably the Robinson hypothesis linking ambiversion to IQ test performance was supported. Introverts recorded longer string lengths than extraverts implicating arousability characteristics of the stimulus used in the Hendrickson procedure. The result suggested that the relationship between individual differences in arousal, the arousability of a stimulus and test, and performance on intellectual tasks should be an area of future research.

7. Stepwise linear regressions suggested that the majority of the WAIS-R IQ variance could be accounted for by IT, RT and AEP parameters. The magnitude of these correlations was surprisingly large, indicating that Eysenck's conceptions of Biological and Psychometric Intelligence are closely related.

8.2 General discussion

Cognitive strategies determine ECT-IQ correlations

A resurgence in reductionist explanations for intelligence over the last decade has lead several psychologists to postulate an alternative mechanism to explain significant correlations between ECTs and IQ. The most popular alternative explanation has been offered by Howe, Cecci and Sternberg who suggest that correlations between ECTs and IQ may only reflect the fact that high IQ subjects employ more sophisticated cognitive strategies than low IQ subjects. At first glance this hypothesis is a persuasive one and can explain differences in IQ test performance, scholastic and occupational performance. If some subjects possess better cognitive strategies than others, then the quality of these strategies may explain differences in a variety of performance indicators. For correlations between ECTs and IQ to be adequately explained by this hypothesis two conditions must be met. First, the tasks (i.e., IQ and ECTs) must be penetrable by strategies. Second, subjects employing a better strategy in say the IQ test must also employ a better strategy in the ECT. Several strategies and methodological variables were assessed in this dissertation and none were shown to cause or to determine the correlation between ECTs and IQ. Thus it would seem sensible to conclude that correlations between ECTs and IQ reflect actual brain processes: speed and efficiency of physiological processes as indexed by IT, RT and AEP procedures are central to performance on IQ tests.

Flynn: The problem of validating ECTs with IQ.

One possible problem with the approach used in this dissertation and in many studies reporting significant correlations between ECTs and IQ is that this approach attempts to validate new measures of intelligence (i.e., ECTs) by correlating performance on these tasks with IQ test performance. This approach assumes that because IQ tests predict scholastic and occupational success and because they are widely regarded as reflecting "intelligence" that IQ tests measure intelligence. Alternatively Flynn (1987) has suggested that IQ tests may only provide a weak correlate of "intelligence" and raises doubts over the validity of validating new measures of intelligence against the older IQ measure. As this is a problem which is crucial to our understanding of the biological basis of "intelligence" the final experiment investigated whether an ECT may in addition to its significant association with IQ, predict scholastic success, a quality commonly used to validate IQ tests as a measure of "intelligence" and also tests Eysenck's (1988) position that ECTs may provide a better measure of "intelligence" than psychometric measures.

Experiment 8

Intelligence, IT and Ecological Validity.

8.3 Introduction

The last experiment addresses the Eysenck (1988) hypothesis that Biological Intelligence measures may provide a better estimate of 'intelligence' than Psychometric Intelligence measures. Specifically this chapter examines the predictive or external validity of IT as a measure of intelligence.

Chapter 5 provided evidence that IT and IQ were significantly negatively correlated. However, whether IT is a correlate of "intelligence" depends on its ability to predict intelligence. The possibility exists that while IT correlates with IQ, IT may not necessarily measure processes which underlie "intelligence". As Maloney and Ward (1973) have explained, IQ tests have been validated against their ability to predict scholastic performance, a quality that is often regarded as reflecting "intelligence". At present there is little information available on whether IT as a correlate of IQ may possess predictive validity in the sense that it predicts performance on variables normally associated or accepted to relate to "intelligence". Therefore, it is of considerable theoretical and practical importance to assess whether the more theoretical and biological processes underlying IT predict 'real world' intelligence. In order to test whether IT predicts scholastic performance, IT, APM and the Alice Heim 5 test (AH5 verbal and AH5 figural) were administered to 50 University students.

8.3.1 Method

Subjects

Fifty psychology students (42 females and 8 males), with ages ranging from 19-34 (Mean= 21.8; SD= 3.3) participated as part of a third-year psychology laboratory session.

Apparatus

A Macintosh LC with a frame rate of 16.6 msecs (60 Hz) was used to present the stimuli to subjects.

Procedure

The testing session[13] consisted of an IT and an IQ session balanced for order. In the IQ session the Alice Heim 5 (AH5) and a shortened version of the Ravens Advanced Progressive Matrices (APM) were administered in a balanced order.

IQ Testing

The AH5 test and APM test were administered to all 50 subjects. Due to time constraints, a short version of the APM was used which included the practice set but omitted the first 12 questions from set II which normally consists of 36 questions in progressive level of difficulty. As a recent standardization study suggested that the first 12 questions did not differentiate subjects (Stough, Nettelbeck & Cooper, 1983) and because of time constraints, it was felt that the administration of a shortened version of the APM, although less than ideal, was not inappropriate.

IT Session

The IT procedure used in this experiment was the same procedure as in experiment

[13] Time and resource limitations allowed the administration of two group administered tests. To be consistent with the previous experiments reported in this dissertation, the APM was administered. The Alice Heim 5 test was also administered because it allows a distinction between verbal and figural processes to be made and which therefore compliments the inclusion of the APM.

6 and employed the lines mask. Each subject completed 20 trials at the following stimulus durations; 16.6, 33.3, 49.9, 66.6 and 83.3 msecs. In addition all subjects completed 20 practice trials (10 at 165 msec and 10 at 150 msec) In total, all subjects completed 120 IT trials. The total correct were recorded and later used to estimate IT at 75% responding accuracy.

The IT procedure is similar to that described by Nettelbeck (1987). Briefly, a cue was presented for 500 msec prior to each stimulus which consisted of two parallel vertical lines 24 mm and 34 mm long separated by 10 mm. Subjects were required to respond by pressing a left button if the shorter line was on the left side and a right button if the shorter line was on the right side. The shortest line had equal probability of occurrence on the left or right side of the long line. The two lines were joined by a horizontal bar across the top of each line. Following the SOA, a mask was presented for 500 msec. The inter-stimulus interval was varied by each subject as the next trial proceeded only after the subject pressed a button. Subjects were instructed to respond as accurately as possible.

Scholastic performance

Subjects were asked to provide their New Zealand Bursary score (final year secondary school examination grade) which represents a score out of 500. The Bursary score consists of five different subjects in which the maximum mark is 100. At this time in New Zealand, students with scores ranging from 250 (pass) to 500 were allowed entry into university courses in Psychology. The range for the current sample (268-460) was sufficiently large to ensure a reasonable representation of scholastic performance in thisr sample.

8.3.2 Results and Discussion

Table 55 presents the Pearson correlations between IQ, IT and final year secondary school exam scores, all of which were statistically significant at the .05 level. As predicted from previous studies (e.g., Lanvin, 1965), scholastic performance and IQ were significantly correlated, indicating that IQ tests are appropriate to use to predict educational performance, although the correlations were weak. Interestingly, IT and scholastic performance were highly correlated (-.74) suggesting that IT may be a useful adjunct to IQ tests within educational settings for the assessment of scholastic ability.

Table 55:
Pearson correlations between IT, IQ and final secondary year exam performance. (N=50; Experiment 8).

	Exam Scores	APM	AH5 Verbal	AH5 Figural	IT (75%)
Exam Scores	-------	.23*	.39**	.39**	-.74***
APM	.23*	-----	.50**	.49**	-.42**
AH5 Verbal	.39**	.50**	------	.56**	-.30*
AH5 Figural	.39**	.49**		------	-.32*
IT	-.74***	-.42**	-.30*	-.32*	-----

*** p < .05, ** p < .01 *** p < .001**

Using the formula provided by Hotelling (1940) to test the difference between correlation coefficients, revealed that IT was a significantly better predictor of scholastic performance than APM ($t_{1,47}$= 4.9, p < .01), AH5 verbal ($t_{1,47}$= 3.1, p < .05) and AH5 figural ($t_{1,47}$= 3.1, p < .01). Although care should be exercised in interpreting correlations from populations which are restricted in range, the magnitude of the correlations indicate that IT is a very strong predictor of scholastic performance in this above average group of subjects. As discussed earlier, IT has a strong theoretical basis (see Vickers & Smith, 1985) and is so elementary in nature that several commentators have expressed the possibility that IT may be less prone to higher order cognitive strategies that are inherent in IQ tests. If this is true then IT may be a more culturally fair test to use in assessing intelligence in racial or socioeconomically disadvantaged groups. The IT task is so simple that performance on the IT task is unlikely to reflect the differences in educational experiences often suggested to underlie performance on IQ tests. It is difficult to conceive how such a simple sensory discrimination may bias members of one culture over another, especially within Western cultures, although this should be the question of future research. The fact that shorter ITs were related to both IQ and scholastic performance variables may suggest that intelligence is at least partly caused by basic perceptual processes. Jensen (1982, pp. 98-99) has discussed the possibility that years of faster information processing may lead to superior acquisition of knowledge. At this stage, the physiological processes underlying IT are unknown, although more recent research is suggestive of at least some influence of sensory systems (White, 1993) as well as later stages thought to integrate visual information (Nettelbeck, 1987). A recent experiment by Stough, Mangan, Bates, & Frank (in press) is suggestive of a role of cholinergic pathways for IT. More research on the physiological basis of IT is obviously required.

8.4 Conclusions

The implications of the present finding, if replicated, are important for theories of intelligence. The correlation between IT and scholastic success may represent a causal link between developmental processes involved in the acquisition and integration of information from the environment. It is this information from one's environment that leads to the development of knowledge. A faster, more efficient perceptual system may process considerably more information per unit time than a less efficient perceptual system. Over several years of development, this seemingly small difference may amount to considerable differences in IQ and scholastic success.

8. 5 Problems

The experiments presented in this dissertation have addressed a common theme. That is, whether various variables and strategies determine the correlation between elementary cognitive tasks and IQ. The results of these experiments indicated that correlations between ECTs and IQ cannot be attributable to cognitive strategies, personality or temperament dimensions, or other methodological variables. Although, the dissertation has been successful in this sense, there are many inadequacies. Many of these inadequacies are due to time and resource limitations. For instance the use of university students in research on intelligence, although necessary in the present situation, does not allow these results to be fully generalised to the entire community. Thus, in terms of generalising the results of the dissertation, this dissertation should be considered as preliminary. Although subjects were chosen to minimise the restriction in range of IQ, as best as possible, the various IQ tests still showed a restriction in range. Future research should replicate the present results, particularly the results of the regression analyses in Chapter 7, testing a more representative sample. Another problem was the relatively small sample size employed in the regression analyses in Chapter 7 (N=60). Larger samples are required to reliably replicate the results of the regressional analyses. Although two IQ tests were employed, it would have been interesting to use additional IQ tests and to establish a general factor common to all of the IQ tests. The WAIS-R was employed in this dissertation because it is very widely used by clinical and professional psychologists and is highly regarded as possessing high external/ criterion validity. A relatively new test which has recently been designed by Jackson (1984) and termed the Multidimensional Aptitude Battery (MAB) is modelled after the WAIS-R but is a group administered test. If it can be established that the MAB is a reliable and valid psychometric test of intelligence then the use of the MAB over the WAIS-R would shorten the time required for testing subjects considerably.

Unfortunately no norms exist for Australia and New Zealand. Another problem relates to the use of the APM as the main group administered test in this dissertation. Unfortunately prior to the work conducted as part of this dissertation, norms for Australia and New Zealand were very limited and based on university samples which were tested in the 1960s. A pilot study published as Stough, et al. (1993) examined the range of scores for the 36 question APM in a large university sample. The results suggested that several of the questions were in the wrong order. In any case, because the norms were so old, it was decided that only raw scores were to be used in the analyses reported in this dissertation. This meant that the age band of subjects needed to be very narrow. Thus the present set of results may not be generalizable to other ages

There were, of course limitations in various technical procedures used in the dissertation. For instance, the EEG measurement was far less than satisfactory. Equipment was only available for the recording of 1 electrode site. Thus it was impossible to collect any information of the effects of laterality on any of the three AEP experiments reported in Chapters 3 and 4. In addition, no topographical maps of brain functioning could be reported. Similarly it was impossible to print the AEPs of subjects tested in this dissertation because of hardware inadequacies. Given the low reliability of the AEP, future studies measuring the string length measure of AEP waveform complexity should administer more than 100 trials. Although Experiment 2 attempted to faithfully replicate the Hendrickson studies and thus to employ the same procedure, a limitation of Experiment 2 was the small number of trials. This problem may have contributed to the lower than acceptable reliability of the AEP waveform before 100 msecs post stimulus. Future studies should carefully evaluate the importance of the first 100 msec post stimulus for intelligence.

There is also the problem of using ECTs of differing modalities. The optimal situation would be to use tasks which do not differ in modality because it is uncertain whether low or non-significant correlations between, for example, visual IT and auditory AEPs reflect actual differences in intellectual processes, or whether the differences are due to factors specific to modality. Auditory tones may not be equivalent to lines or to lights and thus may be represented differently in the brain.

There are a number of unresolved problems employing the Jensen paradigm that have not been addressed by the first three experiments of this dissertation. One problem has recently been suggested by Brebner and Stough (1994), who have argued that there may be other unmeasurable strategies that subjects employ (consciously or unconsciously). Because no error estimates are derived from the Jensen methodology it is difficult to assess whether such processes as the well known speed-accuracy trade-off is operating on either DT or on DT-IQ correlations (Welford, 1986). Nettelbeck (1985) has also discussed performance on this apparatus in terms of the speed-accuracy trade-off, arguing for an intra-subject trade-off. In the Jensen-type apparatus, subjects perform at near 100% accuracy and beyond an 'optimum' level in which an experimenter can detect that a subject is responding as quickly as possible. Although, one might assume that because subjects are instructed to press the button as quickly as possible and because the task is very simple, that all subjects are participating with the same emphasis on speed, but never-the-less this is a difficult assumption to test. It is clear from other RT paradigms that mean RTs are influenced by variables such as personality and temperament (see Brebner & Cooper, 1987). Another problem is that although, RT measures appear simple, it is probable that there are a myriad of cognitive and physiological processes that underlie these measures and their relationship with IQ. Future research should determine the relationship between IQ and the myriad of processes which comprise total RT.

8.6 Future research

Future research should now focus on identifying the biological processes underlying performance on IT, RT and AEPs. Towards this goal, recent and preliminary evidence has suggested that pharmacological agents may be helpful in understanding performance on these tasks. One line of research has been to administer different levels of nicotine to subjects and note their performance on the IT, RT, AEPs and IQ tasks. Preliminary research comparing the effects of nicotine in sham smoking, smoking and no-smoking conditions suggest that nicotine via its effect on central cholinergic pathways decreases Hick mean (masked) DT (Bates, Pellett, Stough & Mangan, 1994), substantially decreases mean IT (Stough, Mangan, Bates, Frank, Kerkin & Pellett, in press), increases mean string length (Stough, Mangan, Bates & Pellett, in press) and increases APM scores (Stough, Mangan, Bates, & Pellett, 1984). Although preliminary, these results are indicative of a role of the cholinergic system for intellectual performance. The results are also consistent with the arousal modulation model proposed by Mangan and Golding (1978) in which it is proposed that subjects smoke to modulate their arousal level. Changes in arousal level affect performance on information processing tasks, and the theory postulates a close relationship between modulation of arousal through smoking and optimal performance in subjects. This modulation in arousal has been hypothesised by Warburton (1981) to reflect alterations in cholinergic activity which are assumed to in turn influence electrocortical arousal. The current results are also consistent with studies examining information processing and memory in subjects with impaired central cholinergic pathways in clinical studies using patients with dementia (Broks, Preston, Traub, Poppleton, Ward, & Stahl, 1988; Kopelman, 1987). The arousal model of smoking, studies in which cholinergic system dysfunction are associated with degraded cognition, and the studies examining the effects of nicotine on IT, RT, AEPs and IQ are all indicative of a role of the cholinergic system in the biological processes associated with intellectual performance.

The finding that ambiverts record significantly higher IQs than extraverts and ambiverts must be the focus of new research. Recent unpublished research at the University of Auckland has replicated this finding in nearly 200 subjects for both the WAIS-R and APM. The exact mechanism for this finding is unclear although once again, differences in extraversion are often held to reflect arousal levels which as Warburton (1981) has concluded may be in part due to cholinergic system activity. Thus, there are at least three converging lines of evidence for a significant role of the cholinergic system in intellectual performance. Educators may wish to examine the effects of different learning environments for extraverts, ambiverts and introverts. Educational settings which do not take into account differences in extraversion may provide inadequate environments for students differing in extraversion.

Other recent research (Tsourtos & Stough, submitted) has provided evidence that IT is significantly longer in subjects with Major Depression but that a significant part of this problem is alleviated by anti-depressant medication. Studies examining the effects of certain classes of anti-depressants on the IT procedure are now under way. This line of research may be helpful in elucidating biological processes important in intellectual functioning and information processing

8.7 Final Conclusion

The series of experiments reported in this dissertation allow the following conclusions;

That correlations between IT, RT, AEPs and IQ do not reflect the use of strategies, methodological shortcomings, or personality and temperament variables examined in this dissertation. That IT, RT and AEPs predict the majority of WAIS-R IQ test performance. That this relationship reflects biological processes and that these biological processes may possess high external or criterion validity.

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