Intelligence, task complexity and tests of sustained attention

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INTELLIGENCE, TASK COMPLEXITY AND TESTS OF SUSTAINED ATTENTION

A Thesis

by

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I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institute of higher learning, except where due acknowledgement is made in the text.

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ABSTRACT

Wittenborn (1943) devised a number of tests of 'attention' which he and others interpreted as measuring a person's ability to perform tasks requiring large amounts of concentration or mental effort. Because of their apparently elementary and algorithmic nature, and their dissimilarity to commonly used measures of intelligence, Wittenborn also assumed that they should not be strongly related to the subject's level of mental ability.

A number of correlational studies were carried out to examine the relationship between accepted measures of intelligence and tasks similar to the tests of attention devised by Wittenborn. The first study included markers of fluid and crystallised intelligence, short-term memory and perceptual/clerical speed, as well as a number of 'attention' tasks derived from Wittenborn (1943). It was found that these attention tasks had their major loadings on the same factor as was defined by the traditional markers of fluid intelligence.

The second study compared the relationships, with intelligence, of the speed and accuracy of performances on a subject-paced version of one of Wittenborn's attention tests. Again a close relationship with fluid intelligence was observed, with both speed and accuracy measures showing approximately equivalent loadings.

Two further correlational studies were carried out to investigate the role of stimulus presentation rate, concurrent memory load, and instructions on strategies, in performances on a SSTM task, and the effect of these variables on correlations with fluid intelligence. It was found that, although some of these variables did produce large differences in average performance, they did not significantly affect correlations with fluid intelligence.

It was concluded that the results of these studies are compatible with an interpretation of fluid intelligence in terms of the ability to perform effortful mental processing. A model is proposed which relates the structure of mental abilities to concepts derived from cognitive theories of attention. This model, based on the distinction between 'diffuse' and 'constricted' neural processes, attempts to provide a more contemporary account of Spearman's (1927) notion that higher g-loading (or more 'complex') tasks are those whose performances require large amounts of 'mental energy'.

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PART I

BACKGROUND

CHAPTER 1

THE CONCEPT OF TASK COMPLEXITY AND ITS RELATION TO THAT OF GENERAL INTELLIGENCE AND TO THE THEORY OF FLUID AND CRYSTALLIZED INTELLIGENCE

1. The Structure of Mental Abilities and the Concepts of General Intelligence and Task Complexity

A consistent and robust finding in the study of mental abilities, is the existence of positive correlations amongst a wide variety of mental tests. The generality of this finding, commonly referred to as the existence of a 'positive manifold' amongst mental tests, is reflected in Guttman's (1973) proposal that it be given the status of being acknowledged as the 'first law of intelligence'. The consequent existence of a common, or general, factor has typically formed the basis, in correlation based theories, of the notion of 'general intelligence'. In such theories, the problem of the nature of intelligence, (the term 'general' is often omitted), is usually seen as understanding the nature of the general factor, 'g', or alternatively, of explaining the positive manifold amongst mental tests.

One of the earliest and most influential of these theories was the single common factor theory proposed by the English psychologist, Charles Spearman (1927). Here, performance on each mental test is described in terms of a single general factor, 'g', and a specific factor, 's', with the specific factors, associated with each of the tests, being uncorrelated. Thus correlations between tests are accounted for solely by their loadings on the single common factor, 'g'. Although Spearman identified, or operationally defined, general intelligence as the common factor, his theorising on its psychological nature derived more directly from his observation that certain types of tests tended, consistently, to exhibit relatively higher g-loadings than others. Two of the more important features which he suggested characterise tests with higher g-loadings are as follows. Firstly, performance on these tasks appeared to require higher levels of concentration, or 'mental energy', than those tasks with lower g-loadings. Secondly, they seemed to involve the processes of reasoning and problem-solving, in contrast to the more mechanistic, or algorithmic, processes which appeared to underlie performances on the lower g-loading tasks. In Spearman's terms, the high g-loading tests exhibit the principle of 'noegenesis', or involve the 'eduction of relations and correlates'. It is important to realise that the existence of such a systematic variation between tests, in the relative sizes of their g-loadings, is not implied by the property of positive manifold (or by the existence of a common factor), but is an additional feature of the correlational structure of performances on mental tests. (In terms of the psychometric models described by Guttman, 1954, it is described by the proposition that the correlations amongst 'diverse' mental tests tend to form a radex, rather than a circumplex pattern.)

Despite the wide influence of Spearman's single common factor theory towards the beginning of this century, data was becoming available which suggested that more than one factor was required to adequately account for the common variance between performances on mental tests. (For example, see Alexander, 1935; El Koussy, 1935; Botzum, 1951; Horn, 1977.) Partly as a response to such data, and assisted by advances in factor-analytic techniques, more 'pluralistic', or 'oligarchic', models based on correlated group factors were gaining popularity in America. Within these models, the concept of general intelligence has little of the importance accorded to it by the earlier 'monistic' model of Spearman. The most well-known of these early pluralistic models was that of Thurstone (1938). In this model, performances on cognitive tasks are described in terms of a number (seven in his original work) of independent, though positively correlated group factors. Although positively correlated, these factors, the 'Primary Mental Abilities', are regarded as 'independent', (or sometimes, 'functionally independent') in the sense that they are held to reflect distinct psychological structures or processes.

The subsequent development of 'pluralistic' models can be thought of as having occurred in two directions, each of which can be seen as an attempt to cope with the ever increasing number of primary ability factors being 'discovered' through the application of multiple-group factor analysis. The first of these, as typified by the work of Guilford (e.g., 1967), represents an acceptance of a large number of distinct ability factors, but attempts to bring order to such diversity by posing the existence of a much smaller number of dimensions, or 'facets', by means of which these ability factors can be classified. (In Guilford's model, for example, upwards of 120 distinct factors are described in terms of three basic dimensions, relating to the 'content', 'operations' and 'products' of the tests defining each factor.) One of the criticisms most frequently levelled against such theories as Thurstone's, or Guilford's, is that they do not give an adequate account of the consistently observed positive correlations between the distinct ability factors, which logically imply the existence of a general factor. In defence of the relative neglect of these correlations is a long tradition of theorising, which focuses on the idea that the existence of a general factor does not necessarily imply the operation of some ubiquitous psychological influence, such as Spearman's 'mental energy' (e.g., Thompson, 1919; Thorndlke, 1926; Tryon, 1935; Ferguson, 1954; Humphreys, 1979). Instead, it is argued that positive correlations between tasks (or factors), may result from the minor 'overlapping' of mental processes measured by the tests, with the nature of this 'overlap' possibly varying with different pairs of tests.

The second direction in which the 'pluralistic' approach may be seen to have developed, is in the formation of models based on incomplete, or 'truncated' hierarchical factoring procedures. In such models (for example, those of Horn and Cattell, 1966, and of Vernon, 1950), the correlations between the primary factors are described in terms of a smaller number of positively correlated higher-order factors. The decision to terminate the factoring procedure at a particular stage is based on substantive psychological, rather than purely statistical, grounds. (Hierarchical factoring can, in principle, continue until either a single highest-order factor, or a set of orthogonal higher-order factors, is obtained. In the ability domain, however, it is generally to be expected that a complete hierarchical factoring of correlations between tests would lead to a single general factor.) More specifically, further factoring is ceased when it is judged, on the basis of substantive interpretation of the last factors obtained, that subsequent higher order factors do not represent 'real', or as 'interesting', psychological mechanisms or processes, as do these intermediate-order factors. For example, in the Horn/Cattell theory of fluid and crystallized intelligence (to be discussed later), attention focuses on a series of positively correlated, second-order factors (Gf, Gc, Gv, SAR, Ga, Gs, etc.). Thus an important similarity between this theory and Thurstone's is the assertion of the functional independence of a number of positively correlated ability dimensions, and the belief that a description in terms of higher order factors, (and in particular the general factor, 'g'), would loose most of what is of psychological significance. (For example, see Horn's 1985, 1986 arguments on the scientific uselessness of the concept of general intelligence.)

In recent years, however, there has been renewed interest by some authors in the concept of general intelligence (e.g., Snow, 1980, 1986; Marshalek, Lowman and Snow, 1983; Jensen, 1982b; Humphries, 1979, 1981). A number of possible reasons for this may be suggested. Firstly, there is the availability of psychometric models, such as Guttman's radex model, or ones based on hierarchical factoring procedures, which do provide for an operational definition of 'general intelligence' without the commitment to the (now obsolete) single common factor model of Spearman. Within these more recent models allowance is made for the existence of independent ability domains (corresponding to the lower-order group factors in the hierarchical model, or the 'facets' in the radex model) in ways which do not necessarily preclude a definition of general intelligence. For this reason, Sternberg (1981b) suggests that such models can be regarded as a synthesis of earlier 'monistic' and 'pluralistic' ones. For example, writers such as Sternberg (1981b), Snow (1980, 1986), and Hunt (1980), have proposed a substantive interpretation of the general factor, 'g', (in terms of strategic, or executive control, functions), while at the same time acknowledging the existence of group factors, or 'special abilities'. (However, the inability of Spearman's single common factor model to describe the observed correlational structure of mental tests was, in fact, used by Horn, 1985, as an argument against the validity of the concept of general intelligence.)

A second possible reason for this increased interest in the concept of general intelligence is that it has suggested, for some theorists, a way of relating ideas which have emerged from the more recent cognitive or information-processing approach to the structure of mental abilities. As mentioned earlier, Spearman and others have suggested that a fundamental difference can be observed in the nature of tasks which exhibit relatively high, and low, g-loadings in mental test batteries. The concept of task complexity has often been used to 'explain' this difference, with tasks which are found to correlate more highly with the general factor being said to do so because of their greater complexity. A number of authors have proposed that this complexity dimension can be understood in terms of concepts derived from relatively recent cognitive theories, especially those in the area of Short-Term Memory (STM) and Attention. For example, one of the currently more popular ideas is that more complex tasks are those for which individual differences in performances are related to the efficiency of executive control and strategic processes (see Hunt, 1980; Sternberg,

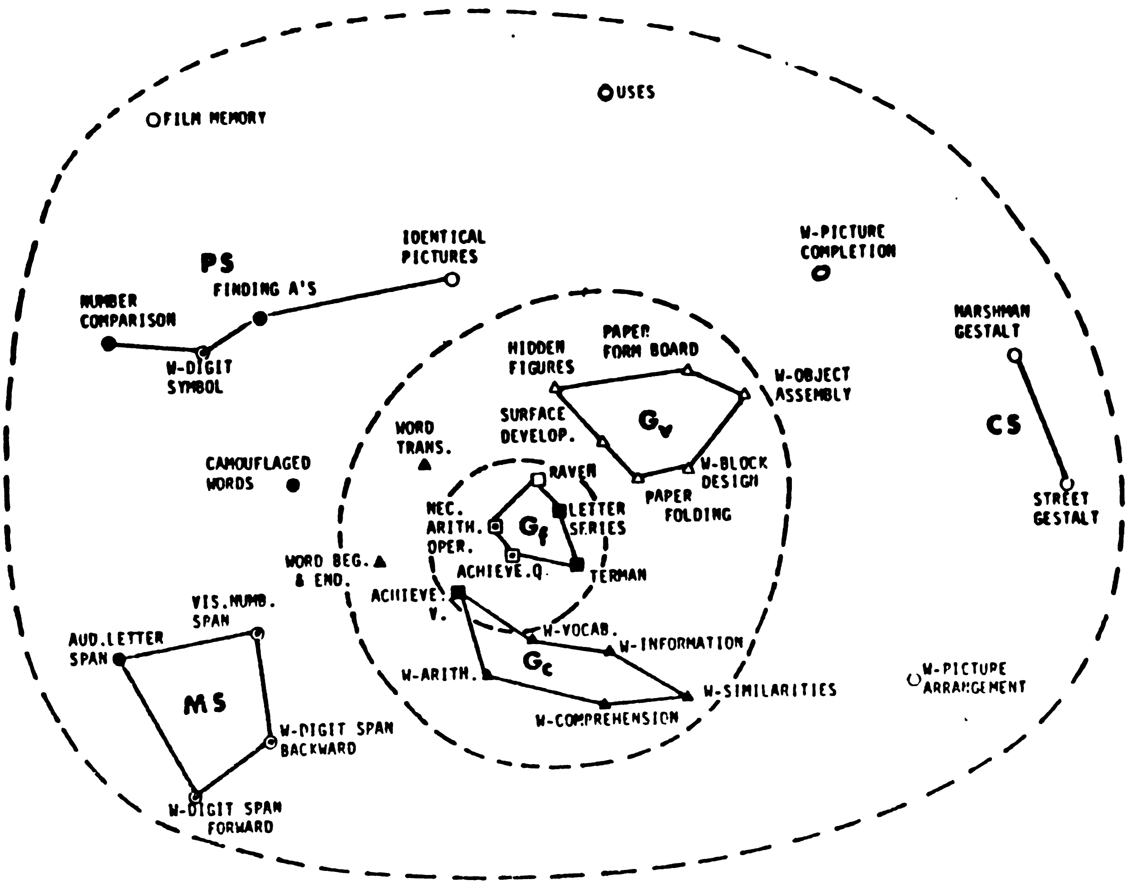


Figure 1 A multidimensional scaling of a battery of traditional mental tests. (Taken from Snow, 1980.)

1983; Campione, Brown and Bryant, 1985), concepts which form an integral part of the so-called 'modal' model of STM and Attention, which evolved from the writings of workers such as Atkinson and Shiffrin (1968). (This, and other, views on the nature of the 'complexity' dimension will be discussed later in more detail.)

A clear illustration of the way in which the notion of task complexity has been related to the structure of abilities can be seen in Figure 1, which has been taken from Snow (1980). (A similar diagram also appears in Marshalek et al., 1983.) This is a multi-dimensional scaling, in two dimensions, of a large number of traditional ability tests, and is an illustration of the radex model of abilities suggested by Guttman (1954). Here, individual tests are represented by points in two dimensional space in such a way as to attempt to place those tests more highly correlated with each other closer together in the plane. In this diagram, tests of higher 'complexity' are those towards the centre, while those of lower 'complexity' are distributed towards the periphery. The angular position around the diagram reflects the various different ability domains (content areas, special abilities, etc.), with figural, or spatial, tasks towards the right, perceptual/clerical speed tasks towards the upper left, a fluency test towards the top, and short-term memory tasks towards the lower left of the diagram. In Guttman's terms, each of these angular regions represents different 'facets' of mental ability. Tasks of varying complexity, but within the same angular region, are said to form a 'simplex' pattern, while those of similar complexity, but representing a selection of different facets, form a 'circumplex'. Alternatively, in terms of the Horn/Cattell theory of fluid and crystallized intelligence, the different angular regions can be seen to correspond to the broad, second-order abilities Gv, Gs, SAR, etc.. (Note that fluid intelligence, Gf, is distinguished from the remainder of the ability dimensions by being located at the centre, rather than defining an ability content area or domain.)

Using the data from which Figure 1 was obtained, Marshalek et al. (1983) also calculated the general factor, 'g', via a hierarchical factoring procedure. They confirmed that an ordering of tests along the radial dimension in that diagram, does in fact, correspond closely to an ordering of tests based on the relative sizes of their g-loadings. (Moreover, an alternative definition of 'g' in terms of the first principle component, does not appear to influence this result.) Thus the major conclusion of their paper was that operational definitions of task 'complexity' based on 'g', (obtained either by complete hierarchical factoring, or as the first principal component), or based on the results of multi-dimensional scaling, do, in fact, converge. One consequence of this finding is that an operational definition of task 'complexity' (or general intelligence) in terms of the first principle component (as preferred by Jensen, 1977), need not necessarily reflect a commitment to the single common factor model of mental abilities.

Jensen's preference for a definition of 'g' in terms of the first principle component, rather than one in terms of the general factor obtained from hierarchical factoring, appears to be based more on pragmatic, than on substantive theoretical grounds. (The reasons stated were that the first principle component maximises the explained variance and is more robust to sampling fluctuations than is the 'g' obtained from hierarchical factoring. However, it should be pointed out that the highest-order general factor is likely to be more stable, under most conditions, to variations in the selection of tests, than the first principle component.)

2. <u>Task Complexity and Task Difficulty</u>

With a fair degree of consistency, the phrase ' task difficulty' is used to refer to a property of a task which is related to the likelihood of people being unable to successfully complete the task. Fewer people are able to solve 'more difficult' tasks. Less commonly, and then usually only for tasks with very low error rates, it may be used to describe the relative times need to complete the tasks; more difficult tasks are more likely to take longer to solve. (Of course, if the rank-ordering of tasks on 'difficulty' is sensitive to the selection of subjects, or to the measure used, then a more sophisticated account is required. However, for the purposes of the present discussion such complications can be ignored.)

Task complexity, as the term was introduced above, and task difficulty, represent independent and distinct concepts. Although there may be some intuitive appeal in the proposition that more difficult tasks are better measures of intelligence, it is, in general, not correct. Jensen (1977) gives an example to illustrate this point. Paired associate learning correlates more highly with IQ when, in the learning phase, the stimuli are presented more slowly, even though the slower presentation makes the task easier. (The explanation offered was that the slower presention allows a greater involvement of higher-order executive control processes, the functioning of which is assumed to be linked, in individual differences, with intelligence.) A similar result was reported by Crawford and Stankov (1983). The immediate recall of digit and letter lists was found to correlate more highly with fluid intelligence than did a similar task which was made more difficult by the inclusion of an interpolated attention-distracting filler task between the presentation and recall of the stimuli. These examples show that, for at least some pairs of similar tasks, task complexity and task difficulty can be negatively correlated. It is, however, easy to find such examples if pairs of dissimilar tasks are considered. A test comprising the easier items of, say, the Raven's Progressive Matrices test, is likely to be more strongly associated with general intelligence than, say, a very difficult visual closure, incidental memory task, or perceptual discrimination task.

It should be noted, however, that the above interpretation of the phrase 'task complexity' is not the only (or even the most usual) one in common use. In the description of concept-learning, reaction-time or memory tasks, for example, the term 'complexity' is often used to denote some task parameter, usually associated with the number of stimulus features present, the number of hypothesised mental steps, or stages, required for task completion, or the 'depth' of processing involved. In these contexts, task complexity and difficulty are invariably positively associated. However, when used in this way, it is not necessarily the case that higher 'complexity' tasks are more highly correlated with intelligence. (For example, see Jenkinson, 1983, for an investigation of the effect of task 'complexity' on correlations with intelligence.)

3. The Theory of Fluid and Crystallized Intelligence: Fluid Intelligence, Rather than 'g', as the Focus of Increasing Task Complexity

This section will consider the relationship between the concept of task complexity and the factorial structure of mental abilities as described by the Horn/Cattell theory of fluid and crystallized intelligence (Gf/Gc theory). It will be suggested that the relationship is best described, not by continued hierarchical factoring to obtain the general factor, 'g' (as suggested by Marshalek et al., 1983, or Jensen, 1977), but by the identification of fluid intelligence (Gf), rather than 'g', as the focus of increasing task complexity.

The desirability of adopting an operational definition of task complexity in terms of Gf, instead of the more usual one in terms of 'g', will be argued for on the basis of factor-analytic data, and the pattern of effects on performance of such factors as age, brain damage and anxiety.

A brief outline of the theory of fluid and crystallized intelligence:

The early formulation of Gf/Gc theory evolved from Cattell's (1941, 1943) proposal on the existence of two 'general' ability factors, rather than one, as in the earlier single common factor theory of Spearman. Cattell suggested that, in addition to a broad ability factor, Gf, substantively interpreted in a manner similar to Spearman's concept of 'g', there exists a second, functionally distinct, though positively correlated, broad ability factor, Gc. The second factor was hypothesised to relate more to individual differences in acquired knowledge, especially that knowledge acquired through the processes of formal education. This contrasts with the interpretation of Gf, which, like that of Spearman's 'g', emphasised ability in the performance of problem-solving or reasoning tasks, and others involving an element of 'novelty.' An important aspect of this theory was the asymmetric causal relationship postulated to exist between Gf and Gc; namely that Gf is more predictive of Gc than Gc is of Gf. This followed from the assumptions, firstly, that Gf, like Spearman's 'g', has a strong physiological and heritable basis, and secondly, that the development of Gc depends on a combination of educational 'exposure' and Gf ability. Also, following from these assumptions is the predicted differential effects, on Gf and Gc abilities, of neurophysiological changes. A general decline in neural efficiency, such as accompanies the process of aging, or the clinical conditions of dementia, is expected to produce a greater decrease in Gf than in Gc. Conversely, individual differences in the cultural environment, especially those related to educational interests and opportunities, are predicted to be more strongly associated with variation in Gc tasks. Empirical evidence supporting Gf/Gc theory was reported by Cattell (1963). Here, two second-order factors, resembling in content the hypothesised Gf and Gc dimensions, were obtained. Furthermore, subsequent investigations on the relation of these factors to other variables generally confirmed their divergent construct and predictive validities, as described above. (See Cattell, 1971, or Horn, 1976, 1986, for reviews of the evidence supporting the distinctness of these factors. Note, however, that the hypothesised stronger heritability of Gf, compared with that of Gc, has not been well supported by the empirical evidence.)

A subsequent study by Horn and Cattell (1966), similar to the earlier one by Cattell (1963), but including a greater variety of mental tests, revealed, in addition to the earlier Gf and Gc dimensions, the existence of three further broad second-order factors. (These were: general vizualization, Gv; general speediness, Gs; and general fluency, F.) Further work in the Gf/Gc tradition has similarly revealed an even greater number of broad second-order ability factors, such as the general auditory factor, Ga, the short-term memory dimension, SAR, and others associated with the speed, carefulness and persistence of performances on particular tasks. (See Horn, 1985, for a discussion of the various ability dimensions obtained in this manner.)

To summarise, Gf/Gc theory can be seen to have evolved from the original almost 'monistic' notion of two 'general intelligences', to the current more 'pluralistic' theory which implies the existence of a much larger number (at least nine) of broad ability dimensions. The most explicit statement in favour of such a 'pluralistic' emphasis within the Gf/Gc tradition was made by Horn (1985, 1986). Here, he argues strongly in support of the distinctiveness of each of the broad ability dimensions obtained from work in the Gf/Gc tradition, and equally strongly against the meaningfulness, and scientific usefulness, of the general factor, 'g', or the associated concept of general intelligence. In this respect, Horn's more recent accounts of Gf/Gc theory follows a similar theme to that of Gardner (1983), who proposed the existence of several distinct 'intelligences' (or 'frames of mind') as an alternative to the notion of a single dimension (or even two dimensions, as in the original statement of Gf/Gc theory) of general intelligence.

Gf/Gc theory and the concepts of general intelligence and task complexity:

Within current Gf/Gc theory, therefore, there is no clear rationale for regarding any particular ability, or group of abilities, as being in any way 'special', or as representing more closely than others the concept of intelligence. Indeed, this was emphasised by Horn (1985) when he described the various broad ability dimensions of Gf/Gc theory (Gf, Gc, Gv, Ga, SAR, F, Gs, e.t.c..), as representing 'several different intelligences'. In particular, there is nothing within Gf/Gc theory which would suggest the finding that, in reasonably diverse mental test batteries, certain tasks (especially typical Gf markers) are consistently found amongst those with relatively higher loadings on the general factor. There is, however, occasional implict acknowledgement in the writings on Gf/Gc theory, of the greater importance, or significance, of these two factors, Gf and Gc. A clear example of this can be seen in Horn, Donaldson and Engstrom (1981) where a diagram is presented to illustrate the findings obtained from work carried out within the Gf/Gc framework. Here, the broad ability factors of Gf/Gc theory are displayed in a vertical hierarchy, with the vertical dimension being defined, somewhat vaguely (as conceded by the author in an accompanying caption) by the 'flow' of function and the developmental stage of acquisition. However, a close relationship can be observed between this ordering of abilities, from the top to the bottom of this diagram, and an ordering of tasks in terms of 'complexity' as would typically be obtained either by the calculation of the general factor, or by the application of the Radex, or similar models. (See, for example, Marshalek et al., 1983, or Figure 1 in this thesis.) Towards the top of the diagram are the factors Gf and Gc, representing the typical high g-loading tasks (such as the Raven's Progressive Matricies and Vocabulary), while further down are those factors marked by the lower g-loading tasks, such as short-term memory or perceptual/clerical speed tests. As discussed above, Horn has argued against the concept of general intelligence, and in favour of regarding each of the broad ability factors depicted in the diagram as representing separate and distinct 'intelligences'. However, the series of upwardly pointing arrows, labelled 'Intelligence', to the left of the diagram do seem to indicate an assumption, that in some sense of the term, human 'intelligence' is more closely associated with the abilities towards the top than with those lower down.

It is instructive, at this stage, to consider more closely the way in which the concept of task complexity has been used in discussions on the nature of the general factor, 'g'. As described earlier, Spearman, and more recent authors (Jensen, 1977; Snow, 1980; Marshalek et al., 1983), pointed to the systematic difference in the nature of those tasks with relatively high, and relatively low, loadings on the general factor. The notion of task complexity is typically introduced as a description of the nature of this systematic difference in the nature of the two categories of tasks. In other words, the concept of task complexity is typically used, not merely as an equivalent way of talking about the relative sizes of the g-loadings for different tasks, but as a label for the type of mental processes which are assumed to account for the observed systematic differences between tasks in the relative sizes of these loadings. That is, tasks more closely correlated with 'g', do so because they reflect individual differences in the more 'complex' forms of mental processing. Of course, for different authors, a variety of concepts might be invoked, (such as mental energy, the involvement of strategic functions, span of attention, or even less precise ones, such as 'abstractness', or the dependence on 'higher-order' mental processes), in order to define more precisely what constitutes more 'complex' mental processing. However, the main point being made here is that when the the term task complexity is used in relation to explanations of general intelligence, it is implied that tasks with higher g-loadings do so because they involve a greater component of a certain type of mental processing.

The next stage in the argument is to suggest that, on the basis of correlational data, such notions of complexity, (either intuitive or theory based), are at least equally consistent with an operational definition of task complexity in terms of fluid intelligence, as with one in terms of the general factor, 'g'. Consider, in the multi-dimensional scaling of Figure 1, sets of tasks within given content areas, but varying in 'complexity'. Here we may note the set Forward and Backward Digit Span, or the set in the figural domain, comprising the tasks Gestalt Closure, Form Board and the Raven's Progressive Matrices. In these sets, as pointed out by Marshalek et al. (1983), an apparently greater involvement of 'higher order' or 'more complex' forms of mental processing is accompanied by the progressive increase in the g-loadings, or closeness to the centre, of the mental tests. It is clear, however, that for the results shown in Figure1, it could have been noted, equally, that increases in apparent task complexity are accompanied by a closer proximity to the group of tasks representing fluid intelligence, labelled 'Gf'. In other words, although Marshalek et al. used these data to demonstrate a relation between the concepts of task complexity and general intelligence, the data are equally consistent with an operational definition of task complexity in terms of the factor, fluid intelligence.

Results of factor-analytic studies, where the selection of tests allow a clearer separation of the broad ability dimensions, do suggest, however, (at least for the sets of tests discussed above), that increases in apparent task complexity are better described in terms of increased loadings on the factor, Gf, rather than by higher correlations with the general factor, 'g'. In these studies apparent increases in task complexity (such as from Visual Closure to Form Boards, to the Raven's Matrices; e.g., see Horn, 1980) are more likely to be accompanied by corresponding increases in the factor loadings on Gf, rather than by either increased loadings on Gc, or by the distribution of their loadings over a larger number of other ability dimensions. (Both of the latter two possibilities could also, in principle, account for variations between tasks in their correlations with the general factor.)

In terms of Gf/Gc theory, the general factor, 'g' (or the first principal component) of common 'diverse' batteries of mental tests can be interpreted as primarily some combination of abilities Gf and Gc, with smaller contributions from the other dimensions, such as Gv, SAR, Gs, etc.. However, it is significant that those authors who have suggested an operational definition of task complexity in terms of psychometric 'g', do invariably describe the psychological basis of 'g' in terms more appropriate to the description of the factor, Gf, than to the description of other abilities contributing to 'g'. Conversely, when interpretations of Gf are being given, it is common to find analogies drawn with Speareman's concept of 'g' (e.g., Humphreys, 1979; Horn, 1986). Spearman's concepts of mental energy and 'noegenesis', or more recent notions (such as 'span' of attention, Working Memory, or executive control and strategic functions), are plausible as descriptions of performances on the reasoning and problem-solving tasks which define most directly the factor, Gf, but seem less appropriate as descriptions of, for example, the tests of acquired knowledge, (such as Vocabulary), which form the basis of crystallised intelligence, Gc. Consistent with the above, is the observation that the test most frequently referred to as the 'archetypical' measure of general intelligence is Raven's Progressive Matrices, (e.g., Jensen,1977; Marshalek et al. 1983). This test, although commonly found amongst those tests showing the highest g-loadings, is, in fact, one of the 'purest' markers of Gf, typically exhibiting near-zero factor pattern loadings on the other ability dimension, Gc, which is also closely associated with 'g'. Rarely are tests of previously acquired 'knowledge' offered as exemplifying the concept of general intelligence, except when it is stated, or assumed, that the acquisition of such knowledge depends to a large extent on the sort of complex reasoning and problem-solving processes reflected more directly in the performance of typical Gf tasks.

For many groups of tasks it may not appear important whether task complexity is operationally in terms of its relation to 'g', or to Gf. Either definition would seem to yield similar conclusions on the relative task complexities. Both definitions would, for example, lead to the same plausible conclusion that Backward Span is more 'complex' than Forward Span, or that the Raven's Matrices is more 'complex' than the Form Board task, which is, in turn, more complex than the visual closure tasks. The two definitions do not agree, however, when the complexity of tests such as Vocabulary and general knowledge, is under consideration. A definition in terms of the general factor would lead to these being regarded as tasks of relatively high complexity, while one in terms of factor-loadings on Gf would result in them being regarded as tasks of lower complexity. If task complexity is taken to refer to the 'complexity' of mental processing <u>at the</u>

time of testing, then there do appear to be good reasons for regarding tests such as Vocabulary as being of relatively low complexity. Firstly, as mentioned above, many theories on the nature of mental processes underlying individual differences in general ability, have suggested mechanisms which are plausible as being important in performances on the sorts of reasoning and problem-solving tasks which mark Gf, but are not plausible descriptions of the type of mental processes occurring during performances on tests of acquired 'knowledge', such as Vocabulary, used as measures of Gc. This is especially true of the more recent cognitive, or information-processing, based theories on the nature of general mental ability. Three types of such theories will be discussed in more detail in a later section. These are, firstly, theories based on notions of a 'span' of attention, or the capacity of some Working Memory or central processing space. Secondly, are those theories involving problem-solving heuristics and strategy selection or choice. Finally, is the idea that general intelligence reflects individual differences in attentional resources, a more recent notion, analogous to Spearman's earlier concept of 'mental energy'.

Another argument in favour of regarding the performance on typical Gc tasks as involving mental processes of relatively low complexity, comes from the consideration of the effects on performance of various forms of mental states, such as fatigue and anxiety, and also the effects of different forms of brain-damage. Regarding the effects of such variables as fatigue or anxiety, a common finding is that if performances on such tasks as Forward and Backward Digit Span are compared, deficits due to these factors tend to be greater for more 'complex' mental tasks. However, the recall of previously acquired information, such as in a Vocabulary test, is relatively less affected than the performance on tasks, intuitively interpreted as requiring higher levels of concentration. Thus, in this respect, Vocabulary and other such tasks, behave as tasks of lower 'complexity'. (A comprehensive review of such data can be found in the book by Michael Eysenck, 1982. Here, it is suggested that performance deficits due to such factors as anxiety are due to a depletion of the amount of attentional resources available for processing. Performance on a Vocabulary task would not, in such an account, be regarded as requiring large amounts of attentional resources, as would performances on typical Gf tests. See also M. Eysenck, 1979.)

A similar conclusion on the fundamental differences in the nature of the critical mental processes involved in performances on typical Gf and Gc tasks can be drawn from the way in which these tasks are used by neuropsychologists to assess the degree of recent decreases in a person's intellectual power, or performance (e.g., see Lezak, 1983, p92). It is assumed that in normal circumstances performances on Gc tasks are a reasonable estimate of a person's general mental power, or efficiency. However, it has been found that a decrease in mental efficiency, as occurs with the onset of various conditions of dementia, leave Gc abilities relatively intact, but does produce large deficits in performances on Gf tasks, which are viewed as more immediately reflecting a person's level of intellectual functioning. Gc tasks are therefore commonly used as estimates of a person's 'premorbid ability level', that is, their general mental ability prior to the onset of the disease state. Yates (1954), for example, suggests Vocabulary as being generally accepted as the best single test indicator of premorbid mental ability. The NART, a test which measures the ability to pronounce phonetically irregular words, has been used in a similar manner (Nelson and O'Connell, 1978). Reflecting the assumption that Gf tasks provide fairly direct measures of current mental efficiency, is the use of differences in the levels of performances on Gf and Gc markers to estimate the extent of mental deficit produced by a particular occurrence of dementia. Thus, subscales of the Shipley Institute of Living Scale, containing vocabulary and verbal abstraction scales, have been used for such a comparison. The Vocabulary and Block Design tests of the WAIS are also frequently used in this way to measure the degree of recent mental impairement (see Lezak, 1983, p. 180). (Although measuring spatial ability to some degree, the Block Design test can be regarded as a reasonable measure of Gf, except for persons with specific spatial ability deficits, and possibly for people of superior Gf ability.)

It should be pointed out, however, that, compatible with the above argument, is the possibility that Gc tasks, such as Vocabulary, can provide good indirect measures of a person's ability to perform complex mental processing. This would be the case if it could be assumed, firstly, that the acquisition of such 'knowledge' required mental processing of high complexity; secondly, that other factors, such as the variation in educational opportunities, are of relatively less importance; and thirdly, that no significant recent changes in intellectual functioning, (such as may occur with the onset of dementia), have occurred. This idea, that the present level of performance on Gc tasks reflects, to a significant extent, previous levels of Gf ability, is contained in the so called 'Investment Theory' of Cattell (1971). A similar notion was suggested by Hunt and Lansman (1982) when considering an interpretation of general intelligence, as measured by tasks such as the Raven's Progressive Matrices, in terms of individual differences in Attentional Resources. They noted that certain tasks, like Vocabulary, which do not seem to require large amounts of attentional resources in their performances, do, nevertheless correlate significantly with such measures of intelligence as the Raven's Progressive Matrices. It was proposed by these authors that this apparent anomaly could be explained by assuming that the acquisition of such verbal, and other, knowledge, involved mental processes requiring high levels of attentional resources.

The arguments presented in this chapter are basically consistent with the accounts of Gf/Gc theory as presented by, say, Cattell (1971). They are, however, in apparent conflict with the idea, recently stated by Horn (1985), that Gf and Gc do not represent fundamentally different types of abilities. Here Horn proposes that both of these factors reflect the extent of acquired 'knowledge', and that they are distinguished only by the nature of this knowledge. For Gc it is primarily knowledge gained through 'acculturation', that is, through the more formal educational processes, with their emphasis on 'fact-absorption', while for Gf, it is primarily knowledge gained from 'casual learning', a form of learning suggested to be less dependent on formal instruction. A similar idea was stated by Hunt (1980), where performance on problem-solving tasks, such as typically define Gf, reflect individual differences in the knowledge, or store, of previously learned problem-solving skills and strategies. This idea will be discussed in more detail in the next chapter, where various theories and ideas on the nature of mental processes underlying the concept of task complexity will be examined.

CHAPTER 2

THEORIES AND IDEAS RELATED TO THE CONCEPTS OF INTELLIGENCE AND TASK COMPLEXITY

In this chapter, the various ideas which have been put forward as underlying the the concept of general intelligence, or that of task complexity, will be discussed. A comprehensive review will not be attempted. Rather, attention will focus on those ideas most relevant to current theorising on the nature of intelligence, and especially those notions which have been suggested by theories from within the information processing, or cognitive, area of psychology.

1. Complex tasks as those reflecting individual differences in 'mental energy' or 'attentional resources'

As mentioned earlier, one of the first to point to the systematic differences between high and low g-loading tasks was Charles Spearman (1927). From this observation, two main concepts emerged as being relevant to this difference, those of 'mental energy' and 'the principle of noegenesis'. In terms of the first of these, general intelligence, as measured by the major common factor, 'g', reflects the varying amounts of mental energy possessed by different individuals. Also, tasks were hypothesised to vary with respect to the extent to which the availability of this mental energy determines level of performance, with performances on more 'complex' tasks, (that is, those with higher g-loadings), being relatively more affected by the supply of such energy.

The influence of the concept of mental energy, and particularly Spearman's assumption of its primarily biological and genetic basis, can be seen in the later writings of authors such as Jensen, Eysenck and Cattell. However, its influence on more modern theories of intelligence has probably not been as strong as that of Spearman's other ideas on the nature of 'g', associated with his 'principal of noegenesis'. A possible reason for this is the problem of circularity in the definition of the term 'mental energy'. An adequate account of the nature of this mental energy, independent of its relation to tasks with observed high and low g-loadings, is, of course, required to remove this circularity. Such an account was not seriously attempted by Spearman, possibly because of a belief that significant advances in the science of neurophysiology were required before this were possible.

One way in which the notion of mental energy may be more adequately defined, (that is, defined independently of its role in determining a task's relation to 'intelligence'), is via the more recent concept of 'attentional resources'. This concept has its origin in theories of selective attention, especially in those so-called late selection models (e.g., Treisman, 1969) which postulated the existence of some form of central processor of limited processing capacity. Such a structure served as the 'bottleneck' in the processing of, or responding to, multiple sensory input. However, the concept of attentional resources is now usually more closely associated with the 'variable allocation' models of Kahneman (1973) or Norman and Bobrow (1975). In these models, 'central' limitations on the simultaneous processing of multiple sources of information is restricted, not by the common involvement of some central mental structure, or 'processor', but by the limited availability of a general-purpose source of attentional resources, which is capable of fuelling concurrent activity in different mental structures.

Three important assumptions in Kahneman's model are as follows. Firstly, tasks may vary with respect to the amount of attentional resources required in their performance. Those tasks requiring relatively greater amounts are said to be less 'automatic', or are 'more effortful'. Secondly, interference between simultaneous mental processes may be due to either competition for the limited supply of attentional resources, or to the common involvement of specific mental structures. Such 'structural interference' might occur, for example, if these processes involved the same input or output modality. Thirdly, systematic differences are assumed to exist in the total amount of attentional resources possessed by individuals. However, the amount available for processing may vary, within individuals, as a result of changes in arousal, and the amount allocated to a particular task may change as a function of such variables as the subject's motivation or perception of the task's difficulty, or the priority given to the task in multiple task situations.

The fairly obvious and direct parallel between Kahneman's notion of attentional resources and Spearman's concept of mental energy was, in fact, noted by Hunt and Lansman (1982), who suggested the following restatement of Spearman's single common factor model. Tasks more highly correlated with the common factor, 'g', are those for which the levels of performances are more strongly dependent on the amount of available attentional resources, while the uncorrelated specific factors, (the s's), reflect the more automatic processes in those mental structures, postulated by Kahneman to underlie the non-central, or 'structural', sources of interference between concurrent mental processing. An obvious difficulty with the above account is the questionable assumption of the single common factor model of Spearman. However, this can be easily modified to a more acceptable form as follows. More complex tasks are those whose performances depend more on the availability of attentional resources, while the more peripheral tasks, (or factors, such as Gv, SAR, or Gs) reflect more the various specific mental 'structures' postulated by Kahneman.

Such an account, while preserving the essential idea that task complexity is linked with the concept of attentional resources, is not inconsistent with more than one common factor being needed to adequately describe the pattern of correlations between mental tests.

In an earlier paper, Hunt (1980) did suggest a connection between the concepts of general intelligence and attentional resources. However, it is interesting to note that in this paper, attentional resources were proposed, not as an explanation of task complexity, but of the consistently found positive correlations between mental tests, that is, the so-called property of positive manifold. Referring to the same diagram as is displayed in Figure 1 of this thesis, Hunt suggested that the essential difference between the more central and the more peripheral tasks, lay in the extent to which they allowed flexibility in subjects' strategies. Individual differences in the performance of central tasks, such as the Raven's Progressive Matrices, it was suggested, are not associated with differences in people's supply of attentional resources, but in the sizes of their 'store' of problem-solving strategies or subroutines. (Such an interpretation of task complexity in terms of 'strategic variability' will be discussed in a later section.) This is interesting because, generally, when the concept of general intelligence is discussed, these two aspects (that is, the explanation of positive manifold, and that of task complexity), are not clearly distinguished. They are, however, logically independent. For example, a complexity dimension may be clearly defined by the radial dimension of a radex pattern, such as shown in Figure 1. However, the obtaining of such a pattern depends only on increasingly positive correlations between tasks of higher complexity. It does not preclude the possibility that tasks of lower complexity, that is those towards the periphery, are negatively correlated.

In view of the widespread use of the distinction between automatic and effortful mental processes in recent work in cognitive psychology, and the fairly direct and obvious manner in which this can be related to the structure of mental abilities, it is perhaps surprising that more attention has not been given to the possibility of such a theoretical link. A number of reasons may be suggested for the lack of serious consideration of attentional resources as an explanation of general intelligence, or of task complexity. Firstly, in some quarters, where the trend is towards a more 'pluralistic' view of human intelligence (or 'intelligences'), the need for such explanations does not arise, and, indeed, would be inappropriate (e.g., Horn, 1986; Gardner, 1983). Among those theorists, however, who do allow of some notion of general intelligence, there is currently a popular alternative view involving the concepts of executive control and strategic processes. (The recent rise in popularity of these concepts as applied to theories of intelligence, is evidenced in Sternberg and Berg, 1986, where a statistical comparison is made of issues discussed in the 1921 and 1986 symposia on intelligence.) As well as providing an alternative account of intelligence, the acceptance of such a 'process' oriented view could also be seen as somewhat antagonistic to a consideration of a more 'structural' explanation in terms of attentional resources.

A further reason for the relative neglect of attentional resources as an explanatory construct for intelligence is simply the lack of direct empirical evidence in favour of such an explanation. One line of investigation which could be seen as being relevant to this issue is the study of individual differences in the performance of dual (competing, or concurrent) tasks. Such studies commonly focus on the question of the existence of a general 'time-sharing' factor or ability. Reviews of the results of these studies have generally concluded against the firm acceptance of such a 'time-sharing' ability. Hawkins, Church and de Lemos (1978) suggested, instead, that different task combinations may call on different specific abilities. In a slightly more positive tone, Sverko (1977), and Ackerman, Schneider and Wickens (1982) argued that evidence does exist to indicate the possibility of such an ability, but that its status is still uncertain. Stankov (1985) reported data which showed that, in certain instances, correlations with 'g' were greater under competing conditions than when presented singly. However, certain aspects of the data, described in that paper, led him to question whether an explanation in terms of Attentional Resources could be used for this finding. Fogarty and Stankov (1987) reported a correlational study containing a large number of single and dual tasks drawn from a variety of different ability domains. Here again, no strong evidence for a general time-sharing factor was obtained, although under some conditions increases in the general factor loadings of dual tasks, over those of the corresponding single tasks, were observed.

Studies such as those described above, were not intended, nor adequately designed, as direct tests of the validity of the concept of attentional resources, or of its manifestation in individual differences as general intelligence. However, the strong connection between the notions of attentional resources and inter-task interference, would have, no doubt, led attitudes towards the usefulness of this concept being challenged by the relatively inconclusive findings of these studies. A number of studies reported by Hunt (1980), Hunt and Lansman (1982) and Lansman and Hunt (1982), using a paradigm more suitable for the investigation of this issue (the 'primary/secondary' paradigm), did, however, produce results generally (though not completely) consistent with the theory that individual differences in attentional resources determine performances on the common measure of general intelligence, the Raven's Progressive Matrices. (The primary/secondary paradigm, it is claimed, more adequately avoids the confounding of central and structural interference, and provides for a more effective control of the manner in which attentional resources are allocated between two simultaneously performed tasks.)

An example of such a study was reported by Hunt (1980). Subjects were given a number of items of the Raven's Progressive Matrices test (Raven, 1965) to solve. For some of these items, subjects were required to simultaneously perform a second task which consisted of holding a small lever between two posts with their left hand. The subjects were instructed that the Matrices task (the 'primary' task) was the most important, and that only 'spare', or 'left-over', effort was to be given to the other ('secondary') task. It was found that the decrement in performance on the secondary task while solving the easier Matrices items was negatively correlated with the ability to solve harder items when these were performed alone. Such findings are consistent with predictions made on the basis of an attentional resources model of performance on the Matrices test. However, after considering other aspects of the results of this experiment, Hunt concluded that it was more likely the efficiency of use of attentional resources on the Raven's Progressive Matrices items, rather than the total amount of resources available, which was related to the deterioration in secondary task performance. It should be noted that this interpretation is more consistent with Hunt's proposal, in the same paper, that the essential difference between high and low g-loading tasks lies in the relative importance of executive control and strategic functions in their performances. Although the possibility of a link between intelligence and attentional resources was raised in a later paper (Hunt and Lansman, 1982), no mention of this idea was made in a subsequent article by Hunt

(1983) entitled "On the Nature of Intelligençe".

Another factor which may have contributed to a lack of serious consideration of such an explanation of general intelligence is the criticism, by a number of authors, of the scientific validity of the concept of a single source of attentional resources, capable of energising diverse forms of mental processes. Allport (1971, 1980a, 1980b), and Naven and Gopher (1979), for example, have argued, on the basis of the observed pattern of interference between different tasks for a multi-processor, or multiple resources model. Such models do seem more suggestive of concept of 'multiple intelligences' (Horn, 1985; Gardner, 1983), than the concept of a general intelligence. An attack from a different direction on the notion of attentional resources came from Spelke, Hirst and Neisser (1976), and Hirst, Spelke, Reaves, Caharack and Neisser (1980) where it was shown that two tasks, after much practice, can be successfully performed simultaneously, and, according to the latter authors, without alternation of attention, and without the tasks becoming 'automatic'.

A different type of task which might be related, at least at an intuitive level, to Spearman's concept of 'mental energy', (though not necessarily to a single-source theory of attentional resources), is one investigated by Wittenborn (1943). He devised a number of tasks, the construction of which was guided by a number of design principles. The most important of these was that their performances should depend upon a continuous, sustained application of mental effort, or concentration. (The nature of these tasks will be discussed more fully in Part II of this thesis, where a study involving them will be described.) It was also assumed by Wittenborn that individual differences in performances on these so-called 'Attention' tasks should not be strongly related to intelligence (or in his terms, 'intellectual level'), nor should they depend to a significant extent on differences in subjects' previously acquired knowledge. Wittenborn's assumption that they should not be strongly related to intelligence can possibly be understood as resulting from the apparently repetitive, or algorithmic, mental processes involved on their performances. However, despite this assumption, there are several indications that they might, indeed, be quite closely related to traditional measures of intelligence. For example, in Wittenborn's (1943) study, these tasks were those with the highest loadings on the general factor formed by a battery of fairly diverse mental tests. (The battery contained markers of the Thurstone Primaries - Number, Space, Perceptual Speed, and Memory.) Such a finding would clearly be consistent, at face value, with Spearman's account of intelligence in terms of the concept of mental energy. However, it is interesting to note the apparent dissimilarity between these tasks, and the typical reasoning or problem-solving tasks which, for Spearman and many other psychologists, exemplified the concept of general intelligence.

Although there has not been a popular acceptance of theories of intelligence based directly on concepts such as attentional resources, there has been, lately, an increased interest in the application of these ideas to the interpretation and design of mental ability tests. For example, a non-verbal ability test battery, recently developed by the Australian Council for Educational Research (the NAT; Rowe, 1985) contains several tests which were seen as measuring various attentional factors. Of particular interest was the finding that those NAT tests (Tests 10 to 14) which were interpreted in terms of 'concentration', or 'sustained attention' (as opposed to other aspects of attention, such as search, selective attention, or vigilance) were found to be amongst those with the highest 'g'-loadings (Rowe, 1986, p.111).

Another interesting finding on the relationship between traditional measures of fluid intelligence and tests more directly interpretable in terms of 'concentration', was recently reported by Stankov (1988). Here it was found that the decline in performance on tests of fluid intelligence with age, could be 'explained' by the decrease, with increasing age, in subject's performance on tests of attention. The negative correlation between fluid intelligence and age, equivalent to a decrease of about three IQ points per decade, was reduced to near-zero when performances on the attentional tests were regressed from the fluid intelligence measures.

2. The Principle of Noegenesis: General intelligence as reflecting 'inventive', rather than 'reproductive', or 'algorithmic', mental processes

A frequently stated (or implicitly assumed) notion is that human intelligence is best measured by tasks requiring some act of mental 'discovery'. That is, tests in which the subject is required to find, for themselves, how each problem is to be solved, rather than tests which measure the speed or accuracy with which some prescribed mental steps can be performed, provide the purest indication of what is understood by intelligent performance. For some writers, this specification may represent the essential meaning, or even the definition, of human intelligence. In such cases it is not appropriate to question the truth of such proposition, although its scientific usefulness may be questioned. However, for others, for whom intelligence is defined independently, such as in terms of the general factor, such an assertion is open to critical evaluation.

As mentioned previously, the above idea was expressed by Spearman in terms of the principle of noegenesis, that tasks with higher loadings on the general factor are characterised more strongly by the processes involving 'the eduction of relations and correlates'. A similar idea was suggested by Guttman (1954), in order to account for the complexity dimension which arose in his simplex and radex models of the structure of mental abilities. Here, the distinction was made between tasks involving 'rule-inferring' and those involving 'rule-application'. Tasks of higher complexity, it was suggested, require subjects to discover the rules implied by the test stimuli, while tasks of lower complexity involve the application of rules given to the subjects.

With the exception of certain tasks, such as Vocabulary, tests which are commonly used as measures of general intelligence, (such as the Raven's Progressive Matrices, or the subtests of Cattell's Culture-Fair Battery), are ones, which when compared with other tasks less strongly related to intelligence, (for example, perceptual/clerical speed or memory-span tasks), do seem to involve more of what Spearman termed the 'eduction of relations and correlates'. (The special case of tasks, such as Vocabulary, and other markers of Gc, was discussed in Chapter 1.) On this basis then, an account of task complexity in terms of the extent to which a task involves 'noegenesis', or 'rule-inferring', does appear to be consistent with the empirical evidence. However, there does exist data which suggests that this may not be always the case. More specifically, there are certain types of tasks, which seem to be more appropriately described as 'rule-applying', but which, although not superficially similar to common tests of intelligence, were found to be relatively closely associated with the general factor, or other measures, such as Gf. Wittenborn's Attention tasks may be regarded as possible examples. (It was noted earlier that the apparent lack of 'noegenesis', or 'rule-inferring', in these tasks is a probable reason why

Wittenborn assumed that they should not be related strongly to intelligence.) More definite evidence comes, however, from a study by Cattell and Horn (1978). Here, it was found that a number of clearly rule-inferring and rule-applying tasks loaded equally on a factor identified as fluid intelligence, Gf. They concluded that such a logical distinction between types of tasks was not reflected in individual differences. A possible argument against this conclusion could be that the rule-applying tasks do nevertheless involve a certain element of mental 'discovery' in the finding of more efficient strategies which would allow faster or more accurate performances in the application of the prescribed rule. However, this merely points to the inadequacy of such accounts of the complexity dimension, which focus on the manifest nature of the task, and not on the nature of the mental processes involved in its performance.

A problem of a more logical, or conceptual, nature is the difficulty of evaluating, a priori, the extent to which a task exhibits the principle of noegenesis. That is, the problem of specifying, by inspection of the task alone, and without a prior knowledge of a task's factorial composition, the extent to which a task exhibits this principle. (This is, of course, necessary if the concept of noegenesis is to serve as an explanation of the complexity dimension.) For example, the perceptual/clerical speed task, Number Checking, a task of known low complexity (see Figure 1), could, on purely logical grounds, be described in a manner which would lead to the expectation of its being a task of relatively high complexity. (Subjects are required to educe the relation between pairs of numbers, or more specifically, to decide if they are the same or different.) In a similar manner, the apparently 'creative' nature of mental processes involved in performances on the visual closure, or gestalt completion, tasks led Jensen (1977) to regard these as tasks of relatively high complexity. (Complexity, here, was defined in terms of the correlation with the first principal component.) However, as can be seen from Figure 1, these are, in fact, tasks of relatively low complexity, located towards the periphery in the figural region on the right. It could be argued that, although tasks such as gestalt closure might involve 'noegenesis', the critical mental processes are too 'perceptual', or too 'automatic'. Thus high complexity tasks, it might be suggested, are those involving noegenesis, but only when this also involves, to use Jensen's (1977, 1979) terms, active mental manipulation, mental work, or conscious mental effort. This, however, introduces the problem of defining these additional concepts, (reminiscent of Spearman's notion of mental energy), and underlines inadequacy of the concept of noegenesis, by itself, as an explanation of task complexity.

3. Complex tasks as those involving a greater number of separate abilities: 'g' as a mixture

In this section we will consider a view which developed as a reaction against an interpretation of psychometric 'g' in terms of a single, ubiquitous psychological influence. Early statments of such a position can be found in the writings of Thompson (1939), Tryon (1935), Ferguson (1954), and more recently in those of Humphreys (1979, 1981) and Horn (1985). Although originally formulated mainly as a reaction against Spearman's account of 'g', it would operate equally against more modern notions, such as general intelligence reflecting the operation of executive control and strategic functions. In this 'mixture' view of general intelligence, the consistently observed positive correlation between diverse mental tests, is due, instead, to the common involvement, or 'overlap', in psychological processes, where the nature of these overlapping mental processes is not the same for all pairs of tests. Thus, for example, the positive correlation between one pair of tests might reflect the common use of short-term memory, while for another pair, it may be, say, the common use of figural imagination. The general factor, 'g', the existence of which is logically implied by the positive manifold between tests, thus represents a mixture of different abilities, rather than some unitary influence. In such a view, then, more complex tasks (i.e., ones more highly correlated with the general factor) are those which involve a larger number of different mental abilities. Less complex tasks, on the other hand, are those which are relatively more pure measures of specific abilities sampled by the particular battery.

An important example of such an approach can be found in the 'new structure of intellect' model of Carroll (1976). This model has some formal similarity to Guilford's (1967) well known 'structure of intellect' model in which psychometric tasks are classified in terms of the types of contents, inputs and outputs required in their performances. In Carroll's model, the tasks are analysed in terms of the cognitive structures and processes hypothesised to be most relevant in their performances. For this analysis, much use is made of the hierarchical multi-store, information-processing, models of mental functioning, as derived from such theorists as Hunt (1971), Newell and Simon (1972) and Sternberg (1977). Following this approach, the positive correlations between pairs of tests are due to the common involvement of some of the cognitive processes or structures. Tasks sharing a greater proportion of these cognitive elements are more highly correlated with each other. (Stankov, 1980, provided some empirical support for this idea. Here a cluster analysis, with similarities between tasks defined in terms of the number of shared cognitive elements, yielded a grouping of tasks similar to that described by the Horn-Cattell Gf/Gc theory.) High g-loading tasks are, therefore, those tasks whose performances involve a greater total number of different cognitive structures and processes, since it is these tasks which are, on average, more highly correlated with other tasks.

It should be pointed out that a theorist who does interpret 'g', or task complexity, in terms of some unitary influence (say, the operation of executive control functions), may nevertheless find the notion of 'overlap' useful in explaining correlations between tests, or factors, which may remain non-zero after 'complexity' has been statistically controlled. In terms of Guttman's radex model, or the analysis shown in Figure 1, overlap in mental processes may explain the placement of tests in the various radial content domains. It is only within the highly restrictive (and now generally abandoned) single common factor model of Spearman that the correlations between tasks are assumed to be solely determined by their g-loadings, or complexities. The interpretation of the general factor in terms of a particular psychological entity, does not necessarily imply a commitment to Spearman's model.

The most common arguments which have been put against such a mixture notion of 'g', are firstly, that the g's derived from different test batteries are highly correlated, and secondly, that, provided that samples which reflect the full range of mental abilities are used, 'g' accounts for a large proportion of the common variance among tests commonly found in intelligence batteries (e.g., see Jensen, 1979). The first of these arguments looses much of its appeal, however, from the observation that, in fact, most of the commonly used test batteries tend to contain similar kinds of tests. The high correlations between the g's of different batteries might simply result from them containing a similar mixture of abilities. (In terms of Gf/Gc theory, these are mainly measures of Gf and Gc, with smaller contributions from Gv, Gs, SAR, etc..) Regarding the second argument, the size of the general factor depends critically on the selection of tests in the battery. A selection of tests from, say, the periphery of Figure 1, would give rise to a much smaller general factor than one derived from common IQ batteries, which typically contain tasks from the more central regions of the diagram. The relative absence of low complexity tasks in common intelligence test batteries can possibly be explained in terms of their lower 'face validity' as measures of intelligence. Intuitively, they may appear too perceptual, or simple, to be judged as appropriate measures of the higher-order, and more abstract, mental functions associated with human intelligence. Furthermore, in the development of test batteries whose function is seen mainly as the measurement of a single quantity, 'intelligence', the tendency has been to remove tests of lower complexity in order to maintain a reasonably high 'internal consistency' for the battery. (Note, however, that Humphries, 1979, argues against the desirability of this practice of imposing this criterion of high homogeneity of tests in intelligence batteries.)

A number of additional arguments may, however, be brought against the view that more complex tasks are those measuring a greater number of separate abilities. One argument is that intuitive interpretations of tasks of higher and lower complexity, have suggested, for many psychologists, that performances on the more complex tasks are, in fact, characterised by mental processes which distinguish them from less complex ones. For example, Hunt (1980), and others, have suggested that the more central tasks involve, to a greater extent, the the processes of executive control and especially the selection of strategies. A second argument comes from results of factor analyses containing tasks of both high and low complexity. The 'mixture' view would suggest a factor pattern matrix in which each of the ability factors are marked univocally by tasks of relatively low complexity, with the higher complexity tasks sharing their loadings on a greater number of these factors. In fact, a much more usual result is that factors of relatively high complexity are formed (containing typical Gf or Gc tasks) along with other factors of lower complexity. Thus, for example, the factor pattern which might be expected, on the basis of a 'mixture' view, from the factor analysis of tests in Figure 1, would be the formation of three correlated group factors, corresponding to the more peripheral tasks in the spatial, memory and perceptual speed regions, with the more central tasks, such as the Raven's Progressive Matrices, not defining separate factors but instead loading on several of the more peripheral factors. Results of factor analysis within the Gf/Gc tradition typically show, instead, the more complex tasks loading on the more central factors, Gf or Gc. The more natural interpretation of such data is that task complexity should be explained in terms of the processes underlying the more central factor, or factors. (In Chapter 1 it was argued that this should be in terms of Gf, and not Gc, if complexity is taken to refer to the nature of mental processes occurring at the time of testing.) This argument must be qualified to the extent that factor solutions may vary as a function of the sampling of tests and of the choice of factor analytic procedures, in particular, the criterion for factor rotation. However, insofar as the structure of abilities described by Gf/Gc theory can be thought of as reflecting psychological 'reality', then such factor analytic results do not suggest an account of task complexity in terms of the number of separate abilities measured by a test.

The strongest argument, however, against a 'mixture' interpretation of task complexity comes from the consideration of the different effects of various forms of mental stress, or brain damage, on tasks of high and low complexity. As discussed in Chapter 1, there does appear to be a tendency for more complex tasks to be affected to a greater extent by such variables as anxiety and diffuse brain damage. It is very difficult to see how a mixture notion of task complexity could be compatible with such a pattern of results. If a number of low complexity tasks are relatively insensitive to the effects of a particular factor (say, anxiety), then a more complex task, representing a mixture of abilities tapped by these lower complexity tasks, would be expected to be similarly insensitive to the effects of that factor.

Such effects are, of course, much more easily explained if it is assumed that more complex tasks involve types of mental processes not tapped by ones of lower complexity. For example, if it were postulated that performances on higher complexity tasks are more dependent on a supply of attentional resources, then the greater effect of anxiety on higher complexity tasks could be explained by assuming that anxiety reduces the amount of such resources available for processing (M. Eysenck, 1979).

A similar argument against a 'mixture' notion of task complexity can be made on the basis of data supporting the 'Spearman hypothesis', that race differences in mental abilities are largely due to differences on the general factor (Borkowski and Krause, 1983; Jensen, 1985; Naglieri and Jensen, 1987). Although the extent and interpretation of such observations have been questioned (Humphreys, 1985), the existence of an interaction between task complexity and group membership would be difficult to account for without assuming that higher complexity tasks tap abilities not present in tasks of lower complexity. If abilities measured by tasks of lower complexity exhibited small group differences, and if higher complexity tasks were merely those tasks which tapped a larger number of these abilities, then higher complexity tasks would be expected to show similarly small group differences.

4. The information-processing, or cognitive approach: More complex tasks as those reflecting strategy selection

Here we shall consider a particular view of intelligence which claims as its conceptual framework ideas which have come from the area of information-processing, or cognitive, psychology. The key concept, which can be traced to such theories of attention and memory as that by Atkinson and Shiffrin (1968), is that mental processes are hierarchically organised into at least two levels of control. On the lower level are the more basic (elementary, simple, etc.) 'mechanistic' information processing functions (Hunt, 1978), or the 'cognitive/performance components'. (Sternberg, 1983) These more basic processes are, in turn, organised and co-ordinated by the higher-order executive control processes, or 'metacomponents'. The important feature of the lower-order, or mechanistic, processes is not that they necessarily represent the smallest unit of analysis possible, but that their qualitative nature is essentially the same across persons or tasks. That is, there is no strategic variation between, or within, subjects in the performance of any particular component process. (Individuals can, however, vary in the speed and accuracy with which these more elementary processes can be carried out.)

Within such a framework, general intelligence is seen as reflecting individual differences in the operation of the higher-order executive control processes, which are held to manifest themselves primarily, at the level of task performance, in the selection of strategies used in the solution of the task. Such a view has been suggested both by those psychologists concerned with the study of group differences, and those seeking to explain the structure of abilities obtained from correlational studies on normal subjects. Campione, Brown and Briant (1985), for example, suggest that differences between groups of varying general ability (children verses adults, retardates versus normals, etc.) in the performance of memory tasks, can be understood in terms of the distinction between 'strategy-free' and 'strategy-intensive' tasks. Strategy-intensive tasks are those whose levels of performances are more strongly determined by the appropriate choice of strategies, than for strategy-free tasks. In terms of this distinction, it is concluded that it is performances on the strategy-intensive tasks which is related to intelligence, as determined by membership of the various groups studied. A similar explanation of group differences in general intelligence was suggested by Borkowski and Krause (1983). Here it was proposed that the observed difference between American blacks and whites in general intelligence could be be mainly attributed to differences in the functioning of the 'executive system'.

Sternberg (1981b), as well as proposing a link between psychometric 'g' and the functioning of executive control processes (his 'metacomponents'), also suggests that individual differences in the lower level processes (the 'components'), are reflected by the more specific abilities, or group factors, such as Gv, SAR, Ga, Gs, etc.. A clear statement of a similar position was given by Hunt (1980) as follows. (Here, Hunt refers to the multidimensional scaling diagram by Snow, 1980, which is similar to the one reproduced as Figure 1 in this thesis.)

> "Tests of more specific abilities, such as the ability to complete incomplete figures, memory span, or perceptual speed measures, were in the periphery. The peripheral tests are those that most resemble the procedures used by experimental psychologists to test specific information-processing functions. They present people with very restricted problem-solving situations, in which there is only one reasonable way to attack the task. Performance in such a situation will be more determined by mechanistic information-processing functions than by a choice of problem-solving strategy simply because of the limited range of strategies possible. By contrast, performance on tests in the centre of the space may be much more dependent on a person's having available a store of strategies to deal with the varied problems presented by different items within each test."

An interesting aspect of this statement by Hunt is that, not only do performances of the more central tasks reflect the effectiveness of strategy choice, but the effectiveness of strategy choice is determined by the 'store' of available strategies, rather than by some more basic information processing capacity limitation on the performance of the executive control system. Such a 'software' emphasis in the interpretation of individual differences in strategic functions is, of course, not essential for a view of general intelligence in terms of executive control and strategic functions. It could, for example, be held that strategic processes are limited by their demands on a finite pool of attentional resources, or by some other limitation on central processing capacity. However, it not an unusual notion among those theorists adopting a 'strategies' approach, that the higher-order strategic functions are related more to the 'software', rather than the 'hardware', components of the information processing system. For example, when Borkowski and Krause (1983) suggested that the observed racial difference in intelligence could be understood as being due to differences in the subjects' 'executive systems', the model was presented, in their terms, as being 'process-oriented', rather than 'structural'. That is, differences in the executive were thought of as being due to differences in the subjects' possession of learned problem-solving skills, differences which might be reduced by the appropriate training at an early age.

Empirical research on mental abilities, within the information processing framework, has followed two main approaches. These Pellegrino and

Glaser (1979) have called the 'cognitive correlates' and the 'cognitive components' approaches. In the cognitive correlates approach, performances on relatively simple cognitive tasks, typically selected from the wide range of experimental paradigms formally used in cognitive research, are correlated with traditional measures of intelligence, or specific mental abilities. A wide variety of 'elementary cognitive tasks', or ECT's as Carroll (1981) called them, have been examined in this way. These include simple and complex reaction-time, memory scan, lexical access, inspection-time and many other paradigms. When reviewing data derived from this type of research, Hunt (1980) concluded that, for subjects in the normal range of ability, correlations between individual ECT's and traditional psychometric measures of general intelligence are only small, with values similar to those produced by common lower complexity tasks, such as perceptual/clerical speed or memory span tests. Keele (1979) described this generally weak result in terms of a '0.3 barrier' in the sizes of correlations between ECT's and intelligence. However, it should be emphasised that, as with other lower complexity measures such as memory span, correlations much higher than 0.3 can easily be obtained if subjects of sufficiently low levels of ability are included in the sample. It is also important to note that this is not simply a question of the restriction of range. Higher correlations between ECT's and intelligence are to be found with groups of lower ability than with groups of higher ability but with comparable ranges of ability. For example, the stronger relation between general intelligence and the digit span subtest of the WAIS for subjects of lower ability, was noted by Zimmerman and Woo-Sam (1973, p. 97) and Matarazzo (1972, p. 194). Nettlebeck and Kirby (1983) reported a similar pattern of results with reaction-time and inspection-time tasks.

In the second main approach, the so-called 'cognitive components' approach, subjects' performances on relatively complex tasks (usually ones commonly used as measures of intelligence, such as analogies and series-completion tasks) are analysed in terms of some stage, or 'componential', model. In such a model, task solution is hypothesised to proceed via a sequence of basic, or elementary, cognitive 'components'. By mathematically modelling individual subjects' performances, regression estimates can be obtained for the speed and accuracy of performances on each of the hypothesised elementary cognitive components (e.g., see Sternberg, 1977). The correlations between these scores and those from traditional mental tests can then be calculated in order determine the relationships between these component mental processes and measures of intelligence. This approach has the added advantage of allowing an examination of the adequacy of the assumed componential model for the particular task, and also, to some extent, the investigation of individual differences in the solution strategies which determine the sequencing of the basic component processes. Regarding the relation between intelligence and these cognitive components, however, essentially the same negative conclusions resulted from Sternberg's componential approach as were drawn from studies following the cognitive correlates approach, namely, that only small correlations exist between accepted measures of intelligence and performances on each of the basic processing components (see Sternberg,1981b).

The finding of relatively low correlations between performances on the cognitive components and measures of intelligence led Sternberg to conclude that intelligence is associated with the functioning of the higher-order control processes (in his terms, the 'metacomponents'), which co-ordinate the operation of the more elementary component processes. As described above, it was essentially the same line of reasoning (but based more on findings from studies adopting the so-called 'cognitive correlates' approach) which influenced Hunt (1980) to suggest a similar interpretation of task complexity in terms of strategic functions. It should be pointed out, however, that not all workers in the area have drawn these sorts of conclusions from investigations on the relationship between intelligence and performances on more basic and elementary tasks. In particular, Hans Eysenck, Arthur Jensen and Philip Vernon are amongst those who have continued to emphasise the significance of this line of study, an approach influenced largely by the belief that factors underlying performances on these more elementary tasks are also of importance in determining individual differences in intelligence. The work of these authors will be discussed in more detail in a later section where the notion of mental speed and its relation to intelligence is considered.

Despite its strong intutive appeal, and its current widespread popularity, a troubling aspect of such a view of general intelligence in terms of strategic functions is the lack of strong, direct, positive evidence in its favour. The most often stated argument for this 'process oriented' approach is the consistent failure, despite an enormous research effort, to obtain correlations between elementary cognitive tasks and intelligence comparable to those obtainable from more traditional mental tests. In general, correlations with intelligence typically obtained from various ECT's are of the same order of magnitude as those for common low complexity psychometric measures, such as perceptual/clerical speed or memory span tasks. There is, however, a substantial amount of evidence generally consistent with, but not directly supporting, such a view of intelligence in terms of strategic processes. A large number of studies have reported systematic differences between groups of varying ability in their use of problem-solving strategies. Such studies have typically involved the comparison of retardates and normals, or children at different stages of development. (See studies quoted by Campione et al., 1985, in favour of their distinction between strategy-free and strategy-intensive tasks, and its relation to intelligence.) Likewise, Sternberg (1977) noted that higher ability subjects tended to spend longer encoding the problem stimuli, and to have a more orderly approach to the solution of analogy problems.

The main limitation of such data, as evidence in favour of the view that it is strategic processes which underly individual differences in intelligence, is that the observed differences in strategies could plausibly be the manifestation of more basic differences in mental capacity. This is emphasised by findings which suggest that lower ability groups have greater difficulty in the learning and the applying of new strategies, as well as the generalising of strategies to different, but similar tasks (e.g., Campione et al., 1985). Such data operates most strongly against what might be termed a 'software' position, where the differences in strategic functions between people of high and low intelligence is assumed to be primarily a result of the 'store' of available problem-solving strategies possessed by the person. These findings do seem more compatible with a more 'structural' view, that such strategic differences reflect a more fundamental limitation in the information processing capacity of the mental structures responsible for the learning and applying of cognitive strategies. This would still be consistent with a view of general intelligence in terms of strategic processes if it were supposed that the functioning of such mental structures could only be manifested in so-called 'strategy-intensive' tasks, that is tasks whose performances are largely a function of the efficiency of subjects' strategic processes. The general failure in finding ECT's, or cognitive 'components' (performances on which are generally regarded as being 'strategy-free', rather than 'strategy-intensive'), which are strongly related to intelligence could, however, be taken as evidence that this is indeed the case.

Despite the large body of data consistent with the view that executive control, or metacomponential functions underlie individual differences in intelligence, there do exist a few, but reliable, experimental results which are not easily explained within such a framework. Cohen and Sandberg (1977) investigated the correlations with IQ of primacy and recency recall on a probed serial recall task. Multistore models of short-term memory, such as those proposed by Atkinson and Shiffrin (1968), or Waugh and Norman (1965), suggest that primacy recall (the recall of items towards the front of a list), and recency recall (the recall of items from the end of a list), reflect different psychological processes. In particular, primacy recall depends on the transfer of items to a relatively long-term secondary memory system. This transfer was thought to be strongly influenced by executive control processes, such as those involved in the choice of efficient rehearsal strategies. Recency recall, on the other hand, was thought of as reflecting recall from a more 'sensory' primary memory system, and was therefore assumed to be unaffected by such control processes. On the basis of these models, it was generally expected that primacy recall would be more strongly related to IQ than would recency recall. These expectations were initially confirmed, but largely with data comparing performances of normals and retardates (e.g., Ellis, 1970). However, Cohen and Sandberg (1977) in a series of separate studies, using normal children, showed that recency recall was consistently more highly correlated with intelligence, than was primacy recall. Their main conclusion was that it was non-strategic processes which were responsible for the higher correlations with intelligence. In a later paper Cohen and Sandberg (1980) suggested that it was the encoding of items under memory load which was responsible for the higher correlations of recency recall with intelligence, an explanation which is highly suggestive of an account of intelligence in terms of such notions as working memory. This approach which will be considered in a later section.

Another set of data which does not seem consistent with an interpretation of general intelligence in terms of strategic processes involves the association between the rate of paired-associate learning and intelligence. In a study by Hughes (1983), subjects were divided into two groups. One group was given explicit instruction on strategies which would assist recall. The second group was given no such strategic instructions. As expected, it was found that the instruction group performed better on the learning task than the no-instruction group. However, correlations with intelligence (as measured by the Raven's Progressive Matrices) were much higher for the instruction group (r=.59) than for the no-instruction group (r=.16). This result would not be expected if correlations with intelligence were assumed to be mediated by subjects' ability to select, by themselves, the most appropriate strategies for the task.

It is interesting to note that Sternberg (1981b), whose interpretation of the general factor, 'g', emphasises the role of executive planning and strategic functions, has suggested a way in which the distinction between automatic and effortful mental processes can be incorporated into his 'componential' theory of intelligence. As described above, this theory gives prime importance to the distinction between strategic and non-strategic mental functions. This distinction is reflected in the operation of either the higher-order 'metacomponents' or the lower-order cognitive 'components', respectively. Within this theory, it is the functioning of the metacomponents, rather than that of the more basic components, which is related to general intelligence. However, Sternberg (1981b) suggested, that a further distinction should be made, similar to that of Schneider and Shiffrin (1977), between controlled and automatic mental processes, and that this distinction should be applied to both componential and metacomponential functions. Of particular interest here, is Sternberg's suggestion that, in terms of the assumed hierarchy of control, <u>the automatic metacomponents operate in a manner similar to the lower-order components</u>. Although not pursued by Sternberg, a plausible implication of this addition to his theory, is that it is the <u>controlled</u> metacomponential processes which are the ones related to individual differences in general intelligence, with the automatic metacomponents, together with the cognitive components, being associated with the more specific abilities, or group factors. Thus, as with several other theories considered earlier, further elaboration on the theory, has lead to the introduction of the distinction between automatic and effortful processing and, although not explicitly stated by Sternberg, with the plausible implication being that it is the more effortful mental processes which are more closely related to intelligence.

If it is accepted that it is the operation of the the non-automatic metacomponents which is related to general intelligence, then the obvious and critical question which arises is the status of effortful mental processing which is not manifest in a variation in subjects' problem solving strategies. The model described by Sternberg (1981b) does not seem to make allowance for such processes, although their existence is not explicitly rejected. It is important to note that if the existence of such effortful processes were allowed, and if it were assumed that they were manifest in individual differences in the same manner as other forms of effortful processing, then the Sternberg's above model would become one in which general intelligence is the result of individual differences in effortful mental process. Executive planning and control functions would then be only one class of effortful processes resulting in differences in general intelligence, rather than being the critical ones, as suggested by Sternberg (1979, 1981a, 1981b) and others (e.g., Hunt, 1980; Campione and Brown, 1985).

5. Span theories of general intelligence: Task complexity as the short-term memory, or span of apprehension, required by a task

The basic notion here is that cognitive tasks, particularly those reasoning tests commonly used as measures of intelligence, require the temporary 'holding in mind' of several items of information, and that the 'complexity' of a particular task is the number of such items needed to be held in mind in order for it to be successfully completed. This idea is reflected in the work of Simon and Kotovsky (1963,) who demonstrated, using a computer model, that a major source of difficulty in a letter series task was the number of items needed to be simultaneously stored in an hypothesised short-term memory buffer. Similar conclusions were drawn by Kotovsky and Simon (1973) and Holzman, Pellegrino and Glaser (1983) in studies on series completion problems, and by Bereiter and Scardamalia (1979) who analysed items of the Raven's Progressive Matrices test in terms of the number of stimulus features required to be simultaneously apprehended for item solution.

The clearest and simplest statement of an account of general intelligence in such terms was provided by Bachelder and Denny (1977a, 1977b). The complexity of a task is defined as 'the number of cues that are jointly, or conjunctively, relevant for the target response.' In this theory, 'Span Ability' is postulated to be the 'structural or innate basis of intelligence' and is the subject variable defined as the complexity of the highest-complexity task that the individual is able to successfully perform. These ideas have a highly intuitive appeal if related to the phenomenal experiences of attempting the more difficult items of tests of intelligence, such as Letter Series or the Raven's Matrices. Bachelder and Denny (1977b) quoted Anastasi's (1968, pp. 273-274) description of the WAIS subtests, and pointed to the clear involvement of span-like notions in her subjective account of these tests.

The major difficulty with such a theory of general intelligence is that simple and direct measures of Span Ability, such as the common memory span test, would be predicted to be a task of high complexity. Bachelder and Denny (1977b) do acknowledge that this somewhat surprising conclusion is indeed implied by their span theory of intelligence. However, they defend it in two ways. Firstly, they argue that memory span is more highly correlated with measures of intelligence than is commonly supposed. To support their position they quote a number of studies in which correlations between memory span and measures of intelligence of as high as 0.79 were observed. However, the possibility of obtaining such high correlations under certain circumstances, (the ones quoted here were always obtained using retardates as part, or all, of each sample), is not, in itself, evidence that 'span ability' is the basis of individual differences in general intelligence. For subjects in the normal range of ability, there is abundant correlational evidence that memory span is a task of only 'moderate' complexity, with other tasks (especially the reasoning tasks which mark Gf) consistently correlating more highly with intelligence. Among the subtests of the WAIS, for example, it is generally accepted that Digit Span is one of the poorer measures of general intelligence, and is of little use for this purpose except at the lower ranges of ability (Zimmerman and Woo-Sam,1973, p. 97; Matarazzo, 1972, p. 194). This view of the memory span task is also consistent with its absence from the central regions of the multidimensional scaling diagram obtained by Snow (1980) and shown as Figure 1 in this thesis. Thus, Snow (1986, p. 129) includes memory amongst those 'specialised', or 'simpler', factors which are less strongly related to general intelligence. Also, in studies within the framework of Gf/Gc theory, memory span has been found to load most heavily on the broad short-term memory factor, SAR, rather than on the more 'central' factors, Gf or Gc. (See discussion of Gf/Gc theory in Chapter 1 of this thesis.)

It could be argued that the high correlations between memory span and intelligence, obtained using samples with a large proportion of subjects below the normal IQ range, is good evidence that, at least for samples of this nature, Span Ability may underlie differences in general intelligence.

Matarazzo (1972), for example, suggests that although for subjects in the normal range of ability, memory span is not a good measure of intelligence, it does, nevertheless, discriminate well between normals and those below the normal range. Other experimental data suggest, however, that this is not necessarily the case. If one considers a variety of other common low complexity tasks which do not reflect Span Ability in any obvious way, (say, those tasks outside the inner contour in Figure 1 but <u>not</u> in the memory region towards the lower left), then high correlations between these tasks and intelligence can also be readily observed for samples containing subjects in the lower IQ ranges. Moreover, it does not appear to be simply the 'restriction of range' which is relevant to the producing of the lower correlations for samples in the normal range of ability. The correlations between typical low complexity tasks and intelligence are found to depend not only on the range, but also on the absolute level of abilities in the sample. (Thus a much higher correlation between intelligence and, say, memory span would be expected for a sample with IQ range 60 to 100, than for one with IQ range 100 to 140.) The above ideas are clearly demonstrated in the results of Nettlebeck and Kirby (1983). These authors administered inspection-time and choice reaction-time tasks to subjects of a wide range of ability. From their pool of subjects they selected a 'normally distributed reduced sample' with a mean IQ of 100 and standard deviation of 15. For this reduced sample, the multiple R squared of the inspection-time and choice reaction-time tasks with IQ was .68. Of particular relevance here, when subjects of IQ greater than 115 were excluded, this reduced only slightly to .61, but when subjects with IQ less than 85 were excluded this reduced to .26.

Bachelder and Denny (1977b) suggested a second possible reason for the relatively lower correlations between memory span and IQ measures than would be expected from their span theory of general intelligence. "Span relates to a more basic capacity than does the concept of IQ, which is also a measure of acquired behaviours and problem-solving skills." These authors are thus suggesting a relationship between span ability and IQ similar to that hypothesised by Cattell (1971) to exist between the more basic and physiologically determined ability, Gf, and the factor Gc, which reflects more the extent to which certain 'knowledge' has been acquired. However, Bachelder and Denny give no convincing evidence in support of their idea that tests such as Forward Digit Span represent the structural and biological basis of either (or both) of the Gf and Gc factors, which form the major ability components of common IQ measures. This is particularly serious in view of the low correlation (typically between .3 and .4) between memory span and general intelligence for subjects in the normal range of ability. The existence of higher correlations for subjects in the lower IQ range is not, as discussed above, sufficient evidence that Span Ability is the structural basis of general intelligence even for subjects in this range, nor does it suggest that Span Ability is, in any sense, causally more basic a measure.

6. Working Memory and related concepts: General intelligence as reflecting the size, or capacity of a central working memory system, or processor

A major difficulty in evaluating the usefulness of span notions as explanations of general intelligence, or task complexity, is the problem of reconciling the apparent success of the span (or immediate memory 'buffer') idea in accounting for the source of difficulty in good measures of intelligence, such as the Raven's Progressive Matrices (Bereiter and Scardamalia, 1979) or Letter Series (Simon and Kotovsky, 1963), with the low association, with intelligence, of direct measures of memory span, such as obtained from the Forward Digit Span task. It may be significant to note that in those situations where span does appear to be related to intelligence, the actual estimates of the tasks' span requirements (typically in the range two to four) are very much less than those of around seven given by memory span tasks. One way of explaining this difference in subjects' effective, or apparent, short-term information holding capacity is via theories which postulate some type of active, or working, short-term memory system in which there is a trade-off between information processing and storage functions. One such theory is the 'M-space' model of Pascual-Leone (1970). In this theory, space in a central working memory system, or processor, is taken up by temporarily stored items of information as well as by mental processes involving planning and control functions. Thus, in a memory span task, most of the available M-space is allocated to the storage of memory items, while for tasks such as the Raven's Progressive Matrices, or Letter Series, more space is taken by the planning and control functions, with a correspondingly decrease in the effective item storage capacity. It is interesting to note the close resemblance between the M-space construct of Pascual-Leone and the concept of Working Memory proposed by Baddeley and Hitch (1974). This concept arose mainly as an explanation of the reduction in the amount of information which can be held temporarily in mind produced by concurrent mental processing. The main findings here are that more difficult, or 'effortful', concurrent mental processing interferes more with the short-term storage of information, and secondly, that there is a strong modality effect. (For example, visual memory is interfered with more by concurrent mental processes involving visual imagery, than by, say, verbal transformations.- see Posner and Rosman, 1965; Brooks, 1967; Wickens, 1980.)

A serious limitation of this M-space theory, however, is that it does not allow the prediction of <u>how much</u> space in the central processor is taken by different forms of mental processes. It would seem plausible to suggest that this could be related to how automatic, or how effortful, are the mental processes involved. However, to avoid circularity, it is, of course, necessary that this distinction between automatic and effortful mental processes be defined independently of the amount of M-space taken up by the particular mental processes. Moreover, the identification of general intelligence with individual differences in the size of this M-space, as suggested by Bereiter and Scardamalia (1979), does suffer from the same difficulty as the account of intelligence in terms of span ability, as was discussed in the previous section. This is because the 'size', or total capacity, of an individual's M-space should still be able to be measured by such tasks as Forward Digit Span, even though, for other tasks, considerable space would be allocated to the executive control processes, as well as to the short-term storage of information. Thus, as with the Span theory of Bachelder and Denny, a theory in terms of M-space would similarly predict that memory span should be a good measure of general intelligence.

The concepts of M-space or Working Memory do, however, suggest a way in which certain results, apparently supporting a link between short-term storage capacity and general intelligence, might be explained. It should be noted that in these cases (as with the results of Simon and Kotovsky, and Bereiter and Scardamalia, described above), estimates of people's short-term storage capacity are well below the seven or so items obtained from typical immediate memory-span tasks. These data can be explained if it is supposed that, under these conditions, estimates of Span Ability represent indirect measures of the degree of interference on immediate memory produced by the concurrent mental processing needed to solve the problem. In other words, intelligence (as measured by performances on the Raven's Matrices or Letter Series tasks) is not related to the size of some short-term memory buffer, in the way in which the results of Simon and Kotovsky, or those of Bereieter and Scardamalia, have been interpreted to indicate. Rather, it is related to some property of the concurrent mental processes (such as 'automaticity') which determines the effective holding capacity under such conditions (that is, under those conditions when estimates of this effective holding capacity are significantly less than the value given by the individual's performance on simple memory span tasks). This interpretation is thus both consistent with the data, discussed earlier, apparently indicating a link between immediate memory and intelligence, and also with the widely accepted finding that the simple memory span task is a relatively poor measure of intelligence.

The above analysis is useful in understanding the constraints, proposed by Case (1972), which should be placed on the types of short-term memory tasks in order to make them suitable for the assessment of a person's M-space. These constraints are, firstly, that M-space can only be properly assessed using tasks involving mental transformations, and secondly, that the storage component of M-space is the number of items of information which can simultaneously be held in mind without direct support from immediate perceptual input. At an intuitive level, therefore, M-space is to be measured by the short-term information holding capacity only under those conditions when there is a significant level of active mental processing simultaneously taking place. Backward Digit Span would therefore be a better measure of Span Ability (though not necessarily an ideal one) than Forward Digit Span. The clear intent of these specifications is to disallow the use of simple, direct measures of short-term memory, such as the Memory Span test, as valid measures of M-space, but to allow M-space to be identified with the short-term holding capacity during, say, the performance of Raven's Matrices or Letter Series items, as was done in the analyses of Bereiter and Scardamalia, and of Simon and Kotovsky, which were discussed above. Note that no such special restrictions were placed on tasks measuring Span-Ability by Bachelder and Denny, (1977a,b), who, as discussed earlier, argued that simple memory span tasks should, indeed, be regarded as good measures of general intelligence.

This attempt by Case to make more attractive an account of general intelligence in terms of individual differences in people's M-space does, however, suffer from a number of difficulties. Firstly, his suggested restriction on the type of tasks which may properly be used to measure a person's M-space is ad hoc in the sense that it does not follow, in any natural way, from the assumptions of M-space theory. Athough the theory does postulate that the central work-space can be shared between both storage and processing functions, there does not appear to be any theoretical reason why the capacity of M-space should not be measured by its 'storage' capacity under those conditions when a relatively small portion of this 'space' is taken up by mental processing. A second difficultly has to do with the exact meanings of the terms 'transformation' and 'direct support from immediate perceptual input', which are essential to Case's specifications. This can be demonstrated by comparing a task which, under Case's specifications, would not be allowed as a proper measure of M-space, namely Forward Digit Span, with one commonly used by those working in the framework of M-space theory, the CSVI (Complex Stimuli, Visual Input) task (Case and Globerson, 1974; Pascual-Leone, 1970).

This task is presented in two stages. Firstly, the subject is required to learn, to some fairly strict criterion of success, a set of stimulus-response relations, $\{S_i \text{ -> } R_i\}$. This might involve, for example, the learning of the associations between a number of spatial locations and a number of different colours, or between sets of words and digits. The subject is then presented in the second, or test, phase, with a number of 'complex stimuli', each comprising an ordered N-subset, $\{S_1, S_2, \ldots S_N\}$, of the previously presented stimuli, S_i. The number of component stimuli, N, is referred to as the 'complexity' of the complex stimulus. The subject is required to respond after each of these complex stimuli with the appropriate complex response, $\{R_1, R_2, \ldots R_N\}$, where the individual responses $R_1, R_2, \ldots R_N$, had previously been paired with the stimuli $S_1, S_2, \ldots S_N$, respectively, in the learning phase. A subject's M-span is measured, using this task, by determining the complexity, N, of the highest complexity complex stimulus for which the subject is able to reliably produce the correct complex response.

If one compares the CSVI task described above to, say, a visually presented Forward Digit Span task, then it is clear that the essential difference is that performance on the CSVI task relies on newly acquired, or 'novel', transformations, (namely the Si -> Ri associations acquired in the learning phase), whereas the common digit span task relies on the execution of highly over-learned, or automatic mental transformations. (These comprise the transformations involved in the initial perceptual encoding of the visual stimulus and leading to the final motor codes associated with the vocal, or written output.) Alternatively, this difference could be stated as the S -> R transformations being of much higher 'compatibility' for the Forward Digit Span task than for the CSVI task. The difficulty that this presents for M-space theory is that it is clear from the above comparison, (and also from the work of Baddeley, 1981, and Posner and Rossman, 1965, which demonstrate a trade-off between the storage and processing functions of Working Memory), that the measure of M-span derived from such a CSVI task depends on the 'compatibility' of the S-R associations on which the task is based. Higher estimates of a person's M-span would clearly be obtained from CSVI tasks employing S-R associations of higher compatibility. This compatibility could vary with the degree of learning, or 'over-learning', of the S-R associations in the initial learning phase of the task, or with the particular selection of stimuli and responses which could affect the 'natural' or 'intrinsic' compatibility of these associations.

The notion that estimates of a person's short-term information holding ability (the size of an immediate memory 'buffer', or 'span ability' etc.), can vary as a function of the nature of the tasks from which such estimates are obtained, can be readily demonstrated as follows. To illustrate the concept of Working Memory, Massaro (1975) described the following 'RST task'. The letters R, S and T are presented one at a time and in a random order, and the subject is required to keep track, at each point in time, of the current, separate totals of R's, S's and T's which have been presented. This 'complex counting' task thus requires that the person hold a number of items in short-term memory (in this case, three items), while simultaneously processing other information. Although not suggested as such, this task could clearly serve as a means of measuring a person's Span Ability, or M-space (as defined earlier), or as a measure of the size of the immediate memory 'buffer', as postulated in the model of Simon and Kotovsky (1963).

Versions of this task, using different numbers of distinct letters to be tallied would be presented. The required measure would thus be the maximum number of distinct letters for which the subject is able to keep track of the separate totals. Performances on such a task would be expected to decrease rapidly when the number of separate letters to be tallied exceeds the size, or capacity of the individual's Span Ability, M-space or immediate memory 'buffer'. However, as Monty, Taub and Laughery (1965) showed, performances on such tasks depend not only on the number of distinct items to be tallied, but also on a number of additional factors such as the speed at which the stimuli were presented and the ease with which the stimuli can be ordered. (The counting of naturally ordered stimuli, such as R, S and T, is easier than that of, say, squares, diamonds and triangles, which do not suggest a ready ordering. This 'orderability' effect can be seen as similar to the 'compatibility' effect discussed above in connection with the CSVI task.) It is clear, therefore, that estimates of Span Ability, M-space or 'buffer' size derived from such a task would vary as a function of the item presentation rate and the nature of the stimuli used. The apparent short-term memory capacity would be smaller at higher item presentation speeds and when stimuli with no natural ordering are employed.

Another way in which a link between intelligence and Working Memory might be more plausibly supported, despite the difficulties discussed above, is as follows. This can be done by assuming, firstly, that the Working

Memory system comprises more than one functional component, and secondly, that at least one of these components contributes to short-term memory performances but is not directly linked with intelligence. Baddeley and Hitch (1974) suggested that, in addition to a general purpose central processor, working memory contains an 'articulatory loop', capable of maintaining a few items in short-term memory without significant cost in processing resources. The articulatory loop was introduced to explain, among other things, why a concurrent memory load of a few items produced no significant interference in tasks clearly requiring the involvement of the central processor, such as verbal reasoning. A further sub-system, similar to the primary memory of Waugh and Norman (1965), was introduced by Hitch (1980). This passive input register, was postulated for essentially the same reasons as was the earlier concept of primary memory, namely, to explain phenomena associated with the serial position effect in short-term memory recall. It was assumed to be capable of temporarily holding a small number of recently presented items, and, most importantly, without the utilisation of the attentional resources of the central processor.

Within this model, short-term memory, as measured by, say, performances on digit-span tasks, would reflect the operation of all three components of working memory, while general intelligence would reflect only individual differences in the limited capacity executive, or central processor. Such a theory of intelligence, in terms of a multi-component concept of working memory, would clearly resolve the apparent conflict between, firstly, the finding that short-term memory is not strongly related to general intelligence, and secondly, the results of studies, discussed earlier, which show that performances on good measures of intelligence, such as the Raven's Progressive Matrices and Letter Series tasks, are strongly determined by the immediate memory, or short-term information holding, requirements of the individual test items. This follows by assuming that the temporary holding of information which is to be actively processed, as in the solving of reasoning tasks, is primarily done by the central processor, rather than by the rehearsal loop or the passive input store.

The existence of a 'passive' component to the mechanisms involved in memory span tasks was, for similar reasons, postulated by Crawford and Stankov (1983). However, here this component was identified as that underlying performances on a passive memory task, that is, a short-term memory with delayed recall after an interpolated attention-distracting filler task. In this study it was found that performance on such a task was an important ability component in memory span, but was one which was negligibly related to intelligence. However, it is unlikely that this passive component in memory span performances can be identified with the operation of either of the two passive sub-systems of Hitch's (1980) working memory system, the rehearsal loop and input buffer. (The interpolated task would effectively prevent rehearsal, and, as evidenced by the absence of a recency effect, delayed recall would be expected to result in the loss of items from the input buffer.)

Regarding the relationship between intelligence and concepts such as Working Memory, the main conclusions which can be drawn from the above discussions may be summarised as follows:

1. A number of studies (e.g. Bereiter and Scardamalia, 1979; Simon and Kotovsky, 1963; Holzman et al., 1983) have shown that short-term memory requirements are an important source of difficulty in performances on tasks, such as the Raven's Progressive Matrices, or series completion, which are generally accepted as good measures of intelligence. This is in apparent conflict with the finding that simple, more direct, measures of short-term memory, such as memory span tasks, are not strongly related to general intelligence.

2. From the above, it can be inferred that if an account of general intelligence is proposed in terms of a capacity for the short-term storage of information, then it is only in situations where there is concurrent 'active' mental processing that such a temporary holding capacity is related to individual differences in intelligence.

3. A theory of intelligence in terms of an active, or working, memory system is more consistent with the empirical evidence if it is postulated that such a memory system contains both 'active' and 'passive' functional components. The active component is the one most directly involved in performances on reasoning tasks of the type found to be good measures of general intelligence, while the passive component(s) are of greater importance in short-term memory tasks not requiring significant active transformation or manipulation of information. Amongst the possible passive functions of the memory system are the rehearsal loop and input buffer in Hitch's model, and those involved in the passive memory task as described by Crawford and Stankov (1983). The active component could be identified with the executive, or central processor in Hitch's (1980) model, or with the effortful, or non-automatic, processes postulated in Crawford and Stankov (1983).

7. Jensen's Level I/II Theory: General intelligence as measured by tasks involving 'transformation' between input and output

Jensen (e.g. 1969, 1973, 1974) proposed that it is useful to distinguish two types, or 'levels', of mental abilities, namely Level I and Level II ablilities. In Jensen's work, and that of others carried out within this framework, Level I ability is typically represented by the relatively simple short-term memory and 'rote' learning tasks, such as would be expected to underlie the SAR dimension in Gf/Gc theory. Tasks most commonly used to represent Level II ability are those, such as the Raven's Progressive Matrices, which are frequently regarded as good measures of general intelligence, or of fluid intelligence, Gf. The major empirical basis for this distinction was Jensen's observation of interactions between level of ability and such variables as race and socio-economic status. (For example, it is suggested that North American blacks and whites differ more on Level II than on Level I ability.) Of greater relevance here, however, is Jensen's theoretical distinction between the two levels in terms of the concepts of complexity, and general intelligence. Level II ability is measured by tasks requiring more 'complex' mental processing, and is described in much the same terms as Spearman's account of 'g'. It represents the more 'productive' aspect of human cognition. By contrast, Level I ability is measured by tasks of lower complexity which are more 'reproductive' in their nature.

When discussing the essential difference between Level I and II abilities, Jensen (1969, p. 110) proposed that this lies in the degree of transformation between stimulus input and the required output response. For Level I ability there is relatively little transformation of the input, while for Level II ability there is considerable transformation of the stimulus input before it eventuates in an overt response. Thus, for example, Forward Digit Span would represent a fairly pure measure of Level I ability, while Backward

Digit Span would, because of the additional transformations required, measure also, to some extent, Level II ability (Jensen and Figueroa, 1975). A similar account, involving the 'degree of transformation', was given by Jensen (1977), of the nature of general intelligence, 'g', and task complexity. (Here Jensen defines complexity in terms of a task's association with psychometric 'g'.)

At face value, there are some difficulties with the proposition that tasks more closely related to intelligence are those involving more 'transformation'. Firstly, there is no apparent reason why tasks which vary in the amount, but not in the nature, of the mental transformations required, should be differently related to intelligence. (If task A requires more of the same type of mental processing as is required by task B, why should task A be expected to be a better measure of intelligence than task B?) Secondly, if one compares tasks such as Mental Arithmetic and Visual Closure, it is not at all clear that the task less related to intelligence, Visual Closure, involves a lesser amount of mental 'transformation', if defined in any formal or objective manner. The relative difficulty which workers in Artificial Intelligence experience in solving the figure-ground problem, compared with the ease with which simple numerical calculations can be performed by computers, would even suggest that it is the Visual Closure task which involves more 'transformation'. It could be argued, however, that for humans, visual closure tasks reflect primarily 'perceptual' and unconscious processes, whereas mental arithmetic reflects processes which are, in some sense, more 'cognitive'. However, it is the degree, or amount of 'transformation' between input and output which is under consideration here, not whether, in humans, the mental processes are 'perceptual', conscious, innate, novel, or whatever.

A more plausible position is that it is the type of mental transformation required by a task which is relevant, rather than the extent to which the required output involves transformation of the stimulus input. There is, in fact, frequent acknowledgement of this in Jensen's writings, when he states that Level II tasks involve "self-initiated" elaboration and transformation, (Jensen, 1969), and that high complexity tasks "require some active mental manipulations, some conscious mental transformation" (Jensen 1976). Again, Jensen (1977) states "Learning is more highly correlated with IQ when it is intentional and the task calls forth conscious mental effort ..." Interpreted in this manner, that is, if more transformation is taken to mean the greater involvement of mental processing of a certain type, (namely those 'active', 'self-initiated' and 'intentional' mental processes which 'call forth conscious mental effort'), then there is, in fact, little to distinguish Jensen's theoretical distinction between Level I and Level II abilities from a theory which more explicitly accounts for 'g', or task complexity, in terms of concepts such as mental effort, attentional resources, mental energy, etc..

8. Speed and Accuracy of Performance in Relation to the Measurement of Intelligence

Closely associated with the question of the nature of the complexity dimension, (and of intelligence), is that of the relation of mental speed, and mental 'power' (or accuracy of performance), to the measurement of these dimensions. For abilities not strongly related to general intelligence, (that is, those sometimes referred to as special, or specific, abilities) it is generally accepted that either speed measures (as in the measurement of fluency, or perceptual/clerical speed factors), or accuracy measures (as with memory span and perceptual discrimination tasks), are relevant to the measurement of these abilities. Also, for tasks more closely related to intelligence, but of the 'knowledge' based kind which form the crystallized intelligence factor, Gc, (such as Vocabulary and general knowledge tests) there is general agreement that it is the power, or accuracy, measure which is the more appropriate. However, there is less general agreement regarding the role of mental speed and power in the performance of reasoning and problem-solving tasks, such as those which form the fluid intelligence dimension, and which are commonly regarded as the more 'culture-fair' measures of general intelligence. (Raven's Matrices, Letter Series, etc.) Views on this issue vary from Eysenck's (1967) that mental speed is the more 'fundamental' component of intelligence, to the one expressed by Horn (1985, 1986), that speed of performance is only weakly linked with intelligence, at least insofar as 'intelligence' is identified with traditional measures of Gf and Gc.

One approach to empirical research on the relation of mental speed to intelligence has been as a part of the so-called 'cognitive correlates' approach, which was discussed in section 4 of this chapter. Here, measures of intelligence (either the 'g' of some traditional mental test battery, or else performance of such tasks as the Raven's Progressive Matrices) were correlated with measures (mostly reaction-times) derived from a wide variety of tasks of the type commonly used in research in the area of cognitive psychology. As discussed earlier, such measures were found to be correlated with intelligence only to about the same extent as more common tests of lower complexity, such as memory span and perceptual/clerical speed tasks. A popular response to this general finding was to see it as evidence in favour of a view of task complexity, or of 'g', in terms of strategic or executive control variables. That is, the inability to find strong associations between intelligence and performances on elementary tasks was interpreted as being due to these tasks being relatively strategy-free. (This view was discussed in detail in section 4 of this Chapter.) However, this interpretation of these data has not been unanimously accepted, with workers such as Eysenck, Jensen and Philip Vernon continuing to investigate correlations between elementary reaction-time measures and intelligence, and to emphasise the importance of these correlations. The continued interest of these workers in the study of such elementary tasks can be seen as reflecting their common belief that intelligence represents a more basic or fundamental source of individual differences than is manifest in the higher-order strategic processes, especially if these executive processes are seen as mainly comprising acquired specific problem-solving knowledge and skills (see Borkowski and Krause, 1983; Jensen, 1982b).

An approach used extensively by these authors involves the use of simple and choice reaction-time tasks of relatively high stimulus-response compatibility (eg., Jensen, 1980a, 1980b, 1982b). (This involves the pressing of buttons in response to the illumination of lights located just above each of the buttons; see Jensen and Munro, 1979, for a description of the apparatus and procedures.) To a reasonable approximation, reaction-times are observed to follow Hick's (1952) law, which states that the regression of reaction-time on the logarithm of number of possible responses/stimuli (or 'task-complexity') is linear. In the so-called 'Hick's paradigm' both the slope and intercept values are correlated separately with standard measures of intelligence. The general finding for subjects in the normal range of ability is that correlations between simple reaction-time and intelligence are about .2, and those involving complex reaction-time, about .3 or .4. Thus, the complex reaction-time tasks can be compared approximately with forward memory span in the strength of their relation to intelligence. (Like, memory-span, however, considerably larger correlations with intelligence can be obtained with samples containing extreme groups, or with subjects in the lower ranges of ability.) Correlations with intelligence of the slope and intercept measures are usually of the same order of magnitude, although there is some question about the repeatability of the results involving the slope measures, and with the expected higher correlations with a greater number of choice (Barrett, Eysenck and Lucking, 1986).

Although these results do not show a strong relationship between 'Hick's paradigm' reaction-time measures and intelligence, their importance is defended by Jensen and Vernon (1986) who stress that their significance lies, not in their potential use as 'practical' measures of intelligence, but in the possibility that such results could point to the nature of the general factor obtained from conventional tests. The demonstration of reliable, though only moderate, correlations between these reaction-time measures and intelligence "...is of major theoretical interest, because the Hick paradigm involves no 'higher mental processes', in the generally accepted meaning of these terms, and has about as little resemblence to conventional unspeeded psychometric tests as one could possibly imagine." (Jensen and Vernon, 1986, p. 156) More specifically, these authors suggest that these results are consistent with Eysenck's (1986) hypothesis that "there is a central core to IQ tests which is quite independent of reasoning, judgement, problem-solving, learning, comprehension, memory, etc.".

It is undoubtably true, as Jensen and Vernon stated, that a comprehensive theory of intelligence should be able to explain these unexpected (though only moderate) correlations between such reaction-time measures and intelligence. However, one possible qualification to the relevance of these findings to the understanding of the nature of intelligence should be pointed out. It is not necessarily the case (although it might be) that the correlations between 'g' and lower complexity tasks reflect the same mechanisms which distinguish the higher g-loading and lower g-loading tasks, and which are the main source of individual differences in the performances of high g-loading tasks, such as the Raven's Progressive Matrices. For example, it is a common finding that Backward Digit Span is more highly correlated with intelligence than is Forward Digit Span (e.g., Jensen and Figueroa, 1975). However, it is possible that correlations between the forward span task and intelligence might be primarily due to one factor (such as the speed, or automaticity, of encoding of the stimuli; e.g. Dempster, 1981), while the increased correlations with intelligence of the backward span task may be due to a different factor, such as an increase in the amount of active mental manipulation, and transformation, of the stimuli. Thus a detailed study of performances on forward span tasks may not necessarily give rise to a greater understanding of the sources of individual differences in higher g-loading tasks. It is true that the existence of correlations between the Hick's slope parameter and intelligence, does give some greater insight into the nature of higher g-loading tasks. However, in view of the limited size and reliability of these correlations, they could not be regarded as strong evidence for a link between the psychometric notion of task complexity, and that concept of compexity defined in terms of the number of alternatives in choice reaction-time tasks.

The relationship between mental speed and intelligence has also been studied using relatively 'less elementary' reaction-time tasks. The most common of these include Saul Sternberg's (1966) short-term memory search paradigm, the name-identity/physical identity paradigm of Posner, Boies, Eichelman and Taylor (1969), and the sentence-verification task, as studied by Clark and Chase (1972). The general finding here is that for these more 'complex' reaction-time tasks (as indexed by average response times) slightly higher correlations with intelligence are indeed found (Vernon, Nador and Kantor, 1985a,b; Vernon, 1983). However, by comparison with more traditional mental tests, these more 'complex' reaction-time tasks could not be regarded as being ones of relatively high complexity. More impressive, at first sight, are the fairly high multiple correlations obtained between intelligence and a diverse set of such reaction-time tasks (e.g., Vernon et al. 1985b). However, this merely parallels the result obtained with sets of more conventional mental tests, namely, that the general factor of a diverse set of lower complexity tasks is found to be highly correlated with the general factor of other diverse of tasks, or with individual high complexity tasks such as typical Gf or Gc markers. While it is an important result, it is essentially a restatement of the problem of general intelligence, rather than a result which points to its solution. The essential idea underlying the notion of task complexity, as this concept is used by Spearman or Jensen, is that there is a fundamental difference in the nature of high g-loading and low g-loading tasks. The finding of a high multiple correlation between high g-loading tasks and a diverse set of low g-loading tests, cannot be taken as evidence that source of individual differences in more highly g-loading tasks is of the same basic nature as that common to the low g-loading tasks. (For example, low complexity tasks were interpreted by Spearman, 1927, as those requiring little 'mental energy', and by Hunt, 1980, as those which are relatively strategy-free. The finding of a high multiple correlation between a high g-loading task and a number of low g-loading tasks does not prove that high g-loading tasks also require little mental energy, or that task complexity cannot be understood in terms of strategic processes.)

In summary, a fair evaluation of the results of research on the relationship between intelligence and elementary reaction-time tasks would be that consistent, though not strong, correlations do exist for subjects in the normal ranges of ability. However, divergent opinions have been expressed on the implications of this finding for an understanding of the nature of general intelligence. A different approach to the study of the relationship between mental speed and intelligence is one which is based on the analysis of responses to the individual items of tests commonly used as measures of intelligence. This approach, and the various interpretations of data derived from it, is discussed below.

The measurement of intelligence obtained from mental test scores typically involves presenting a subject with a number of test items, usually of varying difficulty, with instructions to work as quickly and accurately as possible, with the subject's score on the test being the number of correctly answered items obtained within some fixed time limit. If the time limit is long enough to allow all, or nearly all, subjects to complete all items, then it is sometimes said that the test is given under unspeeded conditions, or that the test represents a 'power' measure of ability. On the other hand, if relatively few subjects are able to complete the test in the time limit, the test is said to be given under 'speeded' conditions. Frequently, though not always, the test instructions emphasise either accuracy or speed in responding, especially when one of these is more important for the scoring of the test. Early studies on the relationship between mental 'speed' and 'power' focused on the effects of varying the time limits imposed on subjects' test performances (McFarland, 1928; Ruch and Koerth, 1923).

The finding of high correlations between speeded and unspeeded versions of the same tests of intelligence led to the common early view that mental speed and mental 'power' do not define separate dimensions of intelligence. However, less consistent opinions resulted from the consideration of the individual item as the unit of analysis. Horn, Donaldson and Engstrom (1981) report a study in which was administered a number of tests of Gf and Gc, and where, for each item, each subject's response (correct, incorrect or abandoned), and the time taken, were measured. From these data the following five measures were calculated for each subject:

1. <u>Accuracy score</u>: The proportion of items correct. (In fact the total number of correct items for those items attempted by all subjects.)
2. <u>Speed to Correct Response, (SPC)</u>: The average, over all correctly answered items, of subject's response times.
3. <u>Speed to Wrong Response, (SPW)</u>: The average response time for wrong answers.
4. <u>Persistence</u>: The average time spent on items which were abandoned.
5. <u>Carefulness</u>: The proportion of wrong responses. (Subjects were instructed not to guess.)

The basic findings from this study were that the Accuracy scores formed two distinct factors. These Horn identified with the Gf and Gc factors found in previous work, in which the more usual more common 'total number of items correct' method of scoring was usually employed. The two speed scores, SPC and SPW, formed two, though not well separated factors, while the Carefulness and Persistence scores each formed well defined separate factors. The accuracy, or 'power', factors, Gf and Gc, were found to be negligibly correlated with either of the two speed factors. From these, and other similar results, Horn (1985) concluded: "Thus, contrary to a widely held belief, speed of thinking and power of thinking are not highly correlated..........and that speed of thinking is a separate capacity to what we call intelligence."

However, from the similar approach of recording responses to individual items, Eysenck (1953) came to the opposite conclusion that it is mental speed which is the more 'fundamental' dimension of human intelligence. Here, he proposed that there are three independent aspects of intelligence as usually measured, namely:

1. Mental Speed: The speed at which correct answers are produced.
2. Persistence: The length of time a person spends on an item which is eventually abandoned.
3. Error Checking: The tendency to give incorrect answers when instructed not to guess.

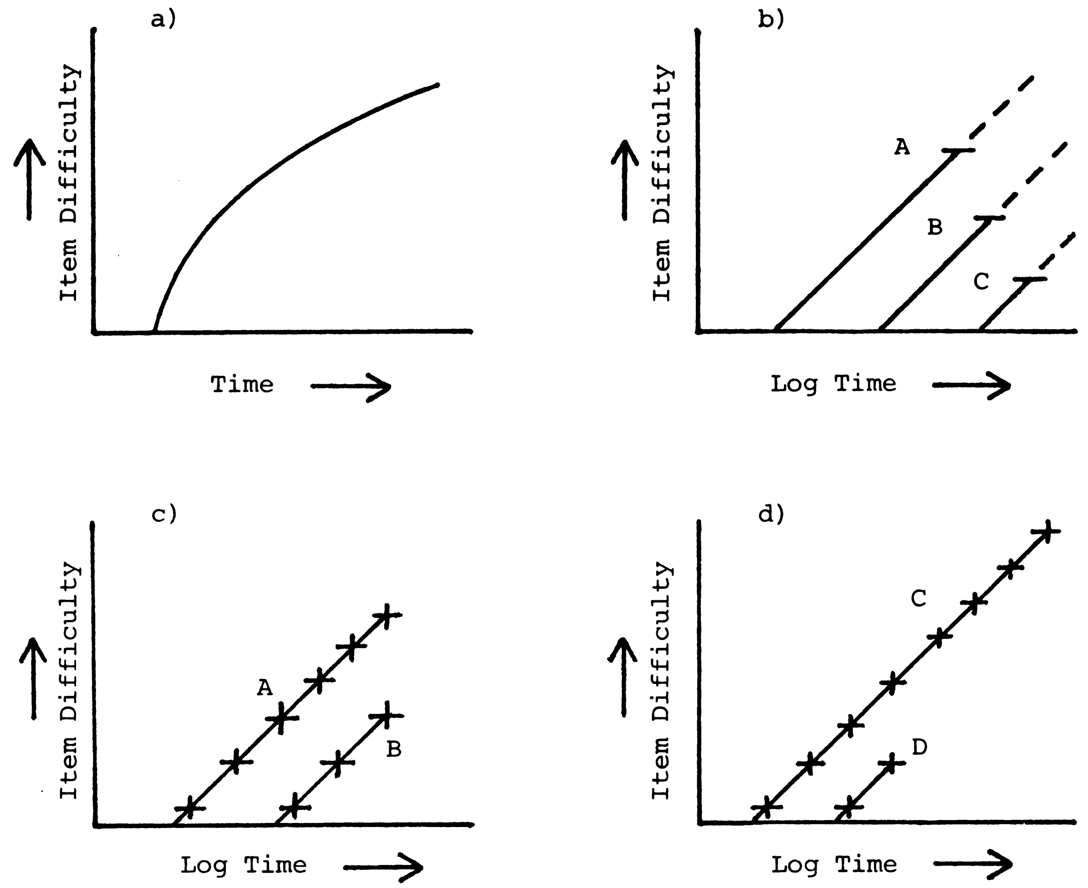


Figure 2 The relation between item difficulty and response times for correctly answered items.

(The last two are essentially the same as the Persistence and Carefulness dimension of Horn, discussed above.)

The apparent contradiction between the views of Horn and Eysenck, on the relation of mental speed to intelligence, might be resolved, to some extent, by a more careful examination of the way in which the mental speed measures are defined by the two authors. The method used by Eysenck to obtain a measure of mental speed is as follows. If, using only the correct responses for a single subject, the response-times for different items are plotted against the item difficulties, then a negatively accelerating curve, as in Figure 2a, is obtained. Eysenck (1967) reported the findings that, firstly, that a logarithmic transformation of the response-times results in a linear relation between the transformed response-times and item difficulties, and secondly, that the slope of the linear regression of item difficulties on the logarithmically transformed response-times, is the same for different subjects. This situation is depicted in Figure 2b, where A, B and C are the linear regression lines for three subjects with different mental speeds. (Figures 2a and 2b are based on those displayed in Eysenck, 1967. The item difficulties defining the vertical axes in these diagrams are defined simply in terms of the percentage of subjects correctly responding to each item.) Individual differences in mental speed can therefore be described solely in terms of the intercepts of these lines with the horizontal axis.

These relations can be expressed mathematically (see White,1982) as:

$\ln E(Tc_{ij}) = mD_i - s_j$

Where:

$E(Tc_{ij})$ is the expected time to correct responding for subject j on item i.

D_i is the difficulty of item i.

m is the common slope of the regression of D_i on $\ln Tc_{ij}$, and

s_j is the speed score for subject j.

Note that in Figure 2b the line for each subject terminates at some level of difficulty and is continued by a broken line. This indicates the absence of correct responses for items with difficulty levels above this value, which was interpreted by Eysenck as reflecting the subject's 'Persistence', or the maximum length of time the subject will remain on an unsolved item before moving on to the next.

Consider now the idealised case of two subjects, A and B, as depicted in Figure 2c. The crosses represent those test items which were correctly answered by the subjects. Here, subject A has a higher mental speed than subject B (as mental speed is defined in Eysenck's model), since A's regression line is to the left of B's. Also, in this example, we have assumed that the Persistences, (that is the maximum times spent on each item), of the two subjects are the same. From this diagram it is clear that the difference between the two subjects in their average response times for correct items, is less than the difference between the subjects' correct response times for items on equal difficulty. This occurs because, although A responded faster than B for items of equal difficulty, A's average correct response time is brought closer to B's because of A's longer correct response times to the more difficult items for which B did not obtain correct answers. An example which illustrates in a more extreme manner the difference between Horn's and Eysenck's operationalisations of 'mental speed', is shown in Figure 2d. Here, as in Figure 2c, subject A has a higher mental speed than subject B, as speed is defined by Eysenck. However, as a result of A's higher Persistence, the average response times for correctly answered items for the two subjects are approximately equal.

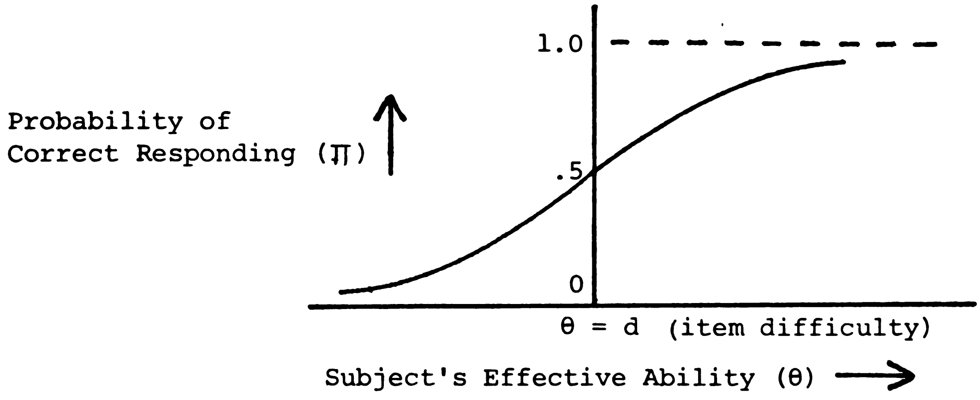
To summarise, the apparent discrepancy between views on the relation between mental speed and intelligence may be lessened by noting that the strength of this relation would be expected to be lower if mental speed is measured by the average time taken for correct responses, (as in Horn's work), than if mental speed were measured in terms of the time taken to solve items of equal difficulty (as is the case with Eysenck's definition). It should be noted, however, that if, for some reason, the distributions of difficulty levels of correctly answered items are the same for all subjects, and if the effects of differences in subject's persistences could be removed, then the two definitions of mental speed would lead to the same results. This is unlikely to occur with common tests of intelligence, in which a fair range of item difficulties is present, and where higher ability subjects tend to do better on the more difficult items. These conditions could, however, be met in a test in which the items were sufficiently easy, and the subjects appropriately instructed, so that the error rate is very low and no abandonments occur. However, the question then arises of whether tests which satisfy such conditions, would, in fact, measure 'intelligence'. Certainly, such tests as perceptual or clerical speed tasks, or choice reaction-time tasks, which would usually satisfy these conditions, tend not to be strongly related to intelligence. It could be argued that mental speed is related strongly to intelligence, but only for the mental processes involved in the more difficult tasks found in typical intelligence measures. However, in view of the earlier discussion on the independence of task complexity and task difficulty (see Chapter 1), there is no reason why, in principle, tasks with near perfect accuracy of performance cannot be found, whose speed of performance is strongly related to intelligence.

A possibly counter-intuitive aspect of Eysenck's model is that it is only subjects' Carefulness (or 'error checking') and Persistence which place an upper bound on the difficulty of items which can be solved. The Span and M-space theories of intelligence discussed in the last chapter would, in fact, predict that this should not be the case. (In such models a person's intelligence sets an upper limit to the difficulty level of items which the subject is able to solve.) However, this model is made more plausible by the observed exponential change, with item difficulty, in item solution times. As a consequence of this, the difference in the expected solution times for subjects with different mental speeds increases rapidly with increasing item difficulty. Thus it is feasible that, even if there were considerabe variation in subjects' Carefulness and Persistence, variation in the upper level of difficulty for items solved could still be primarily determined by individual differences in mental speed.

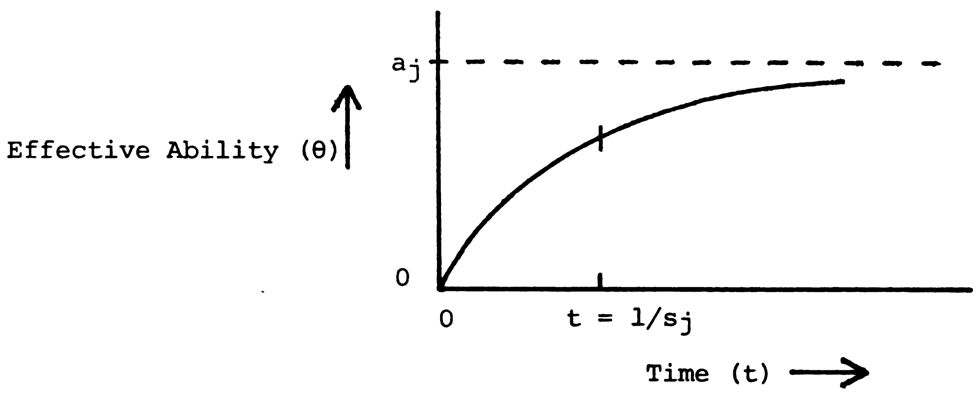
A problem with a definition of 'mental speed' in terms of the time to produce correct responses, as in both Eysenck's and Horn's approach, is that it fails to take into account the possible influence on this measure of an individual's tendency to spend time checking their answers. As Eysenck (1967) acknowledged, the correct solution times also include 'error-checking' time. Thus for more cautious subjects, these solution times may give an underestimate of their true mental speeds. Conversely, a subject's mental speed may be overestimated by the frequent occurrence of correct, but rapidly guessed, 'lucky' responses. The effect of this confounding of 'true' mental speed and individual differences in what might be called 'Caution' in responding, would have the effect of understimating correlations between mental speed and intelligence, as measured by either of the methods of Eysenck or Horn as described above. It should be noted that individuals' 'Carefulness', as defined by the tendency to produce incorrect results when instructed not to guess, need not define the same dimension in individual differences as people's 'Cautiousness', although, intuitively, these two measures should be expected to be positively associated. (People who are more cautious working through the solution, or spend more time checking their answers, might also be expected to produce fewer incorrect responses when instructed not to guess.)

Working in the framework of Eysenck's (and Furneaux's, 1960) approach, White (1973) presented a model which, although containing the older concepts of mental speed and persistence, does, in fact, represent a significant theoretical shift from the older model of Eysenck, especially with respect to the relation beween mental speed and traditional measures of intelligence. White's model could be regarded as an extension of Birnbaum's (1968) model to allow for the consequences (as considered in the earlier writings of Eysenck and Furneaux) of subjects working on individual items for different amounts of time. In Birnbaum's model, the probability of a subject obtaining a correct response to an item, given that it has not been abandoned, Π, is a monotonically increasing (cumulative logistic) function of the difference between the subject's ability, $\O_j$, and the item difficulty, d. Thus this probability is expressed by the equation:

$$\Pr(\text{Correct response/Not abandoned}) = \Pi(\O_j) = 1/(1+e^{-D(\O_j-d)})$$



<u>Figure 3a</u> The probability of correct responding as a function of a subject's effective ability and the item difficulty.



<u>Figure 3b</u> A subject's effective ability as a function of the time (t) spent on an item, the subject's accuracy parameter (a_j) and the subject's mental speed parameter (s_j).

The form of this function is shown in Figure 3a. The parameter, D, determines the slope of the curve at the point when the subject's ability is equal to the item difficulty ($Ø_j$ = d), and is called the discriminating power of the item. (Note that at this point the probability of correct solution, Π, is equal to 0.5)

This model was extended by White in two ways. Firstly, it assumes that the probability that an item will be abandoned is a function of the time, t, spent by the subject on the item, and the subject's persistence, p_j.

$$\mathrm{Pr(Abandonment)} = 1/(1 + e^{-C(t-p_j)})$$

Here, C is a parameter which is assumed to be the same for all subjects. Secondly, the subject's ability, $Ø_j$, is replaced by an 'effective' ability, $Ø_j(t)$, which is postulated to increase monotonically with the time, t, spent on the item, and is given by the following equation.

$$Ø_j(t) = a_j(1 - e^{-s_j t})$$

The 'Accuracy' and 'Mental Speed' parameters, a_j and s_j, respectively, are assumed to vary across subjects, but to remain constant for a given subject across test items. The form of the variation of effective ability with time spent on an item is illustrated in Figure 3b.

Note that in this model there is an upper bound, a_j, to a subject's effective ability. In other words, no matter how long a subject spends on an item, the subject will never achieve a probability of greater than .5 for obtaining a correct answer to a problem with difficulty, d, equal to the subject's Accuracy parameter, a_j. The Mental Speed parameter, s_j, determines how quickly a given subject's effective ability will approach the upper limit given by a_j. (In a time $1/s_j$, subjects would obtain approximately 63% of their maximum effective ability.) It should be noted that the speed of solving items, within a subject's ability range (i.e. $a_j > d$), does not depend only on the subject's mental speed, s_j, as in Eysenck's model, but is faster for subjects with higher accuracy parameters, a_j. (The time after which there is a 50% chance of solving an item of difficulty, d, by a person with mental speed, s_j, and accuracy, a_j, is easily calculated to be: $t = {}^1/_s \ln({}^a/_{(d-a)})$. Also, it is interesting to note that individuals' solution times, although a function of both the subjects' Accuracy and Speed parameters, are more strongly related to the Accuracy scores for more difficult items than for less difficult ones.

Although White presented his model as a development of Eysenck's earlier one, the two models do, in fact, represent quite different positions on the definition of Mental Speed and its relation to intelligence. In Eysenck's model, of the three 'components' of intelligence, (Mental Speed, Persistence and Carefulness), it was the Mental Speed component which was seen as the more fundamental and which was related most strongly to the traditional measures of general intelligence. Intelligence, in this model, was seen primarily in terms of the speed of producing correct responses. By contrast, in the later model by White, intelligence, especially when measured in relatively unspeeded conditions, is reflected mainly in the Accuracy parameter, a_j. Under these conditions subjects' effective abilities approach their accuracy parameters, and the model approaches the original one of Birnbaum, with the subject's ability parameter being the same as the subject's Accuracy parameter, a_j. Thus White's model suggests a concept of intelligence more similar to that suggested by the Span and M-space theories discussed earlier, namely one in which a person's intelligence is directly related to the degree of difficulty of items able to be solved by the person. In this respect, it also represents a view on the relation of intelligence to the speed and accuracy of performances more similar to the one advocated by Horn which was discussed above.

CHAPTER 3

INTRODUCTION TO EMPIRICAL STUDIES

The first part of this chapter summarises those main conclusions drawn from the previous two chapters which are of relevance to the empirical studies reported in this thesis. In the second part of the chapter an overview is given of the rationale and form of these studies.

1. The importance of the distinction between reflexive, or automatic mental processes, and those requiring conscious mental effort

In Chapter 1 it was described how the concept of task complexity has been used to describe the difference between tasks in their correlations with general intelligence, 'g'. It was then argued that a more appropriate definition of task complexity (insofar as this refers to the complexity of mental processes at the time of testing), would be one in terms of fluid intelligence, Gf, rather than 'g'. It was also argued that the relatively high correlations with 'g' of certain tasks, such as Vocabulary and other 'knowledge' based tests, are due, not so much to the complexity of the mental processing at the time of testing, but rather to the efficiency of the complex mental activity involved in the acquisition of this knowledge on occasions prior to the taking of the tests.

In Chapter 2, various ideas on the nature of the complexity dimension were summarised. One of the currently most popular views, that task complexity is related to strategic functions, was seen to be consistent with a variety of data, especially those data derived from the comparison of performances of groups including subjects in the lower ranges of ability, such as children or retardates. For many psychologists this view is consistent with the finding, derived from the 'cognitive correlates' and 'cognitive components' approaches, that only relatively small correlations can be found between intelligence and performances on the more elementary cognitive tasks for which it has been supposed that these performances are relatively free from strategic variation. However, it was noted that reliable data do exist which are not easily explained by the notion that strategic variability is the link between task performance and intelligence. Examples are the findings by Cohen and Sandberg (1977) on the relation between primacy/recency recall and intelligence, and those of Hughes (1983) on the effect of instructions on the correlations between intelligence and the rate of learning. Also, the relative difficulty with which subjects of lower ability are able to learn new strategies, or to transfer the use of learned strategies to new, but similar tasks, could be interpreted as evidence that some more basic limitation on information processing ability underlies the observed strategic differences between groups of varying levels of intelligence.

Several notions of task complexity, not associated with strategy variation, were also considered. Spearman's concept of mental energy was found to be inadequate, without further elaboration, as an explanation of task complexity, mainly as a result of the absence of a plausible and independent definition of the nature of this energy. The identification of this energy with the more recent, and independently definable, concept of attentional resources was investigated by Hunt and Lansman (1982). Despite the moderate success of the authors in producing data generally compatible with an account of intelligence in terms of individual differences in attentional resources, such a theory has not, as yet, attracted serious consideration by these, or other, authors.

Other 'non-strategic' theories of intelligence, involving the concepts of noegenesis, span of attention, Working Memory, M-space and amount of mental transformation, were also examined. In each case it was concluded that the theory was not adequate, by itself, to account for the differences between tasks in their relation to intelligence. Of particular interest was the observation that, in each case, a major limitation of the theory was its failure to acknowledge the distinction between what may be described as active, mental processes requiring conscious effort, and more reflexive, involuntary or automatic mental processes. Thus, for example, it was argued that Jensen's earlier notion, that it is the 'degree', or 'amount', of mental transformation which determines a task's complexity, was not fully appropriate unless the 'transformation' involved active, non-automatic mental processing. Tasks requiring a large degree of 'transformation', but involving only involuntary, highly 'automatic' mental processing, are not found to be strongly related to intelligence. Thus it was suggested that it is the kind rather than the amount of mental transformation which seems to be more related to task complexity. This is, in fact, consistent with the emphasis in Jensen's later writings on the importance of 'active', 'effortful', 'conscious' and 'intentional' mental processes in the performance of tests more closely related to general intelligence (or to Level II ability).

In a similar manner, a consideration of theories based on the concepts of noegenesis, span of attention, M-space or Working Memory led to the same conclusion, namely, that in order to be consistent with the empirical evidence, it is only mechanisms associated with non-automatic, or non-reflexive mental processing which are found to be related to performances on tasks of higher complexity. For example, in the case of theories related to the notions of span of attention or Working Memory, it was concluded that individuals' short-term information holding capacity is related to intelligence only in situations where there is concurrent effortful, or non-automatic, mental processing taking place. Thus a complete theory of intelligence based on concepts such as Working Memory can be seen to depend critically on the distinction between active, or effortful, mental processes and the more passive, or automatic, ones.

2. Rationale and Overview of the Empirical Studies in this Thesis

The studies reported in this thesis are primarily concerned with the investigation of individual differences in tasks similar to those which Wittenborn (1943) devised, and which he, and others, interpreted as the ability to maintain high levels of mental effort, concentration or 'attention'. Of particular interest is the relationship between performances on these tasks, and performances on the well-known reasoning and problem-solving tests (such as Raven's Progressive Matrices, Letter Series, Verbal Reasoning etc.) which are the traditional markers of fluid intelligence, Gf, and which are also commonly regarded as good measures of general intelligence.

Interest in this relation between these attention tasks and the traditional measures of Gf (and 'intelligence') derives from its relevance to different ideas on the 'essential nature' of these latter ability dimensions. Interpretations of Gf based on such concepts as mental energy and Working Memory would suggest that the tests of attention should be a good measure of intelligence. However, interpretations of Gf suggested by other aspects of traditional Gf marker tests would not necessarily lead to this conclusion. For example, Hunt (1980) emphasises such aspects as task novelty, and strategic variability, evident in such reasoning tasks as the Raven's Progressive Matrices, as being the critical characterisics of higher g-loading tasks. In this respect, the somewhat more elementary, mechanistic, or algorithmic tests of 'attention' do not resemble traditional Gf markers. It was, perhaps, a similar concept of intelligence which led Wittenborn (1943) to assume that performances on his attention tests "should not depend too much on intellectual level."

The first study of the thesis (Study I) was designed to investigate the relationship between tests similar to Wittenborn's (1943) 'Attention' tasks, and the typical reasoning tasks which mark fluid intelligence. A correlational study was carried out in which a number of these Attention tests were included in the battery, along with markers of fluid and crystallised intelligence, spatial ability, short-term memory and perceptual/clerical speed. Also include in the battery was a task described by Monty (1968) as one of serial short-term memory (SSTM), and by Massaro (1975) as one directly reflecting the operation of a Working, or Active, memory system. It was included in the battery as it was hypothesised that performances on this task would involve the same abilities as the Attention tests derived from Wittenborn (1943).

The SSTM and Attention tests in the above study involved experimenter-paced auditory presentation of stimuli. A second correlational study (Study 2) was performed, in which a subject-paced version of one of Wittenborn's Attention tests was administered in a manner similar to that commonly used for tests of perceptual or clerical speed. Measures of fluid intelligence, short-term memory and perceptual/clerical speed were also included in the battery of tests. This study was carried out to investigate the relative importance of the speed and accuracy of performances on such 'Attention' tasks in producing correlations with fluid intelligence. (In Study 1 it was found that the experimenter-paced Attention, and SSTM, tests defined the same ability factor as did a number of traditional measures of fluid intelligence.)

In the above two studies the measures of fluid intelligence were presented in a 'once-through' manner. As in Crawford and Stankov (1983), this was done in order to measure any systematic individual differences in the speed at which subjects work through the test items. Such a method of test presentation is not unusual, as it would occur with individually administered tests, or with automated testing. However, it is probably more usual in the measurement of intelligence (especially with group testing) that a 'fixed-time' format is employed, where subjects are required to obtain as many correct answers as possible within some fixed time interval. This raises the possibility, however, that the results of the previous studies (in particular those regarding the relation between the Attention, or SSTM, tests and fluid intelligence) were dependent on the particular manner in which the tests of intelligence were presented. Study 3 was designed to investigate this possibility. Each subject was given two tests, with items in each drawn from the traditional fluid intelligence marker, Raven's on the SSTM task were the rate at which the stimuli are presented and the size of the concurrent memory load. Study 4 of this thesis investigates the effect of variations in the concurrent memory load on correlations between the task and a measure of fluid intelligence. Such effects could be expected from those theories of intelligence (e.g., Bachelder and Denny, 1977a,b; Bereiter and Scardamalia, 1979) where the 'complexity' of a task is postulated to be related to the number of pieces of information needed to be simultaneously held in mind for the task to be successfully completed.

The final study (Study 5) concentrates on the effect of variations of stimulus presentation rate on correlations with intelligence. This is relevant to the issue concerning which of the two concepts, 'mental speed' or 'concentration', is the more appropriate one for interpreting correlations between performances on the SSTM task and intelligence. Also, the effect of giving explicit instructions to subjects on performance strategies, on correlations between this task and intelligence was investigated. Hughes (1983) found that the giving of such instructions on strategies to subjects, prior to a paired associates learning task, increased correlations with intelligence. Because of the relevance of such findings to theories of intelligence which emphasise the importance of strategic functions, is was of interest to see if similar results would be obtained with the serial short-term memory task used in the present series of studies.

Progressive Matrices, with one test being presented in a 'once-through', and the other in a 'fixed-time', manner. Subjects also received serial short-term memory and memory span tests.

The remaining two studies, Studies 4 and 5, investigated in more detail the relationship between measures of intelligence and performances on a serial short-term memory test (Counting Animals), similar to that used in Study 1. The reasons for focusing attention on the SSTM test, rather on one of the attention tasks developed by Wittenborn, are as follows. Firstly, the results of Study 1 suggested that the SSTM test measured the same abilities as the Attention tests of Wittenborn. Secondly, this particular form of SSTM task had been extensively experimentally investigated by Monty and his co-workers. Thirdly, performances on this task do appear to relate in a more immediate manner to hypothesised cognitive constructs and paradigms (such as Working Memory, and the processing of information under concurrent memory load), than do the tasks developed by Wittenborn. Finally, it was the author's opinion (formed on the basis of the conclusions of Monty, Wiggins and Karsh,1969, and also suggested by subjects' comments) that subjects' performances on the SSTM task are relatively free from strategic variation, at least over a wide range of item difficulty.

The experimental work of Monty and his associates (e.g., Monty, Taub, and Laughery, 1965) showed that two major factors affecting performances

PART II

EMPIRICAL STUDIES

STUDY 1: The Relationship Between Tests of Sustained Attention and Fluid Intelligence

Background

In order to investigate the relationship between a number of previously established primary mental abilities and the ability to maintain high levels of concentration (or 'attention'), Wittenborn (1943) devised a number of new tests, guided by the following design principles:

1. The performances should not depend too much upon intellectual level.
2. The tasks should depend to as small a degree as possible upon content and knowledge.
3. The tasks should correlate as little as possible with factors heretofore identified.
4. The scores on the tasks should depend to a large degree upon a continuous, sustained application of mental effort. The tasks should be so constructed that a layman might say they require a high degree of continuous "concentration".

Triplet Numbers test, each block contained twelve successive digit triplets, and for Letter Lists, each block comprised 14 successive letter stimuli.) Subjects were required to respond concurrently with the auditory stimuli in accordance with some prescribed rule which had been previously explained and practiced. It is important to note that it was Wittenborn's intention that performances on these attention tasks should not reflect, to a significant extent, the subjects' understanding of the rules. It was assumed that, through careful explanation and adequate practice prior to the commencement of each of the tests, performances on the tasks would not be limited by an understanding of the rules, but rather by the need to maintain high levels of concentration during the continuous and rapid presentation of items within each block. Furthermore, performances on these tasks were not interpreted by Wittenborn as reflecting individual differences in some form of mental speed. The function of the continuous and fairly rapid presentation of the items, according to Wittenborn (1943), was to prevent the occurrence of task-irrelevant interpolated mental activity, thus ensuring the need for subjects to maintain a constant focus of attention on the task. It was this ability to maintain such attentional control which was assumed to be measured by these newly devised tests.

Wittenborn (1943) did not consider the question of the relationship between his new measures of 'attention' and the construct of general intelligence. This was, no doubt, a result of the influence of his contemporary, Thurstone, who argued against the usefulness of this construct, and, consistent with this viewpoint, advocated multiple group factoring as the appropriate analysis for the study of mental abilities. However, to the extent that the construct of general intelligence is reflected in Wittenborn's term 'intellectual level', it is clear that Wittenborn did not regard these Attention tasks as being closely related to intelligence. Indeed, it was the first of his four design principles (see above), that performances on these Attention tasks "should not depend too much on intellectual level".

At face value, the expectation that these tasks should not be strongly related to general intelligence does seem consistent with a number of common views on the essential difference between tasks more and less closely associated with general intelligence, or 'g', such as Spearman's (1927) characterisation of high g-loading tasks in terms of the principle of 'noegenesis', or that of Guttman (1954), involving the mental processes of 'rule-inferring', rather than 'rule-application'. In terms of these principles, Wittenborn's Attention tasks, which involve the repetitive application of clearly prescribed rules, do not bear a strong family resemblance to the 'reasoning and problem-solving' tasks commonly used as measures of general intelligence, such as the Raven's Progressive Matrices, which Snow (1980) and others have referred to the as archetypical tests of general intelligence. Similarly, more recent statements on the possible association between intelligence and strategic processes (e.g., Hunt, 1980; Sternberg, 1981b) might also suggest that the Attention tasks should not be good measures of general intelligence. Such views commonly stress the importance of 'novelty' in good measures of intelligence. For example, Hunt (1980) describes performances on tasks of high complexity as being "dependent on a person's having available a store of strategies to deal with the varied problems presented by different items within each test." The notion of novelty here, reflected in the term 'varied', does not merely imply that each test item is, in a literal sense, different, but that each item needs to be solved in a different way. Thus, for Hunt, although the individual items of, say, memory span or perceptual speed tests, are different, they are not to a large degree novel (or 'varied') in the manner in which the items are for, say, the Raven's Progressive Matrices test. In this respect, also, Wittenborn's Attention tasks could, at face value, be perceived as more closely resembling the lower complexity tasks, such as memory span, or perceptual/clerical speed tasks, rather than the reasoning tasks commonly used as single-test measures of intelligence.

It is important to note the fundamental differences between Wittenborn's Attention tasks and tasks such as the OTIS Following Directions, or the Directions test included in the Ekstrom, French, Harman and Berman (1976) kit of cognitive tests. In Guttman's (1954) terms, all of the above tests could be described as 'rule applying' rather than 'rule inferring'. However, with

Wittenborn found that these newly constructed tests formed a single 'Attention' factor, distinct from the established Thurstone (1938) primaries, Number, Space, Perceptual Speed and Memory. The two tests with the highest loadings on the Attention factor were Triplet Numbers and Letter Lists. (These names were suggested by French, 1951. Wittenborn,1943, referred to them simply as 'specially constructed'.) In the Triplet Numbers test, sets of three-digit numbers (i.e., digit triplets) were presented auditorily at a fairly rapid pace (approximately one triplet every 2.5 seconds). Subjects were required to respond to each triplet by writing either a plus ('+') or a minus ('-') according to the following rules: "Write a plus if the first digit is the largest and the second is the smallest, or if the last is the largest and the first is the smallest. Otherwise, write a minus." For the Letter Lists test, lists of letters were presented, again auditorily. Within each list, the letters were given at a fairly fast pace of about one letter every two seconds. For a consonant following a vowel, subjects were required to write a minus, and to write a plus for a vowel following a consonant. If two vowels, or two consonants, occurred together, then the next letter was to be responded to by writing a plus.

Each of Wittenborn's newly constructed 'attention' tasks followed the same general pattern. Auditory stimuli, either letters or numbers, were presented at a fairly fast rate in a number of continuous blocks. (For the regard to the concepts of 'noegenesis', or task 'novelty' (with its implication for strategic variability, as discussed above), the Following Directions, and Directions, tasks could plausibly be interpreted as less resembling the lower g-loading tasks, such as memory span or perceptual speed tasks. In these tasks, each separate item involves the comprehension and application of a new set of lengthy and complicated instructions. A plausible interpretation of these tasks might be that the ability to rapidly comprehend the changing instructions is a significant source of individual differences in their performance. By contrast, each of Wittenborn's Attention tasks involves the application of a fixed set of rules, which were carefully explained and practised before the beginning of the test. At least in the evaluation of Wittenborn (1943), the ability to comprehend the rules, and to know how to apply them, is not a major source of difficulty for these tasks.

There does exist, however, some empirical data which does suggest the possibility that Wittenborn's Attention tasks may be more closely related to general intelligence (and in particular to fluid intelligence, Gf) than was assumed by Wittenborn (1943), or than would be predicted on the basis of notions of intelligence discussed above. Firstly, a re-analysis of Wittenborn's (1943) original data by Stankov (1983b), using more modern factor-analytic methods, produced essentially the same results, namely that the new tasks formed a separate Attention factor, along with several others which resemble the well-known Thurstone Primaries of Number, Perceptual, Space and Memory. However, as Stankov noted, it was the Attention tasks which were the ones most highly correlated with the general factor of this battery of tests. As the sampling of distinct ability domains in this battery approaches that represented in the multi-dimensional scaling solution presented by Marshalek et al. (1983) (see Figure 1 in Chapter 1 of this thesis), this result could be taken as evidence that the Attention tasks would be among those of relatively high complexity located towards the centre of the diagram. Secondly, French (1951, p. 204) reviewed a number of factor-analytic studies which, in his evaluation, produced factors similar to Wittenborn's Attention factor. He noted that in two of these studies, these factors also included significant loadings from Syllogistic Reasoning tests, which, in more modern terms, could be regarded as typical Gf markers. These results again suggest a possible closer link between the Attention tasks and general intelligence than was anticipated by Wittenborn.

There are, however, several ideas or models of intelligence which are consistent with the Attention tasks being relatively closely associated with general intelligence. Spearman's (1927) account of general intelligence in terms of 'mental energy', or Hunt and Lansman's (1982) suggestion on a link between 'g' and attentional resources, are both clearly consistent with the Attention tasks being good measures of intelligence. This is especially so if the Attention tests are interpreted, as by Wittenborn, primarily in terms of the ability to maintain high levels of concentration, or 'mental effort'. A second way in which the Attention tasks might be expected to be closely related to intelligence is via theories linking intelligence and the operation of some 'central processor', or Working Memory (active short-term memory, etc.) system, as for example, the M-space theory of Pascuale-Leone (1970) or Case (1974b). Stankov (1983b), Crawford and Stankov (1983) noted the similarity between the Attention tasks of Wittenborn and those Temporal Tracking tasks developed independently by Stankov (e.g., 1983a), namely that they involved the simultaneous processing and storage of information in immediate memory in the manner which exemplifies the operation of a Working Memory system as described by Baddeley and Hitch (1974).

From the above discussion, it can be seen that a better understanding of the relation between the Attention tasks and intelligence is of particular significance when considering the various ideas on the nature of intelligence. At face value (and in accordance with Wittenborn's interpretation of these tasks), notions of general intelligence based on the concepts of 'noegenesis', or of task 'novelty' and strategic variation (e.g., Hunt, 1980) would suggest that these Attention tasks are not likely to be closely related to general intelligence. In terms of such concepts, the relatively repetitive, or algorithmic, nature of these Attention tasks might suggest that they bear a stronger family resemblance to the typical low g-loading tasks, such as memory span and perceptual speed tasks, rather than to the 'archetypical' high g-loading reasoning or problem-solving tasks the RST Task, were also included. This RST Task was not used by Wittenborn but was judged by the present author as probably tapping the same mental abilities as Wittenborn's Attention tests. (Note: It was this task which Massaro, 1975, used as an illustration of the concept of a 'working', or 'active', memory system.)

The presentation of the instructions and the test items for the two tests derived from Wittenborn (1943) followed closely the description given in that paper. However, Wittenborn's procedure was modified slightly to make more secure Wittenborn's assumption that performances on these tests were not affected by subjects' lack of understanding of the rules. This was done in the following way. Before the presentation of test items, subjects were presented with both written and auditorily presented practice items. Subjects were allowed to proceed through the written practice items at their own pace, and the auditory practice items were presented at a rate much slower than in the eventual test. In Wittenborn's study, although the rules for responding were carefully explained and practised before the commencement of the test items, there was no direct test to ensure that the subjects fully understood the rules prior to the commencement of the actual the test. In this study, therefore, Wittenborn's procedure was modified by including a series of pre-test items presented, at a very slow rate, after the instruction and practice phase, but before the test items.

Table 1

Tests Used in Study 1

Term used in text to refer to group of tests	Name of test
Gf tasks:	1. Raven's Matrices
	2. Letter Series
	3. Verbal Reasoning
Gc tasks:	4. Vocabulary
	5. Esoteric Analogies
	6. Proverbs
Gv tasks:	7. Card Rotations
	8. Hidden Figures
	9. Form Board
	10. Gestalt Completion
Digit span tasks:	11. Backward Digit Span (Paced)
	12. Forward Digit Span (Slow)
	13. Forward Digit Span (Fast)
Attention tasks:	14. Triplet Numbers
	15. Letter Lists
	16. RST Task
Gs tasks:	17. Finding a's
	18. Backward Writing

Method

Subjects:

These consisted of 141 First-Year Psychology students, at the University of New South Wales, who were encouraged as a part of their studies to participate as subjects for research. The mean age was 21.4 years with range 18 to 45 years. This sample would be expected to have a higher average, and smaller variation, in abilities related to academic success, than would a sample drawn from the general population.

Procedure:

A battery of 18 tests was presented to groups of subjects in two sessions, each lasting about 2.5 hours. The groups varied from about five to ten subjects. The order of presentation of tests was the same for all subjects and is displayed in Table 2. Tests requiring auditory presentation were given via a tape cassette player (Sony TC 31), with two external loudspeakers placed at the front, and at opposite sides, of the testing room. For all tests, subjects recorded their responses with pen or pencil on prepared answer sheets.

Tests used in the study:

The 18 tests used in this study are listed in Table 1, where they are grouped on the basis of ability dimensions traditionally associated with

Table 2

Descriptive Statistics for Variables Used in Study 1

Variable	Order of Presentation	No. of Items	M	s	r_{tt}
1. Raven's Matrices (a)	A1	18	.88	3.2	-
2. Raven's Matrices (b)			.50	.18	.77
3. Raven's Matrices (c)			2.0	.54	-
4. Letter Series (a)	B1	38	13.2	3.1	-
5. Letter Series (b)			.68	.14	.60
6. Letter Series (c)			2.9	.74	-
7. Verbal Reasoning (a)	B3	30	19.3	4.3	-
8. Verbal Reasoning (b)			.71	.16	.85
9. Verbal Reasoning (c)			4.2	.91	-
10. Vocabulary (a)	A3	36	23.2	6.1	-
11. Vocabulary (b)			.64	.17	.82
12. Vocabulary (c)			10.7	3.1	-
13. Esoteric Analogies (a)	A8	36	14.6	4.8	-
14. Esoteric Analogies (b)			.42	.13	.70
15. Esoteric Analogies (c)			6.5	1.8	-
16. Proverbs (a)	B6	40	19.8	4.6	-
17. Proverbs (b)			.72	.11	.44
18. Proverbs (c)			4.6	.86	-
19. Card Rotations (a)	A5	224	101.4	27.5	-
20. Card Rotations (b)			.93	.08	.60
21. Card Rotations (c)			108.8	26.6	-
22. Hidden Patterns (a)	B5	400	151.5	34.0	-
23. Hidden Patterns (b)			.93	.06	-
24. Hidden Patterns (c)			160.5	33.4	-
25. Form Board (a)	B7	18	8.1	3.8	-
26. Form Board (b)			.58	.22	-
27. Form Board (c)			14.1	4.0	-
28. Gestalt Completion	B9	20	12.2	4.0	.81
29. Backward Digit Span (Paced)	A7	24	14.6	4.5	.79
30. Forward Digit Span (Slow)	A2	12	7.2	2.2	.80
31. Forward Digit Span (Fast)	B4	12	6.8	2.3	.80
32. RST Task	A4	24	58.6	9.8	.85
33. Number Triplets	A9	72	46.3	15.6	.94
34. Letter Lists	B8	90	49.7	17.0	.90
35. Finding a's	A6	-	18.8	4.0	.80
36. Backward Writing	B2	-	34.0	8.0	.83

Notes: A = Session one; B = Session two
a = Total number correct score
b = Accuracy score
c = Speed score

such as the Raven's Progressive Matrices, Letter Series, etc.. However, theories which identify intelligence with some basic limitation in information processing capacity, (e.g., mental energy, attentional resources, Working Memory, mental speed, etc.), do seem to be more consistent with the possibility of a close association between intelligence and these Attention tasks.

Aims and Rationale of Study

The study was designed to investigate the relationship between tasks such to those used by Wittenborn (1943) to define an Attention factor, and a number of ability dimensions described by the Horn/Cattell theory of fluid and crystallized intelligence. (See Chapter 1 for a discussion of Gf/Gc theory.) Of particular interest is the relationship between the Attention tasks and fluid intelligence, Gf. (Note: In Chapter 1 of this thesis it was argued that a more appropriate operational definition of task complexity was one in terms of Gf, rather than one in terms of the first principal component, as suggested by Jensen, 1977, or the general factor, as suggested by Marshalek et al., 1983.) The present test battery contains markers of fluid and crystallized intelligence, as well as tests of memory span, perceptual/clerical speed, visualization and visual closure. The two tests which in Wittenborn's (1943) study had the highest loadings on the Attention factor (Triplet Numbers and Letter Lists), as well as another test, each test. For the purpose of discussion, the terms which will be used to refer to each of the six groups of tests are also listed in Table1. The first three, and the last, of the groups have been labelled in terms of the ability factors marked by the tests in previous work in the tradition of Gf/Gc theory. The group of tests referred to as 'Attention tasks' derive this description from the associated factor in Wittenborn's (1943) study. It can be noted that each of the groups of tests, excepting the Attention tasks, are represented in the main regions of the multi-dimensional scaling of ability tests shown in Figure 1.

The 18 tests, and the 36 variables derived from these tests, are listed in Table 2. The first test, Raven's Matrices, comprises the odd items of Set 2 of the Advanced Progressive Matrices (Raven, 1965). The tests Letter Series, Vocabulary, Esoteric Analogies, and Proverbs, were used previously in work by Horn (1980) and Stankov and Horn (1980). The Verbal Reasoning test was Form A of the test of that name, which is included in the Employee Aptitude Survey battery, developed by Grimsley, Ruch, Warren and Ford (1952-58). The test items for Card Rotations, Embedded Figures, Form Board, and Gestalt Completion tests were taken from the French, Ekstrom and Price (1963) kit of reference tests for cognitive factors. The remaining tests were constructed by the author, with the Number Triplets and Letter Lists tasks being made on the basis of the descriptions given by Wittenborn (1943). (In Wittenborn's paper these are labelled as Tests 11 and 17, respectively.) The RST Task was based on the serial short-term memory task studied by Monty (e.g., 1968, 1973), and used in previous correlational studies by Crawford and Stankov (1983).

For each of the Gf markers (Raven's Matrices, Letter Series and Verbal Reasoning), the Gc markers (Vocabulary, Esoteric Analogies and Proverbs), and the Gv markers (Card Rotations, Embedded Figures and Form Board), three scores were obtained: total number correct, accuracy, and speed (see Table 2). The method used here was similar to that adopted by Crawford and Stankov (1983). For the Gf and Gc tests, subjects were instructed to always work forwards through the test and to stop if they had completed the final item before the time limit. At one minute intervals, signals of 'tick now' were presented via the loudspeakers, and subjects were instructed to place a tick next to the test item they were working on when each of these signals was given. Speed scores for each test were obtained by dividing the number of items attempted by the number of ticks recorded. The accuracy scores were derived by dividing the total number of correct items by the total number of items attempted. (The above definitions applied whether or not a test was completed within the maximum time allowed.) For the Gv tasks (Card Rotations, Embedded Figures and Form Board), no 'tick now' signals were required in order to obtain speed scores since no subject was able to complete all items within the time limits for these tests. Speed scores were obtained for these tests as the number of items completed. For the Gestalt Completion task it was found, in a pilot study, that subjects reported difficulty in keeping to the instructions to work only forwards through the test. In this test, at any one time, several test items (incomplete drawings) are simultaneously in view of the subject. Subjects reported that they would occasionally often 'see' the solution to an item previously attempted and abandoned, while working on another further on through the test. It was therefore decided to have no 'tick now' signals for this test, and to use only total number correct scores.

For all subject-paced tests, subjects were instructed to work as quickly and accurately as possible. For the Gf and Gc markers, accuracy was stressed, and subjects were told to procede to the next item only after having made a serious attempt at the previous one. They were also told that, for these tests, it was not important that they finish all items in the time allowed for the test.

The memory span tests (variables 29, 30, 31) were adaptations of the common digit span tests, such as those included in the WAIS. Jensen (1977) reported that a slower presentation of a paired-associates learning task resulted in higher correlations of performance with intelligence. (It was suggested by Jensen that the slower presentation allowed a greater involvement of higher-order executive control functions in the learning of the associations.) Forward Digit Span tests with both fast and slow presentation rates (variables 30 and 31, respectively) were included to see if analogous results would be obtained for memory span as for the paired associates task. For all memory span tasks, the time allowed for the subject's responses was one second for each digit in the memory set. Subjects were instructed to cease writing as soon as a new item commenced, and to hold their pencils or pens in the air away from the response sheets while the new item was being presented. In this way, the experimenter could easily observe if any of the subjects was not keeping to the test instructions regarding the time allowed for responding. (Note: For the two forward span tasks, this gave ample time for the subjects to write their responses, but for the backward span task, Variable 29, higher scores would have been resulted from longer times to respond. The rationale for the design of this task will be considered in more detail later in the Discussion section.)

A brief description of each of the tests used in this study is given below.

1. Raven's Matrices

For each item the subject was presented with a two-dimensional array of figures with one missing. Subjects were required to choose, from a number of alternatives, the figure which would best complete the pattern. Test items were contained in a test booklet and subjects gave their answers on the separate response sheet.

Time allowed: 10 minutes.

Scoring: Variable 1: Total number correct.

Variable 2: Accuracy score.

Variable 3: Speed score.

2. Letter Series

For each item a list of letters was presented and the subject was instructed to write down the letter which continued the pattern in the series.

Example: D V C W B X _ (Correct response = A.)

Time allowed: 7 minutes.

Scoring: Variable 4: Total number correct.

Variable 5: Accuracy score.

Variable 6: Speed score.

3. Verbal Reasoning

For each item a number of 'facts' were listed, as well as a number of 'conclusions'. Subjects were required to indicate, by writing a 'T', 'F', or 'X', whether each 'conclusion' is implied by, negated by, or logically independent of, the presented 'facts'.

Example: Jim cannot swim.

Kevin and all of his relatives can swim.

Kevin is not a teacher.

Kevin has an uncle who is a teacher.

Conclusion: Some teachers can swim.

(Correct response = T, since conclusion is implied by the above facts.)

Time allowed: 10 minutes.

Scoring: Variable 7: Total number correct.

Variable 8: Accuracy score.

Variable 9: Speed score.

4. Vocabulary

For each item the subject had to choose, from four alternatives, the word which has the same meaning as a given word.

Example: LACERATION: cut oration tumour flogging

(Correct response = cut.)

Time allowed: 6 minutes.

Scoring: Variable 10: Total number correct.

Variable 11: Accuracy score.

Variable 12: Speed score.

5. Esoteric Analogies

For each item three words were presented. The subject was instructed to choose, from four alternatives, the word which has the same relationship to the third word as the second does to the first.

Example: seed : spore; flower : pollen plant fungi fruit

(Correct answer = pollen.)

Time allowed: 6 minutes.

Scoring: Variable 13: Total number correct.

Variable 14: Accuracy score.

Variable 15: Speed score.

6. Proverbs

The subject was required to choose from four alternatives the statement which best describes the meaning of a given 'proverb'.

Example: STRIKE WHILE THE IRON IS HOT.

1. Be quick and alert.
2. Iron with a hot iron, a cold one won't do.
3. That's when it bends best.
4. Do something when the time is right.

(Correct response = number 4.)

Time allowed: 6 minutes.

Scoring: Variable 16: Total number correct.

Variable 17: Accuracy score.

Variable 18: Speed score.

7. Card Rotations

On each line is drawn an irregular shape. To its right are eight drawings of the same shape but rotated by different amounts and in some cases, drawn as a mirror image (i.e. 'flipped over') as well. Subjects were required to work as quickly as possibe, from left to right and one line at a time, crossing out all those figures which had been 'flipped over'.

Time allowed: 4 minutes.

Scoring: Variable 19: Total number correct.

Variable 20: Accuracy score.

Variable 21: Speed score.

8. Hidden Figures

Each line of test items consists of ten, straight line figures. Some of these contain, or have embedded within them, a target figure which is displayed at the top of each page. Subjects were required to work from the left to the right of each line as quickly as possible, ticking all those figures which contain the target figure.

Time allowed: 4 minutes.

Scoring: Variable 22: Total number correct.

Variable 23: Accuracy score.

Variable 24: Speed score.

9. Form Board

For each item a figure is presented, together with a number of smaller figures displayed beneath it. The subject was required to select, from the smaller figures, those which can be 'put together' to form the larger shape above. (Rotations, but not mirror-reversals, of the smaller figures may be necessary.)

Time allowed: 7 minutes.

Scoring: Variable 25: Total number correct.

Variable 26: Accuracy score.

Variable 27: Speed score.

10. Gestalt Completion

Incomplete drawings were presented and subjects were required to write a brief description of the scene, or object, supposedly depicted by the drawing.

Time allowed: 5 minutes.

Scoring: Variable 28: Total number correct.

11. Backward Digit Span (Paced)

For each item subjects heard a series of digits, presented at a rate of one digit per second. After each list had been presented, they were required to write them in reverse order, and to stop writing immediately the next item began. The lists ranged in length from 3 to 8 digits, with 4 items at each length, and were presented in ascending order. The time allowed for each item was one second for each digit in the list.

Scoring: Variable 29: Total number correct. (Note: Each item was marked correct only if all digits were present and written reverse order. No credit was given for partially correct answers.)

12. & 13. Forward Digit Span (Slow and Fast)

For each item subjects heard a series of digits and were instructed to write them down, in the order in which they were presented, as soon as each list had finished. The lengths of the lists varied from 5 to 11 digits, with four items for each length, and were presented in ascending order. For half the items (the odd ones), the digits were presented at the 'slow' pace of one digit every two seconds. The remaining items (the even ones) were presented at the faster speed of about four digits per second. Thus 'slow' and 'fast' items were presented alternately, with two lists of each length for each speed.

Scoring: Variable 30: Total number of correct responses for 'slow' items.

Variable 31: Total number of correct responses for 'fast' items. (Note: As with the previous test, no credit was given for partially correct answers.)

14. Triplet Numbers

Groups of three digits (or 'triplets') were presented over the loudspeaker at a rate of one triplet every four seconds. Each digit was spoken at the rate of one per second, with a pause of one second between each triplet. Subjects were required to respond to each of the triplets by writing either a '1' or a '0' on their answer sheets, in accordance with a previously explained, and practiced, rule. The rule was as follows:

"Write a '1' if the first digit is the smallest and the last the largest, OR if the first is the largest and the second is the smallest. Otherwise, write a '0'."

The items were presented in nine blocks, each of eight triplets. The blocks were labelled A, B, C ... I, and the label for each block was read out prior to the presentations of the items in the block. (This was to reduce the likelihood of subjects becoming and remaining 'out of step' with their responses.)

Scoring: Variable 33: Total number of correct responses.

14. Letter Lists

Nine lists of ten letters each were read at the rate of one letter every 2.5 seconds. Subjects were required to write either a '0', '1', or '2', in response to each, except the first, letter in each list. Their responses were to be made according to the following rule:

"If the letter is a consonant and the one before it is a vowel, write a '2'. If

18. Backward Writing

Using the same pages of prose as were used for the previous test, subjects were required to begin from the bottom of the page, and to write backwards, as quickly and accurately as possible, until a 'stop' signal was given. The procedure was repeated, with subjects again beginning at the bottom of a different page.

Time allowed: Total of four minutes. (2 minutes for each repeat.)

Scoring: Variable 36: Total number of words correctly written backwards.

Statistical Analysis

A series of factor analyses were carried out on selections of variables listed above, using the maximum likelihood procedure developed by Joreskog and incorporated in the SPSS package of statistical programs. In all solutions factors were objectively rotated in accordance with the 'oblimin' criterion, and with the obliqueness parameter, 'DELTA', being set to the default value, zero (Nie, Hull, Jenkins, Steinbrenner and Bent, 1970, p. 485).

Results

The essential descriptive statistics for variables used in this study are presented in Table 2. The split-half reliability estimates shown here were

Table 3

Factor pattern matrices obtained with total number correct scores for Gf and Gc variables (Study 1)

(N = 141)

	Solution 1					Solution 2				
Variables	Gfv	Gc	DSp	Gs	h^2	Gf	Gc	DSp	Gs	h^2
1. Raven's Matrices	56	14	12	03	43	59	06	03	-01	37
4. Letter Series	31	20	06	23	33	37	14	02	21	28
7. Verbal Reasoning	33	30	12	-05	36	46	17	05	-13	35
10. Vocabulary	-13	88	-02	-15	54	-11	87	03	-09	52
13. Esoteric Analogies	11	76	-12	-09	56	12	74	-11	-07	55
16. Proverbs	02	60	12	16	42	13	53	13	16	42
19. Card Rotations	61	-02	05	-02	35					
22. Hidden Patterns	44	-11	01	19	29					
25. Form Board	68	-05	-02	-14	48					
28. Gestalt Completion	31	00	-10	-07	17					
29. Back D Span(Paced)	45	09	37	12	48	66	-08	25	01	47
30. For D Span (Slow)	-04	-03	84	00	67	02	00	80	05	66
31. For D Span (Fast)	-01	-03	99	-13	70	-01	03	99	-04	69
32. RST Task	48	25	-01	19	44	63	10	-10	10	41
33. Number Triplets	45	16	14	-03	37	60	01	03	-14	33
34. Letter Lists	50	10	03	24	39	68	-07	-07	11	37
35. Finding a's	-06	-11	-01	52	24	-10	-05	03	62	21
36. Backward Writing	02	04	-04	73	33	12	00	-02	62	27

Factor Intercorrelations

	Gfv	Gc	DSp	Gs
Gfv				
Gc	42			
DSp	17	27		
Gs	20	-04	20	

	Gf	Gc	DSp	Gs
Gf				
Gc	53			
DSp	31	16		
Gs	22	-15	05	

Notes: Decimal points have been omitted.
Factor-pattern loadings greater than .20 have been underlined.

obtained from correlations between the odd and even items, except for the last two tests, where the correlations between the two repeated subtests were used. The correlations between all variables derived from the tests of this study, upon which all subsequent factor analyses are based, are given in Table 30 in the Appendix.

For the first analysis, total number correct scores were selected for the Gf, Gc, and Gv measures, and the correlations between these variables factor analysed. Root-one criterion suggested the extraction of four factors, and this is shown as Solution 1, in Table 3.

The factor pattern of Solution 1, Table 3, can be easily related to previous work associated with the Horn/Cattell theory of fluid and crystallized intelligence (for example, see Horn, 1980; Stankov and Horn, 1980). The second factor is marked by tests (Vocabulary, Esoteric Analogies and Proverbs) which would, in a larger battery, be markers for the established primary factors of Verbal Comprehension, Cognition of Semantic relations and Cognition of Social Relations, respectively. This factor can thus be compared, in terms of its breadth of content, with the second-order factor, crystallized intelligence, Gc, of Gf/Gc theory. It has therefore been labelled Gc, despite its being obtained at the first order of factoring in this analysis.

The third factor has been labelled DSp (Digit Span) as its major loadings are from the forward and backward digit span variables. The fourth factor is defined by the Backward Writing test and the perceptual/clerical speed marker, Finding a's. As this factor is slightly broader in content than the primary, Perceptual Speed, it has been labelled Gs (General Speediness) after the second-order factor which similar tests have helped define in previous studies (e.g., Horn, 1980,1986).

The first factor is marked by three groups of tests. The first group (Raven's Matrices, Letter Series and Verbal Reasoning) are markers of the established primary factors Cognition of Figural Relations, Induction and Reasoning. A factor defined by these tests would therefore be comparable in content to the second-order factor, fluid intelligence (Gf), of Gf/Gc theory. Similarly, a factor defined by the second group of tests (Card Rotations, Hidden Patterns, Form Board and Gestalt Completion) would be comparable in breadth of content to the general visualization factor, Gv, of Gf/Gc theory. (These tests are markers of the primaries Flexibility of Closure, Vizualization and Speed of Closure.) The third group of tests comprises the two which loaded most heavily on Wittenborn's Attention factor (Number Triplets and Letter Lists) and the serial short-term memory test, the RST Task. As Snow (1980) has pointed out, it is not uncommon that tests, which have been found to form distinct Gf and Gv factors, do in some analyses come together to form a single factor. This occurred, for example in studies within the Gf/Gc tradition, reported by Horn (1985). It was suggested by Snow that in such instances the factor be labelled Gfv, to the letter is a vowel and the one before a consonant, write a '1'. If the letter and the one before it are both consonants, or both vowels , then write a '0' and write a '1' for the next letter no matter what it is."

Scoring: Variable 34: Total number of correct responses.

16. RST Task

Subjects heard lists composed of the letters 'R', 'S', and 'T', presented in random order, and at the rate of about one letter every 1.5 seconds. At the end of each list subjects were required to write down the number of times each letter had occurred in the list. No writing was allowed while the lists were being presented.

Scoring: Variable 32: Total number of correct letter counts.

17. Finding a's

Subjects were presented with pages of simple English prose, and were required to count, and write on their answer sheets, the number of a's in each line. They were instructed to work as quickly and accurately as possible, and to stop as soon as the 'stop' signal was given. The procedure was carried out two times.

Time allowed: Total of 3 minutes. (1.5 minutes for each repeat.)

Scoring: Variable 35: Total number of correct responses.

indicate its content in terms of the well established factors, Gf and Gv. (Note: An alternate identification might be Vernon's, 1950, higher-order spatial, mechanical factor, k:m.) Following the suggestion of Snow (1980) the first factor has been labelled Gfv, although, as can be seen from Table 3, this factor is also defined by the Attention and Backward Digit Span tasks.

It is a particular interest of this study to investigate the relationship between the Attention tasks and fluid intelligence, as this latter dimension is normally defined within Gf/Gc theory. The results shown in Solution 1 of Table 3 suggest a very close association between the Attention and Gf variables. However, it could be suggested that the close association between the Attention tasks and the first factor, Gfv, could be mediated, to some extent, by the spatial ability component in this factor. (This is consistent with the proposal of Monty and Karsh, 1979, that strategies using spatial imagery are used by subjects in their performance on tasks such as the RST task.) A further analysis was therefore carried out with the Gv variables removed, in order to obtain a factor more closely resembling, in content, the factor, Gf, as normally defined within Gf/Gc theory. The results of this analysis are displayed as Solution 2 in Table 3. As with Solution 1, root-one criterion suggested that four factors could be extracted. The chi squared statistic indicated that the four factor solution does give an adequate fit to the data; Chi squared with 41 d.f. = 34.1, $p = .78$. In this second solution, the interpretations of the second, third and fourth factors are essentially the same as for Solution 1, and the factors have been labelled accordingly. The first factor remains the same as for Solution 1, except for the absence of the loadings from the Gv variables, and has been labelled Gf to signify its identification with the fluid intelligence factor of Gf/Gc theory. Most important, however, is the observation that in the second solution, as in Solution 1, the typical Gf markers, Raven's Matrices, Letter Series and Verbal Reasoning, did not separate factorially from the Attention tasks, Number Triplets, Letter Lists and the RST Task. In fact, without exception, the factor-pattern loadings of these tests on the Gf (or Gfv) factor increased with the removal of the Gv tasks from the analysis.

An unexpected feature of these results is the high factor loadings, in both Solutions 1 and 2, of Backward Digit Span on the Gfv or Gf dimensions. However, the presentation of the task in this study differs from what is usual. The extent to which this may explain these results will be considered in more detail later in the Discussion section.

In some previous work (e.g., Horn and Bramble, 1967), it has been the accuracy, rather than total number correct, scores which have formed the basis of the measurement of fluid and crystallized intelligence. (Note: This is not true of the measurement of certain other ability dimensions, such as perceptual/clerical speed, where it is more generally accepted that these abilities are defined in terms of the speed at which correct responses can be produced.) To see if the same close relation between Gf and the

Table 4

Factor pattern matrices obtained using accuracy scores for Gf and Gc variables (Study 1)

	Solution 1					Solution 2				
Variables	Gfv	Gc	DSp	Gs	h^2	Gf	Gc	DSp	Gs	h^2
2. Raven's Matrices	58	19	10	08	47	52	18	06	14	42
5. Letter Series	42	19	05	-07	36	59	-01	-02	-16	30
8. Verbal Reasoning	38	24	09	-08	34	59	04	01	-18	33
11. Vocabulary	-07	82	00	-02	47	13	54	06	-18	45
14. Esoteric Analogies	12	76	-12	02	52	-05	1.04	-06	06	51
17. Proverbs	08	38	16	-03	34	39	08	13	-25	31
19. Card Rotations	58	-05	03	03	37					
22. Hidden Patterns	45	14	00	18	28					
25. Form Board	66	04	-05	-12	37					
28. Gestal Completion	31	00	-12	-07	19					
29. Back D Span(Paced)	49	-06	38	08	48	49	04	32	20	47
30. For D Span (Slow)	-04	02	87	01	67	-08	02	90	08	67
31. For D Span (Fast)	00	02	95	-08	70	02	-05	93	-07	69
32. RST Task	53	-22	00	14	43	58	15	-06	21	40
33. Number Triplets	49	-13	13	-03	37	52	10	06	02	32
34. Letter Lists	58	00	05	13	37	65	-10	-04	22	34
35. Finding a's	03	18	01	37	23	-03	-11	02	48	21
36. Backward Writing	-02	-17	-06	1.04	32	08	03	02	66	26

Factor Intercorrelations

	Gfv	Gc	DSp	Gs
Gfv				
Gc	38			
DSp	18	22		
Gs	14	-25	13	

	Gf	Gc	DSp	Gs
Gf				
Gc	49			
DSp	32	16		
Gs	07	-23	02	

Notes: Decimal points have been omitted.
Factor-pattern loadings greater than .20 have been underlined.

Table 5

Factor pattern matrix obtained with accuracy scores for Gf and Gc variables and with Gv variables removed: Three factor solution based on the same variables as for the analysis of Solution 2, Table 4

Variables	Gfc	DSp	Gcs	h^2
2. Raven's Matrices	65	05	04	42
5. Letter Series	50	02	-09	30
8. Verbal Reasoning	53	04	-12	33
11. Vocabulary	44	02	-58	45
14. Esoteric Analogies	58	-13	-50	51
17. Proverbs	36	14	-25	31
29. Backward D. Span (Paced)	57	29	18	47
30. Forward D. Span (Slow)	01	82	04	67
31. Forward D. Span (Fast)	-01	98	-04	69
32. RST Task	71	-07	12	40
33. Number Triplets	57	07	01	32
34. Letter Lists	61	-03	29	34
35. Finding a's	01	01	44	21
36. Backward Writing	23	-02	46	26

Factor Intercorrelations

	Gfc	Dsp	GcS
Gfc			
Ds	29		
GcS	-07	00	

Notes: Decimal points have been omitted.
Factor-pattern loadings greater than .20 have been underlined.

Attention tasks (as evidenced by the results shown in Table 3) would be obtained with a definition of Gf in terms of accuracy of performance, the previous analyses were repeated, but with accuracy scores being used for both the Gf and Gc tasks. The results of these analyses are shown in Table 4. With the Gv variables included, root-one criterion suggested four factors, and this analysis is shown as Solution 1 of Table 4. With the Gv variables omitted, root-one criterion indicated that three factors could be extracted. However, the four factor solution is reported as Solution 2 (latent root = .92) in view of the easy interpretation of each of the four factors, and to allow direct comparison with the solutions shown in Table 3. For the sake of completeness, however, the three factor solution is also reported, and is shown in Table 5.) The main conclusion which can be drawn from the results of Table 4, is that the use of accuracy, rather than number correct, scoring for the Gf and Gc tasks, does not alter the previous finding regarding the relationship between Gf and Attention measures. In both cases, the two sets of tasks were found to define the same dimension in individual differences.

In the three factor solution of Table 5 it can be seen that the speed factor, Gs, of the previous four factor solution has taken up some of the variance of the Gc accuracy variables, to form the bipolar factor, Gsc. The existence of this indicates the influence of individual differences in speed-accuracy trade-off in the performances of the Gc and Gs tasks. (Note also the negative correlations of -.25 and -.23 between the Gc and Gs factors in the four factor solutions of Table 4.) The remaining variance of the Gc variables has combined with the previous Gf factor to form the factor which has been labelled Gfc. It can be noted that the highest loadings of each of the Attention tests are also on this Gfc factor.

It should be noted that in the two solutions based on accuracy scores for the Gf and Gc variables (Table 4) there can be observed the occurrence of the so-called Heywood case. Factor pattern loadings of 1.04 on the Gs factor in Solution 1, and on the Gc factor in Solution 2, were obtained. Although representing a deviation from the factor analytic model, the interpretation of these results are not changed. With the maximum likelihood method of factor extraction it is not unusual for the Heywood case to occur for factors which are defined by only a small number of variables. In the present situation, both occurrences were on factors defined by only two variables. A factor analysis based on the variables shown in Table 4, but using the principle axis method of factor extraction (option PA2 in the SPSS statistical package), gave essentially the same results. (This method of factor extraction does not allow the occurrence of the Heywood case.)

In addition to the variables considered in the previous analyses, speed scores were obtained for each of the Gf, Gc and Gv tests. (As described earlier, these scores reflect the rate at which subjects proceeded through the test items when instructed to work as quickly and accurately as

Table 6

Factor pattern matrices obtained using speed scores for Gf, Gc and Gv variables (Study 1)

Variables	Gf	DSp	Gs	SGf	SGc	h^2
3. Raven's Matrices(Speed)	-16	01	-02	71	-02	37
6. Letter Series(Speed)	03	02	08	53	02	25
9. Verbal Reasoning(Speed)	-09	09	03	55	12	33
12. Vocabulary(Speed)	-05	01	00	-03	56	22
15. Esoteric Analogies(Speed)	-09	-05	04	36	43	39
18. Proverbs(Speed)	18	03	01	04	70	41
21. Card Rotations(Speed)	41	00	-01	21	11	29
24. Hidden Patterns(Speed)	24	-04	17	07	11	20
27. Form Board(Speed)	15	-11	-04	38	02	23
29. Backward D. Span(Paced)	60	31	02	-13	00	51
30. Forward D. Span(Slow)	04	85	05	04	-04	67
31. Forward D. Span(Fast)	03	94	-05	03	07	69
32. RST Task	64	-03	04	-08	-03	34
33. Number Triplets	56	07	-12	-15	07	35
34. Letter Lists	66	00	07	06	-06	35
35. Finding a's	02	03	42	13	-06	23
36. Backward Writing	05	-03	99	-27	12	30

Factor Intercorrelations

	Gf	DSp	Gs	SGf	SGc
Gf					
DSp	19				
Gs	18	02			
SGf	-04	-17	20		
SGc	29	05	17	39	

Notes: Decimal points have been omitted.
Factor-pattern loadings greater than .20 have been underlined.

possible.) Factor analyses of the speed scores, together with the variables listed in Tables 4 and 5, did not give easily interpretable results. However this is not surprising for two reasons. Firstly, the large total number of variables in such analyses would be expected to result in the relatively unstable definition of factors which are marked by only two or three variables. Secondly, the speed and accuracy, or number correct, measures cannot be considered to be 'functionally independent' in the sense discussed by Horn, Donaldson and Engstrom (1981). Being derived from the same test items, the various scores would be spuriously affected by variation, within individuals, in the speed and accuracy with which the tests are completed. The removal of this problem by the use of different test items of the same test for each of the measures, as suggested by Horn et al. (1981), is not possible in the present study.

For the above reasons, it was decided to factor analyse the speed measures from the Gf, Gc and Gv tasks, together with the variables from the remaining tests. The results of this analysis are shown in Table 6. Root-one criterion suggested five factors and this solution is shown as Solution 1. The first factor is marked wih high loadings from the Attention tasks and from Backward Digit-Span. An appropriate name for this factor would be 'Attention' after the one defined by similar variables in Wittenborn (1943). However, in view of the previous results, shown in Tables 3 and 4, it was decided to regard the Attention tasks as good markers of fluid

Table 7

Correlations between speed and accuracy measures for Gf and Gc tasks (Study 1) (Extracted from Table 30 in the Appendix)

	Accuracy Measures	Speed Measures					
		1	2	3	4	5	6
Gf Tasks:	1. Raven's Matrices	-.50	-.09	-.22	.12	-.11	.17
	2. Letter Series	-.29	-.44	-.28	.05	-.19	.01
	3. Verbal Reasoning	-.31	-.22	-.30	.02	-.16	.06
Gc Tasks:	4. Vocabulary	-.16	-.11	-.01	.37	.05	.35
	5. Esoteric Analogies	-.25	-.26	-.04	.19	-.07	.20
	6. Proverbs	-.20	-.17	-.09	.01	-.09	-.01

intelligence, and to label this factor Gf, accordingly. The second and third factors are the same as the factors DSp and Gs obtained in these earlier analyses. The final two factors represent the speed measures derived from the Gf and Gc tests, respectively, and have been labelled Speed Gf (SGf) and Speed Gc (SGc). This splitting of the speed measures on the basis of whether they derive from Gf or from Gc tasks suggests the possibility that systematic differences might exist in the speed-accuracy trade-off in the performances of Gf and Gc tasks. Table 7 displays the correlations between the speed and accuracy measures for the Gf and Gc tasks. Here it can be seen that there is a consistent trend for the speed and accuracy measures of the Gf tasks to be more negatively correlated than for the Gc tasks. This is most pronounced for the most common markers of Gf and Gc, namely the Raven's Matrices and Vocabulary tests, where the correlations between the speed and accuracy of performances are -.50 and +.37, respectively.

Discussion

The main finding of this study is the close relationship between accepted measures of fluid intelligence, (which are also commonly regarded as good measures of general intelligence), and tasks similar to those measures of 'sustained mental effort', or 'concentration', which were devised and investigated by Wittenborn (1943). This result is interesting for the reason that it may challenge certain common ideas on the nature of general intelligence, at least insofar as this is reflected by assumptions on the essential characteristics of those tasks which are relatively good single-test measures of general intelligence. Wittenborn (1943), for example, assumed, but did not confirm, that performances on his Attention tasks would not depend to any significant extent on 'intellectual level'. Presumably, this assumption was based on the prima facie dissimilarity between these tasks and the typical more abstract reasoning tests which were generally assumed to represent the higher-order mental processes defining 'intellectual level'. Similarly, the characterisation of 'archetypical' measures of 'g', (for example, by Snow, 1980, or Hunt, 1980), such as the Raven's Progressive Matrices, would not readily identify these Attention tests as likely good measures of intelligence. In terms of Guttman's radex model, or the similar description of mental abilities by Snow (1980), the Attention tests do not show a strong family resemblance to the more familiar and widely used tests of higher complexity.

The finding of the present study, and the above interpretation of the Attention tasks are clearly consistent with Spearman's characterisation of general intelligence via the construct of 'mental energy'. However, alternative interpretations of the source of individual differences in the performances on these Attention tasks, consistent with the results of this study, are possible. The most plausible of these is one in terms of the mental speed required to maintain accurate responding at the fairly rapid item presentation rate. It is interesting to note, however, the close relation between this account and Wittenborn's one, based on the ability to maintain high levels of concentration. In Wittenborn's account of his newly constructed tasks, the rapid item presentation rate was regarded as important in the design of the tests, not so that they might be a measure of mental speed, but rather to ensure that any task-irrelevant interpolated mental activity could not take place during the performances of the tests. This is necessary if these tests are to be interpreted as a measure of the ability to maintain a constant high level of attention. Thus, if Wittenborn's assumption on the necessary role of a fast item presentation rate in producing high levels of concentration is accepted, then both interpretations of these tasks (that is, those in terms of 'mental speed' and 'sustained attention') would similarly predict that the item presentation rate would be a major factor determining the levels of performances on the tasks. It should be noted, however, that, on the basis of the results displayed in Tables 3 to 6, if a form of mental speed was postulated to underlie performances on the Attention tests, then this is reliably distinct, in individual differences, from the forms of mental speed represented by the speed factors Gs, SGf and SGc described earlier. Indeed, the results of this study would indicate that such a form of mental speed would be more strongly related to the accuracy of performances on fluid intelligence tasks, than to the forms of mental speed represented by these other speed factors.

Another possible interpretation of performances on the Attention tasks is that they reflect the degree to which the rules for responding have been learned (or possibly 'overlearned') prior to the execution of the test items. Although it can be safely assumed that all subjects understood the rules in the sense that each was able to achieve near perfect responding when the items were presented at a very slow rate, it is nevertheless possible that reliable individual differences do exist in the extent to which the rules were 'overlearned', or became 'automatised' in the learning and practice phases, or even during the presentations of the test items.

A further interpretation which cannot be ignored, is one similar to that suggested by Hunt (1980), and by Sternberg (1983), as the main source of individual variation in the performances of typical high g-loading reasoning tasks, namely individual differences in the selection, or the availability, of problem-solving strategies. Such an interpretation would not seem, however, to be consistent with Wittenborn's evaluation of these tasks, that they involve relatively elementary and mechanistic forms of processing, and that performances do not rely significantly on prior knowledge. At face value, it does seem unlikely that performances on these Attention tasks would depend on strategic choice to a significantly greater extent than other tests of relatively low complexity, such as traditional short-term memory or perceptual-clerical speed tests. Hunt (1980) suggested that the greater importance of strategic choice in reasoning tasks, such as the Raven's Progressive Matrices, is to be expected as a result of the greater 'novelty' of each of the items in the Matrices test. As discussed earlier, so far as the 'novelty' of individual items is concerned, the Attention tests would seem to more resemble such tests of lower complexity than good measures of intelligence such as the Matrices test.

The possible role of strategic variation in mediating the close relation between the Gf and Attention tasks cannot, however, be ruled out. Informal questioning of subjects after they had completed the test battery did, in fact, reveal a number of strategic devices which were used to improve their measured performances. For example, some subjects reported that, during the RST test, if they felt that they were not able to keep track of all three letters, then they would attempt to keep track of only two of the three letters and, at the end of the item presentation, make an educated guess at the tally for the third. Similarly, for the Triplet Numbers test, some subjects reported that if they were not able to complete an item before the presentation of the next, they would ignore the following items until they had completed their response to the previous one, while at the same time keeping track of the place on the response sheet with their finger. They would then turn their attention to the next item to be presented, filling in the missed spaces on the answer sheet with random responses. For the third of the Attention tasks, Letter Lists, a similar strategy was also reported by some subjects.

One result of this study which at first does not appear to be fully consistent with previous research, is the high loadings of the Backward Digit Span test on the Gf factor. As mentioned in the Results section, the more usual finding is that the Backward Span task is much more strongly associated with the short-term memory factor marked by the Forward Digit Span test, than with measures of fluid intelligence (for example, see Stankov and Horn, 1980; Crawford and Stankov, 1983). Although it may be expected that the Backward Span test should show some increase in its correlation with Gf, compared with the Forward Span test (Jensen and Figueroa, 1975), the effect was much stronger here than would be expected on the basis of previous studies. The Backward Digit Span task used in this experiment, however, differed in its manner of presentation in a possibly critical way from that which is more usual. The nature of this difference, and the rationale for its existence, is as follows.

Before the main study, a small pilot study was carried out, using 15 subjects, in order to check the clarity of instructions and to ensure acceptable difficulty levels for the various tests. In this pilot study, the Forward and Backward Digit Span tasks were presented in the usual manner, with all subjects being allowed ample time to complete their responses to the test items. Informal discussion after the completion of the memory span tests suggested that a systematic variation in strategies on the Backward Span task existed between subjects with larger and smaller differences between the two memory span tasks. Subjects with relatively smaller differences between their forward and backward spans tended to report that they would consciously 'hold back' from immediately beginning to write the answer as soon as they were permitted after each digit list had been presented. Instead, they first spent some time rehearsing and learning each list of digits. Only after they were reasonably sure that they had learned each list well enough, in the order as presented, did they begin to write down the digits in the reverse order as required by the test. On the other hand, subjects with relatively poor performances on the Backward Span test (that is, larger differences between their forward and backward digit spans), tended to report that they commenced responding fairly soon after they were permitted, and in fact, comments were made that they wondered why so much time was allowed for responding. Presumably, these subjects did not realise that this extra time could be used to their advantage in obtaining higher backward span scores.

If general intelligence (or Gf) is assumed to reflect the ability to select efficient strategies, then the above observations of systematic strategic variation would be a plausible explanation of the general finding that backward span is more highly correlated with intelligence than is forward span. It would follow, therefore, that the removal of such strategic variation by considerably reducing the time allowed for responding, would lessen the difference between forward and backward span tasks in the strengths of their association with intelligence. However, results such as those of Hughes (1983) discussed earlier, would suggest that a reduction in strategic variation could possibly increase a tasks correlation with intelligence. In the present study, one second per digit in the memory set was allowed for responding, for both the Forward and Backward Digit Span tasks. Observation of subjects' responding under these conditions indicated that this was ample time for responses to be made to the forward span task, but that for the backward span test, performance appeared to be limited by the speed at which subjects could reverse the order of items in the time allowed, with subjects commencing to write their answers as soon as the the memory items had been presented. Thus, the unexpected finding in this study (that is, the considerably higher loading on Gf of the backward span task, compared to that of the forward span task) could possibly be explained in the light of the results of Hughes (1983) discussed previously, namely, that a decrease in strategic variation can lead to an increasing correlation with intelligence. Such an explanation would not be plausible, however, if it were supposed (as suggested by such authors as Hunt, 1980; Sternberg, 1981b; and Campione et al., 1985), that more complex tasks (i.e., those more highly correlated with 'g') are those which allow a greater degree of strategic variation in their performances.

When discussing the distinction between task dificulty and task complexity, Jensen (1977) reported the experimental finding that paired associates learning is more highly correlated with intelligence when the items are presented to subjects at a slower rate. (This was explained by assuming that the more slowly presented version of the task would allow a greater involvement of higher-order executive control functions in their performances.) In order to see if a similar effect would be found with the memory span task, both fast and slow items for this task (Variables 30 and 31) were included in the present battery. The results displayed in Tables 3 to 6 show that such an effect was not found with the forward span task in this study.

The factor analyses of speed scores from the Gf and Gc tasks (Table 6) indicate the factorial independence of these measures and those speed variables underlying the General Speed factor Gs. The Speed factors of this study, SGf, SGC, and SGfc, which reflect the rate at which subjects worked through the Gf and Gc tests, the Gf and Gc tests, can be regarded as some combination of the Correct Decision Speed, Wrong Decision Speed, and Persistence factors found in the study by Horn and Bramble (1967). It is interesting to note that in this study, as shown in the four factor solution in Table 6, the speed scores from the Gf tasks, and those from the Gc tasks, formed the distinct dimensions, SGf and SGc. This result cannot be predicted from the results of Horn (1980) as, in that study, measures from both the Gf and Gc tasks contributed to the definition of the Correct Decision

Speed, Wrong Decision Speed, and Persistence factors. In the present study, however, there does appear to be systematic differences in speed-accuracy trade-off in the performances of the Gf and the Gc tests. From Table 7 it can be seen that there is a consistent trend for the speed and accuracy measures of the Gf tasks to be more negatively correlated than for the Gc tasks; that is, there seems to be a greater speed-accuracy trade-off in the performances on Gf tasks than in the performances on Gc tasks.

These differences in the speed-accuracy trade-off for Gf and Gc tasks is not easily explained. However, it does seem generally consistent with the view expressed earlier in this thesis, and by Hunt and Lansman (1982), that, although both Gf and Gc tasks are closely related to general intelligence, they do reflect different forms of mental processing at the time of testing. For example, as suggested by Hunt and Lansman, Gf tasks might reflect individual differences in the amount of 'Attentional Resources' available at the time of testing. By contrast, Gc tasks may reflect individual differences in previously acquired knowledge, the acquisition of which may have required 'effortful' processing, but whose actual performances involve primarily 'automatic' processing.

The above interpretation of performances on Gf and Gc tests does suggest a tentative explanation of the observed higher negative correlations between speed and accuracy measures for Gf than for Gc tasks. For a given speed of performance, the likelihood of obtaining correct answers would be expected to be more dependent on the amount of available attentional resources for Gf tasks than for Gc tasks. It is also commonly assumed (e.g., Kahneman, 1973) that the amount of Attentional Resources required for a task, for a given level of accuracy, increases with the speed of performance. It therefore follows that for Gf tasks there should be a greater trade-off between the speed and the accuracy of performances, than for Gc tasks. For a Gf task, speed and accuracy can be thought of as both 'competing' for a limited supply of Attentional Resources to a greater extent than for Gc tasks. For Gc tasks, the accuracy of performances is less dependent on the amount of Attentional Resources available, and therefore competes to a less extent with speed for these Resources. Thus, for tasks such as Vocabulary, which possibly involves largely automatic retrieval of previously learned word meanings (e.g., Hunt and Lansman, 1982), the observed positive correlation between speed and accuracy measures is consistent with the plausible assumption that for items successfully answered retrieval of meanings is mostly fast and automatic, and that relatively longer times are spent on the unsuccessful searching through memory for items which are eventually not correctly answered. If this was the case, subjects obtaining a higher fraction of correct items could be expected to proceed through the Gc test more quickly.

STUDY 2: The Speed and Accuracy of Performances on Tasks of Varying Complexity, and their Relation to Fluid Intelligence

Rationale and Aims of Study

In the previous study, it was found that tasks similar to those used by Wittenborn (1943) to define an 'Attention' factor, were closely associated, in individual differences, with fluid intelligence as measured by the traditional markers Raven's Matrices, Letter Series and Verbal Reasoning. Although Wittenborn (1943), and also Moray (1969, p6), interpreted individual differences in the performances of these Attention tasks as primarily reflecting the ability to maintain high levels of concentration or mental effort, a plausible alternative is that they measure some form of mental speed. This latter interpretation is consistent with the comments of some subjects in the last study, that their performances were limited by their not being able to keep up with the fairly rapid presentation of auditory stimuli. The present study explores the relationship of fluid intelligence with the speed and accuracy of performances on tasks similar to one of the tests of 'Attention', Triplet Numbers, which was devised by Wittenborn. The Triplet Numbers task was selected as it was the one with the highest loading on the Attention factor in Wittenborn's (1943) study, and also was the one with the highest loading on the Gf factor in our previous study. In both of these studies, the test stimuli for the Number Triplets task were presented auditorily at a fixed rate. In the present study, the format of the test was modified to one similar to typical pencil and paper measures of Perceptual/Clerical Speed, such as the Finding a's, or Number Checking tests found in the French et al. (1963) kit of cognitive tests. Presented in this way, subjects were given typed columns of stimuli (in this case, three digit numbers) and were required to work down the columns, as quickly and accurately as possible, circling or crossing out the number triplets in accordance with some prescribed rule. As with Perceptual/Clerical Speed tasks, both speed and accuracy measures were obtained from the number and correctness of responses made within a given time interval.

Following the analyses of Horn et al. (1981), White (1982), or Eysenck (1967), we can regard the rate at which a subject moves through the test as being a function of the subject's (a) speed to correct responding, (b) speed to incorrect responding, and (c) time spent on items before abandonment, or 'persistence'. However, on the basis of Wittenborn's interpretation of the task, and also on the basis of observations of subjects' performances in our previous study, it seemed likely that near perfect accuracy of responding would be achieved if this Number Triplets task was presented in the modified, subject paced format. (Note: In the last study, as a part of the practice phase for the Number Triplets test, subjects confirmed their understanding of the rules for responding by working down a column of items at their own pace. It was observed that this was done with near perfect accuracy.) Under these conditions, therefore, the speed at which subjects worked through the items would represent, to a good approximation, subjects' speed to correct responding. It is interesting to note, also, that under these conditions the definitions of 'mental speed' used in Horn et al. (1981) and by Eysenck (1967), do converge. (In Chapter 2 of this thesis it was pointed out that the measures of 'mental speed' used by these two authors could differ under conditions when the distribution of item difficulties for correctly answered items is different for different subjects. It was also suggested that this could possibly explain their opposite conclusions on the relationship between mental speed and intelligence.)

One of the main aims, then, of the present study was to observe the relation between fluid intelligence and mental speed, and accuracy, measures derived from subject-paced versions of the Number Triplets test. This may provide some insight on the mechanisms underlying the close relationship between the Gf and Attention tests observed in the last study. It is also of more general interest because of its relevance to the broader issue of the relationship, with intelligence, of mental speed and mental 'power', or accuracy (e.g., See Berger, 1982). A secondary aim was to observe the effect of varying the 'complexity' of the prescribed rule in such a task, on the relation of speed and accuracy measures with fluid intelligence. This might give a clearer indication of the differences between measures of 'mental speed' (and accuracy) derived from such tasks, and those similar measures derived from the more common Perceptual/Clerical Speed tests. (The subject-paced, pencil and paper versions of the Number Triplets test, with very simple rules for responding, could be regarded, at face value, as being similar to typical Perceptual/Clerical Speed tests.) The manner in which additional tasks were devised, with rules of varying 'complexity', will be described in detail in a later section.

In addition to markers of fluid intelligence, and tests adapted from Wittenborn's Attention test, Number Triplets, a number of different short-term memory tests were also included in the battery of tests. In view of interpretations, by Stankov (1983b), of Wittenborn's Attention factor in terms of a Working, or Active, Memory system, it was thought of some interest to examine the relation between performances on the Attention tasks and various types of short-term memory tasks. Forward and Backward Digit Span tasks were included, as well as a probed-recall serial short-term memory task. The inclusion of this latter task was suggested by the findings of Cohen and Sandberg (1977, 1980) of substantial correlations, in groups of children, between recency (but not primacy) recall and intelligence. (See Crawford and Stankov, 1983, for a discussion of these findings.) The concept of Working Memory is clearly implied in the proposal of Cohen and Sandberg (1980) that it is the encoding of stimuli under a concurrent memory load which gives rise to the association between intelligence and recency recall.

Table 8

Tests Used in Study 2

Test	Order of Presentation
1. Raven's Matrices	1
2. Letter Series	4
3. RST Task	6
4. Forward Digit Span	2
5. Backward Digit Span	3
6. Probed Serial Recall	7
7. Search Task	5
8. Triplets A	8
9. Triplets B	9
10. Triplets C	10

Table 9

Descriptive Statistics for Variables Used in Study 2

Variable	Number of items	M	s	r_{tt}
1. Raven's Matrices (nc)	18	7.69	2.52	-
2. Raven's Matrices (a)	-	.44	.14	.71
3. Raven's Matrices (s)	-	1.76	.56	-
4. Letter Series (nc)	38	16.58	4.17	-
5. Letter Series (a)	-	.61	.12	.63
6. Letter Series (s)	-	2.84	.76	-
7. RST Task	24	54.08	8.60	.87
8. Forward Digit Span	24	11.66	5.32	.93
9. Backward Digit Span	24	15.97	4.21	.84
10. Primacy Recall	15	34.11	8.25	.67
11. Recency Recall	15	38.13	8.77	.75
12. Search (nc)	-	78.80	10.57	.96
13. Triplets A (nc)	-	46.86	9.54	.98
14. Triplets B (nc)	-	36.74	9.02	.96
15. Triplets C (nc)	-	19.98	8.05	.98
16. Triplets C (nc)*	-	21.31	8.64	.96
17. Search (a)	-	.994	.010	.86
18. Triplets A (a)	-	.975	.033	.95
19. Triplets B (a)	-	.965	.029	.84
20. Triplets C (a)	-	.932	.080	.90
21. Triplets C (a)*	-	.949	.074	.82
22. Search (s)	-	79.23	10.48	.96
23. Triplets A (s)	-	48.11	9.78	.97
24. Triplets B (s)	-	38.11	9.33	.96
25. Triplets C (s)	-	21.24	8.00	.97
26. Triplets C (s)*	-	22.25	8.50	.95

Notes: * Variable obtained from last three repeats only. See text.
(nc) = number correct score
(a) = accuracy score
(s) = speed score

Method

Subjects

These were 118 male apprentice students at the Royal Australian Air Force School of Technical Training, Wagga Wagga, N.S.W., with mean age 18.1 years. As their selection for training by the Air Force was based, in part, on the students' performances on a wide range of mental tests, it is to expected that the range of abilities of this sample would be less than that of the general population.

Procedure

A battery of ten tests was presented to groups of between 15 and 20 subjects. Each test session lasted about three hours, and all tests were presented in a fixed order within a single test session. The tests, and the order of their presentation, is shown in Table 8. Those tests requiring auditory presentation were given via a Sony tape cassette player (Model CP31), with two external loudspeakers placed at either side of the front of the testing room.

Tests

The tests used in the study are listed in Table 8, and variables derived from these tests are shown in Table 9. In Table 8, the tests have been grouped under the three main headings of Gf Tests, Memory Tests and Triplets Tests. The first group includes the two traditional markers of fluid intelligence (Gf), Raven's Matrices and Letter Series, as well as the the RST Task. This latter test was found in previous studies (Crawford and Stankov, 1983, and the first study of this thesis) to be a good marker of Gf, as defined by more traditional reasoning and problem solving tasks. These three tests were used in Study 1 of this thesis, and in the present study were presented and scored in a similar manner except for minor changes in their timing. For the Raven's Matrices and Letter Series tests, the time limits were increased from 10 to 15 minutes, and from 7 to 10 minutes, respectively. In Study 1 the stimuli presentation rate for the RST Task was constant at about one letter every 1.5 seconds. In the present study, this rate was reduced to about one letter every two seconds. These changes were made to allow for possible differences in the ability levels of subjects used in the two studies.

The second group of tests comprises the well known Forward and Backward Digit Span tests, and also a probed, serial recall task similar to that used by Cohen and Sandberg (1977) in their investigations into the relations of primacy and recency recall to intelligence. In the present study, the Backward Digit Span test was presented in the usual manner, with subjects being allowed ample time (approximately 3 seconds for each digit in the memory set) to write their responses.

The third group of tests (the Triplets tests) comprises a series of three tests, Triplets A, Triplets B, and Triplets C, which could be regarded as being derived from the Number Triplets task used in our previous study, and by Wittenborn (1943). In each of these tests, subjects are presented with paper test sheets containing columns of three-digit numbers, and are required to work down the columns, as quickly and accurately as possible, circling or crossing out the numbers in accordance with a previously prescribed rule. The three tests differed in the nature of this prescribed rule. For the Triplets C test, the rule was similar in form to that used in the Number Triplets test of our last study, and in the study by Wittenborn (1943). For the Triplets C test, the rule was as follows:

"Circle those numbers for which the last digit is the largest and the second is the smallest, or the first is the smallest and the second is the largest. Cross out the others."

For the above rule, the condition for circling the numbers can be regarded as a disjunction of two component conditions. The rule for the Triplets B task was designed to parallel one of these component conditions. For the Triplets B task, the rule was:

"Circle those numbers for which the last digit is the smallest and the second is the largest. Cross out the others."

This rule can be regarded as involving the conjunction of two separate logical conditions. The form of the rule for the Triplets A test resembled that of each of these component conditions. The rule for the Triplets A test was:

"Circle those numbers for which the first digit is the largest. Cross out the others."

Thus the Triplets A, B, and C tasks can be viewed as involving a sequence of rules whose logical relations can be described as follows. Let p_1, p_2, ... p_7 represent distinct logical conditions, of the following form: 'If the (first/second/last) digit is the (largest/smallest)'. Then the form of the rules for Triplets tests is:

'Circle those numbers for which p (is true). Cross out the rest.';

where, for Triplets A, $p = p_1$;

for Triplets B, $p = p_2$ and p_3;

and, for Triplets C, $p = (p_4$ and $p_5)$ or $(p_6$ and $p_7)$.

The rules for each of the Triplets tests can thus be regarded as forming a hierarchy of tests of increasing 'complexity', with the conditions for responding at one level being formed by the conjunction, or disjunction, of conditions of the form defining the conditions for responding at the next level lower in the hierachy.

The presentation and stimuli for the Search Task is similar to those for the three Triplets tests. However, the rule for responding for the Search test does not conform to the logical pattern underlying the responding rules for the Triplets tests. In this test, the prescribed rule is to circle all those number triplets containing any of the digits 3, 5 or 8, and to cross out the rest. This test resembles, therefore, the well-known Perceptual/ Clerical Speed test, Finding a's, although in its present form it is possible that it does contain a greater motor component. (In the present test, each item is circled or crossed, while for the Finding a's test, only those items containing a's are required to be crossed out.)

A brief description of each of the test used in this study is given below. Except for minor changes, the first five tests are the same as tests used in the last study.

1. Raven's Matrices

For each item subjects were presented with a two dimensional array of geometric figures with one missing. Subjects were required to choose, from 8 alternatives, the figure which would best complete the pattern. Test items were contained in a booklet, and subjects gave their answers on separate response sheets.

Time allowed: 15 minutes.

Scoring: Variable 1 = Number of correct items.

Variable 2 = Accuracy score. (number of items correct ÷number of items attempted)

Variable 3 = Speed Score. (number of items attempted ÷time taken)

2. Letter Series

For each item a list of letters was presented, and subjects were required to write the letter which continued the pattern in the series.

Time allowed: 7 minutes.

Scoring: Variable 4 = Number of correct items.

Variable 5 = Accuracy score. (number of items correct ÷number of items attempted)

Variable 6 = Speed Score. (number of items attempted ÷time taken)

3. RST Task

Subjects heard lists comprising the letters R, S and T in random order, presented at the rate of one letter every two seconds. At the end of each list, subjects had to write the number of times that each letter had occurred in the list.

Scoring Variable 7 = Total number of correct letter counts.

4. Forward Digit Span

For each item, subjects heard a series of digits presented at the rate of one digit per second. Subjects were instructed to write them down in the order in which they had been presented as soon as each list had finished. The lengths of the lists varied from 5 to 11 digits, with four items for each length, and were presented in ascending order.

Scoring Variable 8 = Total number of correctly recalled lists.

5. Backward Digit Span

Same as above, except that subjects were required to write the lists in reverse order.

Scoring: Variable 9 = Total number of correctly recalled lists.

6. Probed Serial Recall

For each item, subjects heard a list of random digits spoken at the rate of about two digits per second, and followed by either of the words 'first' or 'last'. The lists were of lengths 12, 15 or 18 digits, and these lengths were presented in random order. Subjects were instructed that if the word 'first' was heard, then they were to write down as many digits as possible, in their correct order, from the front of the list. Similarly, if the word 'last' was heard, they were to write as many digits, in their correct order, from the end of the list.

Scoring: Variable 10 (Primacy recall) = Number of correctly recalled digits, in their correct positions, for items for which the cue word was 'first'.

Variable 11 (Recency recall) = Number of correctly recalled digits, in their correct positions, for items for which the cue word was 'last'.

7. Search Task

Subjects were presented with columns of digits and were required to proceed down each column, as quickly and accurately as possible, circling all of the digits 3, 5, and 8, and crossing out the rest. The signal 'Ready, set, go!' was given on each trial, and one minute later the signal 'Stop' was given. This procedure was repeated six times using six separate lists of digits. The lists for each trial contained three columns, each of 64 digits. Scoring: See under next group of tests.

8., 9., 10. Triplets Tasks (Triplets A, Triplets B and Triplets C)

Each of these tasks was presented in a manner similar to that of the above test, with six separate one minute trials, and with 'start' and 'stop' signals given for each trial. Subjects were presented with six lists, each of two columns of three-digit numbers. In the first stage of each test, subjects were instructed on a response rule, which was different for each of the three Triplets tests. The test then proceeded as for the Search test, with subjects, on each of the six trials of each test, attempting to circle or cross out as many number triplets as possible in the one minute time interval. This procedure was varied slightly for the Triplets C test, where after each trial subjects were given feedback on the accuracy of their responding. This was done by the correct answers for the first fifteen items being read out, and the subjects being asked to make sure that they understood any errors which they had made. The rules for responding for the Triplets tasks are as follows.

Rule for Triplets A: 'Circle the numbers for which the first digit is the largest. Cross out the rest.'

Rule for Triplets B: 'Circle the numbers for which the last digit is the smallest and the second is the largest. Cross out the rest.'

Rule for Triplets C: 'Circle the numbers for which the last digit is the largest and the second is the smallest, or the first digit is the smallest and the second the largest. Cross out the rest.'

Scoring:

All variables, except for numbers 16, 21, and 26, are averages of the six repeats of each test. For Variables 16, 21 and 26, (marked *), the averages were obtained from only the last three repeats. The accuracy scores below are the number of correct responses divided by the number of items completed. The speed scores are equal to the number of items completed as no subject was able to complete all items in the time allowed.

Variable 12 = number of correct responses for Search test.

Variable 13 = number of correct responses for Triplets A test.

Variable 14 = number of correct responses for Triplets B test.

Variable 15 = number of correct responses for Triplets C test.

*Variable 16 = number of correct responses for Triplets C test.

Variable 17 = accuracy score for Search test.

Variable 18 = accuracy score for Triplets A test.

Variable 19 = accuracy score for Triplets B test.

Variable 20 = accuracy score for Triplets C test.

*Variable 21 = accuracy score for Triplets C test.

Variable 22 = speed score for Search test.

Variable 23 = speed score for Triplets A test.

Variable 24 = speed score for Triplets B test.

Variable 25 = speed score for Triplets C test.

*Variable 26 = speed score for Triplets C test.

Statistical Analyses

A number of factor analyses were carried out on selections of the variables listed above. The maximum likelihood method developed by Joreskog, and incorporated in the SPSS statistical package was used for all of these analyses. Factors were objectively rotated according to the 'oblimin' criteria, with the parameter 'delta' being set at its default value of zero (Nie et al., 1970, p. 485).

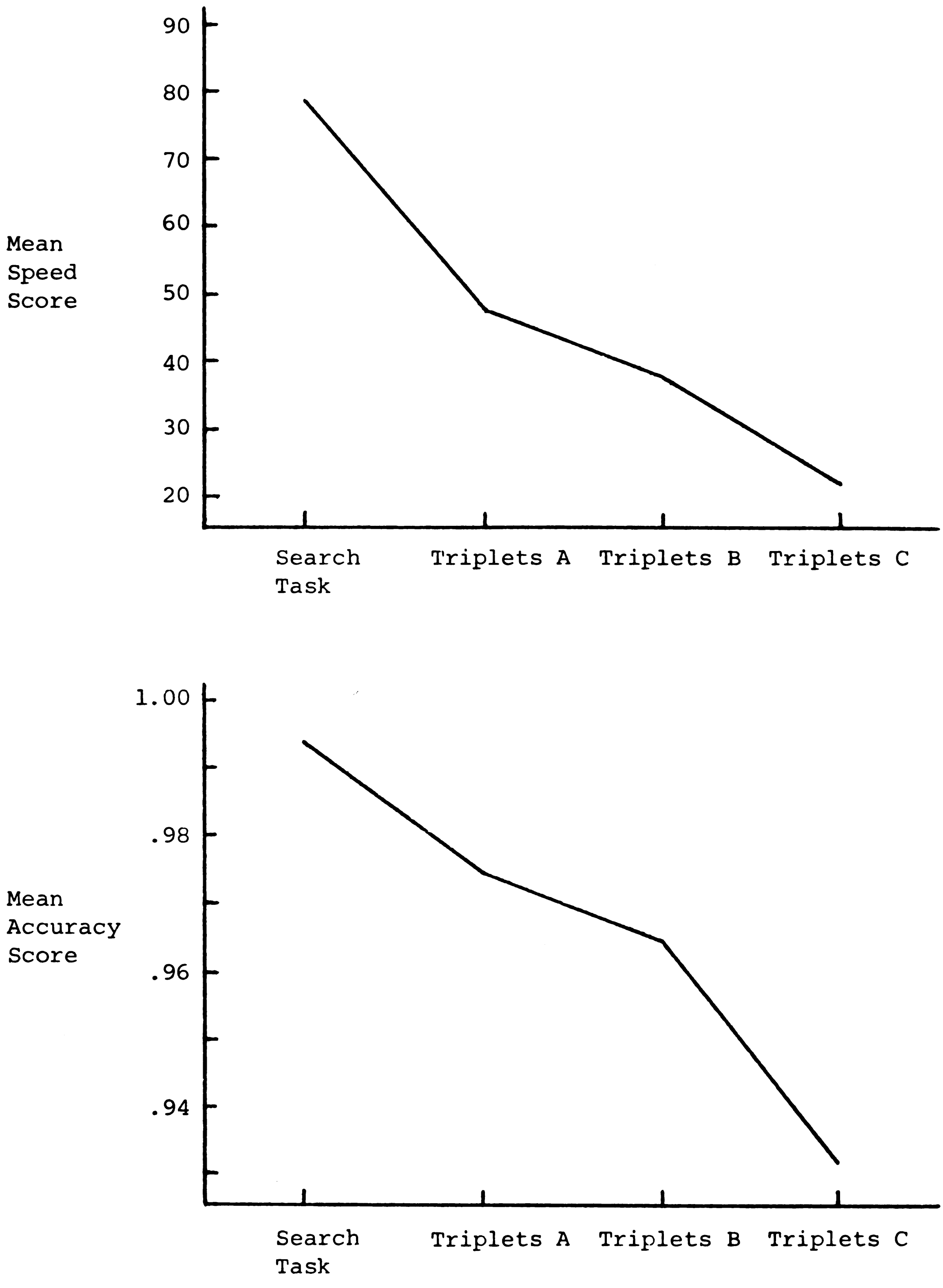
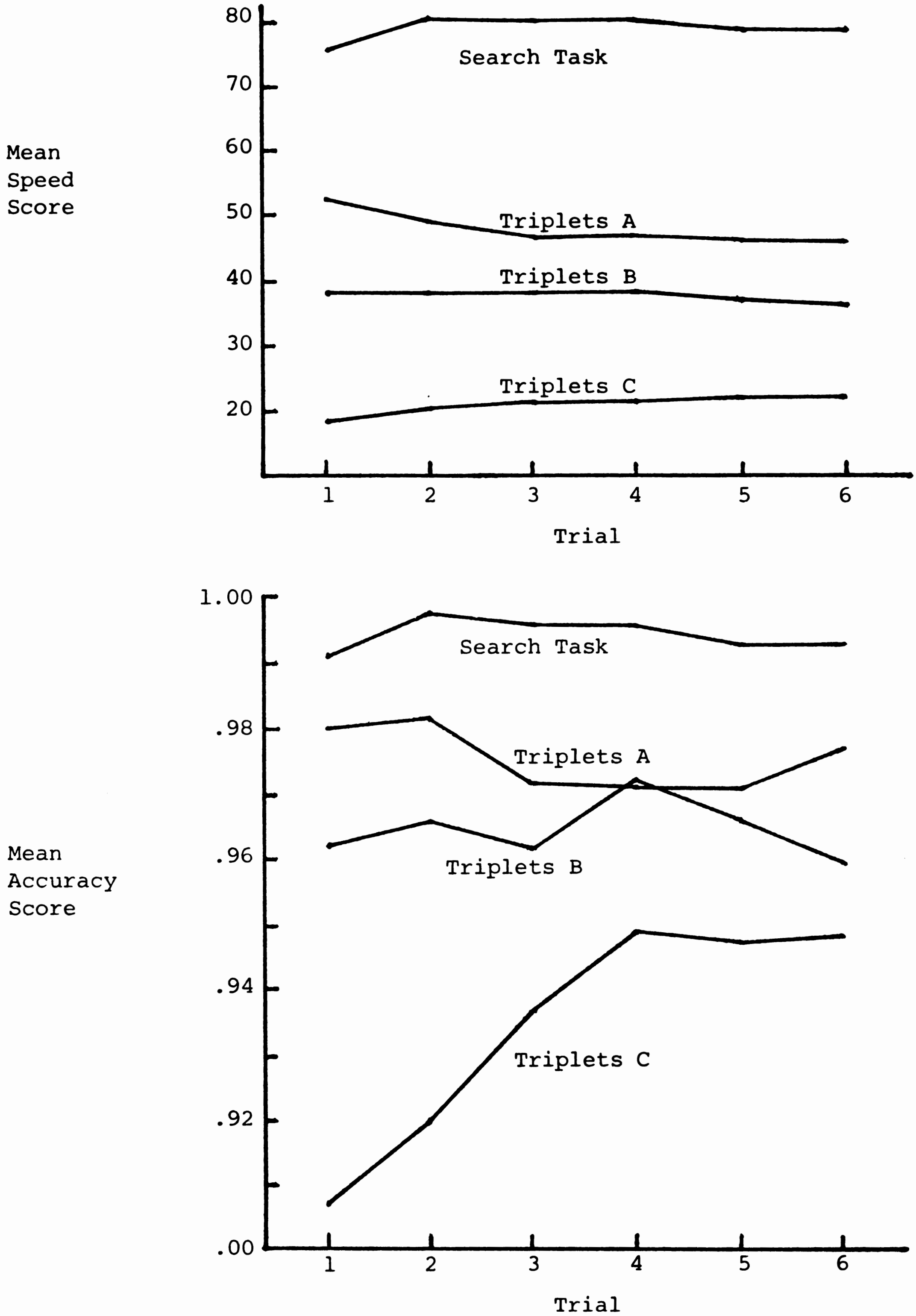


Figure 4 Mean speed and accuracy scores for the Search and Triplets tasks.



<u>Figure 5</u> Mean speed and accuracy scores on the Search and Triplets tasks for each of the six repeated trials.

Results

The means and standard deviations of variables used in this study are shown in Table 9. Where possible, reliability estimates for the variables were calculated from the Cronbach-alpha formula, and are also shown in Table 9. For the Search and Triplets variables these estimates were based on correlations between the six repeated trials within each test, while for the remainder of the tests, odd-even split-half reliability estimates were used. The correlations between all variables used in the study are shown in Table 31 in the Appendix.

Performances on Search and Triplets tasks: The mean values of accuracy and speed measures derived from the Search and Triplets tasks, extracted from Table 9, are plotted in Figure 4. Within the set of Triplets tasks (Triplets A, Triplets B, Triplets C) the decreasing speed and accuracy of performances, with increasing complexity in the responding rule, can readily be seen. The higher levels of performances on the more 'perceptual' Search task, in comparison with the three Triplets tasks, can also be observed. Figure 5 shows the mean accuracy and speed for each of the six repeated trials of each of these tests. The most striking feature here is the relatively strong increase in mean performances over the first four trials (especially in the accuracy scores) of the Triplets C task. This contrasts with the relative lack of systematic improvement over trials for the Search and other Triplets tests.

Table 10

Correlations between Accuracy and Speed Variables for the Search and Triplets Tasks (Study 2) (Extracted from Table 31 in the Appendix)

N = 118

	17	18	19	21	22	23	24
17. Search (a)							
18. Triplets A (a)	12						
19. Triplets B (a)	12	12					
21. Triplets C (a)*	23	-01	20				
22. Search (s)	11	-07	-04	09			
23. Triplets A (s)	11	-10	02	10	69		
24. Triplets B (s)	02	01	-06	05	58	79	
26. Triplets C (s)*	02	01	23	33	39	56	63

Notes: 1) Decimal points have been omitted.

2) * Variables 21 and 26 were calculated using trials 4, 5 and 6 only. See text.

The correlations amongst the accuracy and speed variables of the Search and Triplets tasks are displayed in Table 10. For the measures derived from the Triplets C task (Variables 21 and 26), only those trials for which average performance had stabilised (that is, trials 4, 5, and 6; see Figure 5) were used in their calculation. (The use of all six trials for the calculation of these variables, however, results in essentially the same results; see correlations with Variables 20 and 25 in Table 31 in the Appendix.) The most interesting aspect of this data is the consistently higher correlations among the speed measures, in comparison with those among the accuracy variables. Note that, in view of the high reliability estimates for the accuracy variables shown in Table 9 (which vary from .82 to .90), it is unlikely that the low correlations of the accuracy measures, both amongst themselves and with the speed measures, are due to the lack of reliable individual differences in these measures produced by ceiling effects. Despite the high accuracy scores for these tasks, which might suggest the possibility of ceiling effects, the reliability estimates of the accuracy measures are only slightly less than those of the speed measures. Also, it is interesting to note the absence of substantial negative correlations between the speed and accuracy measures, which might have been expected from the presence of a speed-accuracy trade-off in the performances of these tasks. In fact, a positive correlation of .33 can be seen between the speed and accuracy measures of the Triplets C test.

Table 11

Factor Pattern Matrices from Analysis Using Accuracy and Speed Scores from Gf, Search and Triplets Tasks (Study 2) (Triplets C variables based on the last three repeats only)

N = 118	Solution 1				Solution 2				
Variables	Gf	DSp	S(T)	h^2	Gf	DSp	S(T)	S(Gf)	h^2
2. Raven's Matrices (a)	46	07	14	28	33	10	20	-30	33
5. Letter Series (a)	84	01	-06	70	74	06	-01	-19	69
7. RST Task	35	17	25	29	34	19	25	03	29
3. Raven's Matrices (s)					-01	04	15	69	52
6. Letter Series (s)					-13	07	20	64	51
8. Forward Digit Span	-11	78	01	55	-07	76	-02	06	54
9. Backward Digit Span	18	56	-02	42	22	58	-05	10	45
10. Primacy Recall	00	58	01	33	-03	57	01	-11	34
11. Recency Recall	08	49	06	27	04	49	07	-05	27
17. Search (a)	21	16	03	10	04	18	10	-35	19
18. Triplets A (a)	13	06	-09	03	17	07	-11	06	04
19. Triplets B (a)	31	05	-05	11	31	05	-03	-08	12
21. Triplets C (a)	63	-11	05	36	56	-06	09	-10	34
22. Search (s)	-13	27	69	56	-11	28	68	09	58
23. Triplets A (s)	-05	06	91	83	-06	05	92	-02	88
24. Triplets B (s)	00	-06	89	77	05	-07	86	12	76
26. Triplets C (s)	39	-15	63	56	47	-14	61	15	62

Factor Intercorrelations

	Gf	DSp	S(T)
Gf			
DSp	41		
S(T)	13	12	

	Gf	DSp	S(T)	S(Gf)
Gf				
DSp	35			
S(T)	11	15		
S(Gf)	-22	-11	09	

Notes: Decimal points have been omitted.
Factor-pattern loadings greater than .20 have been underlined.

Factor Analyses: Table 11 shows the results of factor analyses of a number of variables which include speed and accuracy measures from the Search, Triplets, Raven's Matrices and Letter Series tests. For the analyses shown in Table 11, only those trials for which average performance had stabilised (trials 4, 5, and 6; see Figure 5) were used to obtain the speed and accuracy measures for the Triplets C task. This was done so that possible differences between the Triplets C test and the other Triplets tests in their factor pattern loadings could not be readily interpreted in terms of subject's initial learning rates on the Triplets C task. For Solution 1 in Table 11, the speed scores of the Raven's Matrices and Letter Series tests were excluded from the analysis. As in Study 1, this was done to avoid the possible distortion of the factor solution due to the spuriously high negative correlations between speed and acccuracy scores derived from performances on the same set of test items. (See the discussion in the Results section of Study 1.) For this solution, root-one criterion suggested four factors. However, the three factor solution was selected because of the ready interpretation of the factors, and because the Chi-squared test indicated that this was an acceptable solution; Chi-squared = 61.21, d.f. = 63, p = .55. The first factor contains the highest loadings of the traditional fluid intelligence markers, Raven's Matrices and Letter Series. It also contains the major, though smaller, loading of the RST task which was found in Study 1 (and also by Crawford and Stankov, 1983) to load on the same factor as traditional measures of fluid intelligence. The first factor has therefore been labelled fluid intelligence, Gf. The second factor is marked by the two memory span tests, Forward and Backward Digit Span, as well as the two probed serial recall measures, and has been labelled Digit Span, DSp. The third factor contains the major loadings of the speed measures derived from the Search and Triplets tests, and has been labelled Speed(Triplets), S(T).

Unlike in Study 1, the inclusion in the present analysis, of both speed and accuracy measures from the same tests gave easily interpretable results. Solution 2 of Table 11 gives the result of factor analysis with the inclusion of the speed variables from the Raven's Matrices and Letter Series tests; Chi-squared = 55, d.f. = 74, p = .54. The first three factors can be given essentially the same interpretations as the first three factors of Solution 1, and have been named accordingly. The fourth factor is marked by the two speed variables from the Gf markers, Raven's Matrices and Letter Series, and has therefore been labelled Speed (Gf), or S(Gf). However, the definite, though smaller, negative loadings of the accuracy measures of these Gf markers suggests that this factor might also reflect to some extent individual differences in a speed-accuracy trade-off in the performances of the Gf tasks.

For reasons given above, the above two analyses were carried out using Triplets C measures derived from only the last three repeated trials of this test. These analyses were repeated with the Triplets C variables being derived from all six repeats. However, as almost identical factor analytic results were obtained, these results are not reported.

The most important issue to be addressed by these analyses is the relationship between performances on the Triplets tests and fluid intelligence, and in particular, how this is affected by changes in the complexity of the rule for responding. The main finding on this question is the observed increase, in both of the analyses of Table 11, from the Triplets A to Triplets C tasks, in the sizes of the factor loadings on Gf of both the accuracy and speed variables of the Triplets tasks. That is, increases in the complexity of the responding rule is accompanied by increases in the factor loadings on fluid intelligence.

A number of further features of these results can also be noted. Firstly, although there is, in all solutions, a monotonic increase in the factor loadings on Gf from the Triplets A to the Triplets C test, the change from the Triplets B to the Triplets C test is more marked than that from the Triplets A to the Triplets C variables. This effect can be seen to be slightly more pronounced for the speed measures, than for the accuracy measures, of performances on the Triplets tests. Secondly we can observe, particularly in the first solution of Tables 11, the generally higher loadings on Gf of the Triplets accuracy scores, compared with those of the Triplets speed scores. Note, however, that this difference is considerably reduced in the second solutions of these tables, where individual differences in S(Gf) are factored out. This suggests that the higher loadings of the accuracy scores on Gf might be a result of the existence of systematic individual differences in speed-accuracy trade-off, which is reflected in the performances of both the Triplets and the Gf tests.

An aspect of the first solution of Tables 11, which may appear to be counter to initial expectations, is the slightly higher loadings on the Gf factor of the Search task's accuracy score, compared with that of the Triplets A test. An expectation of the reverse finding might plausibly follow from an evaluation of the responding rule for the Triplets C task ('Circle those numbers for which the first digit is the largest'), as involving higher-order, or less perceptual, mental processes than are involved in the rule for the Search test ('Circle those numbers containing the digit 8'). However, as can be seen in the second solution of Tables 11, the factoring out of individual differences associated with the S(Gf) factor resulted in the more expected pattern of factor loadings being obtained. Thus this weak, but unexpected, result can be accounted for if it is assumed that, for some reason which is not immediately clear, the accuracy score for the Search task is more affected by individual differences in speed-accuracy trade-off than the accuracy score for the Triplets A test.

Except for the modes of presentation, there is a strong similarity between the experimenter paced Number Triplets test from Study 1, and the subject

Table 12

Comparison of the Present Study (Study 2) and Study 1, on Correlations Between Fluid Intelligence Composite Scores and the Triplets, or Number Triplets, Tests

Correlations derived from the present study (Study 2)
(N = 118)

	Gf(nc)	Gf(a)	S(Gf)
16. Triplets C (nc)	.40	.38	.14
21. Triplets C (a)	.39	.47	-.15
26. Triplets C (s)	.37	.33	.22

Correlations between similar variables, obtained in Study 1
(N = 141)

	Gf(nc)	Gf(a)	S(Gf)
Number Triplets*	.39	.43	-.18

Notes: Gf composite scores of both studies were formed by adding the z-scores of the appropriate Raven's Matrices and Letter Series variables.

(nc) = number correct score
(a) = accuracy score
(s) = speed sccore

* The Number Triplets test from Study 1 was experimenter paced, so no speed scores are available from this task.

paced Triplets C test in the present study. Table 12 gives the correlations between the variables derived from these two tests, and equivalent measures of fluid intelligence obtained in the two separate studies. The number correct, accuracy and speed Gf composite variables (Gf(nc), Gf(a), S(Gf), respectively) were calculated in each of the two studies by adding the z-scores of the appropriate variables from the Gf markers, Raven's Matrices and Letter Series. It can be seen that, despite the different sources of subjects for the two studies, the magnitude of the correlations are comparable. In particular, there is a strong similarity between the Triplets C accuracy variable (from this study) and the Number Triplets test (from Study 1), with respect to the magnitudes and patterning of the correlations with the measures derived from the Gf tests. As can be seen from Table 6, both these variables show slightly higher correlations with Gf(a), than with Gf(nc), and have small negative correlations with the speed measure, S(Gf).

We may also note in Table 12 the slightly higher correlation with the Gf composite, Gf(a), of the Triplets C accuracy score ($r = .47$), compared with that of the Triplets C speed score ($r = .33$). (This difference parallels the slightly higher factor-pattern loadings of the Triplets C accuracy measures on the Gf factors in the two factor solutions shown in Table 4.) Statistical analysis indicated, however, that the difference between these correlations is not significant for a Type 1 error rate of .05. ($t = 1.48$, $t_{critical}$ (alpha = .05) = 1.66 (one tailed), or 1.98 (two tailed). The 'T_2' statistic, derived by Williams

(1959) from a modification of Hotelling's original 'T_1', was used for this analysis. This statistic was the one recommended by Steiger, 1980, for the testing of differences between two dependent correlations involving a common variable. The formulae used for the present calculations were taken from Steiger, 1980.)

Discussion

One important issue addressed by this study is whether, for performances on tasks involving mental processing of relatively high 'complexity', it is 'mental speed' or the accuracy of performance which is more strongly related to traditional measures of fluid intelligence. The task which was chosen for this study to represent the involvement of complex mental processing was an adaptation of the Number Triplets test devised by Wittenborn (1943) as a measure of the ability to maintain high levels of concentration. (The assumption of this being a task of relatively high complexity derives from the findings of Study 1 of this thesis, and the re-analysis of Wittenborn's original data by Stankov, 1983a.) One main finding of this study was the absence of significant differences between measures of mental speed and accuracy in performances on such a task, in their relation to measures of fluid intelligence, or general intelligence. (The tests used as markers of fluid intelligence in this study, Raven's Matrices and Letter Series, are also commonly regarded as good measures of general intelligence.) The results of factor analyses did suggest that accuracy was slightly more strongly related to intelligence than the speed of performances, but the data indicated that this slight tendency could probably be explained by the existence of systematic individual differences in speed-accuracy trade-off. Moreover, the difference between the correlations, with Gf, of the speed and accuracy measures of performance on the Triplets C test, was found to be not statistically significant.

The second important observation was the increasing sizes of the factor pattern loadings of the Triplets variables, on Gf, with increasing 'complexity' of the rules for responding. This gives some support to the appropriateness of the term 'task complexity' to describe the variation between tasks in their relation to fluid intelligence, a view which was argued for previously in this thesis. Since the markers of Gf are consistently found to be amongst the tests with the highest g-loadings, these results could, however, also be seen as supporting the interpretation of psychometric 'g' in terms of this notion of task complexity, similar to that proposed by Jensen (1977), and Snow (1980). However, the finding of the previous study (Study 1), (that the Number Triplets task had its major loading on the fluid intelligence factor), together with the results of the present study, do suggest that the higher g-loadings of tasks which involve apparently more 'complex' mental processes, are best interpreted as being due to their stronger association with Gf.

STUDY 3: A Comparison of Performances on a Once-Through and A Fixed-Time Presentation of a Subject-Paced Measure of Fluid Intelligence, and Their Correlations With an Experimenter-Paced Measure of Mental Ability

A common method by which measures of mental ability are obtained from test performances is to present subjects with a number of test items to solve, and to obtain a score equal to the number of items correctly answered within some specified time limit. Eysenck (1967), White (1982), and others have suggested that this measure is actually the result of a number of distinct 'performance' components, namely Mental Speed, Carefulness and Persistence. Mental Speed is related to the time required to produce correct responses, Persistence to the time spent on items which are subsequently abandoned, and Carefulness to the likelihood of giving incorrect answers when instructed not to guess, and sometimes interpreted as a measure of a subject's tendency to check their answers. Some models (e.g., White, 1982) postulate a separate Accuracy dimension, in addition to those of Mental Speed and Persistence (see Chapter 2 for a discussion of the various models).

So far as a purely formal, or statistical description of performances on mental tests is concerned, each of these subject parameters could be regarded as being of equal status, that is, as none of them being any more 'basic', or 'fundamental', than the others. Eysenck (1967), for example, writes of 'splitting the IQ' into the three components, Mental Speed, Carefulness and Persistence. However, it does not necessarily follow from the fact that each of these parameters are required to give an adequate account of subjects' test performances, that they should therefore be regarded as 'components' (facets, parts, etc.) of intelligence. From a more substantive, or psychological, viewpoint it is questionable whether certain of these parameters, especially Carefulness and Persistence, should be regarded as '<u>components</u>' of intelligence, or even as representing <u>abilities</u>. Given the substantive interpretations which have been placed on these parameters, it is to be expected that variations in subjects' mood, test motivation, interpretation of test instructions, and other factors related to a speed/accuracy trade-off in performances, would affect these parameters in ways which would not ordinarily be interpreted as reflecting changes in intelligence. It should be noted that, although Eysenck (1967) does talk of 'splitting the IQ' into the three components, elsewhere, it is clear from his writing that it is the Mental Speed component, rather than those of Carefulness, or Persistence, which is regarded as the one more 'fundamental' to the concept of intelligence.

<u>Aims and Rationale of Study</u>

In view of the above discussion, tests similar to those which defined

Wittenborn's Attention factor, are of particular significance. If, as suggested by the results of Study 1, they are good measures of intelligence (or more specifically, fluid intelligence), then such tests, being experimenter paced, do provide a means of measuring intelligence which is relatively free from possible influences associated with systematic individual differences in factors related to speed/accuracy trade-off, such as Carefulness or Persistence. One aim of this study is to investigate a particular task, the 'Swaps Test' which might prove useful for this purpose. This task could be regarded as an auditory version of the familiar 'cups and ball' side-show game. (In this game a small ball is placed inside of one of a number of identical inverted 'cups', and members of the audience have to keep track of the position of the ball as the 'entertainer' executes a number of pairwise swaps of the ball's position.)

The reasons for selecting this task for investigation in this study were as follows. Firstly, at face value, abilities tapped by this task would seem to be similar to those tests defining Wittenborn's (1943) Attention factor or the serial short-term memory test, RST Task, described previously in this thesis. This is especially so if these tasks are interpreted as reflecting the efficiency of Working Memory, that is, the ability to process information concurrent with a short-term memory load. In the light of the results of Study 1 in this thesis, it was therefore hypothesised that this Swaps test might be a good marker for fluid intelligence. A second reason is that experience showed that it was, generally, more difficult to maintain subjects' interest and motivation for their performances on the original Attention tasks, such as the Number Triplet and Letter Lists tasks which were used in Study 1, compared with when they were performing on the more traditional 'problem-solving' tests of fluid intelligence. It was thought that this Swaps test, being derived from a side-show game, at least had the potential (with the appropriate microcomputer graphics, etc.) of being made more 'interesting'. (This is particularly the case for younger subjects, who, the author found, tended to find the original Attention tests especially boring.) A third reason is that, although Wittenborn (1943) specified that performances on his Attention tests should not be a function of subjects' background knowledge, they do, nevertheless, involve certain elementary skills, such as being able to rapidly discriminate between vowels and consonants, or between odd and even digits. It was thought that the Swaps test would be less likely to be influenced by such factors, especially for younger subjects, or those in the lower ranges of ability. Another reason for the choice of the Swaps test as one which might be useful as a measure of intelligence, is the relative ease with which test items of varying difficulties can be generated. (This can readily be achieved by varying the rate at which the 'swaps' occur, the number of possible elements which can be rearranged, or the number of 'swaps' which occur in each item.) This would allow the test to be easily adapted for use in groups with different ranges of ability, and also makes the test particularly suitable for presentation in a tailored-testing format.

The second main aspect of this study concerns the mode of presentation and scoring of traditional tests of fluid intelligence, such as the Raven's Progressive Matrices and the Letter Series tests. In the previous two studies in this thesis (Studies 1 and 2), these tests were presented in a 'once through' format. This method, used by Crawford and Stankov (1983), has the advantage of being able to measure systematic individual differences in the rates at which subjects work through the test items. Although such a mode of presentation is not uncommon, (it typically occurs in individually administered tests, and with automated testing, e.g., see Calvert and Waterfall, 1982; Acker, 1983), it is more common, especially with group testing, that a fixed-time format is used. (By 'fixed-time' is meant the procedure in which subjects are required to obtain as many correct answers as possible in a fixed time limit.) However, the question could be asked whether the results of the previous studies were, in some way, influenced by the choice of a once-through presentation of the Gf marker tests. Of particular interest here was the finding that tasks similar to Wittenborn's Attention tests are more strongly associated with fluid intelligence than are the recognised lower complexity tasks measuring 'specific' abilities such as memory span or perceptual/clerical speed. It could be argued, for example, that Gf scores obtained from a once-through presentation could be more influenced by individual differences in non-ability factors related to speed/accuracy trade-offs, and that these factors may influence correlations with other tests. It is plausible, for example, that, with a once-through presentation, subjects who work very rapidly through the test items and reach the end before the time limit, would, in a fixed-time presentation, utilise the remaining time by working on previously abandoned items, or checking for errors.

The main aim, then, of this study is to examine if correlations of performances on a traditional measure of fluid intelligence with the Swaps test, and with measures of perceptual speed, is dependent on whether the fluid intelligence marker is presented in a once-through, or fixed-time manner. This will be done by giving each subject two versions of the traditional marker of fluid intelligence, Raven's Progressive Matrices, with one version being presented in a once-through, and the other in a fixed-time, format. Correlations of the Swaps and Perceptual Speed tests, with the two versions of the Gf marker, will then be compared to examine the extent to which these are affected by the mode of presentation of the Raven's Matrices test.

Method

Subjects These were 126 students attending New South Wales State High Schools, with average age 16.3 years, standard deviation .50 years. The sample contained a majority of females (86%) but it is not expected that this

Table 13

Tests Used in Study 3 and the Orders of Presentation

Test	Number of items	Orders (a)	(b)
1. Raven's Matrices (Once-through presentation)	18	1	4
2. Raven's Matrices (Fixed-time presentation)	18	4	1
3. Finding A's	-	2	2
4. Number Comparison	-	5	5
5. Swaps	18	3	3

should affect the results of the study.

Procedure The tests were presented to groups of average size about 12 subjects, with all tests being given within one test session lasting about 1.75 hours. The tests were given in a fixed order, except that the orders of the two versions of the Raven's Matrices test were reversed for half of the subjects. Table 13 gives a list of the tests used in this study, and the two orders of presentation. Tests requiring auditory presentation were given via a Sony cassette player (Model CP31), with the two speakers located at either side of the front of the room.

The Tests

Items for the two Raven's Matrices tests (Tests 1 and 2 in Table 13) were obtained by the selection of the odd and even items, respectively, of Set II of the Raven's Advanced Progressive Matrices test (Raven, 1965). For Test 1, the test was presented in the once-through format, which was also used in the previous two studies of this thesis. For this mode of presentation, subjects were required to always work forward through the test at their own pace, and to stop either when they had completed the final item, or when they were told that the test was over. They were also instructed to place a tick next to the item on which they were currently working whenever they heard 'tick-now' signals. These were given via the loadspeakers at one-minute intervals. As with the previous studies, the subjects were instructed to work as quickly and accurately as possible, but were told that accuracy, rather than speed, of performance was more important. Also, subjects were told that there was no penalty for incorrect responses.

For the other Raven's Matrices test (Test 2), a fixed-time presentation was used, with subjects being instructed to obtain as many correct answers as possible within 20 minutes. (The usual time limit for the full Raven's Progressive Matrices test, from which half the items were drawn to for Test 4, is 40 minutes; see Raven, 1965.) The tests Finding A's and Number Comparison, were adapted from the two Perceptual Speed markers in the French et al. (1963) kit of mental tests.

A short description of each of the tests used in this study is given below.

1. Raven's Matrices (Once-through)

For each item subjects were presented with a two dimensional array of figures, with one missing. They were required to choose from eight alternatives the figure which would best complete the pattern. (See above for an explanation of the 'once-through' mode of presentation.)

Time Allowed: 15 minutes.

Scoring: Variable 1 = Total number of items correct.

Variable 2 = Accuracy score. (number correct÷number attempted)

Variable 3 = Speed score. (number of item completed÷time taken)

2. Raven's Matrices (Fixed-time)

Description of items is the same as for the previous test. Subjects were told that they were to try to obtain as many correct answers as they could in 20 minutes, and that there was no penalty for incorrect answers.

Time Allowed: 20 minutes.

Scoring: Variable 4 = Total number of items correct.

Variable 5 = Accuracy score. (number correct÷number attempted)

Variable 6 = Number of last item for which a written response was made.

3. Finding A's

Subjects were presented with lists of words and were required to cross out as many of these words which contain the letter 'a' within 90 seconds. This procedure was carried out twice.

Scoring: Variable 7 = Number of words correctly crossed out.

Variable 8 = Accuracy score. (Variable 7 ÷ Variable 9)

Variable 9 = Speed score. (position of final word crossed out.)

4. Number Comparison

Subjects were presented with columns of pairs of digit-strings, and were instructed to place a cross between pairs for which the digits were not exactly the same, and in the same order. They were required to cross as many as possible within 90 seconds. This procedure was carried out twice.

Scoring: Variable 10 = Number of digit-strings correctly crossed.

Variable 11 = Accuracy score. (Variable 10 ÷ Variable 12)

Variable 12 = Speed score. (Position of the last pair of numbers crossed.)

5. Swaps Test

For each item, subjects heard a series of three instructions, each of which comprised sequences of two, or three, of the following statements: 'Swap A and B', 'Swap B and C', and 'Swap A and C'. These were presented in random order, subject to the restriction that consecutive repetitions of the same statement were not allowed. Subjects were required to imagine the order of the letters A, B and C, starting in that order, being changed successively with each of the instructions, and to write down the final order when the sequence of three instructions had ended. No writing was allowed while the instructions were being delivered. (Subjects had to hold their pencils in the air while the instructions were being given, so that the experimenter could easily ensure that no writing was taking

Table 14

Means, Standard Deviations, and Where Possible, Split-Half Reliability Estimates, of Variables Used in Study 3

Variable	M	s	r_{tt}
1. Raven's Matrices (OT) (nc)	7.49	3.00	-
2. Raven's Matrices (OT) (a)	.42	.17	.65
3. Raven's Matrices (OT) (s)	1.98	.68	-
4. Raven's Matrices (FT) (nc)	9.39	3.22	-
5. Raven's Matrices (FT) (a)	.54	.19	-
6. Raven's Matrices (FT) (ir)	17.59	1.08	-
7. Finding A's (nc)	44.27	9.58	.86
8. Finding A's (a)	.86	.11	.78
9. Finding A's (s)	51.84	9.58	.89
10. Number Comparison (nc)	23.62	5.62	.82
11. Number Comparison (a)	.90	.10	.78
12. Number Comparison (s)	26.34	5.51	.86
13. Swaps	9.34	4.11	.76

Notes:

(nc) = number correct
(a) = accuracy score
(s) = speed score
(ir) = item reached i.e. the number of the last item answered
(OT) = Once-through presentation
(FT) = Fixed-time presentation

place until the instructions had finished. Six stimulus presentation rates were used. These were one instruction every 8.0, 6.0, 4.5, 3.4, 2.5, and 2.0 seconds. Items were presented in three blocks, each of six items, with each block containing one item at each of the six stimulus presentation rates. Within each block, the items were given with an ascending order of stimuli presentation rates. Thus the total number of items was 18, with three items at each of the six presentation rates.

Example 1: Swap A and B, Swap B and C, Swap A and B.
(Correct Answer = CBA)

Example 2: Swap B and C, Swap A and B, Swap A and C.
(Correct Answer = BAC)

Scoring: Variable 13 = Total number of correct items.

Results

The means, standard deviations, and where possible, split-half reliability estimates, of variables used in this study are shown in Table 14. Table 15 displays the correlations among these variables. The main result of the study are the nearly identical correlations, with the Swaps test, of the two versions of the Raven's Matrices test. This applies when either total number correct scoring (r's = .45 and .46), or accuracy scoring (r's = .46 and .47),

Table 15

Correlations Between Variables of Study 3

(For the meanings of the variable labels, see Table 14.)

Variables	1	2	3	4	5	6	7	8	9	10	11	12
1. RM (OT)(nc)												
2. RM (OT)(a)	.99											
3. RM (OT)(s)	-.40	-.44										
4. RM (FT)(nc)	.71	.70	-.39									
5. RM (FT)(a)	.69	.68	-.33	.97								
6. RM (FT)(ir)	-.26	-.28	.35	-.37	-.16							
7. FA (nc)	.20	.18	-.05	.25	.27	.00						
8. FA (a)	.23	.22	.00	.23	.25	-.04	.54					
9. FA (s)	.09	.08	-.07	.15	.16	-.06	.80	-.06				
10. NC (nc)	.21	.19	-.03	.23	.23	-.06	.28	.04	.32			
11. NC (a)	.16	.15	.02	.05	.05	.00	-.02	.13	-.11	.50		
12. NC (s)	.16,	14	-.05	.24	.24	-.06	.34	-.02	.44	.87	.02	
13. Swaps	.45	.46	-.23	.46	.47	.05	.33	.17	.27	.27	.01	.33
	1	2	3	4	5	6	7	8	9	10	11	12

N = 126

r (critical) = .15 for a pairwise type 1 error rate of .05
= .21 for a pairwise type 1 error rate of .01

are considered. Also can be observed the very similar (though consistently lower) correlations of the two Raven's Matrices tests, with the variables derived from the two Perceptual Speed tests, Finding A's and Number Comparison. This is despite the higher average number correct and accuracy scores obtained on the fixed-time version (means = 9.39 and .54, respectively), than those obtained on the once-through version. (Means = 7.49 and .42, respectively.) It should also be noted that, on average, subjects would have spent about twice as much time on the fixed-time version of the Raven's Matrices (time allowed = 20 minutes), as they did on the once-through version. (For the once-through version, subjects completed, on average, 1.98 items per minute, a total of 18 items.)

From Table 15 it can be seen that significant negative correlations were obtained between the speed score for the once-through version of the Raven's Matrices test, Variable 3, and the number correct and accuracy scores of the same test, Variables 1 and 2 (r = -.40 and -.44, respectively). These correlations are consistent with the existence of systematic individual differences in speed/accuracy trade-offs in the performances of this test. Moreover, the negative correlations of Variable 3 with the number correct and accuracy scores of the fixed-time version of the Raven's Matrices test (Variables 4 and 5, r's = -.39 and -.33, respectively), suggest that such a source of individual differences also exerts its influence on the performances of the Raven's Matrices test even when presented in the fixed-time mode. This is supported by the positive correlation (r = .35) between the speed score, Variable 3, and Variable 6 which was derived from the fixed-time version of the test. (Variable 6, representing the number of the last item for which a written response was made, was formed as a rough indicator of whether subjects completed the test in the 20 minutes allowed. This interpretation of this variable is not certain, however, since some subjects may have reached the end of the test but not offered solutions to the final items, despite the instructions that marks would not be deducted for incorrect answers.) However, the small negative correlation (r = .-23) of the speed score, Variable 3, with the Swaps test, Variable 13, does suggest the possibility that these negative correlations may not be fully explained in terms of individual differences in speed/accuracy trade-off, but rather that there is, in reality, a slight tendency for subjects of lower ability to work more quickly through the test. (Such a conclusion would follow if the Swaps test were regarded, like the Raven's Matrices test, as a valid marker of fluid intelligence, but one for which performances are not dependent on individual differences in speed/accuracy trade-off.)

Regarding the Perceptual Speed tests, from Table 15 can be seen the consistently lower correlations of variables derived from these tests, with performances on the Raven's Matrices and Swaps tests, compared with correlations between performances on the Raven's Matrices and Swaps tests. This pattern is seen to hold for both number correct and accuracy scoring for the Raven's Matrices tests, and for both the once-through and fixed-time versions of these tests (i.e., Variables 1 and 2, and Variables 4 and 5, respectively).

Conclusion

The main finding of this study is the very similar correlations of the once-through, and fixed-time, versions of the Raven's Matrices test, with performances on the Swaps test, and also with performances on tests of perceptual speed. These results suggest that the conclusion of the previous studies in this thesis are not a result of the once-through presentation of the fluid intelligence markers used in the previous studies, and that similar results would be expected if the alternative fixed-time presentation were used.

A major conclusion of Study 1 in this thesis is that tasks similar to Wittenborn's test of 'mental effort' or 'Attention', are more closely associated with fluid intelligence (as measured by more traditional markers), than are well known 'special', and lower g-loading, abilities such as memory span, or perceptual/clerical speed. This conclusion is reinforced by the results of the present study. Here, consistently higher correlations were found between the accepted marker of fluid intelligence, Raven's Matrices, and the Swaps test, than between the Raven's Matrices and the common perceptual/clerical speed tests, Finding A's and Number Comparison.

STUDY 4: The Relationship Between Fluid Intelligence and Performances on a Serial Short-Term Memory Task of Varying Complexity

In Study 1 of this thesis, it was found that two of Wittenborn's (1943) tests of 'sustained attention' (Number Triplets and Letter Lists), loaded on the same factor as did a number of traditional markers of fluid intelligence. Another task included in the same battery, the RST Task, was also found to have its major loading on the factor defined by the two Attention tests. This RST Task was described (but not actually used in any study) by Massaro (1975) in order to help explain and illustrate the concept of a Working, or Active, Memory System. (See discussion in Chapter 2.) The RST Task was suggested by Massaro as one for which it could be assumed, at face value, that performances would depend critically on the operation of such a memory system.

Wittenborn interpreted his 'Attention' tasks primarily in terms of the ability to maintain high levels of concentration, or mental effort. However, Massaro's interpretation of performances on the RST Task, taken together with the above findings from Study 1, does suggest an alternative interpretation of Wittenborn's Attention factor in terms of individual differences in the functioning of Working Memory. It is interesting to note that a similar idea appeared in Wittenborn's (1943) paper, when he commented that an important aspect in the performance of at least some of these tasks, was the need to keep track of several constantly changing items in short-term memory. This was not presented by Wittenborn as an alternative account of the source of individual differences in the Attention tests, but as being a feature of the tasks which ensures that high levels of concentration are required in their performance. In a similar manner, French (1951) interpreted factors marked by these tests as involving the ability to hold and process several items of information, or ideas, simultaneously. More recently, Stankov (1983a), noting the similarity of Wittenborn's Attention factor to a 'Temporal Tracking' factor found in his work on auditory abilities, also suggested a similar interpretation of this factor in terms of the operation of a Working Memory System.

As discussed earlier, the finding in Study 1 of a close association between the Attention tasks and fluid intelligence does not seem consistent with Wittenborn's (1943) assumption that the Attention tasks should not be expected to be strongly related to levels of 'intellectual ability'. However, if Wittenborn's Attention tests are interpreted in terms of such concepts as Working, or Active Memory, then this result can be seen as consistent with certain theories which interpret general intelligence, or task complexity, in terms of such concepts. The theories of Bachelder and Denny (1977a,b) Pascuale Leone (1970), Bereiter and Scardamarlia (1979) have suggested that general intelligence can be explained in terms of the efficiency, or capacity, of some central, active short-term memory system. Such theories have been supported by the results of studies by Simon and Kotovsky (1963), Holzman, Pellegrino and Glaser (1983), Bereiter and Scardamarlia (1979), which have demonstrated the importance of the short-term memory load requirements of common measures of intelligence in determining the difficulty level of items. (These measures were Letter Series tasks for the first two of these studies, and the Raven's Progressive Matrices in the third study.) Thus the close association, in individual differences, between Wittenborn's Attention tests (or the RST Task) and typical measures of fluid intelligence is explained by the common demands of these tasks on the capacity of some short-term, active, or 'Working' memory system.

Although the RST Task was presented by Massaro (1975) for illustrative purposes only, similar serial short-term memory tasks were extensively investigated experimentally previously by Monty and his associates (e.g., Monty, 1968, 1973; Monty et al. 1965). In these studies, lists comprising a number, n, of distinct stimuli (shapes or sounds) were presented to subjects in random order, with each of the distinct stimuli usually occurring on a number of occasions. Subjects were required to keep a mental tally of how many of each of the distinct stimuli occurred in each of the lists. For example, in the RST Task used in Study 1 of this thesis, a list of letters, say, 'R, S, R, T, S, R, S, T, S', was presented. Subjects would then attempt to report the separate number of R's, S's and T's, in that order, which occurred in the list. (The correct response to that item would be 3,4,2.)

From these studies by Monty and others, it was found that a major determinant of task difficulty was the number of distinct stimuli present in the list, or task 'complexity'. (The use here of the term 'complexity', follows a common practice in describing the number of distinct stimuli components, ideas, etc. which need to be simultaneously held in mind, or manipulated, in order to successfully complete a particular task.) If we assume the use by subjects of a certain strategy for the solution of these tasks, the task complexity, n, could be alternatively conceived of as the concurrent short-term memory load required by the task. (This strategy, suggested by Monty, 1968, involves subjects maintaining, in short-term memory, the current separate tally for each of the n stimuli, and updating these tallies as each further stimulus is presented.) In addition to task 'complexity', a number of other task variables were also found to be systematically related to subjects' levels of performance. These include the length of the list, the stimulus presentation rate, and the nature of the items. (Shorter lists, presented more slowly, and with the distinct stimuli forming a 'natural order', were found to result in higher levels of performances.)

Aim and Rationale of Study

The main aim of this study was to investigate the effect of varying the 'complexity', n, (or concurrent memory load) of a serial short-term memory (SSTM) task on correlations between the SSTM task and fluid intelligence.

The existence of such an effect is suggested by the Span theory of Bachelder and Denny, or the M-Space theory of Pascual-Leone. In such theories, general intelligence is linked with performances on more 'complex' tasks, where task complexity is defined in terms of the number of items of information required to be simultaneously processed in order to complete the task. This study can, therefore, be seen as analogous to others, such as that by Jenkinson (1983), or by Jensen and Figueroa (1975), where a variation of certain task parameters, assumed on the basis of some theoretical framework to correspond to changes in task 'complexity', is hypothesised to produce corresponding changes in the task's correlation with measures of intelligence. (For Jensen and Figueroa, task complexity was hypothesised to be a function of the amount of transformation, or mental manipulation, required by a task, while for Jenkinson, the concept of complexity was less precisely defined and varied from one task to another.)

The Letter Series test was selected as the marker of fluid intelligence since the work of Simon and Kotovsky (1963), Kotovsky and Simon (1973), and of Holzman et al. (1983), suggested that performances on such common measures of intelligence are strongly related to the concurrent memory load required by the task. Task complexities of $n = 2$, 3 and 4 were chosen for the SSTM task, which was similar to the RST Task (with $n = 3$) used in Study 1 of this thesis. Piloting showed that such a variation in n produced very large differences in task difficulty. Therefore, to avoid floor or ceiling effects for performances on the SSTM task, different ranges of item presentation rates were selected for items with each of the three levels of complexity. Thus, on average, items with n = 2 were presented at the fastest stimulus presentation rates, and those with n = 4 at the slowest. For reasons outlined below, Forward Digit and Letter Span tasks were also included in the battery.

If, as suggested by some writers, general intelligence is related to the capacity of some immediate memory (store, buffer, working system, etc.), then it might be expected that correlations of the SSTM task with the Letter Series test will be higher for the SSTM items of greater complexity, n. For lower complexity items (such as when n = 2), where difficulty levels are maintained by increasing the rate of stimulus presentation, performances on the task would be expected to depend more on some form of mental speed, and depend less on individual differences in the temporary 'holding' capacity of some short-term store, or Working Memory system.

A plausible alternative hypothesis is that the 'holding capacity' of some temporary store is not related to intelligence, but rather more to some other sources of individual differences, such as those measured in common Forward Digit or Letter Span tasks. In this case, it would be predicted that, with increasing n, correlations of the SSTM task with the marker of intelligence will decrease, with a possible corresponding increase in

Table 16

Tests Used in Study 4 and their Order of Presentation

1. Letter Series
2. Counting Animals, Part 1 (Instructions and practice)
3. Forward Digit Span
4. Counting Animals, Part 2
5. Forward Letter Span
6. Counting Animals, Part 3

Table 17

Stimulus Presentation Rates for the Counting Animals Task Used in Study 4

		ITEM SPEED (time per stimulus, in seconds)					
		1	2	3	4	5	6
Stimulus Complexity, n	1	2.50	1.88	1.41	1.05	0.79	0.59
	2	3.20	2.56	2.05	1.64	1.31	1.05
	3	4.00	3.20	2.56	2.05	1.64	1.31

studies (Study 1 and Study 2) of this thesis as a marker test for fluid intelligence, except that a fixed-time presentation was used, rather than the once-through format used for this test in the previous two studies. The Counting Animals test is based on the serial short-term memory tasks described by Massaro (1975) as an illustration of the concept of Working Memory, and on those studied by Monty discussed above. It is also similar in format to the RST Task tests used in Studies 1 and 2 in this thesis. The main experimental manipulation in this task was the number of distinct stimuli which were required to be tallied, that is, the task 'complexity', n. Items were presented with complexities of n = 2, 3 and 4. For items with n = 2, subjects were required to tally the number of 'cats' and the number of 'dogs', which occurred in each of the auditorily presented lists. For n = 3, it was the number of cats, dogs and horses, which were required to be tallied, while for n = 4, it was the number of cats, dogs, horses and pigs. For each level of complexity, six stimulus presentation rates were used. These rates are shown in Table 17.

The Counting Animals test was presented in three parts to minimise boredom and to provide relief from the high levels of mental effort required by the task. Part 1 consisted of the instructions and nine practice items, three at each of the three levels of complexity. Parts 2 and 3 were identical in format, with each containing a total of 18 test items. For each of Parts 2 and 3, the first six items were of complexity, n = 2, for the next six, n = 3, and for the final six, n = 4. Within each block of six items of equal complexity, items were presented in ascending order of stimuli presentation rate, with the rates for each of the complexity level as shown in the Table 17.

A brief description of each of the tests, and the associated variables, is given below.

1. Letter Series

For each item, a list of letters were presented and subjects were required to write down the next letter which continues the pattern in the sequence. The maximum time allowed was 20 minutes.

Scoring: Variable 1 = Total number of correct items.

3. Forward Digit Span

Fourteen lists of random digits, with lengths varying from 4 to 10 digits, were presented auditorily at a rate of one digit per second. After each list, subjects were required to write the list in its original order.

Scoring Variable 2 = number of correctly recalled lists.

5. Forward Letter Span

As above, except that the lists comprised letters, instead of digits, and with lengths varying from 3 to 9 letters.

Scoring: Variable 3 = number of correctly recalled lists.

2., 4., 6. Counting Animals

For each item, lists of either 12 or 13 words were presented auditorily. For some items (those of complexity, n = 2) the lists comprised the words 'cat' and 'dog', for others (those of complexity, n = 3), the words 'cat', 'dog' and 'horse', and for the remainder (those of complexity, n = 4), the words 'cat', 'dog', 'horse' and 'pig'. The total number of items was 36, with 12 items at each level of complexity. For each item, subjects were required to write down the number of times the different words occurred in the list.

Scoring: Variable 4 (CA2) = Number of correct items for lists comprising the words 'cat' and' dog'.

Variable 5 (CA3) = Number of correct items for lists comprising the words 'cat', 'dog' and 'horse'.

Variable 6 (CA4) = Number of correct items for lists comprising the words 'cat', 'dog', 'horse' and 'pig'.

Variable 7 (CAT) = Total number of correct items for the whole test.

correlations with the memory span tests. If this were found (i.e., the more quickly presented, lower n, items were those more highly correlated with intelligence), then an appropriate conclusion would be that some form of mental speed would underlie the correlations between performances on the SSTM tests and intelligence.

Method

Subjects These were 102 students attending New South Wales State Public High Schools, with average age 15.1 years, standard deviation 0.78 years. The sample contained a majority of females (72%), but it is not expected that this should affect the results of the study.

Procedure The tests were presented to subjects in groups, each of about 12 students. All tests were given in a fixed order, with each test session lasting about 1.75 hours. The tests, and their order of presentation are shown in Table 16. As can be seen from this Table, the Counting Animals test was presented in three parts. The first part contained instructions and practice items only, with the other two containing the actual test items.

Tests Used in the Study

The Letter Series test is the same as the one used in the the earlier

Table 18

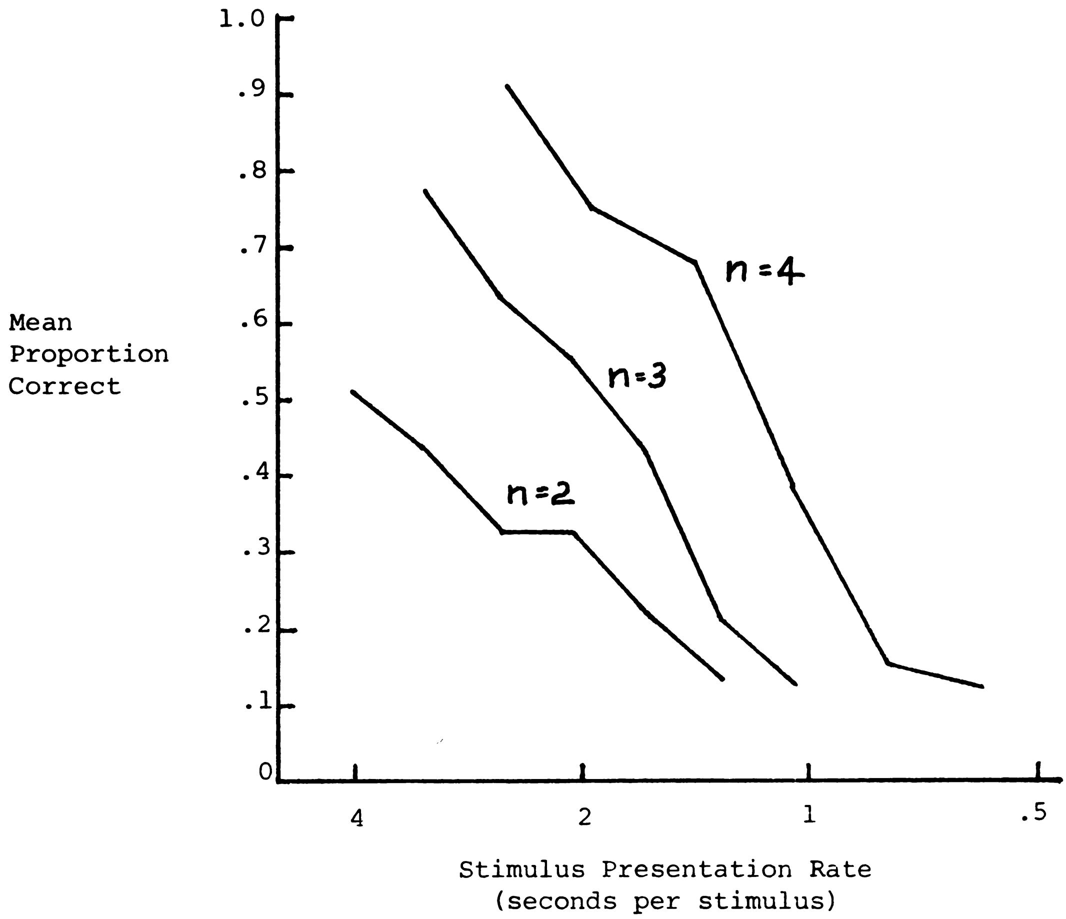
Means, Standard Deviations and, where possible, Split-Half Reliability Estimates of the Variables used in Study 4

Variable	Abbreviation	M	s	r_{tt}
1. Letter Series	LS	19.88	4.8	-
2. Forward Digit Span	FDS	7.27	2.09	.68
3. Forward Letter Span	FLS	7.55	1.71	.44
4. Counting Animals (n=2)	CA2	6.02	2.17	.62
5. Counting Animals (n=3)	CA3	5.48	2.51	.69
6. Counting Animals (n=4)	CA4	3.91	2.62	.60
7. Counting Animals (total)	CAT	15.41	6.02	.75

Table 19

Correlations Between Variables Used in Study 4 (N = 102)

	1	2	3	4	5	6
1. LS						
2. FDS	.16					
3. FLS	.11	.57				
4. CA2	.37	.18	.10			
4. CA3	.44	.19	.15	.57		
5. CA4	.41	.21	.13	.47	.52	
6. CAT	.49	.24	.15	.80	.84	.82



<u>Figure 6</u> Mean proportion of correct responses for the Counting Animals test, for each stimulus presentation rate and for each item complexity, n.

Results

The means, standard deviations and, where possible, split-half reliability estimates (calculated from Cronbach's alpha formula), of the nine variables are shown in Table 18. It should be noted that although the mean scores of the Counting Animals test for the three levels of complexity do vary systematically with the complexity, (means of 6.02, 5.48 and 3.91, for the variables CA1, CA2 and CA3, with complexities, $n = 2$, 3 and 4, respectively), no trend is found with the standard deviations or reliability estimates. A more detailed description of performances on the Counting Animals test is given by Figure 6, in which is plotted the mean performances at each stimulus presentation rate, and for each level of complexity, n. Here, can readily be seen the systematic decrease in performances with increasing stimulus presentation rate, and item complexity, n, as described in previous work by Monty et al. (e.g., 1965). However, as each point on this graph represents only two test items, further analyses will be carried out only on the total scores for each level of complexity.

The correlations among the nine variables are shown in Table 19. The ones most relevant to the aims of this study are those between the three Counting Animals variables, CA1, CA2, CA3, and the Letter Series and memory span variables. The main finding here is the lack of large or systematic variation, with complexty, n, in correlations between the Counting Animals subtests, and either the Letter Series or memory span variables. In particular, there is no systematic increase in correlations with the Letter Series variables with increasing complexity, n, of the Counting Animals subtests. The correlation with the lowest complexity variable, CA2, was slightly smaller than those for the other two, CA3 and CA4; correlations of .37, .44 and .41 were obtained between Letter Series and the variables CA2, CA3, CA4, respectively. These differences are not, however, statistically significant, using a decision-wise alpha rate of .05, and using the method for the testing of differences between non-independent correlations recommended by Steiger, 1980.)

Regarding the relative sizes of correlations between the Letter Series, Counting Animals and memory span tests, it can be seen that the highest of these is between the Letter Series test and the overall performance on the Counting Animals test ($r = .49$). This can be compared with the consistently lower correlations of the Letter Series and Counting Animals variables with scores on the memory span test.

Discussion

Empirical work by Simon and Kotovsky (1963), Holzman et al. (1983), and Bereiter and Scardamalia (1979) gives apparent support to the idea that individual differences in the performances on such common measures of intelligence as the Raven's Progressive Matrices and Letter Series tests, are strongly related to short-term storage, or immediate memory, requirements of these tasks. As discussed earlier, such data has lead some authors to the hypothesis that general intelligence should be understood as individual differences in the size, or capacity of some form of short-term, or immediate, memory store. This empirical work involved the estimation of the immediate memory requirements of individual test items by the theoretical modelling of subjects' performances on the common tests of intelligence. Bachelder and Denny (1977a) suggested, however, that a more direct measure of individual's immediate memory capacity (or 'Span Ability') would lead to a better (less biased, etc.) measure of general intelligence. Moreover, they also proposed that the well known memory span tasks should, in apparent contradiction with more common views, be regarded as such a direct measure of Span Ability, and therefore, of general intelligence. However, the finding, in this study, of a higher correlation with the Letter Series test of the Counting Animals variables, compared with those of the memory span tests, suggests that, if intelligence is to be interpreted as the capacity of some immediate memory store, then a more appropriate 'direct' measure of such a memory capacity might be found in serial short-term memory tasks, rather than in memory span tasks. This idea, that the immediate, or 'working', memory capacity which is related to intelligence is not the one measured by ordinary memory span tests, was also stated by Case (1972a). For Case, the more appropriate alternative to a memory span task was not a serial short-term memory test as used in the present study, but was the so-called 'complex stimulus', or CSVI, task. (See Chapter 2 of this thesis for a discussion of this task.) It should be noted, however, that a common feature of these two sorts of tasks, not shared by simple memory span tasks, is that they involve some form of non-trivial (or non-automatic) mental processing while simultaneous holding information in short-term memory.

The interpretation of correlations between the SSTM test, Counting Animals test, and fluid intelligence as being due to some form of short-term information holding capacity is not, however, supported by the results of this study. The difficulty levels of the Counting Animals tasks varied strongly with both the speed at which the stimuli were presented and the short-term memory load, or complexity, n. There was no tendency for the higher complexity items, which could be assumed to place greater demands on the storage capacity of some such immediate memory buffer, to be more highly correlated with the marker of fluid intelligence, Letter Series.

STUDY 5: The Relationship Between Fluid Intelligence and Performances on a Serial Short-Term Memory Task: The Effects of Stimulus Presentation Rate and Instructions on Strategies

The results of the previous study (Study 4) did not support the view that the complexity (defined in terms of correlations with intelligence) of a serial short-term memory (SSTM) task, Counting Animals, is linked to the immediate memory requirements of the SSTM task. However, the experimental studies of Monty and his associates (e.g., Monty et al., 1965) do suggest that a plausible alternative source of individual differences in performances on such tasks, which might be linked with intelligence, is some form of mental speed. These studies show a strong decrease in the average level of performances with increasing stimulus presentation rate when other task parameters are held constant. An interpretation of performances on the SSTM task used in Study 1 in this thesis (the RST Task) in terms of mental speed, was also suggested by the comments made by subjects after the completion of the test battery. As described earlier, nearly all subjects reported that they felt that a major source of difficulty in the RST Task was the speed at which the stimuli were presented. (In that study, the stimuli for the RST Task were presented at a rate of one every 1.5 seconds.)

Because of the potential relavence of the these informal comments to the

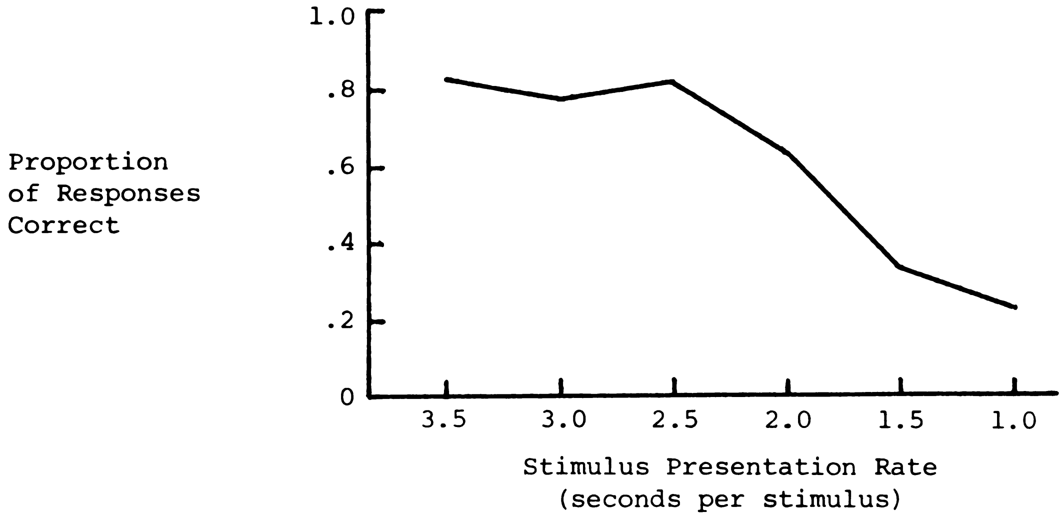


Figure 7a Results of pilot study: The proportion of responses correct for each stimulus presentation rate. (N=27, 4 items at each stimulus presentation rate)

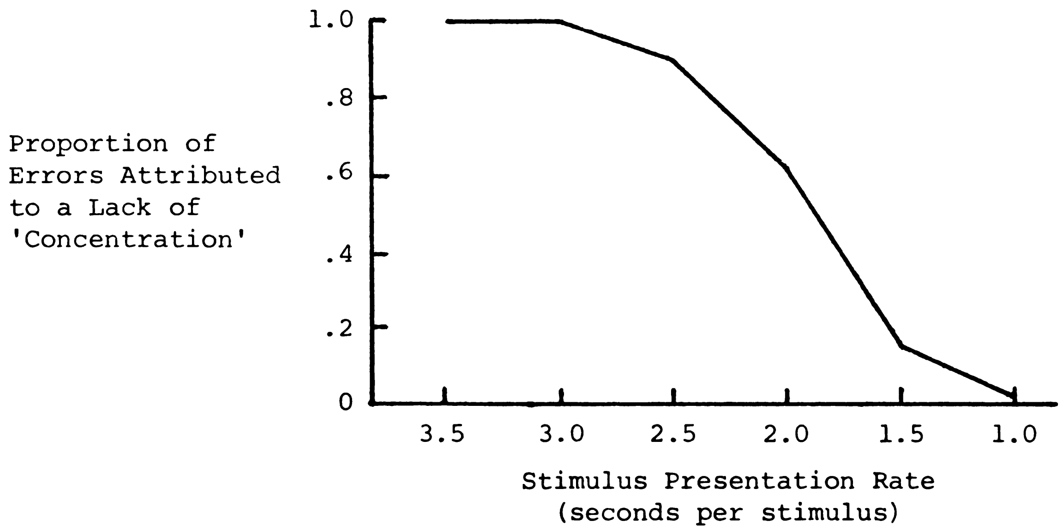


Figure 7b Results of pilot study: The proportion of errors at each stimulus presentation rate attributed by subjects to a lack of 'concentration', rather than 'mental speed'.

interpretation of performances on the RST Task, a small pilot study was carried out. This pilot study was designed primarily to establish approximate difficulty levels for the test items to be used in the main study reported in this chapter. However, as certain aspects of the outcome of the pilot study did influence the design, and the interpretation of the results, of the main study, a brief account of the pilot study is given below.

Test items, drawn from the RST Task used in Study 1, were presented to two groups, of 12 and 15 students, respectively, enrolled in Psychology 1 at the University of New South Wales. However, instead of all items being presented with the same stimulus presentation rate (as in Study 1), items were presented with rates varying from one stimulus per second to one stimulus every 3.5 seconds. (Six item speeds were used, with stimuli being presented every 1.0, 1.5, 2.0, 2.5, 3.0 and 3.5 seconds.) A total of 24 items were presented (apart from the four items used for practice in the instructions), with 4 items for each of the stimulus presentation rates. They were presented in four blocks of six items and items within each block being given with ascending order of stimulus presentation rates. After each item had been completed, the experimenter informed the subjects of the correct response. By means of a show of hands, the experimenter tallied the number of subjects who had made an error, and of those subjects, the ones who thought that it was lack of 'concentration', or lack of 'mental speed', which was most important in their not obtaining the correct answer. Also, at the end of the test session, subjects were individually questioned on their opinions of the strategies used in the performance of the task.

The main findings from the pilot study are shown in Figures 7a and 7b. From Figure 7a can be seen the relatively constant level of performances at the three slower speeds, with performances decreasing with further increases in stimulus presentation rate. Also, from Figure 7b, can be seen the relative greater importance, as perceived by the subjects, of 'concentration' and 'mental speed' at the lower and higher stimulus presentation rates, respectively. It is interesting to note that Wittenborn (1943) acknowledged the importance of both the fairly fast stimulus presentation rate, and also the need to temporarily hold information in memory. However, it is clear that Wittenborn regarded both of these factors as contributing to the same source of individual differences, namely the ability to mantain high levels of concentration, rather than as contributing to separate ability dimensions. The results of the above pilot study do clearly suggest, however, the possibility that separate mental factors may underlie performances at the relatively slower and faster presentation rates, namely, the ability to maintain concentration, and some form of mental speed, respectively.

Regarding the subjects' comments on their strategies, one of the most consistent comments was that these varied depending on the item presentation rate. For most items, that is, all except those which were regarded as 'too fast to keep up with', subjects reported that they would rehearse the current tally of the letters R, S and T, in that order, updating the current tally with the arrival of each new stimulus. A few subjects reported also that they would imagine the three numbers, representing the current tally for the three letters, spatially arranged on the desk, or, more often, in the answer boxes provided on the response sheets. This use of spatial or visual imagery in performances on similar serial short-term memory tasks, was reported by Monty (1968), and Monty and Karsh (1969). However, in the present pilot study, comments on the use of subvocal rehearsal ('saying the numbers over and over to myself') seemed to be more common than those on the use of visual imagination.

In contrast to the fairly consistent comments on strategies employed for the slower items, subjects reported a wide variety of different strategies for those items which they judged were being presented at a rate 'too fast to keep up with', that is, at a rate too fast to employ the strategy, described above, of continuously rehearsing and updating the current tallies of the three letters. For such items, strategies were adopted which would allow at least a greater probability of obtaining the correct answer than would be obtainable by guessing completely at random. One method mentioned was to keep a tally of only one or two of the three letters, and to make an 'educated guess' at the tally for the third. Another technique reported was to count the total number of stimuli presented, and then to make guesses of the individual tallies (based on estimates of the relative frequencies with which the different letters occurred), subject to the constraint that the individual tallies added to this total.

Aims and Rationale of Study

The main aim of this study was to investigate the association between fluid intelligence and performances on a serial short-term memory task, Counting Animals, similar to the RST task discussed earlier, for various stimulus presentation rates. Of particular interest was whether the correlation between fluid intelligence and this task varies from the slower items where subjects report that the ability to maintain concentration is important, to the faster items, where subjects tend to report that it is mental speed which is more important.

The relation between performances on the Counting Animals and memory span (as measured by digit and letter span tasks), was also investigated. The results of Study 1 in this thesis, and of Crawford and Stankov (1983), suggest that different abilities are involved in the memory span and SSTM tasks. (In these studies, the SSTM task had its major loading on fluid intelligence factors, while memory span tasks loaded on distinct short-term memory factors.) However, in both of these studies the stimuli were presented at the relatively fast rates of one every 1.0 and 1.5 seconds. They were thus well in the range where, in the previously described pilot study, most subjects reported that mental speed was the more important factor. It is therefore feasible that at the slower speeds, where 'concentration' was judged as the important factor, that the common involvement of short-term memory functions may lead to higher correlations between the memory span and SSTM tasks. Such a possibility is also supported by the evaluation, by Matarazzo's (1972, pp.204-205) that 'the ability to perform tasks requiring concentrated effort' is an important factor in performances on memory span tasks.

Another factor which was investigated in this study was the effect of explicit instructions on strategies. Hughes (1983) reported that explicit instructions for performances on a paired-associates learning task not only increased subject's level of performances on the task, but also increased the correlation between the task and intelligence. This latter finding is of some significance, since it is the opposite to what might be expected if the link between intelligence and performances on the learning task is assumed to be mediated primarily by subjects' ability to devise, for themselves, appropriate solution strategies. (See Campione et al., 1985, for an example of such a view.) In the present study, the instructions were varied in a similar manner to see if such an effect could be found for performances on the SSTM task, Counting Animals. For those subjects receiving explicit instructions on strategies, both the 'subvocal rehearsal' and 'spatial imagery' techniques, discussed above, were described and practised before the beginning of the test items.

Method

Subjects These were 128 First Year Psychology students at the University of New South Wales, who were required as a part of their studies, to participate as subjects for research. The mean age of the sample was 22.8 years, with a range of 18 to 47 years. As with the similar sample used in Study 1 in this thesis, these subjects would be expected to have higher averages, and smaller variations, in mental abilities related to academic success than would a sample drawn from the general population.

Procedure A battery of five tests were presented to groups of subjects in test sessions lasting about 2.5 hours. The average group size was about five subjects, but no group contained more than eight subjects. The order of presentation of the tests was constant. The Counting Animals test was presented in four separate segments to reduce the effects of boredom or fatigue. Tests requiring auditory presentation were given via a cassette tape player (Sony, Model CP31) with two external speakers located at either side of the front of the room.

Tests Used in the Study

The tests, and their order of presentation, are shown in Table 20. The

Table 20

Tests Used in Study 5, and their Order of Presentation

Tests	Order of Presentation	Number of Items
Counting Animals, Trial 1	1	12
Raven's Matrices	2	18
Counting Animals, Trial 2	3	12
Letter Series	4	38
Counting Animals, Trial 3	5	12
Forward Digit Span	6	14
Forward Letter Span	7	14
Counting Animals, Trial 4	8	12

Table 21

Design of theCounting Animals Test Used in Study 5

1. Stimulus Presentation Rates	1.	2.	3.	4.	5.	6.
(in seconds per stimulus)	3.39	2.50	1.84	1.36	1.00	.74

2. Item Lengths Used: 'short' = 8 or 9 words
(number of words in list) 'long' = 11 or 12 words

3. Total Number of Items = 48; (8 items for each stimulus presentation rate, with 2 items for each length and speed combination.)

4. Items presented in 4 repeated trials; (12 items in each trial, with one 'long', one 'short', item presented at each of the six stimulus presentation rates.)

battery consists of two traditional markers of fluid intelligence (Raven's Matrices and Letter Series), two memory span tasks (Forward Digit Span and Forward Letter Span), and the SSTM task, Counting Animals. The Raven's Matrices and Letter Series tests are the same as those used previously in Studies 1 and 2 in this thesis, except that fixed-time, rather than once-through, presentations were used in the present study for these tests. The memory span tests are those of the same name used in Study 3. Except for differences in the nature of the stimuli, the stimulus presentation rates, and the exact test instructions, the Counting Animals test is similar to the RST Tasks used in Studies 1 and 2, and the test of the same name used in Study 3. A brief description of each of these tests is given below.

1. Counting Animals The main features in the design of this test are summarised in Table 21. For each item, subjects heard lists consisting of the words, 'cat', 'dog' and 'horse', given at a rate which was constant within each item. At the completion of the presentation of each item, subjects were required to write down, on the answer sheets provided, separate totals for the number of cats, dogs and horses, which occurred in the list. The stimulus presentation rates for different items were varied as follows. Six stimulus presentation rates were used, with 8 items for each speed, thus giving a total number of 48 items in the test. The second fastest rate was one word per second, and the second slowest was one word every 2.5

seconds. The remaining rates followed a geometric progression, with a constant ratio between successive rates. This gave the six stimulus presentation rates of 3.39, 2.50, 1.84, 1.36, 1.00 and .74 seconds per stimuli. The two slowest speeds (3.39 and 2.5 seconds per word) represent speeds at which subjects, in the pilot study described earlier, judged that mental speed was not an important factor contributing to their making errors. The next two speeds (1.84 and 1.36 stimuli per second), represent speeds at which subjects nominated a lack of 'mental speed' as being the main reason for error. The two fastest speeds (1.00 and .74 seconds per stimulus), are those which, it is to be expected, a large proportion of subjects would find too fast to use the strategies of rehearsing and updating current tallies, and would revert thus to the alternative strategies discussed earlier, designed to maximise the accuracy of their guessing.

Four item lengths, of 8, 9, 11 and 12 stimuli, were used, with each of these lengths being presented twice at each of the six stimulus presentation rates. For purposes of discussion and statistical analysis, those items containing 8 or 9 stimuli will be referred to as the 'short' items, and those containing 11 or 12, as the 'long' items. Thus the test contains 24 short, and 24 long, items, with 4 long, and 4 short, items for each of the 6 different item presentation rates.

The test was presented as four equal subtests, separated by other tests in the battery. The 48 test items were divided into four equal blocks, A, B, C and D, each containing 6 short and 6 long items, with each of the six stimulus presentation rates being represented once in the set of long, and once in the set of short, items. All subjects did not receive the subtests in the same order. The order of the presentation of subtests was varied according to a latin square design, with equal numbers of subjects (32) receiving the blocks of items in the following orders: ABCD, DABC, CDAB and BCDA. Also, two sets of instructions were used. Equal numbers of subjects (64) received each of the two sets of instructions, with equal numbers (16) receiving each set for each of the four possible orders of presentation of the subtests. Subjects receiving one set of instructions, the 'Strategy Instruction' group (S.I Group) received explicit instructions and practice on the use of the subvocal rehearsal and spatial imagery strategies discussed previously. The remaining subjects, which formed the 'No Strategy Instruction' group, were given similar instructions and an equal number of practice items, except that no mention was made of any strategy which could be used in performing the task. Subjects in both instruction groups were told that they should attempt to keep a tally of all three stimuli, and that no marks would be awarded for partly correct responses. However, they were instructed to guess if they were uncertain of an answer.

Scoring: One point was given for each item correct. (No points were given for partly correct answers.) See the Results section for a listing and description of the variables for this test, corresponding to the different item lengths and stimulus presentation rates.

2. Raven's Matrices For each item subjects were presented with a two dimensional array of figures, with one missing. Subjects were required to choose from a number of alternatives the figure which would best complete the pattern. Test items were contained in individual booklets and subjects gave their responses on separate answer sheets. The instructions were to obtain as many correct answers as possible in the time provided, and that there was no penalty for incorrect answers.

Time Allowed: 15 minutes.

Scoring: Variable 1 = Total number of items correct.

3. Letter Series For each item a list of letters was presented and the subject required to write down the letter which continued the pattern in the series. The test was presented in the same 'fixed-time' format as above.

Time Allowed: 10 minutes.

Scoring: Variable 2 = Total number of items correct.

4. Forward Digit Span For each item subjects heard a lists of digits presented at the rate of one every second, and were instructed to write them down in their correct order as soon as each of the lists had finished. The

lengths of the lists varied from 4 to 10 digits, with two lists for each length, and were presented in ascending order of lengths.

Scoring. Variable 3 = Total number of lists correctly recalled.

(No marks awarded for partly correct responses)

5. Forward Letter Span The same as for the above test, except that the stimuli comprise letters instead of digits.

Scoring: Variable 4 = Number of lists correctly recalled.

Statistical Analyses

Composite measures derived from the fluid intelligence markers, Raven's Matrices and Letter Series, and from the two memory span tests, were correlated with a number of variables derived from the Counting Animals test. Factor analyses were also performed on the correlations between variables derived from the fluid intelligence, memory span and Counting Animals tests. As with Studies 1 and 2 in this thesis, the maximum likelihood method, developed by Joreskog, and presented in the SPSS package of statistical procedures, was used, with oblique objective rotation of factors according to the 'oblimin' criterion, as implemented in the SPSS statistical package (Nie et al., 1970).

Table 22

Means, Standard Deviations, and Split-Half Reliability Estimates for Individual and Composite Variables (Study 5)

Variable	M	s	r_{tt}
1. Raven's Matrices	7.24	2.73	
2. Letter Series	20.78	5.27	
3. Forward Digit Span	8.14	2.22	.58
4. Forward Letter Span	7.92	1.98	.51
5. Gf	0.0	1.71	
6. MSpan	0.0	1.78	.81
7. Counting Animals (CA)	22.38	6.5	.81

Notes: Gf = Composite variable formed by combining Z-scores of Variables 1 and 2.
MSpan = Composite variable formed by combining the Z-scores of Variables 3 and 4.
Variable 7 (CA) = Total score on Counting Animals test.

Table 23

Means, Standard Deviations, and Split-Half Reliability Estimates of Measures of Performances on the Counting Animals Test (Study 5)

Variable	$\bar{X}$	s	r_{tt}	
CA1	6.15	1.46	.46	E.g. CA2 = Number correct, for all
CA2	6.05	1.75	.73	items presented at speed no. 2
CA3	4.98	1.97	.60	(Maximum score = 8)
CA4	3.06	2.04	.53	
CA5	1.29	1.29	.36	
CA6	.85	.91	.16	
S1	3.13	.89	.23	E.g. S2 = Number correct, for all
S2	3.25	.92	.47	'short' items, presented at speed
S3	2.93	1.06	.40	no. 2 (Maximum score = 4)
S4	1.86	1.25	.41	
S5	.75	.86	.61	
S6	.36	.61	.24	
L1	3.02	.96	.29	E.g. L2 = Number correct, for all
L2	2.80	1.19	.65	'long' items, presented at speed
L3	2.06	1.27	.54	no.2 (Maximum score = 4)
L4	1.20	1.17	.46	
L5	.54	.77	.41	
L6	.48	.62	.00	
CAS	12.29	3.43	.69	CAS = Total score for all 'short' items
CAL	10.09	3.65	.73	CAL = Total score for all 'long' items
CA	22.38	6.55	.81	CA = Total score

Results

The means, standard deviations, and, where possible, split-half reliability estimates, for the main variables used in this study are given in Table 22. A composite measure of fluid intelligence, Gf was formed by the addition of the Z-scores of the Raven's Matrices and Letter Series variables. A composite Memory Span variable was also calculated in the same way from the Forward Digit and Letter Span scores. The basic statistics for the above composite variables are also shown in Table 22. Note that the Counting Animal variable (number 5) in this table, CA, represents the total number of correct items for the whole of this test.

Table 23 contains the basic statistics for various measures (not all independent) derived from the Counting Animals task. Variables CA1 to CA6 represent the number correct scores for items with stimulus presentation rates 1 to 6, respectively. Variables S1 to S6, and L1 to L6, give scores for the short and long items, respectively, at each of the 6 speeds. Variables CAS and CAL are the total scores for all the short and long items, respectively, and CA is the total score for all items in the Counting Animals test. It should be noted here the very low reliability estimate for the items at the fastest speed (r_{tt} = .16 for variable CA6). From the subjects' comments in the pilot study, described earlier, it is to be expected that, at this high speed of one stimulus every .74 seconds, subjects would be unable to 'keep up' with the presentation of the stimuli,

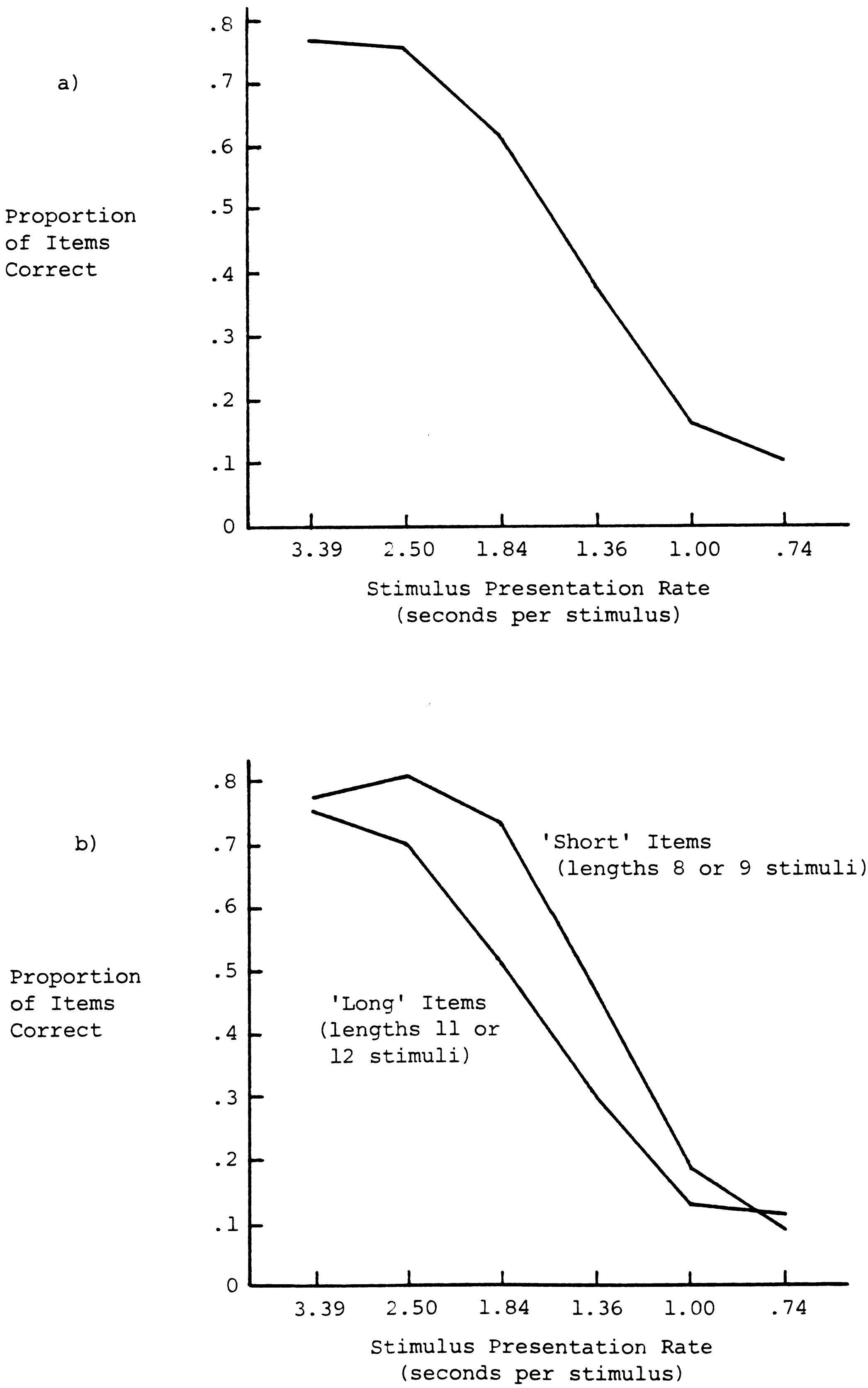


Figure 8 Proportion of items correct on Counting Animals task, a) at each stimulus presentation rate, and b) at each stimulus presentation rate for 'short' and 'long' items separately.

Table 24

Correlations Between Main Variables Derived From Individual Tests (Study 5)

Variables	1	2	3	4
1. Raven's Matrices				
2. Letter Series	.46			
3. Forward Digit Span	.22	.19		
4. Forward Letter Span	.16	.20	.59	
5. Counting Animals	.37	.54	.01	.10

Table 25

Correlations Between Variables Derived From the Counting Animals Test and the Fluid Intelligence and Memory Span Composite Measures and the Correlation Between These Two Composites (Study 5)

a)

	Gf	MSpan
Gf	-	.25
CA1	.48	.20
CA2	.41	.13
CA3	.42	.19
CA4	.43	.08
CA5	.21	.04
CA6	.06	.05
CAS	.48	.13
CAL	.50	.19
CA	.53	.18

b)

	Gf	MSpan
S1	.43	.15
S2	.35	.13
S3	.32	.12
S4	.32	.05
S5	.14	.00
S6	.15	.04
L1	.35	.16
L2	.33	.10
L3	.39	.21
L4	.41	.09
L5	.20	.07
L6	-.06	.03

N = 128

r(critical) = .16 for a decisionwise type 1 error rate of .05
= . 20 for a decisionwise error rate of .0

and that responses are largely a result of 'educated guessing'.

Figures 8a and 8b display the overall performances on the Counting Animals test. Figure 8a gives the proportion of items correct for each of the 6 item speeds, (corresponding to the variables CA1 to CA6). Figure 8b gives the performances on the 'short' and 'long' items separately, for each of these speeds, (corresponding to the variables S1 to S6, and L1 to L6). The decrease in the average levels of performances with increasing item speed, and increasing length of items, as observed by Monty et al. (1965) in his studies on similar tasks, can clearly be seen in these diagrams.

The correlations between the overall performances on each of the tests is shown in Table 24. Here it should be noted that the correlations between the Counting Animals test (Variable 5) and each of the two fluid intelligence markers, Raven's Matrices and Letter Series, (.37 and .54, respectively), are comparable in magnitude to the correlation between these two fluid intelligence markers themselves (r = .46). Also, these correlations should be compared with those consistently lower ones between the fluid intelligence and memory span tasks (r's ranging from .16 to .22), and those between the Counting Animals and memory span tests (r's = .01 and .10).

The main results of this study are shown in Table 25a which gives the correlations between fluid intelligence and memory span composite scores, and the various measures derived from the Counting Animals test. (As described earlier, the composite scores were formed by adding the

Z-scores of the appropriate marker tests.) Here again can be observed the relatively higher correlations between the measure of fluid intelligence and the Counting Animals test (r = .53), compared with the correlation between the Gf and Memory Span measure (r = .25), and the correlation between Memory Span and Counting Animals total score (r = .18). Table 25a also shows the correlations of the performances on the Counting Animals task at the six different speeds with the Gf and Memory Span measures. The most important feature of these results is the very uniform correlations of the Counting Animals task over the first four speeds (r's = .48, .41, .42, .43, respectively). At the two highest speeds, 1.0 and .74 seconds per stimuli, correlations can be seen to decrease markedly (r's = .21 and .06, respectively). It should be noted that at the fastest speed in the pilot study of one simuli per second, all subjects reported that the speed was too fast for them to keep up, and that they were forced to use some form of 'educated guessing' strategy in order to maximize their scores. Also, from Table 25a can be seen the very close correlations of performances on the short and long Counting Animals items, variables CAS and CAL, with the Gf measures (r 's = .48 and .50, respectively).

For the sake of completeness, correlations with the Counting Animals items, at each speed, and for short and long items separately, are shown in Table 25b. It must be noted that each of these Counting Animals variables, S1 to S6, and L1 to L6, are formed by only 4 test items, and the expected

Table 26

Correlations of Fluid Intelligence with Item Speed and Item Length Contrasts for the Counting Animals Test (Study 5)

Contrast	Gf
c1	.09
c2	-.06
c3	.12

Definition of contrasts:

$c1 = 3S1 + S2 - S3 - 3S4$

$c2 = 3L1 + L2 - L3 - 3L4$

$c3 = c1 - c2$

Table 27

Correlations Between Counting Animals Variables:
a) for Different Items Lengths, and
b) for Different Stimulus Presentation Rates, for Long and Short Items Separately (Study 5)

a)

	CA1	CA2	CA3	CA4	CA5
CA2	.52				
CA3	.52	.55			
CA4	.33	.51	.57		
CA5	.17	.19	.27	.43	
CA6	.18	.17	.14	.09	.19

b)

	S1	S2	S3	S4	S5	S6	L1	L2	L3	L4	L5
S2	.40										
S3	.36	.44									
S4	.27	.34	.34								
S5	.04	.10	.15	.25							
S6	.12	.09	.14	.08	.25						
L1	.25	.30	.43	.21	.15	.15					
L2	.37	.37	.36	.41	.07	.08	.32				
L3	.35	.41	.43	.41	.16	.15	.27	.37			
L4	.18	.30	.46	.42	.20	.14	.22	.37	.43		
L5	.09	.12	.16	.38	.25	.06	.13	.21	.25	.33	
L6	.07	.15	.14	.05	.11	.08	.09	.11	-.05	-.05	-.01

low reliability of these variables should be kept in mind when considering these correlations. Nevertheless, a viewing of these correlations does suggest the possibility of a slight tendency, over the first four speeds, for correlations with intelligence to decrease for the short items, and increase for the long items. This suggests the possibility that the decrease in performances with increasing item speeds, may be differently related to fluid intelligence, for the long and short items. However, a series of planned speed contrasts, designed to uncover such an effect, did not produce statistically significant correlations with the Gf variables (see Table 26). The highest correlation ($r = .12$) was between Gf and a contrast measuring the difference between the linear trends, with item speed, of the short and long items. Although not statistically significant (decisionwise type 1 error rate of .05), this small positive correlation may suggest a slight tendency in the data in the direction hypothesised above.

The relatively constant correlations with Gf measures of the Counting Animals performances at different item speeds (at least over the first four speeds), does not necessarily imply that the same ability factors are involved at the higher and lower speeds. Tables 27a and 27b give the correlations between the items of different speeds, with short and long items, both combined and separately. Except for the correlations involving the variables measuring performances at the highest speed (CA6, S6 and L6), these correlations do suggest that more than one factor might be

Table 28

Factor Analysis of Fluid Intelligence, Memory Span and Counting Animals Variables (Study 5)

Factor Pattern Matrix

Variables	Gf	CA(F)	MSp	h^2
S1	.73	-.20	-.04	.33
S2	.67	-.03	-.05	.36
S3	.55	.16	-.01	.43
S4	.29	.49	-.05	.37
S5	.01	.37	-.05	.14
L1	.43	.05	.10	.28
L2	.53	.15	-.04	.35
L3	.49	.25	.06	.37
L4	.25	.53	.03	.41
L5	-.05	.58	.05	.22
Raven's Matrices	.42	.06	.09	.31
Letter Series	.55	.10	.11	.43
Forward Digit Span	.17	-.09	.57	.40
Forward Letter Span	-.14	.06	1.03	.40

Note: Factor pattern loadings greater than .20 have been underlined.

Factor Intercorrelations

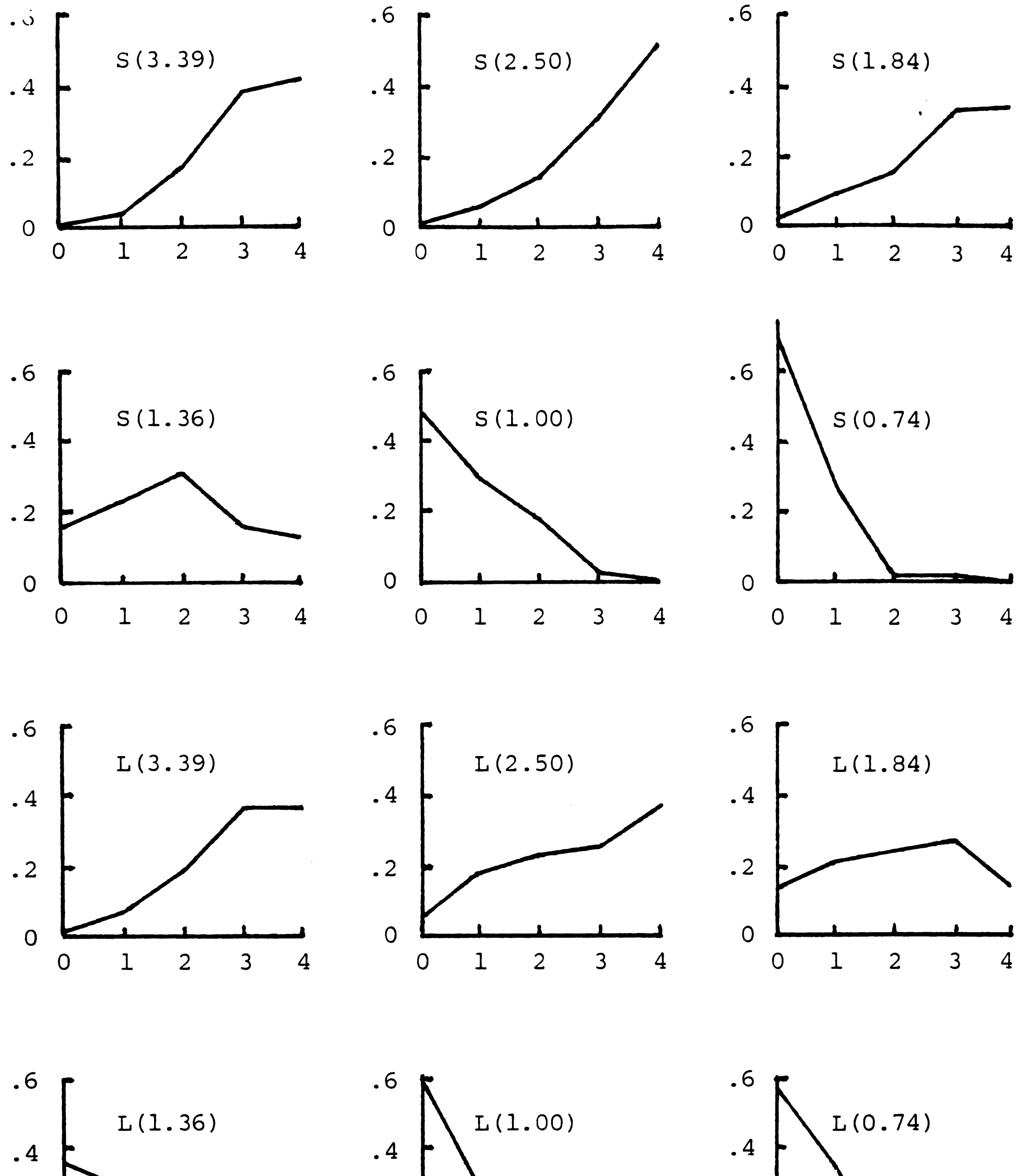
	Gf	CA(F)	MSp
Gf			
CA(F)	.46		
MSp	.26	.06	

Factor Labels: Gf = Fluid intelligence.
CA(F) = Counting Animals (Fast)
MSp = Memory Span

present, with higher correlations existing between items of more similar stimulus presentation rates.

These observations are supported by the factor analysis shown in Table 28. Root-one criterion suggested that three factors should be extracted. Variables measuring performances at the fastest speed (S6 and L6) were removed from the analysis because of their unacceptably low communality estimates (both of .10) obtained when they were included in the analysis. The first factor, labelled Gf (fluid intelligence), derives its major loadings from the three slowest speeds of both the short and long item variables, and from the two traditional fluid intelligence markers, Raven's Matrices and Letter Series. The second factor is marked by loadings from the Counting Animals variables at the two highest speeds, and has been labelled, CA(F) (Counting Animals(Fast)). The third factor is defined by the two memory span tests, Forward Digit Span and Forward Letter Span, and has been labelled MSp (Memory Span).

The apparent conclusion suggested by the above analysis is that performances on the Counting Animals at the higher and lower speeds represent separate, though positively correlated ($r = .46$) ability dimensions, with fluid intelligence, as traditionally measured, being associated with performances at the lower speeds. However, such a substantive conclusion must be questioned in view of the possibility of what have been termed 'difficulty factors'. As discussed by Carroll (1945, 1961), such



Key: S(x), L(x) = 'short' and 'long' items, respectively.
x = stimulus presentation rate in seconds per stimulus.

Figure 9 Frequency distributions for Counting Animals task for 'short' and 'long' items and at each stimulus presentation rate.
(Number of test items for each item type = 4; maximum score = 4)

factors can arise when correlations between variables are spuriously decreased by a combination of their frequency distributions a) being strongly skewed in opposite directions, and b) using relatively few categories of measurement. Figure 9 displays frequency plots for the Counting Animals variables used in this factor analysis. As can be seen from the opposite skewness of variables representing low and high item speeds, and the small number of measurement categories utilized, the present data thus represents ideal conditions for the formation of a spurious difficulty factor, in the manner discussed by Carroll.

Carroll (1945, 1961) suggested methods by which the removal of such spurious effects might be achieved. These involve the use of the tetrachoric correlation coefficient, and mathematical procedures for the correction for guessing. However, the present data are inadequate for the application of such procedures. Tetrachoric correlation coefficients were calculated (as suggested by Carroll, 1961), but are not reported because of their extremely low reliabilities. This was evident from the wide variations in the obtained values when different dichotomisations of the same variable were made for the calculation of the coefficient. (This was done when two possible dichotomisations were about equal approximations to a median split.) This is consistent with McNemar's (1949, p. 177) warning on the low reliability of the tetrachoric correlation coefficient and his suggestion that it should only be used with very large samples. Even if this problem of low reliabilities

Table 29

A Comparison of Performances on the Counting Animals Test of the Strategy Instruction (SI), and No Strategy Instruction (NSI), Groups (Study 5)

a) Means and Standard Deviations of Performances of the SI and NSI Groups for the Total Score, and for Each Repeated Trial.

	NSI Group (N = 64)		SI Group (N = 64)	
	M	s	M	s
CA (Trial 1)	5.44	2.09	5.50	2.33
CA (Trial 2)	5.89	2.15	5.77	2.05
CA (Trial 3)	5.28	2.07	5.32	2.01
CA (Trial 4)	6.06	1.72	5.53	2.06
CA (Total Score)	22.65	6.22	22.12	6.91

b) Correlations Between Fluid Intelligence and the Counting Animals Task, for Each Repeated Trials, and for the Total Scores, for the Total Sample and for the NSI and SI Groups, Separately

	Whole Sample (N = 128)	NSI Group (N = 64)	SI Group (N = 64)
CA (Total Score)	.53	.52	.54
CA (Trial 1)	.40	.31	.48
CA (Trial 2)	.48	.46	.50
CA (Trial 3)	.41	.47	.34
CA (Trial 4)	.39	.38	.43

could be ignored, the effective removal of such difficulty factors might still not be achieved because of the inability to obtain adequate estimates of 'guessing', which is required in the procedures described by Carroll (1961).

Some support for the possibility that the splitting of the Counting Animals variables into two factors is due to spurious effects associated with item difficulties, is given by the following observation. Item difficulties in this task are strongly associated with the item speeds, but, as can be seen from Figure 8b, they are also affected by the item lengths. Thus if the two factors, in fact, represent easy and hard, rather than slow and fast, items, then it can be predicted that a) the shorter, slow items would tend to have higher loadings on the first factor than the longer, slow items, and b) the faster, long items would tend to have higher loadings on the second factor than the faster, short items. Both of the above tendencies can indeed be seen in the factor pattern matrix in Table 28.

Table 29, parts a and b, shows the effects on performances on the variation in instructions given to subjects. From Table 29a it can be seen that no significant differences exist in the average level of performances between the NSI (No Strategy Instructions) and SI (Strategy Instructions) groups. This is true both of the overall level of performance, and for performances at each of the four repeated trials on the Counting Animals test. (The means for each of the repeated trials were calculated since it is plausible that the SI group might show superior performances for the early trials, even though at later trials the self discovery of the appropriate strategies by subjects in the NSI group, might remove such differences.) Table 29b gives correlations between the measures of fluid intelligence and performances on the Counting Animals test for each repeated trial and for all trials combined. Nearly identical correlations were obtained, for the two instruction groups, between fluid intelligence and the overall Counting Animals score, CA (r's = .52 and .54). However, greater variation can be seen in the correlations between the Gf measure and each of the separate trials of the Counting Animals task. The largest differences between the two instruction groups are in the correlations with performances on the first trial, with the correlation being larger for the Strategy Instruction Group (r = .48) than for the No Strategy Instruction Group (r = .31). However, these and other differences between the two instruction groups on these correlations are not statistically significant (using Fisher's Z-transformation approximation, and a decisionwise type 1 error rate of .05).

Discussion

The main finding of this study is the lack of systematic variation in the correlations between fluid intelligence and performances on the Counting Animals test over a wide range of stimulus presentation speeds, of between 3.39 and 1.36 seconds per word. This is despite the strong influence of changes in item speed over this range on the average level of performances, which varies from about 76% of items correct at the slowest speed, to about half this value (39%) at the fastest of these speeds. At faster speeds (item presentation rates of one stimulus every 1.0, and every .74 seconds), correlations with fluid intelligence were observed to decrease. However, this is consistent with the lower reliability estimates of the variables at these speeds, and the possible influence of floor effects, as suggested by the skewed frequency distributions of these variables shown in Figure 9. Also, as subjects' comments in the pilot study suggested , at these fast speeds large individual differences might exist in the adoption of various strategies for 'educated guessing'. It is possible that such a source of individual differences is less related to intelligence than that operating at the slower speeds, where the fairly consistent use of the 'rehearse and update' strategy seems to operate.

Although correlations with fluid intelligence appear constant over the first four stimulus presentation rates, comments made by subjects in the pilot study do suggest the possibility that different abilities might underlie performances at the faster and slower speeds. This possibility is also suggested by the manner in which average performances change with the stimulus presentation rate. As can be seen in Figures 8a and 8b, at the lower end of the speed range performances change much less rapidly with increasing item speed than at higher speed ranges. It is thus plausible that at the lower speeds an ability, such as that suggested by Wittenborn (1943) to maintain high levels of concentration, may be more relevant, while at the higher speeds, where the levels of performance decrease more rapidly with increasing item speed, it is some form of 'mental speed' which is more relavent.

On this question, of whether separate 'concentration' and 'mental speed' factors underlie performances at different stimulus presentation rates, the results of this study do not permit a firm conclusion. With the five fastest speeds included in the analysis, two separate, though positively correlated, factors were obtained, with the first representing performances on the Counting Animals task at the slower speeds, and the second, performances at the higher speeds (See Table 28). However, a substantive interpretation of these two factors as reflecting separate abilities, cannot be made with confidence in view of the strong likelihood that they were produced by the spurious effects associated with item difficulties, which were discussed by Carroll (1945, 1961). This latter interpretation is consistent with the form of the frequency plots for the various item speeds (Figure 9), and with the relative sizes of the loadings on the two factors of the 'short' and 'long' items. (That is, the occurrence of slightly higher loadings on the first factor for the 'short' items, and of slightly higher loadings on the second factor of the 'long' items.) Such a pattern would be expected if it were the effect of item difficulty, rather than item speed, which was determining the loadings on the two factors. It should be noted that if the first of these two factors was interpreted as the ability to maintain concentration over some period of time, then it is the opposite tendency which would seem to be more expected, namely a tendency for the longer items, at the slower speeds, to load more highly on this factor.

No significant differences were found between the group which were given explicit intructions on the use strategies for the Counting Animals task, and the group for which no instructions on strategies were given. This was true both of the average levels of performances , and the sizes of correlations with fluid intelligence. This lack of a difference in correlations with intelligence between the two instruction groups does not give support to the hypothesis that individual differences in the ability to discover the appropriate strategies underlies the correlations between the Counting Animals test and intelligence. (A finding of higher correlations for the group not receiving instructions on strategies could have been regarded as evidence for such a view.) However, the present data does not show the opposite effect, clearly demonstrated in the study by Hughes (1983) with paired associate learning, where performances following explicit instructions on strategies were found to be much more highly correlated with intelligence. There was a slight tendency in this direction for the first repeated trial only, with the correlation with intelligence being slightly lower for the No Strategy Instruction group than for the Strategy Instruction group. (Correlations of .31 and .48 for the Strategy, and No Strategy, Instruction groups, respectively, were obtained; see Table 29b.) Although this difference is in the direction which may have been predicted on the basis of the study by Hughes (1983), it was not statistically significant, (for a decision-wise type 1 error rate of .05).

In conclusion, correlations with fluid intelligence were remarkedly constant for performances on the Counting Animals test over a range of stimulus presentation rates which was sufficient to produce large changes in the average level of performances. On the question of whether different ability factors underlie performances at the higher and lower item speeds, the results of this study do not give a definite conclusion. Factor analysis, and the application of root-one criterion, suggested that separate, though positively correlated, factors could be obtained. However, a substantive interpretation of these factors, as distinct mental ability dimensions, must be questioned in view of the likely possibility that floor effects on the performances on items at the higher speeds may have resulted in the spurious production of 'difficulty factors, as described by Carroll (1945, 1961).

Although not a central aspect of this study, the results obtained also confirm the main finding of Study 1, namely, that of the close association between serial short-term memory tasks, such as the Counting Animals test, and fluid intelligence. Correlations of the SSTM test with the two fluid intelligence markers were comparable to the correlation between the two markers themselves, and performances on the SSTM test were significantly more closely related to fluid intelligence than was memory span ability.

PART III

SUMMARY AND GENERAL DISCUSSION

In this final part of the thesis, the results of the empirical studies are summarised and the practical and theoretical implications are considered. A theoretical model is presented which attempts to account for the psychometrically-based notion of task complexity in terms of concepts derived from models of brain functioning and from cognitive theories of attention. The relationships between this model and several other current concepts of complexity, and intelligence, are also examined.

1. Summary of Studies and Results

The studies reported in the thesis are concerned with the relationship between traditional measures of Gf (or intelligence) and the so-called tests of 'attention' which Wittenborn (1943) devised, and which he, and others, have interpreted as measuring the ability to maintain high levels of mental effort or sustained attention. Unlike common measures of Gf, the intention in the original design of these attention tasks was that they were sufficiently simple and repetitive that their performances should not reflect differences in background knowledge, or in the subjects' 'level of intellect'. Subjects' performances were assumed to be limited, not by their ability to perform each of the test items in isolation, but by their ability to maintain the high levels of concentration required to respond to a series of these items as they are presented continuously and fairly rapidly over some short period of time. In other words, it was assumed that subjects knew equally well (and to saturation point) how to solve each of the items, but that performances on the tasks were mainly a measure of a subject's ability to maintain high levels of concentration, mental effort, or 'attention'.

In the context of theorising on the nature of intelligence, these tests of attention are of particular significance. This is because of the different expectations on their complexity (i.e., the relative sizes of the g-loadings, or association with Gf), which would seem to follow from different views on what are the critical properties of high g, or Gf, loading tests. Perhaps the most popular of the more recent ideas is that the essential aspect of tasks of higher complexity is that individual differences in performances are primarily due to variation in subjects' solution strategies, especially when each test item represents a fairly 'novel' situation requiring the discovery of new strategies, or calls upon a large repertoire of previously acquired solution strategies. Tasks for which there is little strategic variation between subjects, or for which individual differences are mainly due to some other aspect of the tasks, are assumed to be more lowly correlated with 'g', or Gf. (Statements of such a view can be seen in Hunt, 1980, or in Campione and Brown, 1985, where it is presented in terms of the distinction between 'strategy-intensive', and 'strategy-free' tasks.)

Within such a framework, and given the sorts of interpretations placed on them by Wittenborn (1943) and others (Moray, 1969, p. 6; Stankov, 1983b), it does seem that the most plausible expectation is that these tests of attention are not tests of high complexity. A similar expectation would also seem to follow from an older view of the nature of intelligence based on the distinction between tasks which are rule-inferring and those which are 'merely' rule-following (see Cattell and Horn,1978, for a discussion of this distinction). Perhaps even more clearly than for the strategic variability notion, such a view would lead to the expectation that the attention tasks would not be strongly associated with general intelligence. Although Wittenborn was not working within a statistical or conceptual framework which included the notion of general intelligence, it is was probably intuitive notions of intelligence such as these (and particularly the latter) which led to his stated assumption that performances on the tests of attention should not be related to subjects' background knowledge, or their 'levels of intellect'.

However, a number of more 'structural' theories on the nature of intelligence have been suggested which do not necessarily imply that only relatively 'strategy-intensive' tasks are those of high complexity. Examples of these, which have been reviewed earlier in this thesis, include theories of intelligence based on the concepts of span of attention, Working Memory, attentional resources, and the distinction between active, intentional, and effortful mental processes, as opposed to those which are more reflexive, or automatic. Within the framework of any of these closely related theories, especially those directly involving such notions as effortful processes or attentional resources, the usual interpretation of Wittenborn's attention tasks would clearly be consistent with them being good measures of intelligence.

It should be noted that, for the more usual reasoning and problem-solving measures of fluid (and general) intelligence, either type of prescription, (that is the one emphasising the need to choose the correct problem-solving strategies, or the one emphasising 'active', or 'effortful' processing), does seem equally plausible. Indeed, it is common, as in Spearman's original suggestion, that in descriptions of the nature of typical high complexity tasks, these two types of characteristics are listed together, without consideration of whether either, or their combination , is necessary and/or sufficient for a task to be one of high complexity. It is as though an implicit assumption is made, that relatively repetitive tasks do not require 'active' mental processes, and that it is only tasks involving the more flexible strategic processes, or the mental 'discovery' of rules or relationships, which require the exertion of mental effort. The significance of these attention tests is that, when considering their possible relationships with intelligence, they do force a consideration of the separate importance of these two types of properties.

The first study in this thesis investigated the relationship between traditional measures of fluid and crystallised intelligence, and tasks based on the 'attention' tests which Wittenborn (1943) designed and which were interpreted as measuring the ability to maintain high levels of concentration or mental effort. As well as the above tests, the battery contained markers for perceptual/ clerical speed, short-term memory, and tests of spatial ability. The clear finding of this study was that the attention tasks loaded on the same factor as did the three traditional markers of fluid intelligence, Raven's Matrices, Letter Series, and Verbal Reasoning. It was concluded that the attention tests were good measures of Gf, or alternatively, that they could be described as tasks of relatively high complexity.

One implication of this finding is that the common description of the 'archetypical' measure of Gf, or of 'g', can be misleading as a basis on which to theorise on the nature of intelligence or of task complexity. (The Raven's Progressive Matrices tests is often quoted as closely resembling this archetype.) The Attention tests, although showing a low family resemblance to the reasoning and problem-solving tasks which form this archetype, were found to be, in individual differences, factorially inseparable from those tests with a much greater apparent similarity to such an archetype. The results of this study point to the the possibility that other, more 'structural' characteristics of high complexity tasks (such as their demands on attentional resources or on working memory) may be the ones of central importance, rather than those characteristics which are more commonly used to describe the archetypical test of intelligence (such as task 'novelty', strategic variability, or that of being rule-inferring rather than rule-following).

For the attention tasks in the last study, as in Wittenborn's, the test stimuli were presented in a fairly rapid manner. In Wittenborn's interpretation on the tasks, this was to ensure that successful task performance depended on the maintenance of a strict focus of attention, and that any lapses in attention would result in a decrease in performance. However, this does suggest an alternative interpretation to that of sustained attention, namely that of individual differences in mental speed. Mental speed, as measured by common perceptual/clerical tasks, was found in Study 1 to be factorially unrelated to the Gf and attention tests. However, it could be argued that the speed of different sorts of mental processes (possibly less perceptual or motor-related ones) may be more strongly linked with fluid intelligence. Although not consistent with the position expressed by Horn (1985,1986), (that it is accuracy rather than speed which is the more important), such a possibility would be strongly supported by Eysenck's (1967) view of mental speed as being the most basic component of intelligence.

In the second study (Study 2) these ideas were investigated by presenting one of Wittenborn's attention tasks in subject-paced format, similar to that which is commonly used for the measurement of perceptual or clerical speed factors. The results of this study gave no clear separation of speed and accuracy of performances in their relation to fluid intelligence. Speed and accuracy measures on the subject-paced version of Wittenborn's attention task were found to be correlated comparably with fluid intelligence.

In the first study, one of the 'attention' tasks in the battery was a serial short-term memory (SSTM) task, similar to the ones studied extensively by Monty and his colleagues (e.g., Monty et al. 1965). Although not included in Wittenborn's original study, it was judged by the author, and was subsequently found, to define the same ability dimension as the attention tasks which were taken directly from Wittenborn's study. This confirmed the finding of a previous study (Crawford and Stankov, 1983) that a similar SSTM task was found to be a good marker of fluid intelligence. This SSTM task was also of interest because of its being, as suggested by Massaro (1975), a clear demonstration of the operation of a working, or active, short-term memory system.

Two studies were carried out to further investigate the relationship between performances on this SSTM task and fluid intelligence. In the first of these (Study 4), the effect of varying the concurrent memory load (from two to four items) was studied. This was done because of the suggestion by some authors (such as in the Span theory of intelligence by Bachelder and Denny, 1977a, 1977b) that a task's complexity, and hence its relation to intelligence, is related to the number of pieces of information which need to be held in mind simultaneously in order to successfully complete the task. Consistent with the findings of Monty et al. (1965), increases in the concurrent memory load were found to be accompanied by large decreases in the average level of performances. However, no statistically significant changes in correlations with fluid intelligence, for different memory loads, were observed.

The final study (Study 5) explored two further aspects of performances on the SSTM task. These were the effects of different stimulus presentation rates and of explicit instructions on the strategy to be employed in performing the task. As in the studies of Monty et al. (e.g., 1965), increasing stimulus presentation rates were found to be accompanied by decreased levels of performances on the SSTM task. At the fairly slow speeds of up to around 3 or 2.5 seconds per stimuli, where subjects' intuitive judgements were that the speed at which the stimulti were presented was not a limiting factor, performances tended to stabilise at a relatively constant level of slightly above 75% correct. With increasing stimulus presentation rates performances decreased more rapidly, falling to about half this value at a rate of about one stimulus every 1.4 seconds. At these relatively faster speeds, the consensus of subjects' comments was that errors were mainly due to the stimuli coming 'too quickly'.

The finding of most importance here, however, was the lack of a significant difference in the correlations with Gf, of the SSTM task at these relatively slower and faster speeds. The results of this study did not suggest, therefore, that either the notions of 'mental speed' or of 'sustained attention' are more appropriate in interpreting correlations between the SSTM task and fluid intelligence. On the question of whether the same or different abilities are involved in performances at higher and lower speeds, the results of the study were less definite. The pattern of correlations between performances at different speeds did indicate the possibility that different, though positively correlated, abilities may be involved. However, the likely influence of spurious effects related to item difficulty, as described by Carroll (1945, 1961), suggests caution in coming to such a substantive conclusion. Moreover, other aspects of the data supported the likelihood that such potentially spurious effects were operating to produce the appearance of slighlty different sources of individual differences at the faster and slower speeds. (These involved consideration of correlations for items of different lengths, as well as at different speeds.)

The second main aspect of this study related to the effects of giving subjects instruction on strategies. If correlations with intelligence can be attributed, to some degree, to individual differences in strategies, then explicit instruction on appropriate strategies would be expected to decrease correlations with intelligence. Large changes in correlations with intelligence were found by Hughes (1983) to be produced by the giving of strategy instruction on a paired associate learning task. These changes were, however, in the opposite direction to that which might be expected on the basis of the above reasoning. In the present study, the SSTM task was presented with, and without, explicit instructions on strategies. However, no significant differences were found, either in average level of performances or in correlations with fluid intelligence, between the subjects who did and did not receive instruction on strategies. This was consistent with subjects' comments which suggested that a common strategy for performances was discovered and adopted by all subjects after the completion of only one or two practice items.

It should be noted that the main result of the first study of this thesis, that is, the close association of 'Attention' tests and the traditional measures of fluid intelligence, was supported in the results of the remaining studies. In all of these latter studies, in addition to the various 'attention' tests and markers for Gf, there were included markers for the well-known ability dimensions of low or moderate complexity, memory span and perceptual/clerical speed. (In the multi-dimensional scaling of Figure 1, the memory span and perceptual/clerical speed tasks can be seen to be among those tests located away from the centre of the diagram.) It was found in each of the studies that the tests of attention were correlated more highly with the measures of Gf than were the memory span or perceptual clerical/speed tests. This is consistent with the view of the attention tests as being ones of relatively higher complexity than the more peripheral tests of memory span or perceptual/clerical speed.

2. Practical Implications: The Use of 'Attention' Tests as Measures of Intelligence

The finding that tests, which Wittenborn and others have interpreted as measuring the ability to sustain attention, are good measures of fluid intelligence, raises the question of the possible usefulness of these sorts of tests as practical measures of intelligence. If these tests are compared with the more usual problem-solving and reasoning tests of fluid intelligence, such as the Raven's Progressive Matrices, Letter Series and Verbal Reasoning tests, then two possible advantages of the attention tests are apparent. The first of these relates to the effects of speed-accuracy trade-off on the measurement of mental ability, and the second involves the potential use of these tests in tailored, or adaptive, automated testing procedures.

With conventional tests of fluid intelligence, the measurement of ability typically consists of presenting subjects with a number of test items and scoring the total number of correct items which are obtained in some fixed time-limit. As discussed in Chapter 2 of this thesis, test scores obtained in this way are open to the influence of non-ability factors, such as Carefulness (a measure of the tendency to check answers) and Persistence (how long subjects persist with difficult items before moving on to the next).

Such factors are clearly related to a large extent to what may be broadly termed individual differences in speed-accuracy trade-off. The experimenter-paced attention tasks, therefore, have the advantage of yielding ability measures which are not open to the influence of such factors related to differences in speed-accuracy trade-off.

The widespread use of tests presented in the conventional subject-paced format could probably be taken to indicate that, in most situations, individual differences in factors related to speed-accuracy trade-off, do not present a significant problem. This could result from the absence of large variation amongst 'normal' subjects in such factors, and also from the fact that limited variation between subjects in speed-accuracy trade-off may contribute negligibly to the variation in subjects' total scores. (It is possible, for example, that two people of equal ability could obtain the same score, by the first working more quickly, attempting more items, but making more mistakes, and the second person working more slowly, attempting fewer items, and making fewer mistakes.) However, there are situations where the use of an experimenter-paced measure would have a more definite advantage. One situation is where group differences in ability are being investigated, and where there is good reason to suspect that the groups may differ systematically on such factors as impulsivity, carefulness, etc.. This would be the case with the comparison of clinical groups (e.g., Brierley, 1973), or cultural groups with very different educational or test-taking backgrounds. Another situation is in experiments where tests are used to assess changes in mental ability due to such factors as drugs, anxiety, etc.. In these situations, changes in scores from conventionally presented (that is, subject-paced) tests of fluid intelligence could equally plausibly be attributed to changes in ability, or to changes in non-ability factors associated with speed-accuracy trade-off. It is possible that experimentally induced changes in test scores produced by non-ability factors, although small in comparison with the variation in subjects' individual scores, could, nevertheless, produce highly significant differences between experimental conditions. Such differences could easily be misinterpreted as being due to experimentally induced changes in the ability normally assumed to be measured by the particular test.

Tests similar to Wittenborn's attention tests may also have an advantage over more conventional tests of fluid intelligence, in the ease with which they can be used in a tailored, or adaptive, testing format. One of the major problems with this form of testing is the need to obtain a large pool of items of known difficulty levels. Difficulty levels are typically obtained empirically by giving this large number of items to a large number of subjects. This is usually a significant task, as the size of this pool generally needs to be much larger than the number of items used in any one presentation of the test. It is not always easy to obtain such a large number of items with the correct distribution of difficulties over the required range. However, with tests such as the serial short-term memory task, Counting Animals, which was studied in this thesis, these factors do not present a significant problem. Difficulty levels can be easily manipulated by changing the stimulus presentation rate, the concurrent memory load, or the length of the list. (The method most likely to be convenient here is the controlling of stimulus presentation rate.) Also, new test items can easily be generated from different random presentations of the stimuli. These methods of manipulating the item difficulties and generating new items are particularly convenient for the automated presentation of the tailored test which is computer controlled, where items can easily be generated by the computer at the time of testing.

A number of possible disadvantages of these tests, however, should also be mentioned. The first of these is the low face validity of these tests, for many potential subjects, as tests of intelligence. (Wittenborn's, 1943, expectation that these tests are too elementary, or not abstract enough, to be related to subjects' 'levels of intellect', does indicate that, at least for some people, these tests have a low face validity as tests of intelligence.) This could possibly lead to lower levels of motivation for people taking the test, although this may be largely influenced by the test situation and the instructions. Also, intrinsic motivation may be lower for these tests as their especially repetitious and algorithmic nature does render them prone to being perceived as more 'boring' than the more varied conventional reasoning and problem-solving tests of intelligence.

3. Fluid Intelligence as Individual Differences in Mental Energy, or Effortful Mental Processing: The Problem of Circularity

The main findings of the studies in this thesis, then, are as follows. Firstly, tests of 'attention', despite their apparent dissimilarity to the traditional measures of Gf, were found to be, in fact, closely related in individual differences to the commonly used reasoning and problem-solving measures of fluid intelligence. Secondly, the results of several studies failed to provide evidence that the correlations between the attention tasks and measures of Gf could be understood, in any simple or direct way, in terms of such concepts as mental speed, working memory-load, or strategic variation.

Perhaps the simplest way of interpreting these results, (though not necessarily the most scientifically adequate), would be to propose that fluid intelligence can be understood in essentially the same terms as Wittenborn's (1943) account of his tests of sustained attention. In other words, this is to assume firstly, that there is some scientifically valid classification of mental processes which corresponds to intuitive notions of tasks being more, or less, effortful, demanding of concentration, etc., and secondly, that fluid intelligence represents individual differences in the ability to perform more 'effortful' mental processing. Although such a theory would seem to contrast strongly with Wittenborn's assumption that performances on the attention tests should not be strongly related to peoples' 'level of intellect', it is in obvious harmony with Spearman's notion of 'mental energy' underlying 'g', and also with Jensen's (1977, 1979) emphasis on active, intentional, and effortful mental processes (rather than reflexive, or automatic ones) as those involved in the performances of high g-loading tasks.

The most obvious difficulty in a theory of intelligence based on such notions as 'mental energy' or 'active mental processing', is the problem of avoiding circularity in the explanation by providing accounts of these concepts which are independent of the observed correlations with intelligence, or 'g'. One response to this problem is to postulate a correspondence between these concepts and ones which can be defined independently, but which bear a fairly direct logical relationship to these concepts of mental energy, etc.. An example of this approach is Hunt and Lansman's (1982) suggestion that mental energy can be identified with the concept of attentional resources, a concept which is defined, in theories such as that of Kahneman (1973), via models seeking to explain performance deficits in concurrent or dual tasks. Similarly, the notion of a time-sharing factor could be regarded as having a fairly direct logical connection with notions of mental effort, and therefore could provide a means of developing a non-circular theory of intelligence based on these notions.

Despite the strong intuitive appeal of the underlying idea that intelligence is associated with performance on tasks requiring more 'mental energy' (or that are effortful, rather than reflexive and automatic, etc.), attempts to provide empirical support for such a theory by linking these notions with the more precise ones of attentional resources, or a time-sharing factor, have met with limited success (see discussion in Chapter 2 of this thesis). An alternative approach would be to pursue theories of intelligence which do not have as key explanatory concepts ones such as mental energy or effortful processing, but rather utilise concepts which can be related more closely to observable task parameters, or the nature of subjects' performances. Examples of such theories, reviewed earlier in this thesis, would be those based on the immediate memory requirements of a task (e.g. Bachelder and Denny, 1977a; Bereiter and Scardamarlia, 1979.), the degree of 'transformation' between input and output (Jensen, 1975), or on the notion of mental speed (Eysenck, 1967). Theories based on strategic functions could also be thought of in this way since, with the appropriate techniques, differences between subjects in their solution strategies may be more or less directly observed. Although there does not exist a strong logical connection, there is an intuitive consistency between these theories and the basic idea that better measures of intelligence are those which require more mental effort or energy. Holding a number of items in immediate memory, transforming rather than reproducing the stimulus input, working quickly, and having to work out the best solution strategy, are all plausible examples of the sorts of mental processes which, intuitively, have the property of needing relatively more concentration, mental effort, or mental energy. Nevertheless, notions such as mental energy and 'active' mental processing could be regarded as being, themselves, too vague to form the formal basis of a scientific theory of intelligence.

This apparent advantage of theories based on memory load, transformation, speed, etc., over ones based on concepts such as concentration or mental effort, may, however, be to some extent illusory. In Chapter 2 of this thesis, a number of these theories were critically examined. A conclusion which seemed to constantly emerge was the presence, in many of these theories, of an unacknowledged, but necessary distinction between what, intuitively, may be termed effortful and automatic mental processes. For example, one theory considered was that high g-loading tasks are those which have a large 'amount' of transformation between input and output. An examination of a number of examples, however, made it clear that this was a plausible theory only if the 'amount' of transformation was interpreted as implying active, effortful, mental transformation. Tasks which may involve a large 'amount' of transformation are not found to be high g-loading ones when only highly automatic mental processes are involved. Similarly, theories which revolve around the ability to maintain information in immediate memory, were shown to be valid only if this also involves the concurrent 'active' manipulation of information. The short-term holding capacity in situations where no such 'active' mental processing is simultaneously taking place, as with performances on the familiar forward memory span tasks, does not appear to be strongly related to intelligence. Similar conclusions were reached for other theories not making explicit reference to such notions as automatic or effortful processes. Even in the case of a strategies oriented view of general intelligence, the same conclusion may be drawn. Certain data, such as that involving the generalisation of learned strategies to similar but not identical tasks, seems to indicate the existence of some more basic, or 'structural', limitation on subjects' ability to select appropriate strategies. A consideration of various possible 'structural' limitations seems to lead, in turn, to these notions of effortful and automatic processes.

With regard to theorising on the nature of intelligence, the above conclusions do appear to present a dilemma. On the one hand, attempts to make such notions of mental energy or effortful processing more explicit and scientifically acceptable have not lead to strong experimental evidence, or significant support amongst psychologists, for a theory of intelligence based on these concepts. On the other hand, (if the validity of the arguments presented in Chapter 2 of this thesis is accepted), various theories of intelligence not making explicit reference to such notions, do appear to rely, if only implicitly, on these concepts. It is as though these various theories provide, collectively, an ostensive definition of intelligence, by enumerating those types of mental processes, or task characteristics, which apply to different sorts of high g-loading tests, but with none of these providing a necessary condition for a task to be a good measure of intelligence. Furthermore, it appears that this is achieved by pointing to those situations where individual differences are primarily determined by the efficiency of active or effortful, rather than reflexive or automatic, mental processing.

A possible explanation for this apparent dilemma is that, firstly, there does exist a fundamental distinction which can intuitively be described as active and effortful, as opposed to reflexive and automatic, mental processing, but that, secondly, this distinction is not adequately described by the particular models which have formed the framework for empirical evaluations of theories of intelligence based on this distinction. For example, it would be an essential part of the meaning of terms such as 'effortful', 'demanding concentration', or 'requiring mental energy', that such mental processes would, in general, tend to interfere more with other concurrent mental processes, especially those which are also described in similar terms. However, this does not imply that a theory of intelligence based on these concepts must necessarily rely on a particular model which reflects these properties, such as that of a single distributed capacity, or pool of attentional resources, as proposed by Kahneman (1973).

In the following section, a plausible basis for this distinction between the two types of mental processes is suggested. Although sharing many of the properties of existing attentional theories, it is suggested that it is better suited as a way of making more precise, and scientifically acceptable, a theory of intelligence based on such notions as mental energy and effortful processing.

4. Attention and Intelligence: A Model Based on the Distinction Between Diffuse and Constricted Neural Processes

In this section a way of relating the psychometrically based notion of task complexity to concepts derived from cognitive attentional theories, and from models of neurological functioning, will be suggested. This is done in an attempts to give a more precise interpretation to Spearman's (1927), and Jensen's (1977) proposal that more complex tasks are those requiring more 'mental energy', or require active and effortful, rather than reflexive and automatic, mental processing. In this respect, the model can be seen as serving a similar purpose as the suggestion of Hunt and Lansman (1982), discussed earlier, that psychometric 'g' can be understood in terms of Kahneman's (1973) Attentional Resources theory of attention. However, in the present model, the distinction between effortful and automatic mental processes is made, not on the basis of the extent to which the processes require some hypothesised general-purpose supply of attentional resources, but on the basis of the nature of the critical neural activity underlying performances on the relevant task. More specifically, it is proposed that 'effortful' mental processes be defined as those reflecting the efficiency of more diffuse, or more spatially distributed, neural pathways, while 'automatic' mental processes are identified as those critically involving the more constricted, channelled and isolated, neural pathways.

The main elements of the proposed model derive from previously existing concepts or theories, rather than representing any major new concepts or assumptions. The model can best be regarded as a demonstration of how a number of previous ideas can be linked in such a way as to give a plausible basis to the intuitive notion that more complex tasks are those which involve more effortful mental processing. In the presentation of the model, no attempt will be made to critically examine, or argue for, the correctness of these previous concepts or theories. Instead, the emphasis will be on, firstly, demonstrating how these previously stated ideas can be used to relate attentional concepts to the notion of task complexity, and secondly, to compare the resulting model with alternative current theories and models. The most important of these existing notions which form the basis of the model are as follows:

a) From the area of cognitive attentional theory is the distinction between structural and capacity-limited forms of interference between concurrent or dual tasks, and the definition of 'automatic' and 'effortful' mental processes in terms of the extent of interference between concurrent task. (Kahneman, 1973; Wickens, 1980)

b) From neurological, or 'quasi-neurological', models of information processing, is the idea that neural pathways can be 'distributed', or spread over, an area of the brain's cortex. The two aspects of this notion of most relevance here are, firstly, that interference with the neural activity in a part of such a distributed pathway results in only a proportionate decrease in the efficiency, and not a total disruption, of the related mental processing. Secondly, is the idea that the actual neurons can be 'general-purpose' in the sense that they may, individually, be involved in more than one neural pathway. The 'holographic' model of Pribram (1971, p. 140), and the so-called pattern-associator models of distributed processing (e.g., Rumelhart and McClelland, 1986, pp. 33-37) give possible mechanisms to explain these two properties.

c) One of the ideas most central to the proposed model, is Kinsbourne and Hick's (1978) concept of 'functional cerebral space', and the associated hypothesis that the degree of interference between performances on concurrent tasks is largely dependent on the proximity, in the brain's cortex, of the critical neural processes required by the two tasks. Also relevant is the notion that more 'highly automatized' mental processes generate a 'minimal spread' of neural activity in the brain's cortex. (Kinsbourne, 1981) Conversely, more 'effortful' tasks are those whose neural pathways utilise, or activate, a greater proportion of the area of the brain's cortex.

d) Next, is the generally accepted view that the brain's cortex is organised into areas with lesser, and greater, degrees of functional localisation, and that systematic differences exist in the nature of the more localised, and less localised, mental processes. Neural activity in the less specialised regions of the cortex is commonly described as being associated with the more 'higher-order', or 'more complex', mental processes which control and co-ordinate the activity of the more specialised, and more localised, ones. (For example, see Walsh, 1987; Lezak, 1983; Luria, 1973.)

e) Finally, building upon the ideas in d) above, is Cattell's (1971, Ch. 3) proposal that the broard ability factor, fluid intelligence, Gf, can be interpreted, neurologically, as reflecting the efficiency of processing in the less specialised areas of the brain's cortex, the so-called tertiary association areas.

The model will be presented as follows. Firstly, a number of existing theories of attention will be briefly reviewed in terms of the concepts of structural and processing capacity limitations on dual task performances, and the distinction between automatic and effortful mental processes. (This account follows closely the analysis presented by Wickens, 1980.) Where applicable, parallels which have been suggested between the different attentional models and theories of intelligence will be noted. Secondly, an attentional model will be suggested which can be regarded as an extension of Kinsbourne's neurological theory of inter-task interference which takes into account of the ideas on cortical functioning outlined in d) above, and incorporates the distinction between structural and resource-limited forms of dual task interference. Thirdly, an attempt will be made to show how this attentional model, taken together with the neurological interpretation of Gf given in 'e' above, can be used give to a non-circular, and less intuitive, basis to Spearman's, or Jensen's, suggestion that higher complexity tasks are those which involve more 'effortful' mental processing. Finally, the resulting interpretation of the structure of mental abilities will be compared with other well known theories of intelligence. Since the interpretation of intelligence, and of task complexity, which emerges has a close similarity to views expressed by Jensen and Eysenck, special attention will be given to differences between these views and the proposed model.

i) Models of Attention:

Amongst the numerous meanings of the term 'attention' (e.g. Moray, 1969, p. 6), the one most often suggested as a possible explanation of individual differences in general mental ability, is that which has emerged from attempts to explain the pattern of performance deficits which occur in dual, or concurrent, task paradigms. One possible account of dual task performances is that interference between two concurrent tasks occurs when both tasks require the use of one or more specific information processing 'structures', which are assumed to be serial in operation, and are unable to simultaneously share the processing required by the two tasks. In such 'structural' theories, it is common that one of these structures (often termed the executive, or central processor) has a special and important place in the mental architecture. This derives from its position at the top of an assumed hierarchy of mental control, and its role in the execution of 'higher-order' mental processes, sometimes identified with consciousness or effortful mental processing. (e.g., Kerr, 1973.) Automatic processes refer to those not involving, or only minimally involving, the operation of the serial central processor. However, it is not always the case that such an 'executive' structure is postulated. Allport (1980a, 1980b), for example, argues strongly against a strong hierarchical structure of control, and instead, for a system of 'co-operating experts'. Here, the concept of automaticity is suggested to be unnecessary, and even to be circular in its definition.

The most popular alternative to such structural theories are those such as proposed by Kahneman (1973), or Norman and Bobrow (1975), which postulate a limited supply of processing capacity, or attentional resources, capable of being shared between (or 'energising') a number of concurrent mental processes. Thus interference between performances on concurrent tasks can occur, not only as a result of competition for some specific mental structure ('structural interference'), but can also occur between tasks not utilising common structures. This can occur as a result of competition for a limited supply of 'general purpose' attentional resources. Although, in theories such as Kahneman's, the existence of specific, serial processing, structures is allowed, no distinct 'structure' with the functions of an executive, or central processor is assumed. However, it is generally regarded that 'executive', and 'higher order' forms of processing are those (more 'effortful') ones which require relatively greater amounts of attentional resources. Those (more 'automatic') processes needing less attentional resources are lower on the hierarchy of cognitive control. Although single resource theories tend to focus on resource limitations in producing inter-task interference, the concept of structural interference is retained in order to account for what Wickens (1980) termed structural alternation effects. This is where the pattern of interference amongst pairs of tasks appears to be related to specific task content, or input/output modalities, and not only on the 'effortfulness', or resource requirements, of the individual tasks. (For example, pairs of verbal tasks, or pairs of spatial tasks, tend to produce more interference than pairs comprising a verbal and a spatial task.)

The main ways in which structural and resource-limited interference may be operationally distinguished resides in the way in which performance on one task is affected by changes in the difficulty, or the priority given to, the other task. (This is provided that the level of performance on the second task does not alter as its difficulty or priority is varied. See Roediger, Knight and Kantowitz, 1977, for more detailed discussion on this point.) Progressively decreasing levels of performance on one task as a result of increasing difficulty, say, of the other, would be taken as evidence of interference due to resource limitations. Structural interference, on the other hand, is characterised by a more discontinuous pattern of interference, with the presence of a concurrent task producing performance deficits which are not sensitive to changes in the difficulty, or priority, of the concurrent task.

A third, and more recent, type of attentional theory is one which postulates a number of distinct pools of processing resources (Naven and Gopher, 1979). It is frequently suggested that each of these pools is associated with different neural sub-systems of the brain, such as hemisphere of processing, or those neural structures associated with different input/output modalities or modalities of more central processing. Experimental evidence for the existence of more than one form of resources derives from the resource-like characteristics of apparently content-specific sources of interference between concurrent tasks (Wickens, 1980). However, much of the appeal of such a model derives from its apparent consistency with the commonly held view of the brain as containing a number of distinct, though interacting, functional sub-systems, capable of operating in parallel without cost to performance. There does not appear to be, according to common interpretations of brain functioning, a neural system or mechanism which could plausibly be identified with an executive, or central processor, or with a single, general-purpose pool of attentional resources. For example, Allport (1980a) argued strongly against monistic attentional theories (either based on a central 'executive' structure, or an undifferentiated supply of attentional resources), largely on the basis of this multi-system view of neurological functioning.

ii) The relation of attentional models to the structure of mental abilities:

There are two main ways in which the above attentional concepts have been related to theories of intelligence. First are the suggestions that individual differences in attentional resources, or in the operation of an 'executive' system, might underlie differences in people's general intelligence. It is sometimes suggested, also, that the operation of the specific mental structures, such as are assumed by Kahneman and others to produce 'structural interference' between concurrent tasks, correspond to the lower g-loading group factors, or special abilities. (See earlier discussion in Chapter 2 of this thesis on such ideas as stated by Hunt and Lansman, 1982, and by Sternberg, 1981b.)

The second way in which these concepts have been related to the structure of mental abilities, is associated with the model of brain functioning consistent with the multi-processor attentional theory of Allport (1980a), or the multi-resource models of Naven and Gopher (1979) and Wickens (1980). Thus Gardner (1983) identifies separate neural sub-systems, or functional cortical regions, with each of his various human 'intelligences'. A certain degree of cortical localisation was, in fact, one of Gardner's (1983) eight criteria for the identification of each of his so-called 'multiple intelligences'.

Generally, supporters of such pluralistic models of attention, and of mental abilities, do regard the prevailing view of the brain functioning as supportive of their pluralistic emphasis. Such a emphasis is also consistent with the more recent trend in the results of studies on dual task performances to find evidence against the notion of a single pool of processing capacity (Wickens, 1980). On the other hand, if attentional theory is to be linked to the correlational structure of mental abilities, then this structure, as described by hierarchical factor models, or by radex models, does strongly suggest a more 'monistic' attentional theory as its basis. This is evidenced by the suggestions, mentioned earlier, made by various authors on a single attentional resource model, or the operation of an 'executive' processor, as underlying individual differences in general intelligence.

iii) The pattern of localisation of function in the brain's cortex.

As emphasised by the advocates of pluralistic models of attention, or mental abilities, neurological evidence (brain-damage studies etc.) has shown that certain types of mental processes, especially those related to specific sensory and motor functions, or to specific 'content' (verbal, spatial, etc.), do tend to be localised in different areas of the brain's cortex. Thus different broad regions of the cortex are primarily responsible for the perception and processing of visual, auditory, verbal, spatial, musical, and tactile material, and the co-ordination of the various motor outputs. (The exact list and location of the functional areas is not important for the present discussion.) It is this functional division of cortical areas which have been hypothesised as corresponding to the distinct parallel processors of Allport (1980a), the pools of attentional resources of Wickens (1980).

However, superimposed on this organisation of the cortex into different broad functional areas, there does exist another pattern of organisation of a more hierachical nature. A generally accepted aspect of the operation of the brain's cortex is that there is there is significant variation between the different cortical locations in the degree of specialisation of function. (The general model of cortical functioning described in this section is widely found in neuropsychology texts such as Lezak, 1983, or Walsh, 1987.) Within each of the various broard regions of the cortex are found smaller areas of more highly specialised function. These are the so-called primary association, or projection, areas. Damage to these areas can produce a marked decline in the less complex, and more specific, forms of mental processing. Surrounding these centres of more specialised function are, firstly, the secondary, and then the tertiary, association areas. As one moves away from the primary association areas, functions become progressively less localised, and involve mental processes of higher apparent complexity. The tertiary association areas of each hemisphere of the brain merge to form a continuum in both form and function, and serve to co-ordinate the activities of the more specialised regions of the cortex. As well as being less content or modality specific, processing here appears to be more highly distributed. Damage to small local areas of the tertiary association areas produces minimal cognitive impairment, and the effects of damage to these areas seems to more closely follow the so-called 'law of mass action'. (Cattell, 1971, p. 187) That is, the degree of mental impairment is proportional to the mass, or volume, of damaged brain tissue.

It is important for later discussion to note that those mental functions which are more localised in the cortex, include not only the less complex, and largely innate, sensory and motor functions. Localisation of function also appears to occur for highly overlearned skills, such as in the understanding and production of language, the playing of musical instruments, or riding a bicycle. Localised cortical lesions in the appropriate locations can produce large deficits in the performances of such highly overlearned skills.

iv) An attentional model:

The view of the brain as being organised into a number of functionally distinct regions is suggestive of the structure-specific, multi-capacity attentional models of Wickens (1980), or of Naven and Gopher (1979). However, the hierarchical organisation of regions of the cortex into areas of greater localisation of function, surrounded by areas of more distributed and less specific processes, does suggests a slightly different way of accounting for the patterns of interference between concurrent tasks. Moreover, it will be argued, in the following sections, that such an attentional model does allow a more acceptable account of the observed structure of mental abilities, than do either the single, or multi-, resource (or processor) models which were discussed earlier.

Central to this model is the distinction, described above, between firstly, the more isolated and localised neural processes involved in the less complex (and also highly overlearned) mental functions, and secondly, the more distributed, or diffuse, neural processes which correspond to the more complex (or not overlearned) processes of the secondary and tertiary asssociation areas. The model can be summarised as follows:

a) The concepts of automatic and effortful mental processes are defined in this model in terms of the above neurological distinction. Automatic processes are those corresponding to the more isolated, (or 'channelled'), and more functionally specific, neural pathways. Conversely, the less automatic, or more 'effortful' processes, are those involving more diffuse, or distributed, neural pathways. (These definitions make more explicit the essentially similar ideas expressed by Kinsbourne, 1981, on the differences between mental processes associated with a greater, and lesser, spread of neural activation.)

Note that the concept of automaticity here is closely associated with, but does not correspond exactly to, that of the localisation of brain functions. The key concept here is that of the 'diffuseness' of neural pathways. A highly automatic task may involve critical neural pathways in numerous and widespread cortical locations, so long as these pathways are relatively constricted and functionally isolated from other neural processes.

Also, it should be emphasised that the terms diffuse and constricted represent a continuum in the nature of neural pathways, as do the corresponding notions of automatic and effortful mental processes. At the one end are the most highly automatic, and largely inate, processes of the primary sensory projection areas. Slightly more diffuse, and less automatic, processes would include those of the surrounding secondary association areas, and also the relatively localised neural pathways related to highly overlearned (or 'automated') skills. At the other end of the continuum are those neural pathways which may be postulated to involve the whole of the tertiary association areas of the cortex, of a hemisphere, or (more likely in the author's view), large portions of these association areas.

b) Interference between concurrent tasks is assumed to be a function of the amount of 'overlap' in the neural pathways involved in the performance of the tasks. Thus the model does not postulate one or more sources of attentional 'energy' (resources, capacity, etc.). In this sense, (but not in the stricter sense used by Kahneman, 1973, or by Wickens, 1980), all interference between concurrent tasks can be regarded as 'structural' interference. This is essentially the same idea suggested by Kinsbourne and Hicks (1978), and Kinsbourne (1981), that the amount of mutual interference between performances on dual tasks is determined by the proximity of the 'functional cortical space' associated with the performances of each of the tasks.

c) <u>The nature of the interference between concurrent tasks</u> differs depending on whether this results from interference (or overlap) between relatively diffuse, or constricted, neural pathways. Competition for functional cerebral space (to use Kinsbourne and Hick's, 1978, term) by the overlapping of more <u>diffuse</u> neural pathways would tend to produce the type of interference between the tasks which Wickens (1980) suggests is indicative of <u>resource</u> limitations. That is, interference between the tasks is not 'all or nothing', but exhibits a more or less continuous trade-off between performances on the tasks as they compete for 'cortical space', in much the same way as is explained in models where tasks compete for some hypothetical neuronal energy supply, or supplies. In such a situation, more 'attention' being given to the performance of one of the tasks is interpreted, in this model, as more cortical space being allocated to the processing of that task, at the expense of cortical space being available for the other task.

The notion that the efficiency of distributed neural processes can vary as a function of the amount of cortical space utilized is compatible with Pribram's (1971, p. 140) 'holographic' model, and other suggested distributed processing models (Anderson and Hinton 1981, Ch. 1; Anderson, 1983; Rumelhart and McClelland, 1986, p. 33) In such models mechanisms are proposed which explain how the removal of a part of distributed neural pathway can result in only a decrease in processing efficiency, and not the complete disruption of the mental process. (By analogy, a holographic image can be reconstructed, for example, from only a portion of the original hologram, but with decreased information content as manifest in lower contrast and greater blurring of the image. Similarly, in distributed pattern association, or associative memory, models information is distributed over the strengths of the linkages between large numbers of 'elements' or 'modules'.)

Interference between tasks due to highly constricted neural pathways, however, would tend to occur in a more 'all or nothing' manner, which Wickens (1980) describes as being being evidence of so-called 'structural' interference. Since the constricted pathways are more isolated and functionaly more specific, this would be more likely to occur only when both tasks require the same, or very similar, forms of processing. Also, since the more highly automated neural processes tend to be those associated with specific sensory input and motor output, this is consistent with the types of 'structural' interference suggested in the primarily capacity-based models of Kahneman (1973) and others. However, the somewhat constricted neural pathways involved in the performance of overlearned sensorimotor, language and other skills, may also give rise to a more 'structural', rather than resource limited, form of interference between concurrent tasks.

d) The process of automatisation and the 'constriction' of neural pathways

It is common in neurological models of distributed processing, that the consolidation of neural pathways is hypothesised to occur through the increased conductances of the synaptic connections between neurones, which occurs as a result of repeated activation of these connections (Hebb, 1949; Anderson, 1983). That is, the transmission of a signal along a given pathway becomes 'easier' (more rapid, etc.) with greater use. A second assumption which will be made here, is that, accompanying such a process is a progressive constriction, or contraction, of the initially more diffuse neural pathways. Although such a notion is not usually found in mathematical models of distributed processing/memory, it is consistent with the neurological evidence on the difference between the degree of cortical localisation of new and highly practised old learning.

Although no mechanism for this contraction of pathways is offered here, the functional explanation is clear. Firstly, a greater constriction of pathways would produce less interference with neighbouring neural activity, thus conserving precious cerebral space, and also making the pathway less vulnerable to outside neuronal 'noise'. Secondly, with greater ease of passage of the signal through individual synaptic junctions, fewer neurons are needed to convey the signal with the same level of reliability. (An analogy, suggested by Pribram's holographic model of distributed memory can be noted here. It is a property of a hologram that, for a given amount of information storage, a larger area is required if only low contrast fringes are possible. However, if more definite fringes are allowed, say through longer photographic exposure, a smaller area of the hologram is able to carry the same information.)

v) A brief comparison with other attentional models:

Like Kahneman's (1973) theory, the present model does provide for both 'structural' and 'resource limited' patterns of interference between concurrent tasks. (As described previously, this distinction is between a relatively discrete, versus continuous, trade-off in performances between two concurrent tasks, as the difficulty or priority of one task is changed.) Resource-like effects, however, are assumed to occur through the competition for cortical area by overlapping diffuse neural pathways, rather than for a limited supply of some mental energy. However, the model is similar to the multiple resources, rather single resource theories, insofar as it does allow minimal interference between apparently resource consuming tasks in some situations (see Allport, 1980a, for examples of these). This would occur when each task involves large areas of distributed processing, but which are spatially well separated on the cortex, such as may occur if the tertiary association areas of separate hemispheres were involved.

The main differences between the proposed model and the multiple resources ones of Naven and Gopher (1979) and Wickens (1980) are two-fold. Firstly, the distinction between automatic and effortful processes is an important part of the present model, as is the distinction between resource-like verses 'structural' interference effects. Multiple resources models, however, are more likely to dispense with the notion of automaticity, as it is not needed to explain cases of minimal interference between apparently 'effortful' tasks. This can be simply explained by these models by assuming that different pools of resources are used by the two tasks. Also, the concept of structural interference (generally used to explain so-called structural alternation, or content-specific, interference effects) is not needed as the assumption of a number of distinct resource pools allows of an alternative explanation for these effects. (Note, however, that Wickens, 1980, presents evidence for both a number of separate attentional resources, as well as sources of structural interference.) Another difference is that although the different regions of the cortical association areas may produce effects somewhat similar to those which would follow from the assumption of distinct pools of attentional resources, the various regions are, to varying degrees, continuously connected with other regions. Thus interference effects would tend to follow the arithmetic of a multiple resources model if remote cortical regions are involved, that of a single resource model if the same region is involved, and some intermediate model if adjacent regions are involved in the performance of concurrent tasks. It should be noted that, although this model does differ in important ways from single attentional resource models (such as Kahneman's, 1973), it does share the important property that more 'effortful' tasks are, in general, more likely to be disrupted by other ongoing mental processes, and are more susceptible than tasks which are performed more 'automatically' to various factors whose influence on mental performances have been interpreted as being due to a depletion in the amount of 'attentional resources' being available for processing (e.g., M. Eysenck, 1979, 1982).

The distinction between automatic and effortful processing was retained in the proposed model, mainly because of the easy way in which these concepts could be related to neurological concepts (i.e., diffuse verses constricted neural pathways), and because of the natural way in which the development and 'automation' of skills can interpreted within the model. In particular, it gives a ready explanation of the effect of more highly overlearned, or 'automatic', skills apparently consuming less 'attentional resources'. This follows immediately from the assumption of the progressive contraction of neural pathways with increased automation, and the interpretation of resource-like effects as resulting from the interference between more diffuse, or distributed, neural pathways. It also does it in a way which avoids many of the difficulties of the strict single resource, or multiple resources, attentional models. It also avoids the conceptual problem of relating the 'energy-supply' notions of these attentional 'resource' theories to plausible neural mechanisms.

vi) The relationship of the attentional model to the structure of mental abilities:

The central proposal here is that, in normal individuals, the efficiency of the more diffuse, or distributed, mental processes in the different regions of the cortex is reflected in individual differences by a single ability factor, which can be identified as closely resembling the fluid intelligence factor, Gf, of Gf/Gc theory. This proposal can be regarded as a restatement of Cattell's (1971), that Gf reflects the efficiency of processing in the less specialised regions of the cortex, the tertiary association areas. In terms of the concept of task complexity, as discussed earlier in this thesis, complex tasks are those for which individual differences are largely a result of individual differences in the efficiency of more diffuse neural processes.

most situations) the 'g' of a diverse battery of tests may provide a more reliable estimate of Gf than would be obtained from the administering of a number of relatively pure Gf markers. Gf tasks would, in general, be more susceptible to such state factors as fatigue and anxiety, and, for a given testing time may produce a less reliable measure than a Gc task like Vocabulary. The inclusion of Gc tasks, although possibly introducing some systematic bias due to variation in educational opportunity, etc., may nevertheless result in the 'g' of the battery giving a more stable estimate of a person's 'true' level of Gf ability than would a series of more pure Gf markers. This would not be expected to be the case, however, for samples containing a wide variation in age or educational levels, or where subjects have experienced recent changes in their levels of mental efficiency. As an extreme case, Gf and Gc measures diverge greatly in patients suffering from recently occurring dementia, with Gf tests being generally regarded as the most direct measure of current mental efficiency, and Gc tasks being used as estimates of general mental ability prior to the onset of the dementia. (See Chapter 1) For such patients the psychometric 'g' of common test batteries, which contain a substantial component of Gc ability, would clearly be inappropriate as an measure of their present ability to perform complex mental processes.

Hunt and Lansman (1982) suggested that Kahneman's notion of an undifferentiated pool of attentional resources might be a way of giving

Alternatively, if the term 'effortful' is defined as in section 4 above, then both Gf and the notion of task complexity can simply be interpreted in terms of individual differences in more effortful mental processing. Tasks for which individual differences are more a result of differences in the more constricted, or localised, neural processes are associated with numerous other ability factors, with varying degrees of association with Gf. As a general rule, those highly localised and largely innate processes which are related to sensory and motor functions seem to be the ones least correlated with Gf. Somewhat more highly correlated with Gf are those relatively localised processes where it can be assumed that the localisation is the result of prior learning, that is, where the degree of localisation can be assumed to depend to some greater degree on the prior efficiency of more diffuse processes. In cases where individual differences in the efficiency of localised processes is primarily a function of the efficiency of prior more diffuse neural processes, (most plausibly in the case of tasks such as Vocabulary, and other Gc markers), then relatively high correlations with Gf may occur. This may happen even though mental processing of relatively low 'complexity' is generating individual differences in such tasks at the time of their performance.

It is important to note the different relationship, in the proposed model, of individual differences to 'effortful' and 'automatic' processing. The efficiency of effortful processes, irrespective of their nature or location in the cortex, is postulated to be reflected in a single ability dimension, namely Gf. It therefore makes sense to talk of individual differences in the ability to perform effortful mental processing. By contrast, there is no analogous meaning to the concept of individual differences in automatic processing, as no single ability dimension is assumed to correspond to this description. However, such a description could meaningfully be used to specify a class of ability factors which may share important common properties. For example, it would be meaningful to propose that more automatic mental processes are relatively less affected by anxiety, fatigue, or global dementia, but are more easily disrupted by localised cortical lesions. This is consistent with automatic processing being reflected in numerous distinct ability factors, although it is true that significant variation in such factors in a particular sample would tend to increase the magnitude of positive correlations amongst this category of tasks.

vii) The relation of the above interpretation of the structure of mental abilities to other theories and concepts:

The model suggested above is most obviously similar to those theories which interpret general intelligence in such terms as mental energy, attentional resources, and effortful mental processing. However, important differences between this model and other such similar ones should be noted. The main dissimilarity with Spearman's (1927) original single common factor model, apart from its attempting to give a more precise account of the notion of 'mental energy', lies in the assumptions on the nature of the factors associated with the lower complexity tasks. In Spearman's model these factors (the s's) were assumed to be task-specific and uncorrelated. In the present model, these are allowed to be correlated, and are assumed to be much broader in content, with an importance comparable to that of the second-order factors Gv, SAR, Ga, etc. of Gf/Gc theory. Another important difference is that in Spearman's and other similar statements (e.g., Jensen, 1977, 1979) individual differences in mental energy, or attentional resources, is assumed to be reflected in the 'g' of batteries of diverse tests. In the present model it is suggested (as was also proposed by Hunt and Lansman, 1982) that certain types of high g-loading tasks, such as Vocabulary and other common Gc markers, do not directly reflect individual differences in effortful, or 'complex', mental processing at the time of test performance. For this reason the present model identifies Gf, rather than 'g', as reflecting more directly individual differences in effortful mental processing.

It should be explained that the above emphasis on Gf, rather than 'g', as being more appropriate for an operational definition of task complexity, has been based primarily on theoretical considerations. From a practical point of view, however, it is possible that in certain situations (possibly even in substance to Spearman's concept of mental energy as the source of individual differences in intelligence. Thus, in common with the present proposal, intelligence is seen as being associated with effortful mental processing. However, as emphasised earlier, in the present model the concept of effortful processing has a close, but not exact, link with that of a single, general purpose, pool of processing capacity. Here, effortful processing is defined in terms of the involvement of diffuse neural pathways, which may produce in certain circumstances, but not always, trade-offs in the performances of concurrent tasks of the form which would be predicted from a single attentional resource model such as Kahneman's. 'Effortful' concurrent tasks which involve diffuse, but spatially well separated, neural pathways would give rise to lower mutual interference than would be expected from a single attentional resource model. This is an important difference between the model being proposed here and a theory of Gf (or of 'g'), such as that suggested by Hunt and Lansman (1983), which is based on the concept of a single supply of attentional resources. The latter model would predict that two concurrently performed high Gf-loading (and therefore 'effortful') tasks would always show high levels of capacity-like mutual interference. The proposed model, however, would allow, for certain combinations of high Gf-loading tasks, that lower levels of inter-task interference could occur in such dual task situations. Thus, for example, concurrently performed verbal reasoning and spatial visualisation tasks (both relatively good markers of Gf) could be expected to show lower levels of mutual interference on the basis of the proposed model, than would be expected on the basis of the model suggested by Hunt and Lansman (1983). (This would follow if the 'diffuse' neural pathways associated with the performances on each of the tasks were well separated on the cortex, and not greatly overlapping, as might be expected if different hemispheres were primarily involved in the performances of the verbal and spatial tasks.) The finding of a relatively low level of interference between such tasks might be taken as evidence for a multi-processor, or multiple resources, attentional model (e.g., Allport, 1980a, Naven and Gopher, 1979). However, such multi-processor, or multiple resources, models would <u>not</u> explain why both these tasks are good measures of Gf. It is the particular strength of the proposed model that it can accomodate the sorts of data commonly used to support multi-processor, or multiple resources, attentional models, but as well give an account of concept of task-complexity, which does seem to be more easily related to single attentional resource, or 'central processor', types of attentional models.

In terms of the factorial description of the structure of mental abilities, the theory which most closely relates to the model being proposed in this thesis is the Gf/Gc theory of Horn and Cattell. The model suggested above could be regarded as an attempt to relate Gf/Gc theory to the notion of task complexity, and to those attentional theories which may give some basis to the notions of effortful processes or mental energy. The connection between the proposed model and Gf/Gc theory is particularly close for the presentation of this theory by Cattell (1971) in which Gf is linked with the operation of the tertiary association areas of the cortex. The further development of these notions in terms of the concept of task complexity in this thesis, however, does give Gf a special and central place in the architecture of mental abilities, an emphasis which is not usually found in presentations of Gf/Gc theory. In this sense, the elaboration of Gf/Gc presented here does give greater acknowlegement to the radex-like structure of abilities, as displayed in Figure 1 of this thesis, and to the notion of task complexity which is emphasised by others (usually those writers supportive of the concept of general intelligence) working outside of the conceptual framework of Gf/Gc theory.

More recent statements of Gf/Gc theory by Horn (1985, 1986), are however, less consonant with the above interpretation of Gf/Gc theory. Here the equivalent status of the different human intelligences (corresponding to the various broad second-order factors of Gf/Gc theory) is emphasised. This would also apply to other more 'oligarchic', or 'pluralistic' types of theories, such as that of Gardner (1983), where the term 'multiple intelligences' is often used as a means of emphasising the equivalence, in importance or status, of a number of distinct ability domains. It should be pointed out, however, that from the perspective of structural organisation of functioning in the brain's cortex, there is one sense in which the proposed model could be regarded as 'pluralistic'. One of Gardner's (1983) eight criteria for the specification of a separate 'intelligence' is its potential isolation by brain damage. Now it is consistent with the present model that damage to large areas of the tertiary association areas in one region of the cortex will result in significant deficits in the complex processing of material associated with nearby more localised processes, while complex forms of processing occurring in the other undamaged tertiary association areas may be relatively unaffected. Thus, for example damage to large areas of the tertiary association region of the right cortex would produce large deficits in the ability to perform spatial/visualisation tasks of high complexity, while leaving relatively intact the ability to perform a complex verbal task, whose critical processing is located in the association areas of the left hemisphere. Thus, from a structural perspective, the model does have similarities to the multi-processor one of Allport (1980a,b), and the multiple intelligences approach of Gardner (1983). However, as a theory of intelligence it would be more appropriately regarded as 'monistic', as it is proposed that (at least for non brain-damaged people) various forms of more complex processing are related to a single dimension in individual differences. This follows from the assumption in the model that the efficiency of more highly diffuse or distributed neural processes is reflected in a single dimension in individual differences (namely Gf), irrespective of the cortical localisation of the processing.

Except for the operational definition of task complexity in terms of 'g', rather than in terms of Gf, the theoretical account of task complexity given by Jensen (1977, 1979) is largely consistent with the ideas being suggested in this thesis. Jensen describes complex tasks as being intentional and involving 'some kind of conscious mental effort', rather than being reflexive or automatic. He does not, however, attempt to define these notions in terms of any specific attentional theory. The present model can be seen as an elaboration of these ideas so as to make such a notion more acceptable as a scientific theory of intelligence. Similarly a close parallel between the present model and Jensen's (1969, 1973, 1974) earlier Level I/II theory can be drawn provided that some qualifications are made. It is clear from his theoretical descriptions of these abilities, and the tasks used to operationalise them in his empirical studies, that Level I and Level II abilities correspond to tasks of relatively low and high complexity, respectively. Apart from the issue, discussed above, of whether it is 'g' or Gf tasks which more appropriately represent 'complex' mental processes, is the question of how Level I ability can be related to this model. How this may be done depends largely on whether 'Level I' refers to a single low-complexity ability dimension, associated with the short-term learning and memory of symbolic material (roughly equivalent to the SAR dimension of Gf/Gc theory), or whether it refers, collectively, to the set of all ability factors of relatively low complexity (cf., Jensen, 1982a). The central aspect of Jensen's theoretical definition of Level I tasks is that these are low g-loading tasks which involve mental processes of relatively low complexity. However, when giving examples of actual Level I tasks, or when choosing marker tests of Level I ability for use in empirical research, it is the lower complexity tasks involving short-term memory and rote learning which are usually selected, rather than lower complexity tasks in other ability domains, such as those tasks involving fluency, perceptual speed, or spatial ability. Jensen's Level I/II theory would more closely relate to the model presented above if 'Level I' was regarded as a collective description of various distinct ability factors which represent mental processes of relatively low complexity.

Not so apparently consistent with the model presented in this thesis is the importance give by Jensen (e.g.,1980a, 1980b, 1982b), and also H. Eysenck (1982, Ch. 1), to the study of elementary reaction-time tasks and their relationship to intelligence. Correlations between such tasks and intelligence are typically of the same order of magnitude as are found for other more common low complexity tasks, such as perceptual/clerical speed or memory span. (This does not necessarily mean that these correlations are always small. With the use of extreme groups, or with subjects in the lower ranges of ability, high correlations can be obtained, as is the case, with, say, the simple forward memory span test; see discussion in Chapter 2 of this thesis.) In the model proposed earlier, such reaction-time tasks would therefore be interpreted as primarily reflecting individual differences in relatively automatic forms of mental processes, as are the various other types of tasks of relatively low complexity.

The above disagreement, however, should be regarded as being primarily methodological rather than theoretically substantive. The main attraction, for these authors, towards the study of elementary reaction-time tasks is that the finding of a significant relationship between these tasks and traditional measures of intelligence would be strong evidence against what they see as a popular, but erroneous, notion on the nature of intelligence. This notion is that 'our current standard tests of intelligence measure nothing but a particular class of specific knowledge and acquired cognitive skills or strategies...', and that 'individual differences in intelligence are attributable to differences in opportunities afforded by the environment for acquiring the specific items of knowledge and skills that are called for by the standard tests of intelligence' (Jensen, 1982, pp 93, 94). While in basic agreement with Jensen and Eysenck on this point, the model proposed earlier would suggest that a type of task which is more suitable for their purposes is one similar to the serial short-term memory test studied in this thesis, and others similar to Wittenborn's (1943) tests of sustained attention. As with reaction-time tasks, performances on these so-called tests of 'sustained attention' could be regarded as relatively free from acquired knowledge or skills, but unlike reaction-time tests, they have been found to be good direct markers of fluid intelligence (see Study 1 in this thesis, and also Crawford and Stankov, 1983). Furthermore, from a theoretical perspective, there does seem to be a more natural consistency between the use of such 'attention' tasks (rather than reaction-time tasks) and Jensen's (e.g., 1977) agreement with Spearman that higher g-loading tasks are those which seem require more 'mental energy', or involve active, rather than reflexive, mental processing.

Consistent with Jensen's and Eysenck's views on intelligence are the findings of D. E. Hendrickson (1982), and of Ertl and Schafer (1969), on the close relationship between certain auditory evoked potential measures and intelligence. Although not inconsistent with the model proposed earlier in this thesis, there is no immediately apparent way in which these results could be predicted from the model. The main difficulty here is finding a way in which such physiological measures, which are taken when subjects are in a relaxed state of mind, can be related to individual differences in the performances of effortful, rather than automatic, mental processes. However, the interpretation of these findings in terms of the accuracy of neuronal propagation of signals in the brain (A. E. Hendrickson, 1982) does suggest a possible (though speculative) explanation of this connection. In our previous discussion of the nature of more highly diffuse neural pathways it was suggested that these forms of processes are likely to be relatively error-prone, in comparison with the more localised, or 'constricted', neural pathways which determine performances on more automatic mental processes. It is plausible, therefore, that individual differences in the efficiency of more diffuse pathways (as measured by performances on more complex tasks) are related to some general physiological property of the brain which determines the 'error-proneness' of the neuronal processes. If Hendrickson's (1982) hypothesis, that the auditory evoked potential measures reflect the accuracy of neuronal signal propagation, is correct, then it follows that these evoked potential measures would also be related to a person's ability to perform tasks requiring 'effortful' mental processing.

It is interesting to note that if the above was the case, and if it were also supposed that the factors governing the more localised or 'automatic' processes are less related to general properties of the brain, but rather have different developmental or genetic determinants, then this would explain what was presented earlier as an assumption in the proposed model. This is the assumption that the efficiency of diffuse neural processes in <u>different</u> regions of the association areas reflect the <u>same</u> dimension in individual differences (namely Gf), while the efficiency of the more constricted pathways in <u>different</u>, more specialised, regions reflect <u>different</u> ability dimensions, as measured by various lower complexity tasks.

Jensen's (1979) view on strategies, as a basis for the understanding of intelligence, is that they are a 'red herring'. To the extent that this implies that tasks whose performances are not strongly determined by a subject's choice of strategies can nevertheless be good measures of intelligence, the model presented above is in agreement with Jensen's statement. However, the model does imply a close and fundamental relationship between intelligence and what have been termed executive control and strategic processes. This follows from the generally accepted idea that a hierarchy of control exists between the functions of the more specialised, and the less specialised, regions of the cortex. Psychoneurological accounts of the functions of the tertiary association areas emphasise their role in the co-ordination and control of the more specific and more localised neural functions. Such processes are also generally assumed to be more 'flexible' (or less 'ballistic'), and more directly associated with conscious or voluntary control, than are the more specific and localised processes. In other words, a major role of the tertiary association areas is the performance of what cognitive psychologists have termed executive control and strategic functions, and which have been postulated by numerous authors as underlying individual differences in general intelligence.

There is, therefore, a certain consistency between those more 'process-oriented', or strategies-based, theories of intelligence and the model being suggested in this thesis. However, these theories do diverge from the one being presented here on whether the efficiency of processing in these association area might be measured by tasks of an algorithmic, or mechanistic nature, for which performances do not depend significantly on individual differences in strategic processes. That this can be done is suggested by the supposed critical involvement of the tertiary association areas in functions other than strategic ones (Lezaik, 1983, pp. 269, 270). Examples are tasks requiring the temporary holding in mind of information concurrent with other non-automatic forms of processing. Such tasks have been described as reflecting the operation of an active', or 'working' short-term memory systems. (The use of the Counting Animals test used in this thesis is a good example.) Because performances on such tasks reflect the efficiency of the less localised neural processes, then, according to the model presented, they would be expected to be strongly related to intelligence, even though they do not directly reflect the role of the more distributed neural processes in being associated with the operation of more 'flexible' strategic functions.

viii) Summary of model and its relation to intelligence:

An attempt has been made to relate concepts from attentional theories to the observed correlational structure of abilities. This involved the postulation of an attentional model, suggested largely by commonly accepted aspects of the functional organisation of the cortex, and which relies heavily on the definition of automatic and effortful processes in terms of the extent to which the critical neural pathways are 'constricted', or are more 'diffuse'. Such a model was seen to give rise to both limited resource, and structural interference, effects as defined in attentional models which focus on the explanation of concurrent task performances. However, significant differences were noted between this model and other currently popular single resource, or multiple resources, attentional models.

The model of mental abilities which was related to the above attentional concepts closely resembles that of Gf/Gc theory, but also incorporates the notion of task complexity. As a result, it shares some conceptual similarities with the more 'monistic' theories which developed from the single common factor model of Spearman. The 'synthesis' between Gf/Gc theory and the concept of task complexity, was made, not as has been previously suggested, by relating this to the 'g' of the battery of tests, but rather by the identification of Gf as the factor representing differences in the ability to perform 'complex' mental processes. This was related to the above attentional model by the assumptions that 'complex', mental processes can be identified with processing involving the more diffuse neural pathways of the association areas, and the less complex ones with the more constricted and automatic processes of the more specialised areas of the cortex. As well as being being consistent with common interpretations of neural functioning, this model gives a more scientific basis to the often stated view that more 'complex' tasks are those involving mental effort or concentration, rather than being reflexive and automatic. This is achieved by the identification of these largely intuitive notions with concepts for cognitive theories of attention, which can be independently operationalised via dual-task, and other, experimental paradigms.

Although suggesting a primarily 'structural', or 'hardware' basis of individual differences in intelligence (or more specifically, Gf), the model does imply a close relationship with those theories of intelligence based on executive or strategic processes. This follows from the neurological interpretation of the tertiary association areas having as their main function the 'higher-order' control and co-ordination of the more specialised areas of the cortex (e.g., Luria, 1973). The model does suggest, however, that relatively strategy-free tasks can` also be good measures of intelligence, by reflecting the efficiency of 'more diffuse' mental processes in ways other than their involvement in strategic functions. From aspects of the attentional model relating to performances on concurrent tasks which were discussed earlier, it follows that such tasks could be described, at the psychological level, as measuring individual differences in effortful, rather than automatic, mental processing. Thus, although in basic agreement with Jensen's (1979) statement that strategies are a 'red herring', the proposed model does suggest a close relationship between the efficiency of the so-called higher-order executive or strategic functions, and psychometrically based notions of task complexity.

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APPENDIX

Table 30

Correlations Between All Variables Used in Study 1

Variable Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14
2	99													
3	-45	-50												
4	34	33	05											
5	38	40	-29	52										
6	-08	-09	38	43	-44									
7	31	33	-17	19	31	-14								
8	36	38	-31	16	36	-22	91							
9	-21	-21	39	-01	-28	34	01	-30						
10	26	29	-16	19	29	-11	30	27	-01					
11	26	29	-16	19	29	-11	30	27	-01	1.00				
12	13	12	15	15	05	07	13	02	18	37	37			
13	38	37	-20	24	27	-03	38	33	03	66	66	25		
14	37	39	-25	22	28	-06	35	34	-04	63	63	19	96	
15	-01	-11	38	07	-19	29	-01	-16	35	05	05	28	08	-07
16	24	24	-04	35	23	08	41	32	13	47	47	32	45	35
17	17	17	-20	17	36	-17	43	41	-09	37	37	01	34	31
18	17	17	11	30	01	24	15	06	24	35	35	41	31	20
19	40	40	-05	20	13	04	23	19	08	11	11	10	27	23
20	40	41	-29	30	39	-16	33	37	-29	21	21	03	26	24
21	30	29	05	12	-01	12	14	08	18	05	05	11	21	17
22	29	29	-04	33	24	04	10	09	06	-04	-04	07	09	05
23	39	39	-24	34	41	-09	24	27	-12	-01	-01	-02	09	11
24	20	19	04	25	13	07	03	01	12	-04	-04	08	-07	02
25	42	43	-13	27	36	-08	29	28	-09	13	13	-01	25	27
26	45	47	-31	23	45	-23	32	34	-17	19	19	-06	27	30
27	02	01	30	12	-08	26	02	-03	18	-05	-05	07	06	05
28	14	15	-11	07	16	-12	04	05	-04	10	10	-07	12	14
29	46	47	-27	38	29	-02	34	33	-05	20	20	08	24	25
30	19	19	-10	15	07	-02	14	13	-03	10	10	04	07	05
31	22	22	-11	16	17	-04	22	19	03	17	17	07	07	05
32	38	39	-16	39	35	-07	42	36	-09	26	26	11	34	36
33	43	43	-21	21	29	-08	31	35	-23	22	22	05	36	33
34	39	39	-09	38	27	05	35	29	02	16	16	04	18	15
35	00	-17	13	13	-03	12	-08	-01	-14	-23	-23	-03	-17	-20
36	18	17	-09	16	-01	08	-01	-03	02	-12	-12	10	-03	-05
	1	2	3	4	5	6	7	8	9	10	11	12	13	14

Note: Decimal Points have been omitted. (Continued next page)

Table 30, continued

	15	16	17	18	19	20	21	22	23	24	25	26	27
16	26												
17	−09	62											
18	41	76	−01										
19	11	21	01	27									
20	−09	14	18	01	45								
21	17	19	−06	30	95	17							
22	16	06	−04	14	28	13	26						
23	−14	04	17	−12	13	35	01	45					
24	22	05	−10	20	25	01	28	96	18				
25	−10	15	12	07	42	41	32	23	29	16			
26	−20	12	20	−02	31	51	16	26	32	18	81		
27	18	08	−11	19	24	−04	28	02	−06	04	43	−11	
28	−04	05	12	−03	20	16	17	23	11	22	23	27	−01
29	−17	34	21	26	30	40	19	24	34	16	28	33	00
30	−07	20	20	08	06	06	04	08	12	06	01	05	−09
31	−05	27	25	15	13	12	10	04	11	01	04	11	−12
32	−01	34	28	20	33	38	23	19	21	15	39	38	06
33	01	31	28	20	39	37	29	20	21	14	24	30	02
34	06	30	16	24	35	30	28	29	30	22	32	36	−04
35	14	01	−12	08	02	−06	03	00	07	−03	−02	−05	00
36	09	13	04	20	14	09	12	27	11	25	00	−02	00
	15	16	17	18	19	20	21	22	23	24	25	26	27

31	15							
32	−09	41						
33	−07	43	88					
32	17	45	12	11				
33	05	43	17	22	35			
34	07	42	12	13	46	36		
35	04	01	04	00	06	−05	09	
36	−03	20	10	02	21	06	23	39
	28	29	30	31	32	33	34	35

Table 31

Correlations Between all Variables Used in Study 2

Variable	1	2	3	4	5	6	7	8	9	10
1. Raven's Matrices (nc)										
2. Raven's Matrices (a)	98									
3. Raven's Matrices (s)	-17	-25								
4. Letter Series (nc)	21	18	26							
5. Letter Series (a)	43	44	-21	55						
6. Letter Series (s)	-16	-19	52	54	-32					
7. RST Task	25	26	06	27	37	00				
8. Forward Digit Span	12	13	02	15	17	02	20			
9. Backward Digit Span	20	23	-01	25	36	00	25	49		
10. Primacy Recall	18	20	-07	00	18	-13	26	43	31	
11. Recency Recall	23	24	-06	20	21	05	25	36	32	30
12. Search (nc)	18	17	21	28	05	27	22	23	17	24
13. Triplets A (nc)	19	19	20	22	06	21	30	13	09	10
14. Triplets B (nc)	16	16	20	26	05	28	30	06	06	05
15. Triplets C (nc)	32	30	15	30	29	15	33	05	11	05
16. Triplets C (nc)*	31	30	14	31	34	11	33	08	14	06
17. Search (a)	17	19	-26	12	23	-17	17	15	06	10
18. Triplets A (a)	-01	-02	-04	12	12	16	-02	10	10	07
19. Triplets B (a)	01	01	-10	04	27	-22	05	09	20	15
20. Triplets C (a)	33	30	-11	19	38	-15	26	-01	11	07
21. Triplets C (a)*	30	32	-13	31	48	-10	27	06	13	13
22. Search (nc)	17	16	23	27	04	29	21	22	17	23
23. Triplets A (s)	19	20	20	19	04	21	28	11	07	09
24. Triplets B (s)	15	16	21	25	02	30	29	05	03	03
25. Triplets C (s)	27	25	19	29	24	19	29	06	11	03
26. Triplets C (s)*	28	27	17	29	29	14	30	07	13	04
	1	2	3	4	5	6	7	8	9	10

Notes: * Variable obtained from last three repeats only. See text.
(nc) = number correct score
(a) = accuracy score
(s) = speed score
Decimal Points have been omitted.

Table 31 (continued)

	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
12.	16														
13.	14	68													
14.	10	58	80												
15.	11	41	58	68											
16.	12	38	55	63	98										
17.	32	18	11	04	07	06									
18.	00	-07	08	03	01	00	12								
19.	09	-03	04	07	21	24	12	12							
20.	07	12	15	13	42	45	30	00	33						
21.	10	10	10	08	38	44	23	-01	20	70					
22.	14	99	68	58	41	38	11	-07	-04	09	09				
23.	14	69	98	79	58	55	11	-10	02	15	10	69			
24.	08	58	79	99	65	60	02	01	-06	08	05	58	79		
25.	09	41	59	69	99	96	-01	02	17	28	28	42	58	67	
26.	11	39	57	66	97	99	02	01	23	37	33	39	56	63	97