REASONING

IN

ORGANIC BRAIN DISEASE

A THESIS SUBMITTED FOR PHD EXAMINATION

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ABSTRACT

Whilst the measurement of reasoning ability in the normal population is well established and reliable, the assessment of the reasoning powers of people who have suffered brain damage remains problematic. This is due in part to the prejudicial effects of motor and sensory impairments on classical tests of reasoning and in part to the confounding effects of focal cognitive impairments. A new test of inductive reasoning in organic brain disease has been developed, which attempts to minimise these constraints. The new test has six sections, matched sets of odd one, analogy and series problems, presented in verbal and non-verbal formats.

Following a pilot study, three experimental series were constructed to serve as both standardisation and validation samples. They comprised a control sample of 155 adults and two series of 40 patients who had suffered unilateral cerebral lesions to the right and left hemisphere. All subjects attempted the new test and a selection of established tests of cognitive function.

Standard measures of reliability and validity were demonstrated to be at an acceptable level. The normative data from the control sample was used to analyse the scores of the two lesion series. The left lesion group was impaired on all six sections of the new test; the right lesion group was intact on verbal odd one and verbal analogy, but impaired on all three of the non-verbal sections and verbal series.

It is concluded that the left hemisphere has a crucial role in inductive reasoning problems, whether presented in verbal or non verbal format and that some right hemisphere functions are implicated in arithmetic reasoning. Because reasoning ability was not shown to fractionate as a result of acquired brain damage, the theoretical model of reasoning ability remains remarkably close to Spearman's original description of *g*.

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1. INTRODUCTION

The ability to reason and solve problems has long intrigued investigators. The idea that such a pervasive and elusive ability could be measured simply, in rigorous and comparative terms, has been compelling. Many large studies have attempted to define and demonstrate the intellectual skills of normal people. Some investigators have devoted their energies to developing instruments to calibrate individual intellect. Others have striven to describe damaged brain functions in similar psychometric terms.

There are two potential gains from the study of reasoning in organic brain disease: a better understanding of the intellectual functioning of a brain damaged person may, firstly, improve the knowledge about these conditions available to patients and staff and hence facilitate rehabilitation, and secondly, it may throw light on intact brain function. The present study embraces both these aims.

Before the development of the new test is described, the theoretical basis of intelligence testing and the concepts of intelligence and problem solving will be discussed. Then sample tests devised for measuring individual intelligence in intact populations will be reviewed. Next the effects of brain damage on cognitive function will be considered, followed by a critique of current tests used to assess problem solving in organic brain disease. Most of the progress in understanding intelligence has occurred as a result of statistical advances. The methods that led to the most important studies are described in the next section.

1.1 STATISTICAL METHODS AND MENTAL TEST THEORY

1.1A EARLY DEVELOPMENTS

Galton (1885) was the first to use the normal distribution in psychology. He is credited with inventing the percentile rank. It was Galton also who discovered the technical concept of correlation, a quantitative index of co-relation. Correlation relies on the assumption that two measures taken on a given sample and showing a high degree of association may be regarded as measuring the same phenomenon. But Galton did not appreciate its usefulness with regard to mental tests, applying it only to his genetic work which studied the degree of physical resemblance between parents and children. It was left to Pearson (1857-1936) to develop *r*.

For a couple of decades there was a vogue for amassing sets of sensory discrimination data, but this line of development was brought to a halt when Wissler's 1901 paper showed that there was no correlation among individual American college students' scores on these tests and the test scores did not correlate with college grades.

Spearman wrote one of the first applications of correlation procedures to mental tests (1904) and he also tried to deal with error in test results. In 1910 he produced the Spearman-Brown formula for test reliability. Yerkes' (1921) report of the Army Alpha test program is an early use of multiple correlation in psychological testing. Correlations among the separate tests were computed to see which tests best contributed to the overall scores.

With these methodological advances, the two traditions of intelligence investigation became more clearly separate. The first is "factor analysis", which is concerned to identify "dimensions" of mental ability. The second is "mental test theory", which is concerned to reliably measure mental abilities.

1.1B FACTOR ANALYSIS

The relationship of technical advances in factor analysis to theories of intelligence is discussed by Jensen (1980). The problem of factor analysis is perhaps best thought of as determining how many common factors are needed to explain the correlations among a set of variables. Kline (1991) explains that the value of factor analysis is that variations in scores on a number of variables can be expressed in a smaller number of dimensions or constructs. These are the factors. The factor analysis shows the correlation of each of the variables with the dimensions. Factors are defined by these correlations, called factor loadings.

Spearman had used factor analysis in an attempt to validate his two-factor theory. He attempted to show that variance shared by more than one variable represented a common element, which was called *g* for general. Thurstone's method of factor analysis was designed to produce the most parsimonious and thus the most meaningful description of test data. He called this style of analysis "rotation to simple structure". The aims were to have as many small (or preferably zero) loadings as possible and to concentrate as much of the total variance in each test on as few factors as possible. Thurstone hoped to devise factor–pure tests.

However there were "common factors", which were shown to manifest themselves on more than one test variable. *G* was pervading all the tests. Simple structure can not be achieved as long as there is a substantial general factor. Thurstone adopted oblique rotation, whereby the axes and angles can be moved around, rather than be held at right angles to one another. The general factor variance is thus converted into correlation among the factors themselves.

Thurstone used mathematical concepts of determinants and matrix algebra to generalise Spearman's model of factor analysis. This technique led to Thurstone's nine *Primary Mental Abilities* (1938), which was based on the first major study of mental tests which used the multiple factor analysis method. Whilst it was impossible to devise any kind of test involving complex cognitive function that does not have a considerable loading on *g*, it was possible to construct tests that load on *g* and only one group factor, as do Thurstone's PMA tests. Most of these original factors remain in contemporary analyses using electronic computers. Multiple correlations of large numbers of variables are now within researchers' grasps. The identification and description of relationships among variables has been much facilitated.

Cattell (1978) has supported Thurstone's original notion of simple structure with empirical work. He demonstrated that simple solutions are replicable and yield meaningful factors in cases where the factors are known. However Cattell also demonstrated that factor analysis must be technically adequate to obtain simple structure and the majority are technically flawed.

Considerable problems remain in factor analysis. For example, there is no clear agreement about how best to estimate what proportion of variance in each variable should be assigned to the common factor space—the "communality". This largely arises because of problems in determining the extent of error variance. A second problem comes when deciding on the most psychologically meaningful structural description. In theory, there is an infinity of factor matrices which could generate any specified correlation matrix. Analytical methods of rotation to simple structure have been developed, but all have been shown to give similar results with large data sets. The purpose of rotation is to achieve the simplest possible description of variables, by making as many as possible of their loadings at or close to zero.

Joreskog (1969) developed a significance test for the structure of the data. Maximum likelihood methods are used to fit target matrices which may be specified with varying degrees of precision. However Kline (1991) notes that with large matrices, the chi-square test of fit finds it difficult to choose between target matrices unless these are grossly different (Nunally, 1978). Once again, science is reduced to subjective judgement in practice.

Kline (1991) reviews recent advances in factor analysis and technical standards.The principal factor analysis will be subjected to an oblique factor analysis, in which significant factors are rotated to simple structure by a procedure which maximises the number of zero loadings. He thinks that such a factor analysis should yield factors which are replicable and which account for much of the variance in the matrix.

Confidence has been increased by the finding that different forms of factor analysis give much the same results when large numbers of observations are involved. For example, Ree and Earles (1991) analysed the scores of 9,173 young Americans on a multiple-aptitude test battery. The methods used were unrotated principal components, unrotated principal factors and several variants of hierarchical factor analysis. Fourteen estimates of *g* were obtained, all highly correlated with each other (0.930-0.999). The solutions ranked individuals in almost the same order.

Jensen (1980) repeats the cliche that nothing comes out of factor analysis that the investigator did not put in originally, but points out that the factors that are obtained from correlations among variables were not previously known, although their existence may well have been hypothesized. A factor is a construct operationally defined by its factor loadings. Factors are interpreted by inspecting which variables have high and which have low loadings on them and thus their psychological identity is indicated.

There is continuing controversy regarding whether two or more items can be considered to be measuring the same ability and how they might be related to an underlying continuum—a “latent trait”. Correlations and factor analysis assume that all items administered measure a single ability.

1.1C ASPECTS OF MENTAL TEST THEORY

Kline (1986) lays down the principles that govern the construction of a good test. Reliability refers to the internal consistency of the test. The items must be measuring the same variable and should therefore be intercorrelated to a large extent. However, highly similar items can raise reliability at the expense of validity. A very high internal reliability should therefore be treated with caution.

A test's validity means how much it measures what its author claims it measures. There are three ways to assess validity. The concurrent validity is how well a test correlates with other similar tests. This raises the obvious problem that there may be no criterion test available for comparison and, if there is, there may be no need to develop another. Ideally a new test should do the same job better, or more quickly, or with an extended group of the population.

The second form is construct validity, which involves testing hypotheses concerning the variable. The real world can rarely provide a clear cut demonstration. Face validity is how a test looks and is received. Adults may not complete a test that they perceive to be silly.

Norms are samples of populations which provide a range of scores against which an individual score can be judged. Large normative samples enhance the credibility of interpretations. The assumption also remains that abilities tend to be distributed normally and many traits measured in fundamental units (e.g. adult height) tend to produce this distribution. If the assumption is valid, abilities may be presumed to be measured on interval scales. But of course, many equiprobable events can generate a normal distribution (e.g. repeatedly tossing a coin), and thus the observed normal distributions could be the result of mathematical artefact.

These statistical methods and theories of test construction are the stepping stones by which researchers have reached the current state of knowledge. The next section describes the steps that were taken en route.

1.2 THE SEARCH FOR UNDERLYING MENTAL STRUCTURE

1.2A EARLY WORK

In the early part of the 20th century, American workers such as Whipple (1910) began to develop mental tests which could be administered in a group setting. Subjects were asked to answer as many questions as they could within a given time, in contrast to the Binet scale where the a level of competence is determined as a point on a linear scale. At the same time, the "multiple choice" form of administration became widely adopted. The First World War led to the development of the Army Alpha Examination, on which a million American soldiers were assessed. Educational researchers were impressed by the army's test and produced many imitations to help teachers assess school children.

Psychologists such as Thorndike and Thurstone had been involved in the army project and went on to develop techniques of "standardization" and "validation" in their peacetime work. An example would be Thorndike and colleagues' CAVD test (1927) which comprised completion, arithmetic, vocabulary and directions. Spearman published the first empirical study which suggested an underlying, common factor for all mental test scores. In *The Abilities of Man* (1927), he explained how a matrix of correlations among scores and academic ranks could be arranged hierarchically to demonstrate that each test measures a general factor, which it shares to a greater or lesser extent with other mental tests, and a specific factor, which is unique to any one test.

Spearman produced a proof that the *g* of one set of tests was the same as the *g* from another set of tests, provided that each test involves only *g* plus a specific factor and that at least two tests are common to both sets (Spearman and Jones, 1950). Later he began to write about group factors existing alongside the general factor *g*, when it became clear that specific groups of intelligence tests were more highly intercorrelated than would be predicted by his original two–factor theory.

Perhaps the first cogent overview of the nature of intelligence was published by Thorndike (Thorndike, Bregman, Cobb and Woodyard, 1927). He thought that intelligence was characterised by the capacity to form bonds among ideas and concepts. By 1935, when the Psychometric Society was founded at the University of Chicago, group mental testing had become widely adopted throughout all levels of education.

Although the PMA battery (Thurstone, 1938) never reached high standards of standardization and validation, its importance was that it showed how mental ability could be considered in terms of functionally separable factors. Thurstone's seven main factors were: P, perceptual ability; N, numerical ability; V, verbal ability; S, spatial-visualizing ability; M, memory; I, induction; and D, deduction.

Each factor was thought of as a distinct underlying entity that would be called into action by any test that required its use. It follows from this model that an average score on a test composed of widely differing items could result from a number of combinations of ability levels on different factors. Another aspect of the model was that an individual could be considered as having a pattern of abilities involving some weaknesses and some strengths and hence the idea of aptitudes for specific occupations gained currency.

Over the next fifty years, the emphasis in test development was on tests that would be of practical use for educational and vocational counseling in high schools. The exception to this was the Second World War, when psychologists were required to help with the selection and training of the forces.

1.2B GUILFORD

Guilford was one of the specialists involved with the American Army Air Force. His war work led him to develop a twenty year project to measure mental abilities. He produced a new model of intelligence, which he called the structure of intellect (SI, Guilford, 1956).

He argued that there was no *g* factor of mental ability, because of zero correlations among some mental tests. However as Jensen (1980) points out, *g* may still be a valid theoretical concept, even if it does not extend into every aspect of human ability.

Guilford's tests are specially constructed to minimize their *g* loadings. His subjects are drawn from a narrow ability band which would be expected to reduce the variance on the *g* factor. Later he claimed the confirmation of 98 factors of cognitive ability (Guilford and Hoepfner, 1971). They were a subset of 120 different, orthogonal factors from his SI model, generated from four types of Contents, five types of Operations and six types of Products. All of these categories are generally considered to be rather arbitary and intuitive.

Tests have not yet been devised for all of the 120 abilities. There has been some methodological reservation about the subjectivity of Guilford's data. He specifies target matrices, that is, the factor loadings of the variables are specified in advance from theory. Factors are rotated to a position which is as close as possible to the target matrix. Horn and Knapp (1973) showed that such rotations could match target matrices from both random data sets and data sets built with opposite hypotheses. Some workers now believe that Guilford's model is best thought of as a classification of tests. *G* remains without serious challenge.

1.2C CATTELL

Another influential worker who has attempted to characterise mental structure is R.B. Cattell. At the same conference, both Cattell (1941) and Hebb (1941) suggested that two distinct concepts of intelligence should be recognized. Hebb described Intelligence A, which represented potential, and Intelligence B, which represented realised intelligence.

In 1943, Cattell developed his suggestion that two group factors should be placed alongside *g*: *fluid* intelligence and *crystallized* intelligence. Horn and Cattell (1966) explain that the primary abilities, which involve intelligence to a significant degree, are organized at a general level into two principal dimensions. Each of these two new factors was postulated to have several narrow, lesser factors associated with it, along the lines of Thurstone's Primary Mental Abilities. The authors began to argue for a move away from a single all-purpose intelligence test (e.g. Horn, 1968).

Fluid intelligence is thought of as basic capacity and crystallized intelligence is thought of as acquired ability, for example the results of experience and learning. Tests loaded mostly on the fluid factor are those with relatively small information content, but where the solver is required to recognise complex relationships among often simple elements. Examples would be series, classifications, analogies, block designs and matrices.

Cattell (1987) specifies that the items must be presented in a format which is neither verbal nor pictorial, but couched in shapes that would be equally accessible to people of differing backgrounds. Horn (1985) has shown that even verbal tests of the analogy or series form can be made to load on fluid intelligence very substantially, if the words are chosen to be within the vocabulary of the solvers. Fluid intelligence was thought to reduce the complexity of relationships, without recourse to answers already stored in memory.

Tests loaded mostly on the crystallized factor are those which have a significant informational content and draw on acquired knowledge. Examples would be information, vocabulary and formal logic problems. Spearman had noted that tests of arithmetic separate on *g* depending on whether they consist of problem or mechanical arithmetic. In problem arithmetic, where the arithmetic operations are not explicit and the subject must choose, the *g* loading is very high (.7 to .8). However, in mechanical arithmetic the operations required are explicitly stated and the *g* loading is moderate (.4 to .6). Cattell (1987) explains that the judgment and discrimination exercised by tests of crystallized ability have either been taught systematically or exercised before.

Fluid and crystallized intelligence have not always been clearly distinguishable in factor analysis. Kline (1992) considers that fluid and crystallized intelligence are both Spearman's *g*, split by more efficient factor analysis. There are other lines of evidence that the two factors may have a psychological reality. For example, tests that load differently on fluid and crystallized intelligence show different trends across ages. These findings are discussed in Section 1.6, which reviews evidence for the organic basis of *g* in the normal population.

Another difference between fluid and crystallized intelligence is that, for any given age range, there are greater individual differences for fluid than for crystallized intelligence. The standard deviations are almost 50% greater for fluid intelligence tests.

In 1974, Hakstian and Cattell published a very diverse and extensive sampling of cognitive abilities. 343 adults sat 57 tests. Each test was constructed to be as homogeneous as possible. Factor analysis of the results yielded nineteen primary factors. They were intercorrelated. *G* was found to account for 36% of the total variance. The highest *g* loadings were for speed of closure and inductive reasoning. The smallest *g* loading was for mechanical knowledge.

The latest developments in the theoretical explanation of mental abilities have come from the information processing approach of cognitive psychology.

1.3 COGNITIVE MODELS OF INTELLIGENCE: PROCESS

Many psychometricians have raised the problem that factors derived from statistical analysis of large groups of test scores do not help us understand how people reason. Spearman (1923) devised an information processing approach, when he attempted to explain the processes that might underlie the general factor that he had found: apprehension of experience, eduction of relations and eduction of correlates.

Cattell (1971) also tried to remedy this problem. Hunt (1978) explored this limitation and identified another, which is that an identical score on a test achieved by two individuals does not mean that their cognitive processes were identical when they achieved the score. Kline (1992) rejects the notion that non-linear processes mediate problem solving, on the grounds that seventy years of factor analysis can not be wrong. Parsimony demands a linear model in the absence of convincing data against it.

Whereas the fundamental unit in most psychometric theories is the factor, cognitive approaches to modelling intelligence have described the information processing component as the fundamental unit of analysis. Sternberg has been a major force in developing this approach (e.g. Sternberg, 1988).

He suggests three kinds of information processing components: "Metacomponents" for executive planning, monitoring and evaluation; "Performance components" which execute various strategies, such as encoding, inferring and applying; lastly, "Knowledge–acquisition components" which are processes involved in learning new information and storing it in memory. His work on knowledge acquisition has relied on subjects working out the meaning of an artificial word, which may bear little relation to real psychological processes.

Psychologists using the individual difference tradition have chosen their tasks in one of two ways. Either they have sampled broadly from the wide range of available tasks (described by Sternberg (1988) as "placing the burden of task selection upon one's predecessors"). Or they choose tasks on the basis of their correlations with other tasks that are somehow related to the task being investigated. There is clearly a risk of ending up with a selection of closely related variants that have no theoretical structure to unite them.

Sternberg (1982, p229) set out four criteria for task selection:

1. Quantifiability, which is the assignment of numerals to objects or events according to rules.
2. Reliability, which is the extent to which a given set of data is systematic, across item types and across subjects.
3. Construct Validity, which means that it is theory based.
4. Empirical Validity, which is achieved by an extent of empirical support, obtained by correlating task performance with an external criterion.

1.4 COGNITIVE MODELS OF INTELLIGENCE: REASONING

Reasoning and problem solving have played an important part in every significant theory of intelligence. They can be thought of as attempts to combine elements of old information to form new information. Spearman's two "principles of cognition" were important components of reasoning. They were the eduction of relations and the eduction of correlates. Reasoning was one of Thurstone's seven primary mental abilities (1938). Some of the best known tests of intelligence comprise reasoning or problem solving items (e.g. Raven's Progressive Matrices, Cattell's culture fair test of *g*).

Sternberg (1988) has described a unified theory of reasoning, such that his specified mental processes are sufficient to define a reasoning task. The processes are:

1. Selective encoding.
2. Selective comparison.
3. Selective combination.

The encoding will decide which information is relevant to the task. The comparison involves the consideration of potential solutions. The combination is the construction and storage of the solution. Because there is an interaction between the solver and the task, and because there are a number of component processes involved, reasoning can be considered as a continuous (rather than a discrete) variable.

As well as processes, reasoning requires the application of rules. Procedural rules are linked to the problem format. For example, it is not appropriate to choose the odd one of the four given numbers, if the correct solution is to identify the next number in the series. Declarative rules are linked to problem content and will often be concerned with semantic knowledge. For example, when choosing the odd one of "canary, banana, lemon, apple", it is the colour and not the category that discriminates.

1.4A INDUCTION

Inductive reasoning has often been considered as central to intelligent function. Three examples of inductive reasoning are:

1.	Analogy. e.g. hand is to glove as foot is to	shoe or cardigan?
2.	Series. e.g. which number comes next:	3, 4, 5, ?
3.	Category. e.g. which is the odd one:	cat, dog, rabbit, banana?

Inductive reasoning has often been thought to be closer to the intelligence required outside of the laboratory, because there is no certain conclusion, as there is in deductive reasoning. Instead the solver can only ever hope to reach an inductively probable conclusion. Sternberg (1988) gives the following example. Consider the series completion task 1,2,3,4,?. 5 is not the only possible answer. The typical generating equation is (n+1), where n is the value of the previous item. However, {(n-1)(n-2)(n-3)(n-4)+n} would fit the given series just as well, generating 29 as the fifth value. Whereas some solutions are more parsimonious than others, there is no one logically correct answer.

Holyoak and Nisbett (1988) point out that inductive processes must deal with uncertainty in two ways. Any mental representation must take account of variability in the world and this knowledge of variability must be used to reduce uncertainty. These could be seen as mechanisms for generalization and specialization. Generalization means increasing the range of examples that are covered by a rule.

But induction must be constrained, otherwise we would become overwhelmed by fruitless hypotheses. Holyoak and Nisbett quote the philosopher Charles Saunders Peirce, who mentions people's "special aptitudes for guessing right". They identify two biases that constrain human induction. Firstly there are adaptive heuristics and secondly there are cognitive limitations. The hypotheses generated must be plausibly useful and the irrelevant and insignificant must be ignored, in order for enough resources to be free to process essential information.

Analogies have been the most widely studied form of inductive reasoning. Spearman (1923) used analogies as prototypes of intelligent performance. A recent attempt to model the processes involved in analogy by Byrne (1991) outlined three requirements. Firstly the solver must retrieve a base domain or set of ideas with which they are familiar. Then they must map the information from the base domain to the target. Finally they must generalise, or induce a general set of information on the basis of the analogy.

Byrne's model takes account of the complexities of analogies, which are comparisons involving multiple relationships among objects, that may also have striking differences. It also takes account of the two ways in which analogies can be made more difficult. Firstly there is the obscurity of the terms and the associated verbal semantics. Secondly there is the obscurity of the target relationships; this can be enhanced by the use of distractor items which bear some semantic relation to the given word, but do not share the target relationship with the given word.

Sternberg (1988) identified seven components involved in all inductive reasoning:

1. Encoding, whereby the solver recognises the terms of the problem and accesses attributes of the terms that are stored in semantic memory and might be relevant to the task solution.

2. Inference, which relates the first two items of the analogy.
3. Mapping, determining the higher order relation between the two halves of the analogy.
4. Application, when the solver uses the relation inferred between the terms in the first half of the analogy , maps it to the third term in the second half of the analogy and thus generates an "ideal" solution.
5. Comparison, when the ideal solution is compared with each of the given answer options.
6. Justification, the decision whether any of the given options are close enough to the ideal solution.
7. Response, when the solver indicates their chosen solution.

One important aspect of this theory is that encoding is an essential prerequisite step for any inductive reasoning process. In their 1988 review of induction, Holyoak and Nisbett emphasize this: "If some property of the input is not coded in the appropriate representation, it will be impossible to make any inductions involving that property" (p.62).

Rather than cataloguing the variations among different individuals, the information processing approach uses stimulus variation to isolate elementary units of intelligence. Performance on tasks is thought to rely on combinations of elementary information processing components and it is these interrelations which characterise each specific type of reasoning. It follows from this that whereas an information processing model can be shown to be wrong, it can never be proved right, because perfectly correlated processes can never be disentangled.

There are similarities to the factor analysts who study data collected from large groups. Information processing theorists also seek commonalities between tasks. They try to demonstrate that the same information processing model applies across tasks. They test whether values of a given parameter differ significantly across tasks. They seek to show that any manipulation that has a certain effect on a given component in one task has a comparable effect on a given component in another task.

1.4B EXPERIMENTAL EVIDENCE

Sternberg has made several attempts to validate his theories with data from normal subjects. He has developed a task known as People Pieces which are figures which vary on four binary characteristics. Any four of these figures can be arranged to form an analogy which the solver must decide is right or wrong. By varying the amount of information given before the figures are seen, Sternberg claims to have excluded some of the component processes from the formal task reaction times. In 1977 he reported that undergraduates attempting schematic-picture, verbal and geometric analogies produced reaction times that produced strong support for his theory. A later study of series completions and classifications showed the theory could be successfully extended to other induction subtypes (Sternberg and Gardner, 1983).

In their attempt to find out how similar these three types of inductive reasoning are, Sternberg and Gardner (1983) identified several criteria for commonalities in information processing by normal subjects. First, there is the demonstration of comparable latencies and error probabilities across tasks for component processes alleged to be the same. Secondly, there is high correlation across tasks between problems subjected to the same experimental manipulation. Thirdly, the proposed theory should fit latency, error rate and response data across tasks despite stimulus variation. Fourthly, there should be high correlations of comparable process scores on various tasks. Fifthly, there should be good agreement with established reference tests.

Thirty young adults attempted 90 inductive reasoning problems. One third were analogies, one third were series and one third were classifications. In a variant on the multiple choice protocol, the subjects were required to rank order four given solutions, in terms of their appropriateness. The patterns of the response choices across the three tasks were highly similar.

Sternberg applied his model of information processing components (1977, 1988) to the second experiment (Sternberg and Gardner, 1983). Starting from the premise that response time in reasoning is equal to the sum of the amounts of time spent on the various information-processing components, the authors inferred that, whereas the response component applies equally to all three types of reasoning problem, other components are used differentially. They hypothesised that the analogy task requires all seven; series completion does not use the mapping process, and thus requires only six components; and the classification task does not use either the mapping process or the application process, thus it requires only five components.

Thirty-six young adults attempted 90 reasoning tasks, one third of each type as in the first experiment. They were asked to select one solution from a choice of two and their responses were timed. The rank order of processing time was that predicted by the model, that is analogies took the longest, series were the next slowest and classifications were the quickest. High correlations were obtained between response times on different tasks within subjects.

Thus the basis of Sternberg's approach is to correlate an individual's score on each component of inductive reasoning, with scores on standard psychometric tests of inductive reasoning and perceptual speed abilities. The second study was less equivocal than the first in showing strong correlations between Sternberg's inference, mapping and application components and psychometric tests of induction. However the components were not correlated with tests of perceptual speed—interestingly those subjects with the highest scores on standard tests of intelligence were slower at encoding. It emerged that about half the time taken over an analogy problem is spent on encoding.

Apart from this last empirical point, Kline (1991, p116) describes Sternberg's model as banal and vacous. The components are built into the linguistic meaning of analogy, Kline explains, and must be true if language has meaning.

Sternberg, concluding his 1988 review of inductive reasoning, notes that there seems to be a consensus that many information processing components are at least overlapping across a range of induction tasks. He suggests that this may explain why many tests of general intelligence are highly correlated, yielding the ubiquitous *g*. Tests of general intelligence usually involve some induction items and some (e.g. Raven, 1938, 1962) only include induction items. The general factor may arise as a function of common information processing components, that are relevant to problem solving across induction items and probably other items as well.

1.5 INDIVIDUAL TESTING OF NORMAL SUBJECTS

1.5A EARLY WORK

Drawing on the psychophysical tradition of sensory discrimination, which had been developed by Fechner (1860) and Wundt (1862), Galton (1883) believed that simple tests of speed and acuity were direct indicators of mental ability. From 1884 to 1890, he collected data from the normal population and noted that the distribution of their test scores was Gaussian.

J.M. Cattell (1890) introduced the term "mental test", but despite a large database he and his co-workers were unable to demonstrate that his tests could predict the academic success of his students. Binet continued the work of measuring people's ability on simple tasks until finally he came to the conclusion that more complex tasks were required. Adopting a pragmatic approach, he constructed a scale of tasks for children, which systematically increased in difficulty. The administration and scoring of the test were standardized. He defined levels of typical performance of children at different chronological ages, calling them "mental ages" (Binet and Simon 1905). An important advance made by Binet was to consider intelligence as a continuous variable, rather than as a typology which was the contemporary view. He also realised the importance of validating his test by demonstrating that it correlated with some independent criterion.

The tasks were varied but all tapped the ability to reason, with either verbal or nonverbal materials. The Stanford-Binet scale, which was devised to distinguish mentally handicapped children from their peers with normal intellectual development, was the starting point for many individual intelligence tests all over the world. As the Binet scale was developed, groups of tasks came to replace the original single items for each mental age. It was a German psychologist called Stern (1912) who first showed that a ratio could be obtained with a standard deviation constant over chronological age if mental age was divided by chronological age. This was the intelligence quotient.

Terman (1916) produced a variant of the Stanford-Binet scale in which means and standard deviations were constant over different age ranges. Implicit in this contruction is its application to children at the upper ranges of ability, as well as to normal and mentally handicapped children. Mental age was found to change little after 14 or 15 years. Mental ages of adults were divided by 14 or 15, instead of by the individual's chronological age, as in children. This method was found to be unsatisfactory and raw scores were converted into standard scores for each age group. This method was adopted by Wechsler (1938, described below).

Even in later versions of the test, items are grouped together by difficulty rather than type. As Mackintosh (1989) points out, because of their empirical basis, IQ tests developed as a technology, rather than as a branch of theoretical or experimental psychology. Only one score, the IQ, is produced (Terman and Merrill, 1960). The wide variety of items increases the validity of the test, but it is only really suitable for children aged between 4 and 17.

The Stanford-Binet test and *g*

Cattell and Johnson (1986) have shown the Stanford-Binet mental ages correlate between 0.76 and 0.82, depending on age range, with vocabulary scores. This is a strong indication that Binet's test measures crystallized ability.

1.5B THE WECHSLER SCALES

The Wechsler scales are a benchmark in the measurement of individual intelligence and they have a long pedigree. The first was the Wechsler Bellevue Scale (1939) which was later developed into the Wechsler Adult Intelligence Scale, or WAIS (1955). Some of the items are very similar to those found in the Stanford-Binet, but one of Wechsler's advances was to group the items by type into independent subtests. Other improvements included extending the range of item difficulty and sampling from a wider range of occupations and geographic areas.

The current adult version comprises eleven subtests which are divided into verbal and performance subscales. The verbal subtests are: Information, which tests general knowledge; Comprehension, which examines common sense and social competence; Vocabulary, which requires the subject to define a graded list of words; Similarities, which asks the subject to say how pairs of words are alike; Arithmetic, a graded set of arithmetic problems; and lastly Digit Span, requiring the repetition of strings of digits either forwards or backwards.

The five performance subtests utilise pictorial and spatial materials: Digit Symbol, a recoding task which requires the subject to write appropriate abstract symbols under printed numbers; Picture Completion, where the subject must indicate which important part is missing from each of 21 line drawings; Picture Arrangement, where small groups of drawings are laid on the desk in scrambled order and the subject must rearrange them to make a sensible story; and lastly Object Assembly, where the subject must assemble a complete two-dimensional object from the several flat fragments scattered before them on the desk.

The six verbal subtest scores are summed as part of the calculation of the Verbal IQ and similarly the five performance subtests are added together to obtain the Performance IQ. The Verbal, Performance and Full Scale IQ's are calculated by reference to normative data. As well as for the three IQ's, age-referenced norms are also tabulated for each of the eleven subtests. The latest standardisation (Wechsler, 1981) includes 1700 people, stratified by age, sex, region of the USA, urban or rural residence, race, occupation and years of education. Not surprisingly, it is the most widely used individual test of intelligence.

The WAIS and *g*

The Block Design test has been shown to be a good measure of *g*. It correlates well with several WAIS subtests, including Comprehension, Information and Vocabulary. Block Design correlates more highly with these verbal subtests than the pairs of verbal subtests do with one another.

Cattell and Johnson (1986) have demonstrated that the verbal tests load more highly on crystallised ability and the performance tests load more highly on fluid ability. This is not surprising, because the verbal tests clearly rely more on knowledge. The exception is Digit Span, which does not load especially on either fluid or crystallized intelligence.

Das *et al* (1979) have suggested that two separate cognitive mechanisms mediate the Wechsler Digit Span subtest. Forward digit span is a marker test for sequential processing, whilst backward digit span requires the implementation of a strategy. Jensen and Figueroa (1975) found a higher correlation between backward digit span and IQ than between forward digit span and IQ.

1.5C RAVEN'S MATRICES

Raven, Court and Raven (1985) describes how the Matrices were derived from a wall chart of geometry shapes that Spearman used to investigate an individual's conceptual grasp of relationships. Each problem in the Matrices comprises an abstract geometric pattern with a small part missing. To solve the item, a subject must select one of the alternative pieces of pattern printed underneath, by inspecting the main incomplete figure and determining the logical relations that govern it.

The Standard Progressive Matrices (hereafter "SPM") has five sets of twelve problems. They were originally developed in the mid-1930's (Penrose and Raven, 1936; Raven, 1939). They were revised and standardised in Ipswich in 1938 (Raven, 1941). There have been many revisions and the SPM referred to in this study is the most recent (1983). The range of Matrices and normative samples now available mean that almost all populations can be assessed on this test, from 5 year olds to graduate adults.

The Matrices and *g*

Spearman had included Raven's Progressive Matrices in his battery and had found them to be the most highly *g* loaded. The Matrices are widely regarded as the best measure of fluid ability, probably because they are presented in a format which is likely to be equally novel to all solvers. Cattell and Johnson (1986) have shown that almost all of the variance in the Matrices can be explained by fluid ability and a factor which relates to the item form. It should be noted that Raven also produced an accompanying vocabulary scale to provide a complementary measure of crystallized intelligence.

1.6 ORGANIC BASIS OF *G* IN NORMAL SUBJECTS

Wechsler in 1958 thought that *g* could never be described in concrete operational terms. He states that "it is in essence not an ability at all, but a property of mind". Some psychologists have likened *g* to the efficiency of a machine. It is a function of how well the parts fit together to achieve something. If this is the case, then it is unlikely that *g* will be identified with any particular cerebral structure or process. It is merely an index of the efficiency of integrated action.

Spearman (1923) had suggested that *g* was a measure of general mental energy available to the brain, but this explanation does not consider why some mental tests are more *g* loaded than others or why the loadings on *g* should relate to complexity and conscious mental manipulation. Spearman's suggestion was that different parts of the cerebral cortex had specific energies. He thought of these specialised areas as engines and *g* as general neural energy.

Thorndike sugested that *g* was the total number of available neural connections. In 1927 he stated categorically that the *g* loading of a test was directly related to the number of connections it involved. Thompson, in his 1951 book *The Factorial Analysis of Human Abilities*, developed Thurstone's ideas to include the notion of sampling. Actions of the brain were thought to involve numerous structures and functions of various types. If various kinds of behavioural tasks involve sampling many elements, the degree to which performance is correlated across tasks will depend on the number of elements that they have in common. This is an earlier statement of Sternberg's component theory of reasoning, which has already been discussed in Section 1.5A.

Kline (1991) states that fluid ability is ultimately dependent on the neural efficiency of our brains. Some modern factor analytic research equates fluid ability with Spearman's *g* (Undheim 1981). The physical measures that have been shown to correlate with *g* are discussed below.

1.6A PHYSIOLOGICAL CHANGES DURING REASONING TASKS

Cerebral glucose metabolism, as measured by PET scans, provides an index of brain activity either at rest, or when performing some task. Between subject comparisons are made to determine which areas are more active during certain tasks. One study has found correlations between changes in glucose metabolism and solving the Raven's Matrices (Haier *et al*, 1988). Another has correlated verbal fluency with changes in glucose metabolism (Parks *et al*, 1988). Both found that better performance on mental tests was associated with a lower absolute level of cortical activity. This would fit with the neural efficiency model, which predicts that those with higher intelligence can solve more complex problems and expend less energy in the process.

Risberg and Ingvar (1973) recorded cerebral blood flow through the dominant hemisphere. Their control group were psychiatric patients without neurological abnormality. When the subjects performed a reverse digit span task, increases in cortical blood flow were recorded in the temporal and temporal-occipital regions. The largest increases were found in the prerolandic and anterior frontal cortex, an area implicated in logical operations.

A second, more established, form of reasoning test was also used by Risberg and Ingvar (1973). Eight of their subjects were asked to select the odd one of five from sets of geometric figures. Blood flow recordings during this task showed the same marked increases in the prerolandic and anterior frontal regions that had occurred during the backward digit span task. This is further evidence for backward digit span to be considered as a test of fluid intelligence, rather than just a measure of a person's capacity to remember lists of unrelated numbers. However in addition, the odd one task caused increased blood flow to the occipital areas and sensory and motor speech areas, which is another clear hint that the solution of standard reasoning tasks requires the succesful participation of many cerebral regions.

1.6B SPEED AND MENTAL ABILITY

There is a common belief in speed at solving complex problems as an indicator of underlying intelligence. Attempts to characterise this experimentally have led to studies linking reaction time to intelligence. Galton in 1883 had suggested this relation. It was not confirmed experimentally for many years. This may in part have been due to the inaccuracy of early timing devices. A more fundamental problem for the early models was the variation in reaction time that each individual has. They also often failed to appreciate the importance of sampling a wide range of the population. Spearman (1927) was adamant that neither reaction time nor any other physiological correlates would define level of intelligence.

Hick (1952) demonstrated that simple reaction time (hereafter "RT"), which is the individual's response time to a single stimulus, is significantly quicker than any RT task involving a choice. The increased time is thought to reflect mental processing. Hick's law states that choice RT increases as a linear function of the amount of information to be processed. Later work has suggested that Hick's law cannot be applied universally (Barrett *et al,* 1986). However, although RT has been shown to correlate with IQ at a low level, Barrett *et al* (1986) showed that the means and standard deviations of RTs and WAIS scores loaded on separate factors. Attempts to link inspection time to intelligence have been similarly disapointing.

1.6C INTELLIGENCE AND AVERAGED EVOKED POTENTIALS

Although correlations have been reported across a number of different populations, there have been unexplained failures to replicate. The best correlations to date are between IQ and the Hendricksons' string measure (the length of the contour perimeter of an AEP waveform, Hendrickson and Hendrickson 1980). For example, the full scale WAIS IQ's of 219 adolescents were correlated significantly with their string measures, giving a correlation of 0.72 (Hendrickson, 1982). Vernon (1991) suggests that the best theoretical basis for interpreting these findings has been in terms of neural adaptability (Schafer, 1979). The extent to which the brain invests resources in responding to stimuli is a function of the stimuli's expectedness.

1.6D INTELLIGENCE AND NERVE CONDUCTION VELOCITY

Vernon and Mori (1989) measured 85 undergraduates on 12 reaction time tasks, standard intelligence tests and a noninvasive test of nerve conduction velocity (NCV). Intelligence and reaction time were correlated -0.44. Full scale IQs and NCV correlated 0.42. This is rather surprising, because NCV is not a cognitive function and it is also a peripheral measure. Reed (1984) considered that the link between NCV and IQ might be explicable in terms of genetic variability in the structure and amount of transmission proteins. Proteins involved in the transmissions of impulses along nerves set limits to information processing rates and, hence, to intelligence.

1.6E EFFECTS OF AGE ON MENTAL TEST PERFORMANCE

The growth curve of fluid intelligence is closer to that of physical growth curves (Horn and Cattell, 1966), relatively rapid growth peaking at around twenty and then a gradual decline which sharpens at around 55 or 60 years. However the crystallized intelligence tests show a much more gradual increase in competence; decline does not occur until perhaps 60 to 70 years of age.

As Jensen (1980) points out, whilst performance on Raven's Matrices peaks at around 20 years of age, vocabulary scores go on increasing up to 60 or 70 years of age. For people aged over 60, test with high loadings of crystallized intelligence are better indicators of the person's optimal level of functioning. The extent to which tests do or do not hold up with age is closely linked to their loadings on crystallized and fluid intelligence.

In summary then, experiments with normal subjects strongly suggest that some physical and directly physiological measures relate to *g*. The evidence for an organic substrate for *g* from studies of the cognitive functions of patients who have suffered brain damage is considered next.

1.7 EFFECT OF BRAIN DAMAGE ON FLUID INTELLIGENCE

1.7A THEORIES FROM WORK WITH NORMAL POPULATIONS

Investigators who have spent most of their professional lives increasing our understanding of how the normal brain works have often associated fluid intelligence with physiological integrity. As early as 1941, Hebb was describing his Intelligence A factor in terms of neurological potential, rather than observable behaviour. Horn (1968) states that fluid intelligence underlies the most sensitive measures of brain malfunction, because fluid intelligence declines with brain damage and aging. He states that a relatively large proportion of the reliable variance in fluid intelligence reflects a pattern of physiological influences.

Those who were studying normal intelligence often speculated about focal deficits that might arise from brain damage. With considerable insight, Horn (1968) explains that if brain damage causes the loss of neurons from an "over-determined pattern", then there is virtually no influence on function, because vast numbers of neurons continue to fire in that pattern. However, if the neurons are lost from an "under-determined pattern", then there can be a loss of functioning of the entire pattern.

Crystallized intelligence was thought to be the behavioural counterpart of an over-determined neural pattern, because it relied on a mutually supportive set of cognitive skills. It should, therefore, be relatively unaffected by brain damage. Fluid intelligence should be more sensitive to changes in efficiency of neurological functioning. Indeed Hebb (1949) had already reported evidence that test scores thought to reflect fluid intelligence were more severely affected by brain injuries than tests thought to reflect crystallized intelligence.

An early investigation (McFie and Piercy, 1952a) considered the patern of deficits that could result from brain damage and concluded "that intelligence is composed of more or less independent abilities or groups of abilities, which are selectively impaired by circumscribed lesions in different locations." 58 patients with localized cerebral lesions were assessed on tests of abstraction, memory and subtests of the Wechsler-Bellevue (Wechsler,1944). McFie and Piercy (1952a) interpreted their overall results in the terms of Spearman's and Thurstone's theories of *g*. A slight localized lesion was thought to result in intellectual loss, whereas a severe lesion implicated the mechanical substrate of each factor. For example, loss of the verbal factor leads to aphasia.

However, mixed groups of patients with varying types of brain damage are not likely to produce evidence of focal deficits which result from a specific small area of the brain being damaged. For example, reading has been demonstrated to be generally resistant to brain damage (for example, Nelson 1982) and it is a good example of crystallized intelligence. Yet some specific damage to the left parietal lobe can lead to dyslexia (for example, Marshall and Newcombe 1973). This section discusses evidence from lesion studies concerning the effect of brain damage on fluid intelligence. The following section, 1.8, discusses the effect of brain damage on crystallized intelligence.

1.7B ABSTRACTION AND BRAIN DAMAGE

Goldstein and Scheerer (1941) thought that abstract and concrete thinking were qualitatively different. There was no continuum of functioning. The brain damaged person was consigned to the lower level of concrete thinking. This view was challenged by Reitan (1958b, 1959b), who reported findings on the Category test of the Halstead-Reitan

Battery, which is described in detail in section 1.10. Patients could improve their performance on this test of abstraction after experience with the test stimuli. If they no longer had access to the higher planes of abstract thought, as Goldstein and Scheerer (1941) had claimed, such improvement would not have been possible. In the face of Reitan's evidence, Goldstein suggested that some patients only differ quantitatively from normal functioning, wheras others are restricted to a qualitatively different level of conceptual thought (Goldstein, Neuringer and Olson, 1968).

Later work studying patients with acquired brain damage has continued to focus on the different sytems which might mediate the application of learned information and the solution of new problems. Shallice (1982) suggested that a supervisory attentional system was necessary for novel problem solving and that this system was disrupted by prefrontal lesions. Routine selection of stored information could be achieved without the integrity of the supervisory attentional system. Shallice's model implies that conventional intelligence tests will fail to expose deficits in the supervisory system, if they largely measure established cognitive routines and do not present novel problems for solution.

Aphasia and abstraction

There is some evidence that aphasic deficits are related to poor performance on tests of abstraction. For example, McFie and Piercy (1952) showed that patients with left hemisphere lesions did less well than right hemisphere cases on the Weigl sorting test (Weigl, 1927). However, within the left hemisphere group, aphasics were no worse than non-aphasic patients. Costa and Vaughan (1962) also found that aphasia reduced performance on the Weigl, leading them to suggest that even such an apparently non-verbal test of conceptual thinking might be helped by internal verbalization.

The lack of difference in performance between aphasic and non-aphasic patients on abstract reasoning tests led to the suggestion that the dominance of the left hemisphere for intellectual tasks was independent of its dominance for language. Other workers around this time reported ahasic patients performing significantly worse that non-aphasic patients on several tests thought to measure non-verbal reasoning. Colonna and Faglioni (1966) used Elithorn's Maze Test (1955).

De Renzi *et al* (1966) found that not only did aphasic patients perform poorly on a transformed Weigl, with five criteria of classification, but their scores varied with the severity of their comprehension deficit. The discrepancy held true when the groups were equated with respect to their score on a general intelligence test, Raven's Progressive Matrices (described in section 1.6C).

Russo and Vignolo (1967) used one of the earliest tests of spatial thought, the Gottschaldt test, which required subjects to identify an abstact shape from within a complex geometric mask. Goldstein (1927) thought that this task related to more than just spatial competence, and tapped a more general capacity to isolate a coherent concept from within any distracting context.

In perhaps the most thorough investigation of this test with brain damaged people, Russo and Vignolo (1967) tested four groups of subjects: normal controls, non-aphasic patients with left hemisphere damage, aphasic patients with left hemisphere damage and patients with right hemisphere damage. Not only were the last two groups impaired compared to the first two, but the aphasic patients were significantly worse than the patients with right hemisphere damage. A similar finding was reported by Weinstein and Teuber (1957).

Benowitz *et al* (1990) used a standardized battery to assess the cognitive functions of 41 patients who had suffered unilateral right hemisphere damage. Impairments in abstracting information from narrative pasages were as prevalent and as severe in magnitude as constructional apraxia. The extent of linguistic and visual-spatial deficits was highly correlated.

Vilkki (1988) investigated whether anterior brain lesions caused more severe deficits of problem solving than posterior lesions. 57 patients were studied, divided into four groups according to the quadrant of their lesion. The test material was eight plastic tokens, combining the features of red or blue, big or small and round or square. The tasks were comprehension, naming, categorization, identifying a hidden token by asking questions about its features and a sorting task.

As would be expected, the left anterior-lesioned group were slower on the routine verbal operations and the anterior groups were significantly worse on the question and category tasks. Surprisingly, the anterior groups were not significantly worse on the sorting task, after the language deficits were taken into account. A sorting task so like the Wisconsin Card Sorting Task (Milner, 1963) would be expected to be equally reliable at discriminating frontal dysfunction. The finding emphasises the difficulty of assessing reasoning skills in neurological patients, where other necessary cognitive skills have also been affected and how subtle the interaction is between language and fluid intelligence.

Another quick test of abstraction that is extensively used clinically is the explanation of proverbs (e.g. Benton 1968). For example, a patient with concrete thought processes might explain the proverb "too many cooks spoil the broth" in terms of there being too many people in the kitchen. Clearly this test is vulnerable to aphasic deficits.

1.7C LOCALISATION OF FLUID INTELLIGENCE FUNCTIONS

As would be expected from the contradictory findings regarding the role of aphasia in apparently non-verbal tests of reasoning, the evidence does not always support the functional division between the right and left hemispheres in terms of verbal and non-verbal skills for reasoning tasks. McFie and Piercy (1952b) found that impairments on the Weigl test were more frequently found in left hemisphere cases. The Wechsler Similarities test was also thought to involve abstraction and McFie and Piercy's left hemisphere cases were more impaired on Similarities. The authors went on to conclude that "the process of abstraction is in fact specifically impaired by dominant hemisphere lesions."

The frontal lobes and reasoning

The observed difficulties of patients who have suffered lesions to the frontal lobes are often explained in terms of failures of reasoning. The pattern of deficits likely to be observed in a patient with frontal lobe damage is much less predictable than the patterns observed in association with damage to other areas of the brain. Among the reported signs accompanying frontal lobe damage are distractability, lethargy, overactivity, disinhibition, concrete thinking, failure to generate alternatives, generally disorganized behaviour, perseveration and failure to plan.

Although there is a strong feeling among clinicians that the frontal lobes subserve reasoning to a significant degree, the research data (especially replication data) have often been disappointing. A recent review by McCarthy and Warrington (1990a) includes a summary of localisation studies for problem-solving tasks. There is a suggestion that tasks requiring the subject to generate strategies or display efficient use of high level motor functions might be more closely associated with left frontal lobe damage. Because the evidence is so equivocal, the role of the frontal lobes in reasoning is considered separately and not within the sections devoted to the individual cerebral hemispheres.

Perhaps because of the complexity of the processes, the cognitive neuropsychology of the frontal lobes is, as yet, only at a tentative stage. Luria thought that language mediated and controlled attention and planning, writing extensively about the internalization of speech. He noted that patients with frontal lobe lesions often demonstrated a dissociation of speech and action and thought that this might be the primary cognitive deficit underlying the disordered behaviour of patients with frontal lobe lesions. However, many aphasic patients can solve abstract problems (e.g. Warrington, James and Maciejewski, 1986). In addition, the planning failures can be restricted to verbal problems (e.g. Costello and Warrington, 1989).

1.8 EFFECT OF BRAIN DAMAGE ON CRYSTALLIZED INTELLIGENCE

As discussed in section 1.3, cognitive tasks which rely on efficient use of stored knowledge are the ones which load heavily on crystallized intelligence. In broad terms, stores of verbally mediated information, such as names, the rules of arithmetic or how to spell, are more likely to be disrupted by damage to the left hemisphere. In contrast, stores of visual or spatial information, such as familiar faces, visual characteristics of objects or routes around town, are more likely to be disrupted after damage to the right hemisphere.

Many simple dichotomies have been offered to explain the specialization of the two cerebral hemispheres, but today most functional differences are recognised and demonstrated to require subtle definition. Before considering how damage to knowledge stores might affect performance on current tests of cognitive function, some examples of focal deficits that have been described in brain-damaged adults will be discussed.

1.8A FOCAL DEFICITS AFFECTING KNOWLEDGE STORES

(i) THE LEFT HEMISPHERE

A Language

Since the middle of the last century, disturbances of language function have been reported to occur in the context of damage to the left cerebral hemisphere. There have been many studies which have sought a more precise localization for various specific aphasic deficits. Coughlan and Warrington (1978) demonstrated that patients with left temporal lobe lesions were more impaired on naming tasks than patients who had suffered lesions to other regions of the left hemisphere. The finding was later replicated in a study of unilateral lesions (McKenna and Warrington, 1980).

Sentence comprehension can be impaired as a result of left hemisphere damage. The most widely used clinical test utilises abstract coloured shapes, which must be moved to command (De Renzi and Vignolo, 1962). Swisher and Sarno (1969) validated the Token Test for English subjects, using two shapes, two sizes and five colours of plastic tokens. This latter study compared aphasic patients with left hemisphere lesions, with a non-aphasic right hemisphere group. The control group consisted of hospitalized patients withouut cerebral damage. The left hemisphere aphasic group did less well on the Token Test overall than either the right hemisphere patients or the control group. In addition, the right hemisphere, non-aphasic group did less well than the controls on the last two sections, which invoved more complicated commands.

De Renzi and Vignolo (1962) had noted that even patients who were apparently able to comprehend normal speech were shown to fail on the Token Test. This example illustrates a point that is very pertinent to cognitive assessment. Even when patients are fortunate enough to be able to continue with their routine daily tasks, the integrity of their intellectual functioning is far from proven. The everyday situation is predictable, rarely tests the limits of their knowledge and will often contain many extra cues and a great deal of redundant and repeated information.

For instance, small details of context may be essential to maintain appropriate function. McCarthy and Warrington (1987) report two patients who could follow instructions concerning two plastic tokens, as long as both tokens could be moved. However the patients were unable to follow the same instructions if one token was fixed; the reprocessing necessary to work out how the other token must be moved to achieve the target arrangement defeated them.

B Arithmetic

Jackson and Warrington (1986) constructed a graded difficulty Arithmetic test consisting of 12 additions and 12 subtractions. There was a normal control group of 100 volunteers and two experimental groups with unilateral left and right hemisphere lesions. The left hemisphere lesion group performed significantly below the other two groups, between which there was no significant difference. The finding is in line with other studies, for example Dagenbach and McCloskey (1992), which have concluded that there is a store of arithmetic rules and number knowledge which can be disrupted by left hemisphere damage.

Specific knowledge about numbers can be impaired in one modality. Warrington (1982) described a patient, STH, who could hardly comprehend spoken numbers and was unable to make simple size comparisons between single digits presented aurally. However her aural comprehension of other words was demonstrated to be above average. There have been attempts to identify other cognitive functions, aside from calculation rules, that are necessary for arithmetic problem solving. Some of these studies have implicated the right hemisphere and spatial skills in aspects of arithmetical problem solving, for example Hecaen (1962).

C Verbal Memory

Deficits in verbal short term memory can be demonstrated by asking the patient to repeat lists of digits. For example, Warrington and Shallice (1969) described a patient who could reliably repeat one, but not two, digits. The relation of this constraint to aural comprehension is not straightforward (McCarthy and Warrington, 1990b), but it almost certainly compromises the encoding and manipulation of verbal material.

Other long term stores may be disrupted by damage to the left cerebral hemisphere. Of particular interest here is the verbal semantic system. For example, it is the semantic store which furnishes the knowlege that a canary is a yellow bird which is often kept as a pet and sings. Patients have been reported with specific semantic impairments (e.g. Warrington, 1975). In addition categories of knowledge have been demonstrated to be differentially affected (McCarthy and Warrington, 1988).

(ii)THE RIGHT HEMISPHERE

A Spatial Ability

From the disabling disorder of visual disorientation, described vividly by Holmes (1918), to problems with integrated spatial analysis, such as counting the number of blocks in a two dimensional line drawing (Warrington and Rabin, 1970), spatial impairments resulting from right hemisphere damage have been extensively documented. Typically, the patient is no longer able to process spatial arrangements and relations efficiently. A test of spatial skills which has been shown to be differentially sensitive to right hemisphere damage is Elithorn's Mazes (1955). It consists of a triangular lattice with large black dots scattered across a number of the intersections. The patient must find a route which passes through a specified number of dots. The maze task was found to correlate highly with non-verbal and verbal intelligence tests, suggesting that there is a significant reasoning component to performance on this task.

Another spatial reasoning task that has been studied in the context of brain damage is the mental rotation of figures. Ratcliff (1979) used front and back view drawings of a human form, one hand of which was enclosed in a black circle. The patients, who had all suffered penetrating missile wounds during the Second World War, were required to say whether the circled hand was the right or the left one. For upright figures, lesion site was not a significant variable. However the right posterior brain-damaged group were significantly impaired when the human figures were inverted.

B Visual Perception

Cognitive impairments of visual perception have been documented at both a simple and a complex level of processing. The component discriminant functions of shape, colour, acuity and localization have been shown to dissociate (e.g. Warrington, 1986). Object perception can also be affected and this is particularly striking if the patient is asked to identify pictures of objects from an angle that distorts the prototypical view (Warrington and James, 1988).

Empirical demonstrations of this particular pattern of impairment have used sets of incomplete line drawings, which could not be identified by many patients with right parietal lesions, and photographs of everyday objects, taken from an atypical angle, which caused many right parietal patients to ignore the foreshortened long axis and thus fail to identify the objects (Warrington and Taylor, 1973).

Patients with a classical apperceptive agnosia would have no difficulty in describing the physical attributes of an object, but they would be unable to integrate their fragmented visual percepts into recognition of the object as a whole. For example, a pencil might be described as a long thin blue thing, which is flat at one end and pointed at the other. The patient would have no idea of the object's name or use, because that would require them to perceive the whole item. They are no longer able to do this, because their store of object percepts cannot be used effectively.

c Visual Memory

There are visual memory systems which are similar in type to the verbal memory systems. Tasks used to document short term visual memory deficits include tachistoscopic exposure to groups of abstract symbols (e.g. Alajouanine, 1960) and a version of digit span which requires the patient to tap out a series of positions on a board (Milner, 1971).Visual memory functions also mediate the recognition of maps, scenes and routes (see Whiteley and Warrington, 1978). Spatial and perceptual learning has been demonstrated to rely on right hemisphere function (Kimura, 1963; Warrington, 1984).

1.8B DISRUPTION OF COGNITIVE ROUTINES

The following two sections describe impairments of attention and voluntary movements, two skills which can be thought of as relying on established cognitive routines. Although there is no clear cut distinction from knowledge stores, attention and movement are primarily actions rather than answers. Perhaps because they comprise action routines, these two areas have not been illuminated by graded tests, in the way that cognitive functions mediated by specific knowledge stores have been.

(i) THE NEGLECT DISORDERS

There is considerable evidence in the literature that a specific class of spatial disorders can result from brain lesions, which render the patient inattentive to events or certain categories of stimuli in the hemispace contralateral to the lesion. It is thought to occur as a result of disruption of the processes governing attention. These unilateral neglect disorders, as they are known, are most commonly the result of damage to the right cerebral hemisphere. This observed asymmetry has led to speculation that the right hemisphere has a bilateral role in attentional processes, whereas the left hemisphere only monitors right space.

The neglect disorders are of considerable theoretical interest because they illustrate fractionations of various attentional mechanisms (in the reading of lines of text, individual words, reproduction of pictures, drawing, descriptions of remembered scenes and in putting on clothes, for example). The range of difficulties experienced by this group of patients has been extensively studied.

De Renzi (1982, p85) quotes an early and clinically useful test for detecting neglect that was described by Axenfeld in 1894. It simply requires the patient to bisect horizontal lines. Colombo, De Renzi, and Faglioni (1976), found that 45 of their 103 patients with unilateral brain lesions were more off centre than the worst control subject. 42 displaced to the side ipsilateral to their lesion, the remaining three displaced toward the contralateral side. Information about this phenomenon was extended by Heilman and Valenstein (1979), who demonstrated that the amount of the displacement was sensitive to the spatial position of the line. There was no advantage from indicating the whole line to the patient before the bisection.

Hecaen and Marcie (1974) reported a patient who crowded all his written words into one half of a sheet of paper. Albert (1973) asked his patients to cross through diagonal lines which were drawn all over a sheet of paper. Clear omissions were made by the patients with neglect. Similarly De Renzi and Faglioni (1967), asked their patients to copy small numbers of crosses drawn on one sheet of paper onto a blank sheet. Again, there were omissions by the patients with neglect.

There is even some evidence that, not only are stimuli on the contralateral side ignored, but stimuli on the ipsilateral side may draw attention to them. De Renzi *et al* (1989) compared 18 patients with right hemisphere unilateral lesions with 10 control subjects on two tests of neglect. The first was to read aloud a sentence. The second was to point to circles drawn over a page. On this basis, 8 of the right brain-damaged group were judged to neglect. The main experiment was the presentation of sets of four letters in the right half of the screen. The position of the letters in the horizontal row was not found to affect the reaction times of either the control or non-neglecting right brain-damaged group.

In contrast, the patients with visual neglect showed a marked progressive decrease in reaction time with the target letters' increasing distance from the centre. When the target letter coincided with the fixation point, in the centre of the screen, the patients with visual neglect took three times as long as the patients without visual neglect. The authors speculate that this might be the result of an uncontrollable gaze deviation towards the rightmost extremity of structured space.

(ii) DISORDERS OF VOLUNTARY MOVEMENT

A wide range of voluntary actions has been demonstrated to be sensitive to acquired brain damage. These include single repetitive movements (e.g. Wyke, 1967), unfamiliar actions and action sequences (e.g. De Renzi *et al*, 1980), familiar gestures (e.g. Hecaen, 1978), object use (e.g. Poeck and Lehmkuhl, 1980) and constructional tasks. This latter class is perhaps the most likely to degrade performance on conventional tests of intelligence and these will be discussed in more detail.

Constructional apraxia is characterised by failures in the organisation of complex actions in space. Tests of copying and drawing are widely used to detect this disability. Benton (1962) developed a set of geometric drawings which patients copy. An error score is obtained, which is compared to the distribution of scores recorded from a normal sample. Other investigators have studied patients' difficulties when constructing block designs (e.g. Arrigoni and De Renzi, 1964).

There have been suggestions that the types of apraxic difficulties following right and left hemisphere lesions are qualitatively different. For example, Hecaen and Assal (1970) tested 32 patients with unilateral cerebral lesions on tasks involving drawing, copying and arranging stick patterns. Differences were noted in the performance of the right and left hemisphere groups. If landmarks were given, the left hemisphere group was helped, which the authors suggest means that the left hemisphere patients were failing to plan their constructions effectively during the original trial.

Another difference demonstrated was that if the scoring was on the basis of absence of correct lines, then the right hemisphere group was best; however if the scoring was on the basis of extra lines wrongly placed, then the left hemisphere group was best. Interestingly, apraxics who also presented with language disturbance obtained more benefit from furnished landmarks than those apraxics without aphasia. This thoughtful study by Hecaen and Assal (1970) serves to highlight the complicated interdependence of the mental skills which underlie even simple constructional tasks.

1.9 CURRENT TESTS OF BRAIN DAMAGE

1.9A THE HALSTEAD-REITAN NEUROPSYCHOLOGICAL TEST BATTERY

(i) CONTENT

The Halstead-Reitan Battery was developed to measure a comprehensive set of cognitive abilities in people who had suffered brain damage. There are five categories:

1. Input measures
2. Tests of verbal abilities
3. Measures of spatial, sequential and manipulatory abilities
4. Tests of abstraction, reasoning, logical analysis and concept formation
5. Output measures.

The tests cover a broad range of difficulty. Attention, concentration and memory are distributed throughout "just as they appear to occur in the tasks that people face in everyday living" (Reitan and Wolfson, 1986, p137).

The battery is arranged according to hierarchical principles. The first level of central processing represents attention, concentration and memory. Some patients' testing will not proceed beyond this point if their deficits are severe. Next, differential functions are assessed. Various levels of conceptualization are required by the tests of right and left hemisphere function.

The best example of a reasoning test in the battery is the Category test. There are 208 test figures, varying with respect to size, shape and colour, divided into 7 subtests. The subject attempts to ascertain a rule by making serial judgments about whether two-dimensional geometric forms, presented sequentially, fit the rule. Feedback on the judgements is a pleasant bell or an unpleasant buzzer. As Reitan says, "limited ability at any of the levels of central processing may be responsible for a poor performance on the Category test" (1986, p138). Finally, motor functions on each side of the body are evaluated.

The Halsted-Reitan Battery has been extensively researched. It has been constructed on the basis of performance comparisons between patients with unequivocal brain damage and control subjects with no history or evidence of cerebral disease. The authors see this as an advantage, compared to tests designed to measure constructs such as intelligence, which they consider too ill-defined to target empirically.

(ii) VALIDITY

Initially the battery was validated with data from heterogeneous lesion groups and there are numerous reports in the literature (e.g. Reitan, 1955, 1958a, 1959a,). There were also many studies showing that the Wechsler scales were not as sensitive as the Halstead-Reitan Battery at detecting cerebral dysfunction (e.g. Reitan, 1955, 1960, 1964). Lateralized lesion cases have shown differential dysfunction on the battery (e.g. Reitan, 1960, 1964). The battery scores of patients with anterior versus posterior lesions have also been documented (Reitan, 1964). Various types of cognitive deficit and various organic pathologies have been investigated with the Battery.

(iii) INTERPRETATION

The procedure for interpreting the Battery is first to complete the WAIS whose verbal subtests are used, when judged to be unaffected by the brain damage, to estimate the patient's pre-morbid level of functioning. Next four measures from the battery are used to give a general indication of the presence of any organic cognitive deficits. The third step is to evaluate measures that relate to the lateralization and localization of damage, which is a largely intuitive process for which it is "impossible to offer a simple set of rules" (Reitan and Wolfson, 1986, p143). The next stage is to discern the course of the lesion and finally inferences are drawn about the type of lesion and the neurological disorder that may be present (Hom and Reitan, 1982, 1984).

(iv) AS A MEASURE OF REASONING

The Halstead-Reitan Battery has been developed and organized to reflect major areas of behaviour related to impaired brain function. It is a very sensitive and widely researched test. However it is its very sensitivity to brain damage, in the context of its hierarchical organization, that makes it an inappropriate tool for assessing reasoning and abstract thought in a brain damaged population. As discussed above, the Category test was constructed to rely on subsidary functions of memory, verbal comprehension and perception. For example, the correct solutions to subtests 5 and 6 depend upon the subject taking account of how many quarters of each briefly presented figure are outlined by broken, as opposed to solid, lines. There are so many cognitive trip wires in the Halstead-Reitan for the brain damaged person, that patients stand little chance of managing to solve the complexities of the reasoning problems, whatever their residual reasoning ability.

1.9B THE LURIA-NEBRASKA NEUROPSYCHOLOGICAL BATTERY

(i) CONTENT

The Luria-Nebraska Battery (hereafter "LNNB") is based on Luria's functional systems theory of brain organisation (Luria, 1966, 1973). It was reported that Luria was against standardization of his assessment techniques, but standardization was thought to be a prerequisite of acceptance by the West. Christensen (1975a,b) worked with Luria to record his use of the battery and her standardization work has been extanded by Golden and his colleagues (Golden, Hammeke, Purisch and Moses, 1984).

There are 269 items and 700 test procedures. The battery is arranged over 11 ability scales, which broadly correspond to the 11 areas of ability outlined by Luria (1966):

1. Motor. These items measure co-ordination, speed, drawing and praxis.
2. Rhythm. Attention and discrimination are assessed.

3. Tactile. Recognition of verbal and abstract stimuli is tested, as well as location and direction.
4. Visual. Identification of pictures of varying clarity is tested, as well as overlapping outlines of objects. Also various spatial tasks are included, for example orientation and counting blocks drawn stacked together.
5. Receptive Speech. The scale measures phoneme discrimination, comprehension of single words and understanding of grammatical rules.
6. Expressive Speech. The patient is required to articulate sounds, words and sentences, to identify objects from drawings or aural description and to construct grammatically correct sentences.
7. Writing. Motor and phonetic functions are tested, including spontaneous writing.
8. Reading. Items include letters, syllables, sentences and a paragraph.
9. Arithmetic. The patient is required to read and write single and complex numbers, to perform computations and demonstrate comprehension of mathematical signs.
10. Memory. The scale includes tests of short term memory, paired associate learning and recalling the gist of a paragraph.
11. Intelligence. This section includes the comprehension of pictures and text and concept formation, tested by definitions, analogies and other forms.

In addition, three other scales can be derived. The first, the pathognomonic scale, is an index of brain dysfunction. The last two are designated left and right hemisphere and take separate account of the right and left hands' performance respectively.

It should be noted that many of the items featured in the photographs and drawings of Christensen's published version of the Luria battery (1975a) belong to at least the previous generation of Western technology. For example G10, one of the perceptual stimuli, is a degraded outline view of a Jean Heiberg Bakelite telephone, which was first introduced in 1936 and ceased production in 1952. More generally the test stimuli are very small, including items from the Raven's Matrices that are reduced to 10% of the original size.

(ii)VALIDITY

A subset of the LNNB items has been shown to be effective at localizing the site of patients' lesions. Using this subset, Golden *et al* (1981) obtained accurate localization for 74% of their 87 patients. A factor analysis of all of the LNNB items produced 34 factors, 4 of which were found not to discriminate between brain-damaged patients and intact controls (McKay and Golden, 1981). The same study produced normative data for the factor scales.

Several studies have demonstrated the LNNB'S ability to identify brain-damaged people. For example, Golden, Hammeke and Purisch (1978) selected 285 items from the LNNB and found that medical control patients performed significantly better than neurological patients on 253 of them. A set of 8 localization scales has been developed by McKay and Golden (1979). They achieved correct localization of lesion in 89% of their patient sample. The LNNB has also been shown to correlate highly with WAIS IQ's (Picker and Schlottman, 1982).

Interestingly, there have also been statistical comparisons of the Halstead-Reitan and the Luria-Nebraska Batteries (e.g. Shelly and Goldstein, 1982). Correlations of 0.6 or better were found between indices of global impairment for the two batteries. Factor analysis led to the conclusion that both batteries assess similar abilities and that laterality measures from the two batteries were tapping similar skills.

(iii) INTERPRETATION

Golden states that the LNNB can be interpreted only in the light of clinical experience and knowledge of the literature. The use of other tests is considered a beneficial supplement, not a source of confusion (Golden and Maruish, 1986). Education is used to estimate the pre-morbid level, along with age. Various calculations are made, effectively applying the rule that if the person's score on three or more of the ability scales falls more than one standard deviation below the expected mean and if the parthognomic scale also exceeds this critical level, then brain damage is indicated. In contrast, if only one or none of these scores exceed the critical level, then normality is indicated. Pattern analysis is then made of the ability and localization scales.

(iv) AS A MEASURE OF REASONING

Despite the extensive nature of the original Battery, the shortened form does not include many items which are devoted exclusively to reasoning. In addition, they make no attempt to lessen the demands of language or perception, that may of themselves render the item impossible for a patient to solve. There is no attempt to measure reasoning without complex language and perception components. Similar with the Halstead-Reitan, the LNNB is a collection of items which people with brain damage have been shown to fail.

1.10 CURRENT TESTS AS MEASURES OF PROBLEM SOLVING

Whilst we have at our disposal several extensively validated cognitive tests to detect brain damage, there are problems in using established measures to assess the reasoning skills of patients with acquired cognitive deficits. For example, the Halstead-Reitan, the Luria-Nebraska and the WAIS have been shown to be equally good at identifying the presence of acquired organic cognitive impairment (Kane, Parsons and Goldstein, 1985). In this section it will be argued that if these three tests are all equally sensitive to brain damage, then they are all equally unsuitable to measure reasoning ability in the context of organic cognitive deficits.

There have been suggestions that sensitivity to generalized organic impairment should not be the priority of a neuropsychological test (Mapou, 1988). Instead, the goal of a neuropsychological test should be to delineate a patient's cognitive function. There are pitfalls in using tests that are exquisitely sensitive to organic impairment in a clinical setting.

In the next section the argument is put forward that focal cognitive deficits can disrupt a patient's performance at testing on a wide range of psychometric tasks. For example, a focal deficit such as an aphasia or an apperceptive agnosia may exert a disproportionate effect on a patient's performance on tests designed to indicate their general level of intellectual functioning. Therefore, we should be striving to develop more valid ways of assessing a patient's specific intellectual functions. In addition, to formulate a rehabilitation programme or advise on prognosis, it may be what patients can do, rather than what they can not do, that matters. Their detectable competences are at least as important as their detectable deficits.

1.10A IN RESEARCH STUDIES

Any attempt to measure the cognitive function of a brain-damaged person is confounded by the very pattern of deficits that the psychologist is trying to illuminate. For example, in the paper by Russo and Vignolo (1967), which was outlined in Section 1.7B(i), both right brain-damaged patients and aphasic left brain-damaged patients were significantly impaired at locating a geometric shape masked by an abstract pattern. Further inspection of their results revealed that the right brain-damaged patients' scores correlated highly with their scores on a neglect test, which required them to copy a pattern of small crosses.

Rather than jumping to the immediate and mistaken conclusion that both the right and left hemisphere-damaged groups could not perform abtract reasoning tasks (or could not process spatial information efficiently), the investigators had sufficient sophistication to try to demonstrate that two separate cognitive deficits were resulting in the failures of the two different lesion groups. The left hemisphere damage had resulted in aphasic difficulties, which had made the task too demanding for that group. The right hemisphere damage had resulted in spatial perceptual disorders, which had significantly disadvantaged the second group on the same task.

This example illustrates the mesh of cognitive interactions that mediate reasoning. Assessments of the functions of the damaged brain can not take the competence of any cognitive process for granted. Many tests currently in widespread use for assessing acquired cognitive dysfunction were designed and standardized for normal populations and were not designed to tease out reasoning ability, distinct from other cognitive processes.

A demonstrated association between a cognitive impairment and a poor score on an intelligence test is open to at least three interpretations:

1. The focal impairment and the poor score on the intelligence test are the result of dysfunction in one cognitive system that underpins both.
2. It is the focal impairment that disrupts performance on the intelligence test because it hampers the encoding, anlysis or output required by intelligence test.
3. The focal impairment has no direct functional relation to the intelligence test score. The associated observations merely result from lesions coincidentally involving areas of the brain which subserve the two separate functions

Let us see how the WAIS and the Matrices have helped to decide between these two hypotheses.

1.10B PROBLEMS OF USING INDIVIDUAL TESTS DEVISED FOR INTACT POPULATIONS

(i) THE WAIS

Whilst the WAIS provides a reliable indication of an intact person's current general level of intellectual functioning, it is, in some ways, a rather blunt instrument for assessing reasoning skills in the context of acquired cognitive deficits.

A Perceptual deficits and failures on the WAIS

For example, a large retrospective study of 656 patients with unilateral cerebral lesions demonstrated that Verbal IQ was impaired in all groups of patients with left hemisphere lesions, irrespective of lesion site (Warrington, James and Maciejewski, 1986). However, Performance IQ was impaired in only one of the groups of patients with right hemisphere lesions and that was the group who had suffered damage to their right parietal lobes.

Further evidence that the integrity of the right parietal lobe is apparently disproportionately influential in determining a person's WAIS Performance IQ comes from an early PET study (Chase *et al* 1984). Measuring a mixed group of 5 normal volunteers and 17 patients with Alzheimer's disease, Chase's team found that performance IQ correlated best with right hemisphere function, especially right parietal function. This is probably the result of the disruption of perceptual and spatial processes, which rely on the right parietal lobe (Warrington and James 1967). As a result, a patient could be unable to meet the task demands of the performance subtests of the WAIS, regardless of whether they have suffered a general intellectual decline.

B Aphasia and failures on the WAIS

Aphasic deficits can disrupt any aspect of language function, including comprehension, speech, reading and writing; sometimes, tragically, the aphasic disability can be global. Such patients pose a challenge to the assessor, because so many of the standardized measures are irretrievably compromised by the restrictions on input and output of verbal information. In the PET study described in the section above (Chase *et al* 1984), Verbal IQ was found to be closely related to cortical metabolism in the left cerebral hemisphere, especially in the left temporal lobe. However, not only WAIS verbal tests are affected by aphasia.

A large series of patients with left hemisphere damage was assessed on four subtests of the Wechsler-Bellevue Performance Scale (Basso *et al*, 1981). Language skills were evaluated and 141 of the 173 patients were classified as aphasic. The presence and severity of aphasia were associated with low scores on the Wechsler tests. Type of aphasia was not related to Wechsler scores. Benton (1962) pointed out that implicit and explicit verbalizations might play a part in the performance subtests of the WAIS.

c Apraxia and failures on the WAIS

All performance subtests require a timed response and all, except Picture Completion, require a manual response. Patients with right hemisphere lesions, selected as having no or minimal motor weakness, have been demonstrated to be significantly worse than controls at placing shapes into the directly visible Seguin Form Board (Meier, 1970).The right hand being the preferred hand of patients admitted to research series, clearly left hemisphere patients might be further disadvantaged on the WAIS performance scale.

218 aphasic patients were assessed on the Wechsler Bellevue Performance scale (Alajouanine and Lhermitte, 1964). Whilst only 15% of the total sample exhibited constructional apraxia, 80% of the patients with IQ's below 80 (that is in the borderline defective range or below), were impaired on construction tasks. Arrigoni and De Renzi (1964) found that patients with constructional apraxia performed much more poorly, on both the Wechsler Verbal and Performance Scales, than patients who were not suffering from constructional apraxia.

Vega and Parsons (1969) assessed the role of sensory-motor functions in WAIS scores by using four tests from the Halstead battery (1947; this battery was discussed in detail in section 1.10a). They were the Purdue Pegboard Test, the Finger Tapping Test, the Tactual Performance Test and the Dynanometer Test. Each of the four tests was performed with each hand. Twenty-six left hemisphere patients were compared with twenty-five right hemisphere patients. The only significant difference between groups on the WAIS was the left hemisphere group being weaker on the Verbal scale. The sensory-motor data confirmed that the left hemisphere group had right sided deficits and the right hemisphere group had left sided deficits. In addition, significant relationships were found between WAIS scores and sensory-motor deficits for the left hemisphere group, but not for the right hemisphere group. Basso *et al* (1973) assessed praxic skills in their series of 173 patients with unilateral lesions. Whilst constructional apraxia was related to poorer scores on the Wechsler, ideomotor apraxia was not.

These findings, that aphasia and apraxia can disadvantage patients on the performance subscale of the WAIS, raise the possibility that left hemisphere damage might result in lower scores on both scales of the WAIS, which would reduce the quantitative difference between left and right hemisphere patients. These confounding factors may explain why the WAIS has not been found to be especially effective in large localization studies.

(ii) RAVEN'S MATRICES

Raven's Matrices are a test of choice for the assessment of reasoning in brain damaged patients. The strengths of these test batteries for this patient population are:

1. They are comparatively non-verbal (every clinician has seen a foreign patient who speaks no English rattle through the Matrices, the task being immediately obvious to him from the page lay–out).
2. They do not require any manipulation of objects.
3. They can be answered by pointing or speech.

Theoretically they are widely held to be a very appropriate tool for studying the effects of brain lesions on intelligence and "perhaps the best of all the nonverbal tests of *g*" (Gainotti *et al*, 1986). However, disorders of spatial thought and perception (which have been discussed in section 1.8A(ii)) may prejudice a patient's performance on any test presented in a complicated visual format.

McFie *et al* (1950) commented that right brain-damaged patients with spatial deficits did less well on Raven's Matrices than would be predicted by their overall intelligence level.

Further confirmation of this bias was claimed by Piercy and Smyth (1962), who showed that right hemisphere-lesioned patients with constructional difficulties, were more impaired on the Matrices than left hemisphere-lesioned patients with constructional difficulties. The two groups were within normal limits on a test of verbal intelligence.

The last study illustrates the difficulties of trying to account for related deficits when assessing patients with brain damage: the patients with left hemisphere lesions, who were nevertheless able to score at a normal level on a test of verbal intelligence, may have been above average pre-morbidly. If this were the case, then their spared right hemisphere skills would be likely to be above average. Therefore their performance on the Matrices would be more competent.

In contrast, for the patients with right hemisphere damage, it is likely that the verbal reasoning test more accurately reflected their premorbid ability. It is not surprising that they did less well on the Matrices, which rely on functions subserved by their damaged right hemisphere, than the "matched" left hemisphere-damaged group. Pre morbid ability levels would be enough to account for the discrepancy between the two groups.

Further evidence for different cognitive processes mediating the solutions to the conventional Raven's Matrices was collected by Denes *et al* (1978). They tested patients with cerebrovascular events during the acute phase and two months later. The patients with left hemisphere damage were most improved on Part A at retest, which means that they showed the greatest improvement on items of increased perceptual difficulty. In contrast, the patients with right hemisphere damage were most improved on Part B at retest, which means they showed most recovery on analogical reasoning. There are several interpretations of these results, but the importance of these findings to this argument is that functionally separable cognitive processes have been demonstrated to contribute to a test of reasoning, which is in widespread clinical use.

A Neglect and failures on the Matrices

Investigators have noted that some patients with brain damage tend to favour response alternatives situated in the hemifield ipsilateral to their lesion. Clearly contralateral neglect would affect a patient's score on the Matrices, resulting in a poor score that was not the result of deficient spatial reasoning. Piercy and Smyth (1962) and Gainotti (1968) used Raven's Progressive Matrices and reported the observation that many brain–damaged patients failed to scan the ipsilateral side efficiently and that this was most marked for patients who had suffered damage to the right hemisphere.

Costa *et al* (1969) evaluated Raven's Coloured Matrices with 70 patients who had suffered unilateral cerebral damage. 28 of his patients displayed a position preference and the proportion of correct responses was less on the preferred side. An important finding in the Costa group's work was that patients with left hemisphere lesions, who exhibited position preferences on the Coloured Matrices, had deficits as severe as patients who had suffered right hemisphere lesions. This study also identified a group of patients who repeatedly chose the same position for each response, thus scoring essentially at a chance level.

In an effort to resolve this uncertainty, Basso *et al* (1973) analysed the position preference of 159 patients with unilateral brain damage who attempted the Coloured Matrices. The patients tended to choose response alternatives located on the side of the page ipsilateral to the damaged side of their brain. Even with position partialed out, patients with right posterior lesions were significantly more impaired than patients with anterior right hemisphere lesions.

Gainotti and colleagues (1986) designed an important experiment to further investigate the effect of focal cognitive deficits (and especially visual neglect) on brain-damaged patients' performance on the Matrices. The subjects were 76 normal controls, 74 right brain-damaged patients, 87 aphasic patients and 61 patients with left hemisphere damage who were not aphasic.

The Coloured Matrices were given a new format which preserved the essential features of the task. Gainotti's group rearranged the possible answers to each problem to form a vertical line under the main pattern. In addition, the position of the missing section in each main pattern was altered so as to appear in the hemispace contralateral to the patient's damaged cerebral hemisphere. The idea was that any bias in horizontal scanning would be neutralized by this presentation.

The results of this study were that hemispheric locus of lesion was not a significant source of variance within the brain-damaged patients. Gainotti *et al* (1986) conclude that the lower scores obtained by right hemisphere patients on the conventional Matrices are due more to the influence of visual-spatial neglect, than to the primary perceptual and spatial demands of the Matrices. The authors do not advocate the use of the reformatted Matrices for general clinical use, but rather as a research tool for when the examiner aims to precisely assess the intellectual ability of the patient, partialling out the effects of unilateral neglect.

There are several reservations about the Gainotti *et al* (1986) study. One is that the new formatting of the Matrices assumes that the patient's neglect will always occur at the page stimulus level. There are many cases documented in the literature where the stimulus unit that is neglected is smaller than the whole page, for example at the level of words, paragraphs, or even individual drawings, and it can be demonstrated wherever the stimulus is on the page (for a summary of this work, see section 1.8B(i)).

Secondly, there are considerable limitations to the clinical use of the new format Matrices, which must be an important consideration for a test designed to provide a purer measure of reasoning in the context of organic deficits. Not least of these constraints is that it is apparently only helpful for patients with circumscribed unilateral lesions, and the examiner must know in advance which side of the patient's brain is damaged.

B Perceptual deficits and failures on the Matrices

Gainotti *et al* (1986) used the Coloured Matrices, which is the easiest form and not sufficiently stringent for most adult patients. The appropriate forms for the majority of adult patients are the Standard and Advanced sets. Both of these sets are considerably more complex in their perceptual and spatial demands and they do not provide colour cues, which are recognised as making the Coloured Matrices easier to attempt. If these tests for normal adults had been investigated, it may be that the effects of right hemisphere damage on visual-spatial skills would have been apparent.

Basso *et al* (1973) had recorded both visual field defects and the mixed figure test (De Renzi, Scotti, Spinnler, 1969), which was intended to evaluate the perceptual analysis of complex patterns. After they had adjusted the scores of their right hemisphere cases, to take account of spatial and perceptual deficits, the patients with right posterior damage were still doing less well on the Coloured Matrices than the right anterior group. Basso's team suggest that there is an area in the right hemisphere, situated close to the visual discrimination functions, which is critically involved in the eduction of logical relationships existing among different patterns.

C Aphasia and failures on the Matrices

There have been many reports over a long period that aphasic patients do badly on the Matrices. For example, Colonna and Faglioni (1966) found that aphasia was significantly related to low scores on the Matrices. Basso *et al* (1973) demonstrated that aphasic patients were only able to achieve low scores on the Coloured Matrices, but their scores did not correlate with the severity of their aphasia, meaured by the Token Test and a naming test. Even after attempting to allow for abstract thinking, by using the patients' score on the Weigl sorting task, the inferior performance of the aphasics on the Coloured Matrices was still apparent.

A later study (Basso *et al*, 1981) did demonstrate a connection between low scores on the Coloured Matrices and severity of aphasia (determined by the Token Test, De Renzi and Faglioni 1978). Interestingly, type of aphasia was not related to Matrices performance.
In the experiment with the reformatted Coloured Matrices described above (Gainotti *et al*, 1986), the presence of aphasia was found to be a highly significant factor in hampering the performance of patients with left hemisphere damage. Further investigation of the aphasic difficulties of the patients revealed that severity of language impairment was not a significant source of variance. However the presence of a "semantic-lexical" disorder at the receptive level significantly influenced the Raven's scores. The Gainotti group point out that their demonstration that language comprehension was closely associated with poor performance on the Matrices is in line with their previous findings.

D Apraxia and failures on the Matrices

Arrigoni and De Renzi (1964) found that patients with constructional apraxia due to left hemisphere lesions had lower scores on the Matrices. Similar findings were reported by Piercy and Smyth (1962) and Costa *et al* (1969). Basso *et al* (1981), in their study of 173 patients with left hemisphere damage, found that whilst constructional apraxia was associated with low scores on the Coloured Matrices, ideomotor apraxia was not related to patients' scores on the reasoning test. It has been suggested that there may be deficits in visual discrimination and space exploration that are mediating the impaired performances on both the Matrices and the praxis tests (Basso *et al* 1973).

It becomes extremely difficult to compare the degree of impairment in reasoning skills of groups of patients with differently localized lesions because of the confounding effects of the different lesion sites. De Renzi in his authoritative book (1982, p185) says:

"What is mandatory in future research is that lower level abilities must be systematically checked when comparing brain-damaged groups on mental tasks involving them."

1.11 AIMS OF THIS RESEARCH

The development of theories of intellectual structure from group studies has been discussed and a consensus was shown to emerge in favour of an underlying factor, *g*. This ability has been characterised as having fluid and crystallized components which underpin novel and learned intelligent behaviour. Examples of individual tests designed for normal and brain damaged populations have been considered, as well as reservations about these tests' suitability as measures of reasoning and problem solving in the context of acquired cognitive deficits. The aim of this research was to develop a new test of reasoning that would be more robust to the effects of focal deficits.

Piercy (1964, 1969) suggested that models of normal intelligence led to three theories of how brain damage might impair intellectual function:

1. If general ability is diffused throughout the cerebral cortex, then the severity of the handicap resulting from brain damage will reflect the size, not the site, of the lesion.
2. If there is a hierarchical organization of cognitive functions, including a particular area of the brain having assumed a pre-eminent role in sustaining the superordinate ability, then damage to this area would result in the disruption of any intellectual task.
3. If intelligence consists of primary mental abilities, it is likely that they are subserved by separate cortical localizations. Injury to different areas will result in differing patterns of deficit. Perhaps any attempt to compare groups with differently localized lesions, in terms of their general mental efficiency, would then be meaningless.

There has been no definite answer to these experimental questions, largely because good performance on standard intelligence tests requires not only intact pure intellect but also other cognitive skills, such as language, perception and the organization of purposeful movement. Depending on the particular localization of the lesion, there may be impairment of the specific ability essential for the performance of the test. It is a logical possibility that the differential impairment of patients with cerebral damage on intelligence tests may simply result from the presence of aphasia, apraxia or agnosia.

It was hoped that the development of the new test would produce two results: a test of reasoning for clinical use which would be less affected by secondary cognitive deficits than current tests and also a theoretical contribution to the understanding of reasoning processes.

2 THE EXPERIMENTS

2.1 OVERVIEW OF METHODOLOGY

Mapou (1988) identifies the steps needed for initial development of a neuropsychological test that is not designed to detect brain damage *per se* but rather a specific deficit in an identified cognitive skill.

1. The focus of the test should be a specific cognitive function.
2. Content validity should be established by reviewing relevant literature and obtaining expert judgement on items prior to data collection.
3. A large number of items must be included on the initial measure, to ensure that there are enough items after selection to meet statistical criteria.
4. An appropriate normal sample must be collected, especially in terms of age and ability spread.
5. Initial pilot testing should be performed by administering the test to a normal subset of the target population. Item selection should be made with considerations of item consistency and an adequate distribution of total scores.
6. The revised measure and other measures should be used to assess construct validity.
7. Item responses and overall test scores must be analyzed to assess internal consistency and discrimination, an adequate spread of ability and, where possible, reliability.
8. Construct validity can be formally assessed by showing the new test's relationship to tests which are thought to measure similar functions and tests which measure less similar functions.

2.2 THE PILOT STUDY

The first two of Mapou's steps were covered in the introduction. The third step is the pilot study described here. It was decided that the content of the test should draw on classical types of reasoning problems. Jensen (1980) notes the common finding that reasoning ability is a more influential factor during the acquisition phase of learning many complex skills (and hence there is a higher correlation with *g*) than in performance after training. It follows that some degree of novelty is an important feature of reasoning tests and an effort was made to generate problems which would be unfamiliar to the subject.

2.2A METHOD

(i) THE TEST BATTERY

Inductive reasoning problems were selected because of their similarity to everyday reasoning problems, in that there is usually a number of possible solutions. (Deductive reasoning is different in this respect, problems of this type having a unique correct solution). Inductive reasoning problems with high *g* loadings include verbal analogies and series completion and figure analogies and classifications. In an attempt to explore the contributions of language and perceptual skills to reasoning, parallel sets of problems presented in verbal and traditional "non-verbal" format would be required.

The presentation of the tests was an important consideration. Basso and his colleagues in 1973 had stated that "a test purporting to assess the intelligence level of unselected samples of brain-damaged patients should not require responses involving either verbalization or skilled manipulative activity or subtle differentiation of visuospatial data, although there is probably no intelligence test that fully satisfies these requirements..." It was decided that all words used as stimuli in the verbal forms should be high frequency (Thorndike and Lorge, 1936, category A or AA words), to reduce the handicap of aphasia. Similarly, the "non-verbal" forms should be drawn to require the least perceptual and spatial discrimination possible. For example, there should be no answer dependent on counting groups of dots or decisions between similar shapes. In addition the problem and response alternatives should be available for the patient's inspection, to reduce memory load.

It was decided that a multiple choice format was preferable on several counts. First, it would be less stressful for patients to choose a response, than to have to generate their own answer. This format has been demonstrated to be resistant to affective factors in another neuropsychological test, in this instance of memory function (Coughlan and Hollows, 1986). Secondly, it would allow patients to respond by speaking or pointing. In an extreme example, a patient who was paraplegic could still respond to the verbal forms by having the problem read aloud and then blinking once or twice to indicate "yes" or "no" to the alternative answers. Thirdly, it would make scoring relatively simple and unequivocal, with the potential for future computerisation.

Test items were constructed, according to the principles outlined above, in both verbal and non- verbal format and in three styles of inductive reasoning problem: odd one out, analogy and series. The correct responses were positioned in a pseudo random way among the response alternatives, so that position preference would confer no advantage on a subject. The aim was to produce six finished tests of twenty five items each, but many more would have to be generated for the pilot study so that sufficient good items could be selected. The number of items that were piloted is given in the Table 1.

format	**type**	**n**	**format**	**type**	**n**
verbal	odd one	52	non-verbal	odd one	76
	analogy	54		analogy	50
	series	50		series	35

Table 1. Number of items piloted for each of the six sections of the new test.

(ii) ADMINISTRATION OF THE BATTERY

The administration of the new tests should also be designed to reduce the secondary effects of acquired brain damage. The instructions and practice items should be arranged to minimise problems resulting from limited concentration and memory function. For reasons of efficiency, it was decided that the pilot study could rely on normal subjects filling in a questionnaire alone, with completed examples at the top to explain the task and instructions to guess any item of which they were unsure. Details of the test administration would be rigorously defined for data collection from the experimental series.

(iii) THE TEST SUBJECTS

AGE	18y-40y	40y-54y	55y-69y	Male:Female	ALL
verbal					
odd one	22	14	14	14:36	50
analogy	20	19	11	21:29	50
series	20	19	11	24:26	50
non-verbal					
odd one	18	20	12	19:31	50
analogy	16	18	16	23:27	50
series	18	21	11	16:34	50
TOTALS	114	111	75	117:183	300

Table 2. Age and sex distribution of pilot subjects.

The aim was to pilot each of the six sections on fifty normal people. The majority of subjects were friends and relatives of patients attending the Out Patient Department of the then National Hospital for Nervous Diseases, Maida Vale. A handful were ambulance crew or nurse escorts. Any subject who did not have time to complete the entire test was excluded from the sample. The pilot subjects' responses were monitored throughout data collection. Inspection of the scores of the first nineteen pilot subjects to complete the fifth section, non-verbal analogy, suggested that the items were too difficult. The section was amended and piloted on a further fifty subjects. The age and sex distribution of the subjects are given above in Table 2.

Inspection of Table 2 reveals that the pilot samples for each section covered a reasonable spread of ages, each age band being represented with approximately similar numbers although with slightly less in the eldest group. There was a sex bias in the pilot sample towards women: 69% females against 31% males. The sex bias was fairly constant across all six tests and across all three age bands. For the purposes of a preliminary examination and grading of items, the slightly skewed sex ratio was not likely to be a confounding factor.

2.2B RESULTS

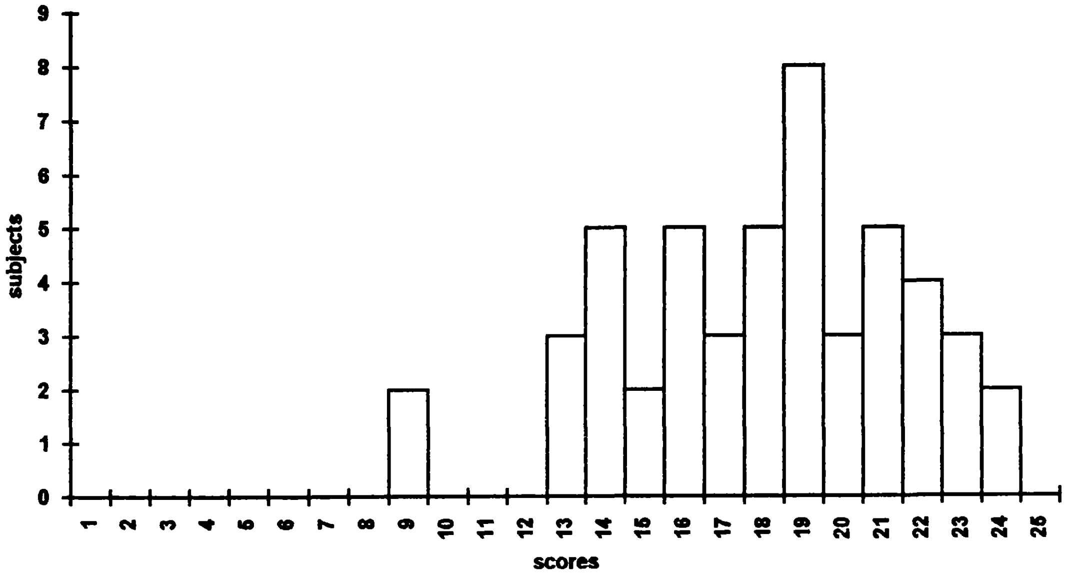
Each pilot test was carefully examined and twenty five items were selected from each on two criteria:

1. The selected items were valid discriminators. The level of difficulty of each item was calculated from the proportion of pilot subjects responding correctly to it. An item was considered a valid discriminator if it was usually passed by subjects scoring at or above the item's level of difficulty and usually failed by subjects scoring below the item's level of difficulty.
2. The pilot subjects' scores across the twenty five items selected should approximate a normal curve.

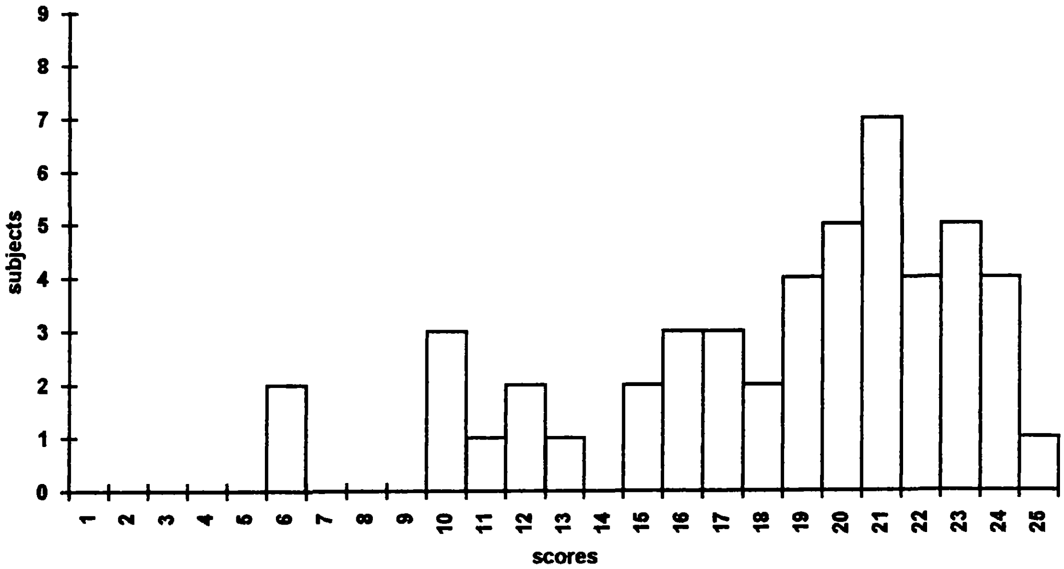
The initial selections of twenty five items for each section were made. The distribution of scores from the pilot subjects on these selected items is given in the following six graphs.

Figure 1 Distribution of scores of fifty pilot subjects on the twenty five selected items from each section of the new test.

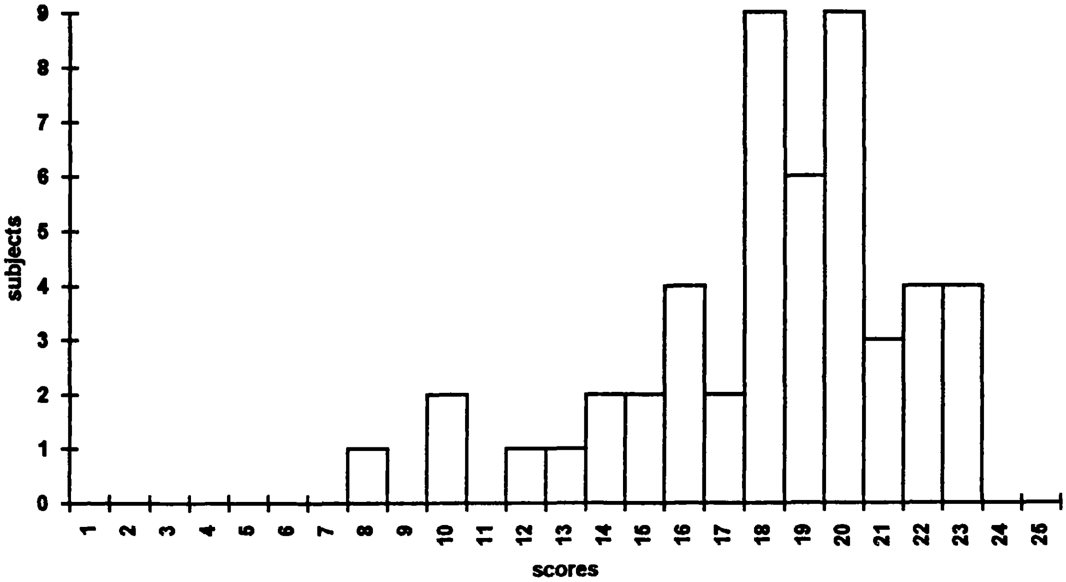
1. Verbal odd one.



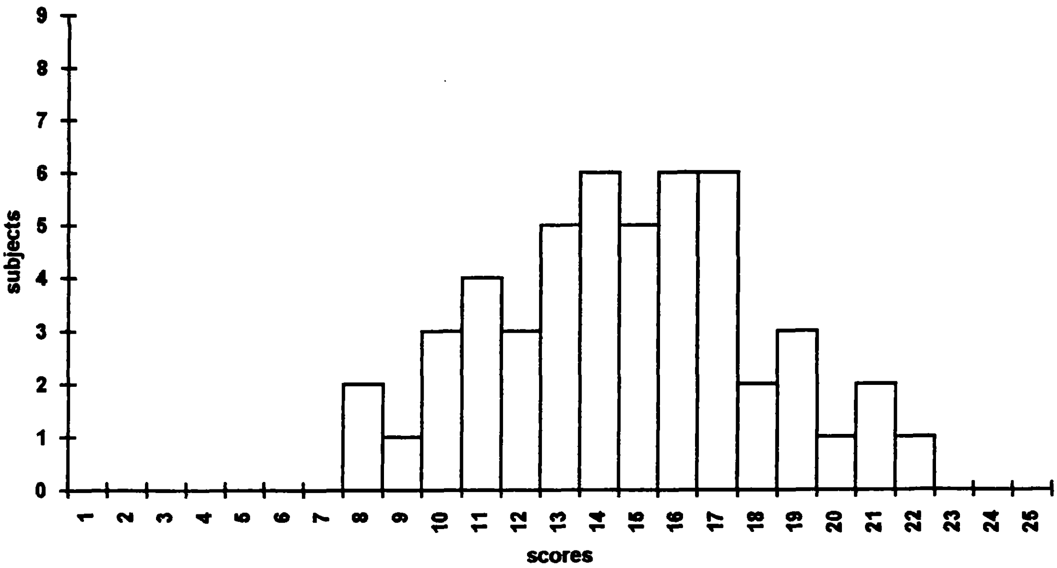
2. Verbal analogy.



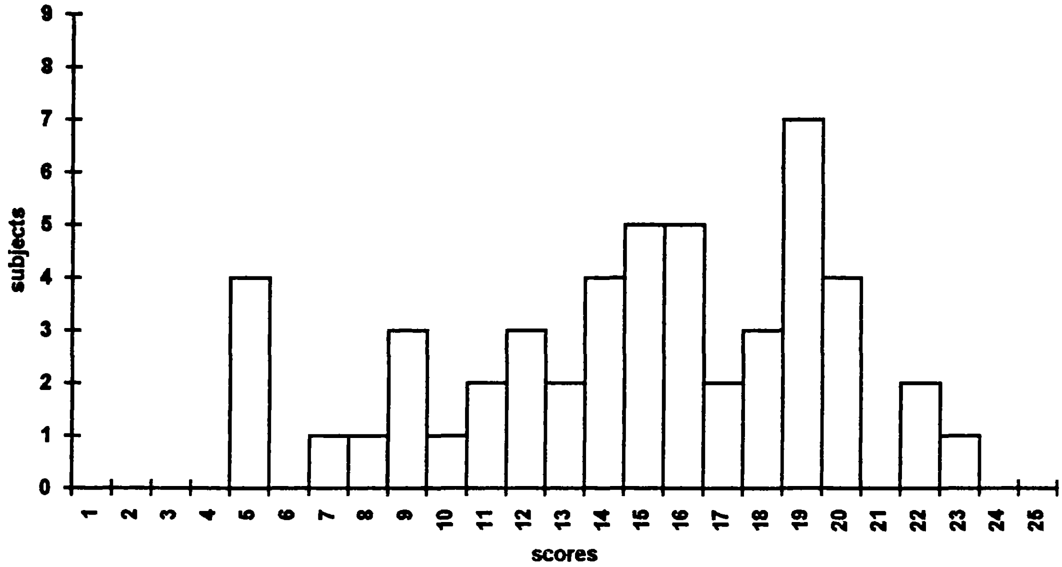
3. Verbal series.



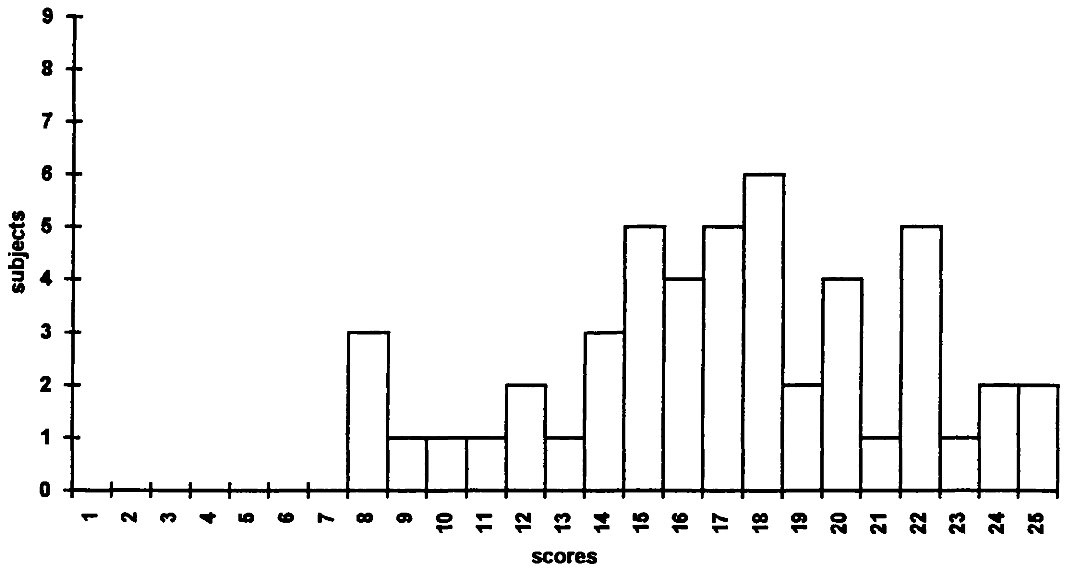
4. Non verbal odd one.



5. Non verbal analogy.



6. Non verbal series.



Four of the sections to be used for the normative sample were constructed from twenty five items taken directly from the piloted problems. These sections were verbal odd one, verbal series, non-verbal odd one and non-verbal analogy. Of the remaining two sections one, non-verbal series, had only one new item in its final set of twenty five. The new item was devised because all of the items found to be of the required level of difficulty were judged to be too visually complex. The new problem was of four shapes in a rotating order and similar to a piloted problem that had been selected.

The second section to incorporate new items at this stage was verbal analogy. The pilot study showed that the section lacked hard items (see graph 2 above). Twenty five of the most promising items from the pilot were selected and eight of these were made more difficult. Eighteen fresh pilot subjects completed this amended set of twenty five verbal analogy items and on the basis of their responses, seven of the eight new problems were included in the final version of the section.

Inspection of Figure 1 reveals an encouraging set of graphs from the pilot study. The final selected sets of 25 items each appear to cover a good spread of ability and each roughly approximates a normal distribution. The next task was to ascertain whether these characteristics of spread and normality would be confirmed by a carefully constructed validation sample of control subjects.

2.2E CONCLUSION

The results of the pilot study allow the tentative conclusion that a new reasoning test could be constructed, such that the verbal stimuli are all common words and the non-verbal stimuli make low demands on perceptual and spatial processing, and at the same time the problems can cover the normal range of ability in an urban working population. The six sections of the new test had been assessed separately, each utilising one type and presentation format of classical inductive reasoning. Sets of classification, analogy and series problems had been presented in separate sections of verbal and non-verbal stimuli. The pilot data indicated that each of these six sections could be validated separately and raised the possibility of examining the effect of acquired cognitive dysfunction on different reasoning problem types and formats.

2.3 THE CONTROL SAMPLE

2.3A METHODOLOGY

(i) THE TEST BATTERY

It was thought that the new test should be compared with established tests of intellectual ability. Accordingly, the control battery comprised:

1. Four WAIS subtests (Wechsler, 1955): Similarities, Digit Span, Picture Completion and Block Design.
2. The National Adult Reading Test (Nelson, 1982).
3. The Schonell Graded Word Reading Test (Schonell, 1945).
4. The Standard Progressive Matrices, scales B,C and D (Raven, 1958).
5. The Graded Arithmetic Test (Jackson and Warrington, 1986).
6. The new test of reasoning in organic brain disease.

The Wechsler subtests were included because of the importance of these intelligence tests, which has been discussed in the introduction. Similarities was selected because it is a widely used test of verbal reasoning. Digit Span was selected because of the relationship of backward digit span to *g* and also the brevity of the test recommended it as the second verbal Wechsler subtest. Picture Completion and Block Design were selected as the two non-verbal Wechsler subtests, as examples of both concrete and abstract stimuli and also both requiring relatively little verbal explanation. The two reading tests were selected as indicators of a subject's general level of intellectual functioning and together they provide a measure across a wide range of ability levels. Raven's Matrices have been discussed in the introduction. The A and E sections were not given because they test the extremes of the normal range of reasoning and it was felt that the BCD sections would together cover an adequate range of difficulty to serve the purpose of this study. The Graded Arithmetic test was selected because it was felt to be less reliant on aural comprehension than the WAIS arithmetic subtest, for example.

(ii) ADMINISTRATION OF THE BATTERY

A Published tests

All of the published tests were given in accordance with their authors' instructions, with the following minor exceptions:

1. The NART was given before the Schonell and, if the subject made ten or less errors on the NART, then the Schonell was not given and a perfect score assumed.
2. Both the NART and the Schonell were discontinued when a subject had made eight errors in any ten responses.

Timing was carried out with a hand held digital stopwatch.

B The new test

The items of each section are given, presented in their final order, in Appendix VI. Five practice items were constructed for each of the six sections. The first three were shown to the subject with as much explanation and specific detail as the subject required, in addition to the standard instructions which are listed in Appendix I. The subject was encouraged to attempt an answer to each of these first three items (labelled a,b,c, in Appendix VI), but was not required to do so. In contrast, the subject was required to solve the following two "screen" items (labelled d,e in Appendix VI). Before the subject answered either of the two "screen" items, only general information about the task was given. For example, on verbal odd one, the psychologist would repeat that there were four items and one differed from the other three in some significant way. Once a subject had given an answer to a screen item, as much explanation and specific detail was given as the subject required, including correction if necessary.

If the subject answered at least one of the two "screen" items correctly, the full twenty five items of the section were given. During the test proper, no further specific detail or correction was given. Repetition of the general task was allowed. Subjects were required to guess if they were unsure of the correct answer. Most control subjects required little or no explanation and rattled through the first dozen items presented to them. However the procedure had to be defined so that the administration would be identical for the lesion series, if reliable normative data was to be produced.

c General administration details

The battery of tests was arranged in two orders which were given alternately to control subjects. The two orders were constructed to reverse the order in which new and established tests of similar cognitive skills were attempted by control subjects, to reduce practice effects. The two orders of tests for control subjects are given in Appendix II.

All control subjects were tested individually alone with the experimenter, across a desk in an office, with the exception of volunteers from an Oxfam shop, who were tested across a camping table in the garage, in the yard behind the shop. The purpose of the study was explained at the start and the subject's consent was obtained verbally. After the first test, the author checked that the subject was happy to continue. At the end of testing, each control subject was given a leaflet outlining the purpose of the study and repeating the assurance of confidentiality of results. The text of the leaflet can be found in Appendix III.

(iii) THE TEST SUBJECTS

The test scores of 155 control subjects were included in the normative data sample. Their ages ranged from 18-70 years. 100 were in full time employment, having volunteered via their employing organisations. The text of the letters sent to the organisations and of the recruitment pamphlets used for individuals is given in Appendix IV, as well as a list of the organisations that supported this research. 23 control subjects were retired people living independently, having volunteered via adult education centres or via the Oxfam shop where they now worked on a voluntary basis. The remaining 32 control subjects were in-patients of either the National Hospital for Neurology and Neurosurgery, Queen Square or St. Mary's Hospital, Paddington. They had no known CNS involvement above thoracic level and the patients were screened for a history of head injury or psychiatric illness.

A Refusals

There were two outright refusals, both by inpatient Controls. One was a 68 year old man with an L3/4 cord compression. It was 10.30am on a Friday and he was waiting to see his consultant and then go home. The second was a middle-aged man who had had a lumbar laminectomy. He had already volunteered for one psychology test and felt that that was enough.

B Unfinished and excluded cases

The scores of two patients were excluded from the control series after consideration of their performance at testing. One was a 26 year old man who, it transpired during testing, had never learned to read. The second was a 67 year old woman with myasthenia gravis who was only able to obtain a raw score of 1 on the WAIS Similarities subtest. From this it was assumed that some cerebral deterioration had occurred and she was not admissible as a control subject. A further two working men, aged 51 and 54 and both managers,were excluded by the psychologist because they appeared to be very anxious. The first constantly talked about the £1000 mortgage arrears that he had discovered that morning. The second repeatedly asked if there was any evidence from the tests that he was suffering from Alzheimer's Disease. Seven working controls were excluded from the sample because they stopped before completing five sections of the new test. Of these seven, six were unable to finish the battery because they were called back to work. The seventh, a forty two year old accountant, felt that he had done enough.

Thirty one working controls who completed the battery were excluded from the normative sample to create a more equal distribution of ages and more normal distribution of NART scores. This was achieved by drawing the best curves through bar charts of age and NART scores and then removing the required number of controls at each NART error score level on the basis of "last collected first out".

c Missing data

Twelve In Patient controls did not complete the battery but were still included in the final normal sample of 155. Eleven of them had attempted all six parts of the new test and one had attempted five parts. Eight were discharged before their second testing session, two complained of too much pain, one wanted to watch the film *On The Town* on the ward television set, and one was unwilling but did not give a reason.

test	n=
verbal odd one	155
verbal analogy	155
verbal series	155
non-verbal odd one	155
non-verbal analogy	154
non-verbal series	155
WAIS Similarities	155
WAIS Digit Span	153
WAIS Picture Completion	152
WAIS Block Design	152
NART	155
Schonell	150
Graded Arithmetic	154
Standard Progressive Matrices	147

Table 3. Numbers of control subjects attempting each test to show effect of 12 cases in sample who did not complete the battery. Total n=155.

The numbers of subjects attempting each test in the battery are given above in Table 3. Inspection of the table will reveal that the amount of missing data from within the normal sample was very small and unlikely to have biased the results in any significant way.

2.3B RESULTS

(i) DEMOGRAPHIC CHARACTERISTICS

	age	18-30y	31-40y	41-50y	51-60y	61-70y	**totals**
men		14	10	6	16	12	58
women		22	18	22	16	19	97
totals		36	28	28	32	31	155

Table 4. The distribution of age and sex in the control sample.

The demographic characteristics of the control sample were considered. Firstly, the distribution of age and sex was calculated and the frequencies are given in Table 4. A chi square was performed to determine whether the age distributions by sex of the control sample were biased in some way. The calculation resulted in a chi-statistic of 5.3, with 4 degrees of freedom, giving a non significant probability of 0.26. Next, the distribution of sex and social economic class was calculated and the frequencies are given in Table 5.

An initial inspection of this data raised the possibility of an interaction between sex and social economic class. It was observed that there was a proportionately higher percentage of men in social class 2 and a higher percentage of women in social class 3. It seems unlikely that there was a consistent bias in volunteering throughout the many companies and organisations that the author visited, such that men were more likely to volunteer if they were a higher social class and women were more likely to volunteer if they were a lower social class. It seems more likely that this reflects the composition of a working urban population, where a married women is, on average, likely to work in a lower status job than her husband.

	ses	1	2	3	4	5	6	HW	n =
controls									
all	%	5	39	44	3	8	0	2	**155**
male	%	7	60	21	3	9	0	0	**58**
female	%	3	26	58	3	7	0	3	**97**

Table 5. The distribution of sex and social economic status in the control sample. "HW" denotes housewife.

The effect of the sex of the subject on the test scores was considered. Partly this was because the sample had proportionately more women than men and partly because there is evidence in the literature for subtle differences in cognitive skills between large groups of males and females (e.g. McGee, 1979; McGuinness, 1976).

These and other findings tend towards females being more skilled on verbal tasks and males being more skilled on non-verbal tasks. To determine statistically the effects of social economic status, sex and age on the new test for this sample, each control subject's scores on the three verbal sections of the new test were added together to produce a total verbal score. Similarly, their scores for the three non-verbal sections were added together to give a total non-verbal score. Two multiple regressions were performed to assess the contribution of age, social economic status and sex to the variance of the total verbal and non-verbal scores.

For the total verbal score, social economic status and age were the most significant variables and together gave an R square of 0.30. Although sex as the third variable

1. y = total verbal score		2. y = total non-verbal score	
1st variable:	SES	1st variable:	SES
Significance of F	<0.001***	Significance of F	<0.001***
R Square	0.25	R Square	0.18
2nd variable	AGE	2nd variable	AGE
Significance of F	<0.001***	Significance of F	<0.001***
R Square	0.30	R Square	0.28
3rd variable	SEX	3rd variable	SEX
Significance of F	<0.001***	Significance of F	>0.05
R Square	0.34		

gave a significant F value, when sex was added to the regression model the R square rose to only 0.34. For the total non-verbal score, social economic status and age were again the most significant variables and together gave an R square of 0.28. For the total non-verbal score, the F value of sex did not reach the usual 0.05 criteria for inclusion in a regression model.

The most significant contribution to the variance of both composite scores was social economic status, which reflects the competence level of an adult in society. It is not surprising that it apparently overlaps with a working adult's ability to solve formal reasoning problems. Age explained 5% of the variance of the verbal item scores and 10% of the variance of the non-verbal item scores.The same trend has been demonstrated on the Wechsler scales, where the age corrections for Similarities are less than those for Block Design. Because sex only explained 4% of the variance of the composite verbal score and was not a significant variable for the composite non-verbal score, its influence was felt to be trivial in this sample. It was concluded that the sex of the control subject was not influential in determining individual scores on the new test.

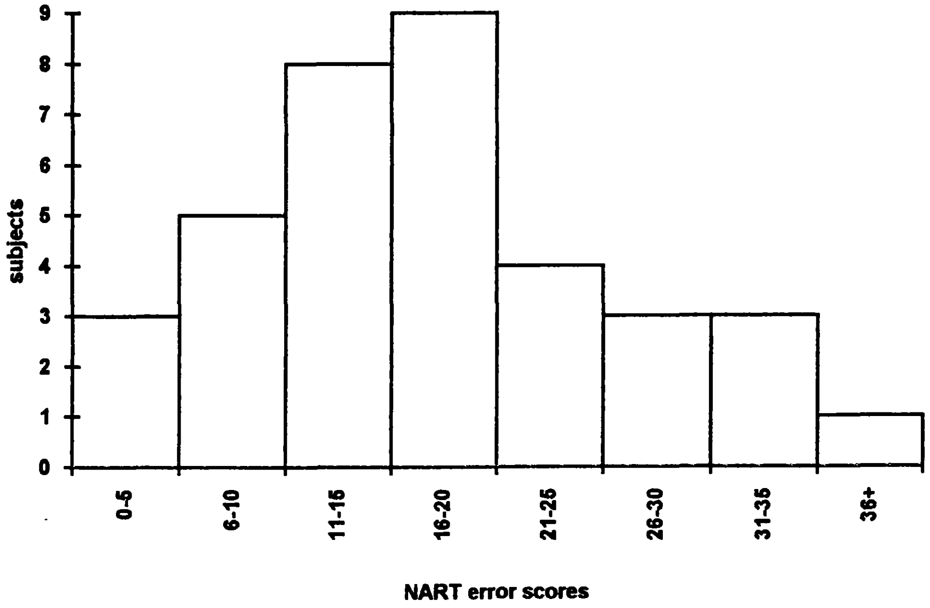
(ii) DISTRIBUTION OF IQ

To ascertain whether intelligence was normally distributed across the entire age range of the control sample, frequency distributions were constructed of both NART error scores and pro-rated Full Scale IQ's for each of the decades represented in the control sample. The distributions of the final 155 control subjects' scores on the National Adult Reading Test, by age, are given in Figure 2.

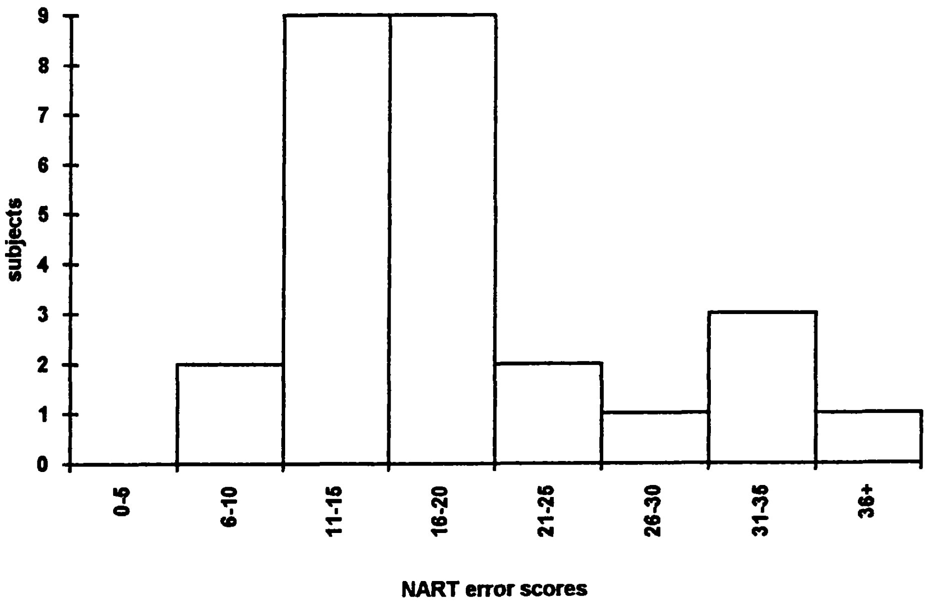
The distributions of NART error scores for each of the five decades represented in the control sample approximate the normal curve, covering a wide range of adult ability. A further demonstration of the extent to which the control sample reflects a normal urban adult population is provided by the Full Scale IQ distributions. The Full Scale IQs were pro rated from the four WAIS subtests that the control sample attempted and then eight points were subtracted from each WAIS IQ to give an indication of how the score would relate to a current normal sample (the WAIS-R standardisation has shown a difference of eight points between the score distributions of subjects who attempted both the WAIS and the WAIS-R, Wechsler, 1981). The IQ distributions for each age group are given in Figure 3.

Figure 2. The distribution of the control subjects' NART scores, for each age group.

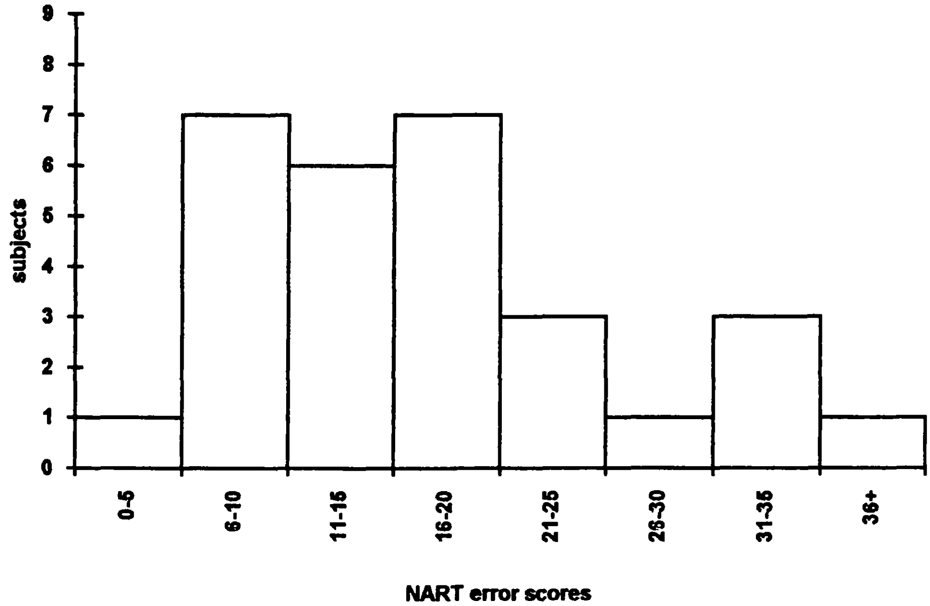
1. Controls aged 18-30 years.
n=36.



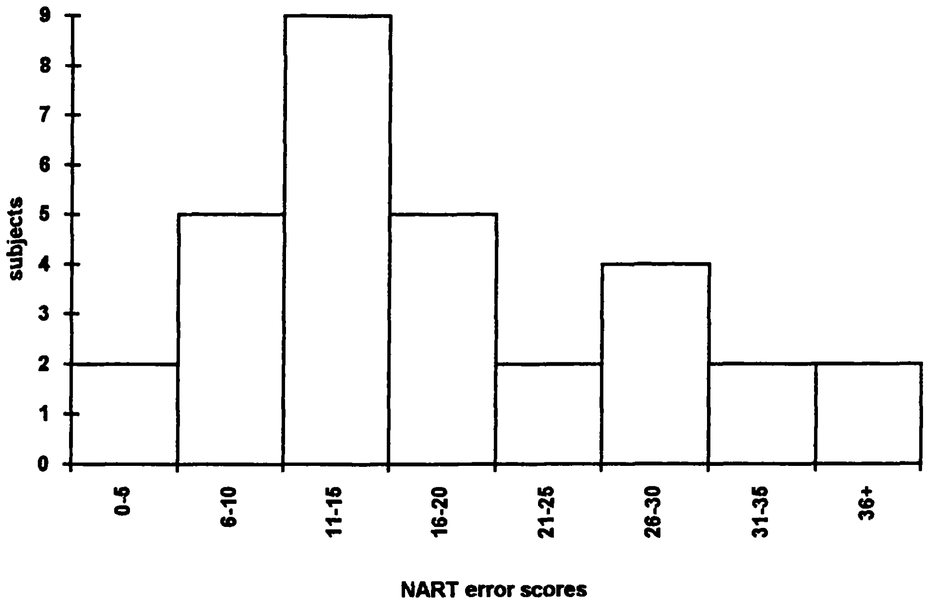
2. Controls aged 31-40 years.
n=27.



3. Controls aged 41-50 years.
n=29.



4. Controls aged 51-60 years.
n=32.



5. Controls aged 61-70 years.
n=31.

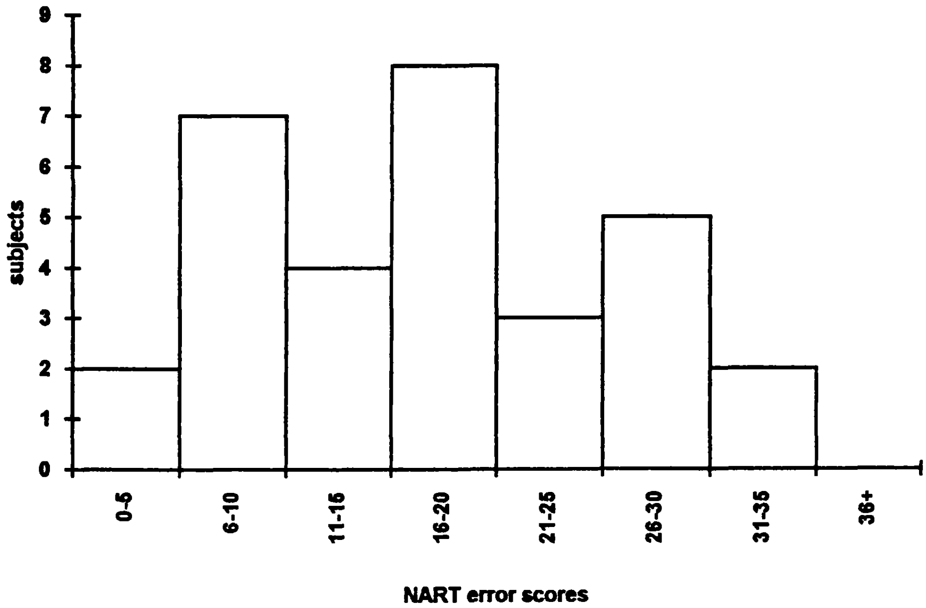
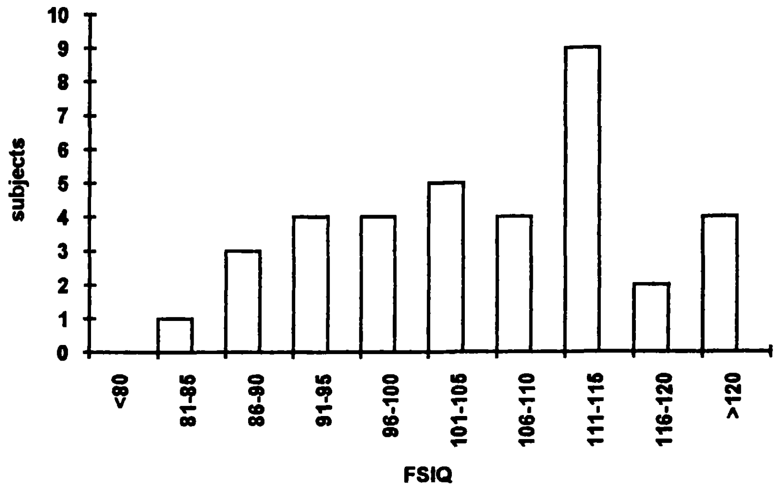
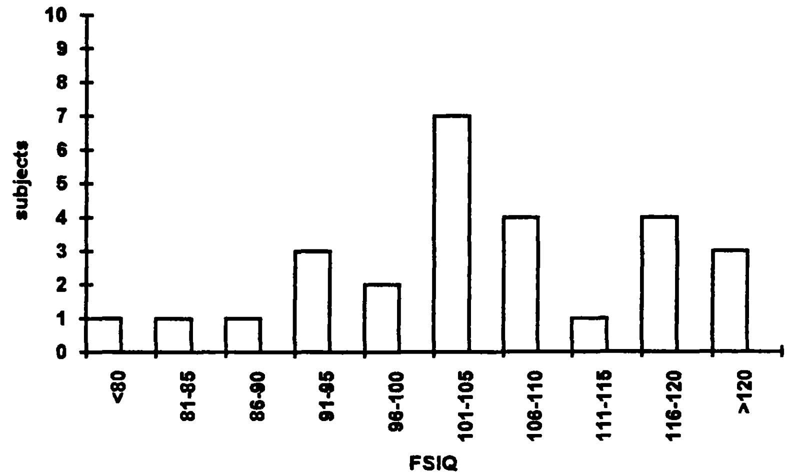


Figure 3. The distribution of the control subjects' Full Scale IQ's, for each age group.

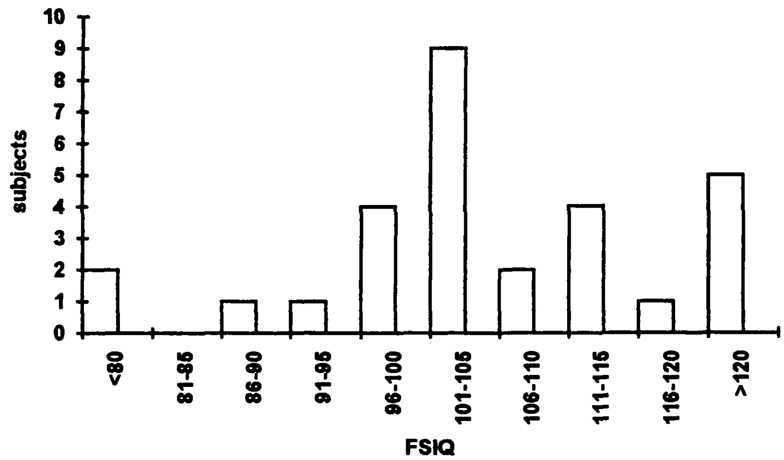
1.Controls aged 18-30 years.
n=36.



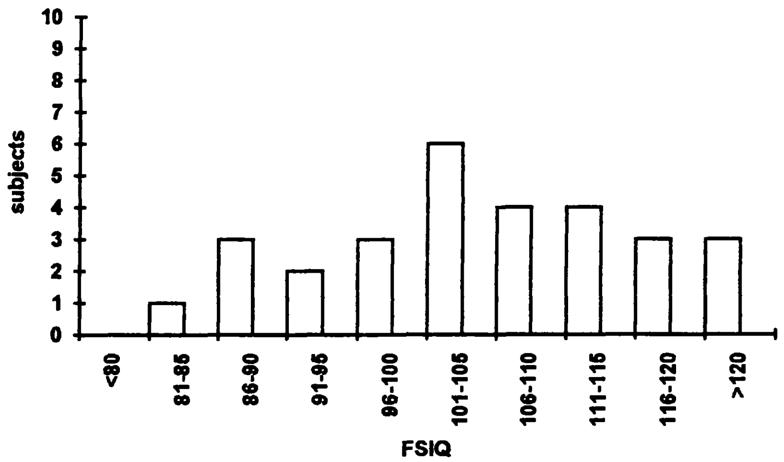
2. Controls aged 31-40 years.
n=27.



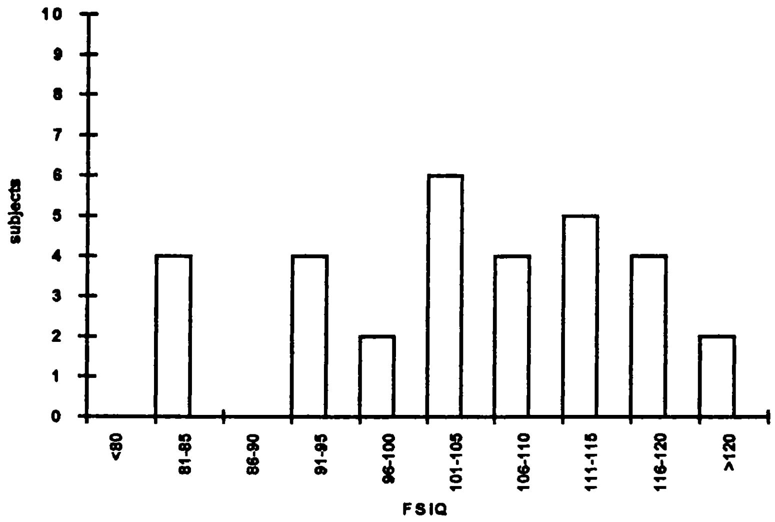
3. Controls aged 41-50 years.
n=29.



4. Controls aged 51-60 years.
n=32.



5. Controls aged 61-70 years.
n=31.



The means and standard deviations of the Full Scale IQs were calculated from the data set used for Figure 3. In addition, the NART error scores were used for two other estimates of the IQ distribution of the control sample. For the first, the Nelson (1982) standardisation was used, with eight being subtracted from each subject's score to take account of the most recent control group data that has been collected on the entire WAIS (Wechsler, 1981). The second estimate of the control sample IQ distribution used the more recent Nelson and Willison (1992) NART standardization, which gives a direct WAIS–R IQ. These descriptive statistics are given in Table 6. An examination of the table reveals that all three estimates of full scale IQ give a very regular and consistent set of distributions across the age ranges. Precisely, the column 1 mean IQ's vary by only 0.9 across the five age ranges, the column 2 means by 1.2 and the column 3 means by 1.1. The Full Scale IQ means are slightly above 100 for all three, with the Nelson and Willison (1992) data giving the highest means. A sample mean above 100 is a consistent finding in control groups collected at both this centre and others (e.g. the Nelson and Willison sample mean FSIQ was 107.4), and is thought to reflect an urban population.

AGE	1. NART error (Nelson, 1982)	2. NART error (Nelson and Willison, 1992)	3. WAIS subtests
18-30 years n=36	105.0 (7.5)	108.6 (11.1)	105.7 (12.6)
31-40 years n=27	104.7 (6.6)	108.0 (9.7)	105.0 (12.1)
41-50 years n=28	105.6 (7.5)	109.0 (11.0)	105.2 (12.9)
51-60 years n=32	105.2 (8.1)	108.0 (12.2)	105.5 (12.0)
61-70 years n=31	105.6 (7.3)	109.2 (10.8)	104.6 (12.2)

Table 6. The means and standard deviations of three estimates of Full Scale IQ for the five control age bands The standard deviations are given in brackets. The estimates in columns 1 and 3 have had 8 points subtracted from each score, to take account of the most recent Wechsler standardization (1981).

(iii) CONCURRENT VALIDITY OF NEW TEST

The relation of the new test to established tests will now be considered and descriptive statistics will be given first. Means and standard deviations of the control subjects' raw scores, for five age bands, are given in Table 7. Inspection of the descriptive statistics of the raw scores reveals that the tests previously demonstrated to be more stringent for older

test	18-30y n=36 mean (S.D.)	31-40y n=27 mean (S.D.)	41-50y n=29 mean (S.D.)	51-60y n=32 mean (S.D.)	61-70y n=31 mean (S.D.)
NART errors	17.7 (9.2)	18.3 (7.8)	17.5 (8.9)	17.9 (9.8)	17.3 (8.7)
Standard Progressive Matrices	29.8 (3.6)	28.6 (5.7)	24.3 (7.4)	26.1 (6.3)	22.6 (6.7)
WAIS Similarities	16.9 (2.8)	16.2 (4.4)	15.6 (3.9)	14.7 (3.6)	14.1 (5.4)
Digit Span forwards	7.6 (1.6)	7.1 (1.2)	7.3 (1.3)	6.8 (1.8)	7.0 (1.4)
backwards	5.4 (1.8)	5.2 (1.4)	5.4 (1.4)	4.7 (1.6)	4.4 (1.1)
total	12.9 (3.0)	12.3 (2.3)	12.6 (2.4)	11.8 (2.6)	11.4 (2.2)
Block Design	40.8 (6.5)	39.9 (7.1)	35.0 (8.7)	33.8 (10.5)	31.0 (6.9)
Picture Completion	15.8 (2.3)	16.2 (2.6)	15.3 (2.3)	14.5 (3.0)	14.7 (4.0)
Graded Arithmetic	15.8 (5.3)	14.5 (5.8)	14.8 (6.0)	14.9 (4.9)	11.9 (5.7)
Verbal odd one	17.6 (2.5)	17.5 (3.1)	17.1 (3.2)	16.13 (3.7)	15.3 (3.6)
analogy	19.0 (2.6)	18.8 (3.3)	16.8 (3.8)	16.7 (4.7)	16.2 (3.7)
series	18.1 (2.5)	18.0 (3.8)	16.8 (4.3)	17.1 (3.9)	16.6 (4.2)
Non-verbal odd one	17.2 (2.3)	17.0 (2.3)	16.7 (2.0)	16.3 (2.4)	15.7 (2.3)
analogy	20.1 (2.9)	19.3 (3.5)	17.8 (4.0)	17.8 (4.5)	16.7 (3.7)
series	22.1 (1.4)	21.5 (2.4)	20.6 (2.7)	20.5 (2.8)	19.0 (3.7)

Table 7. Means and standard deviations of control subjects' raw scores for the five age groups.

Consideration of the descriptive statistics has supported the conclusion from the multiple regressions in section 2.3B(i), that age is an important variable in determining scores on the tests of reasoning and intelligence that the control sample completed. In order to demonstrate the relation of the new test to established tests, correlations of the control subjects' raw scores were calculated separately for three age groups. These were 18 to 40 years, 41 to 55 years and 56 to 70 years, which seemed to reflect the important differences in the age groups, whilst retaining samples large enough for the calculation to be reliable. The means and standard deviations of the control subjects' raw scores for the three age groups are given in Appendix V, along with correlation tables for the three groups.

It was decided that two-tailed tests of significance were the most appropriate for examining the relationship between the test scores, because there did not seem to be any overwhelming theoretical basis for assuming *a priori* that control subjects should be performing better or worse on any one test in the battery, compared to another. The decision to use two-tailed tests meant that any evinced significant correlation could be taken as a strong indication of a relationship.

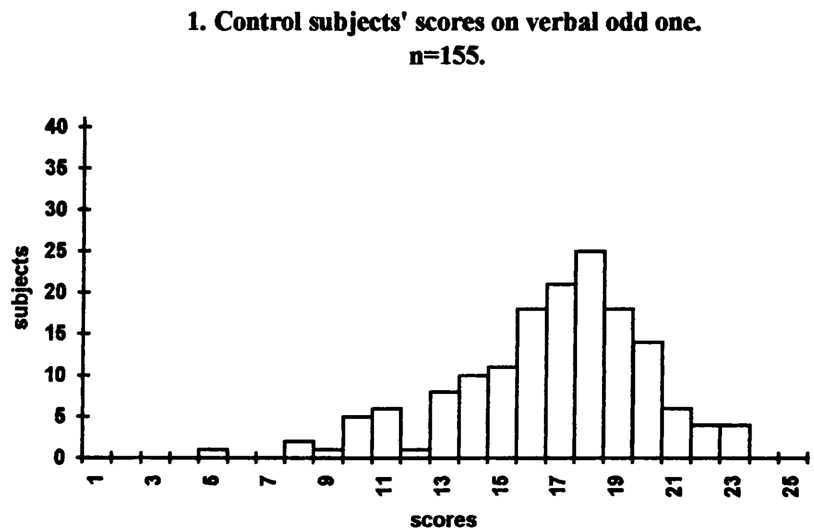
Inspection of the correlation tables reveals that, for all three age groups, the NART score correlated significantly with the Matrices and the WAIS Similarities and Block Design. It correlated significantly with Picture Completion in the two younger age groups and with Digit Span in the eldest age group. Similarities correlated significantly with both Block Design and Picture Completion in the two younger age groups. A strong interrelation among these tests is to be expected. The Graded Arithmetic Test correlated with Digit Span, Block Design and Picture Completion in all three groups. It also correlated with the Progressive Matrices and WAIS Similarities in the two younger groups.

The new test of reasoning correlated well with the established tests overall. With one exception (Verbal series in the 18 to 40 year old group), all three verbal sections of the new test were significantly correlated in all three age groups with the NART, the Matrices and WAIS Similarities. The non-verbal sections of the new test were all significantly correlated with the Matrices in all three age groups with one exception (Non-verbal odd one in the 41 to 55 year old group). The non-verbal sections of the new test are also intermittently correlated with the two WAIS Performance subtests. Digit Span is only demonstrated to be clearly related to all parts of the new test in the eldest age group. There is a strong pattern of significant correlation among the six sections of the new test in all three age groups, but only the eldest age group attains significance for all possible pairings.

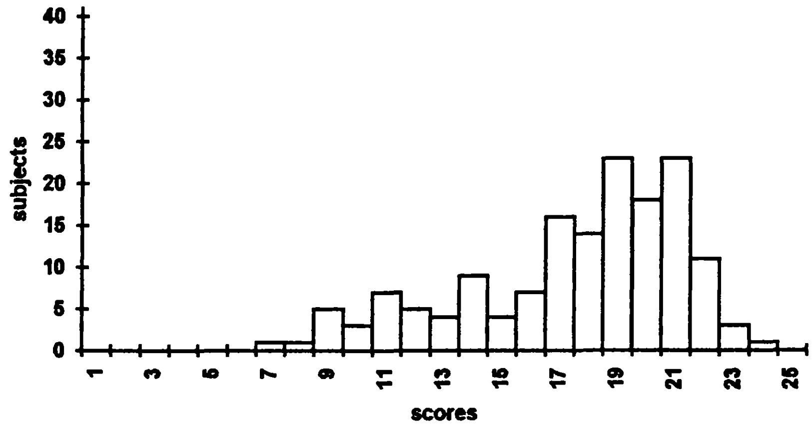
(iv) DISTRIBUTION OF SCORES ON THE NEW TEST

To ascertain whether each section of the new test gave both a good spread across the urban adult ability range and also approximated a normal distribution, frequencies of scores on each section recorded from the control sample were calculated. Distributions of scores on the new test by control subjects on each part of the new test are given in Figure 4.

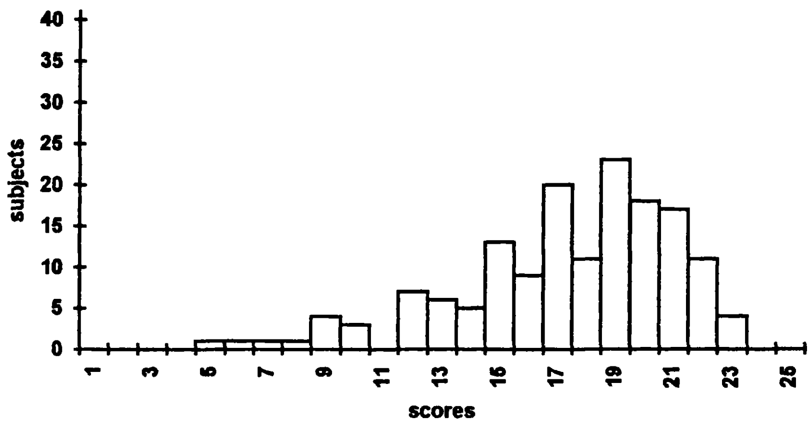
Figure 4. The distribution of scores obtained by the 155 normal control subjects on each section of the new test.



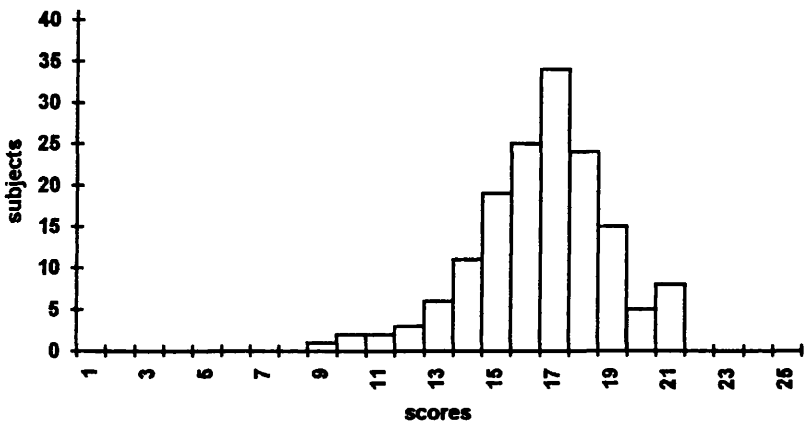
2. Control subjects' scores on verbal analogy section. n=155.



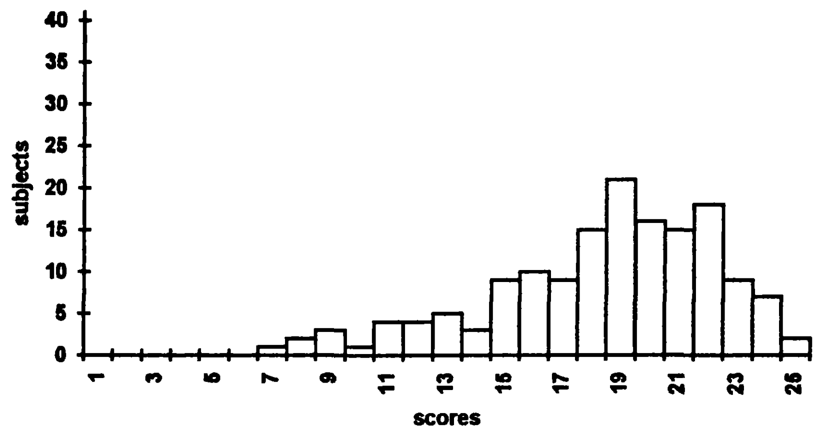
3. Control subjects' scores on verbal series section. n=155.



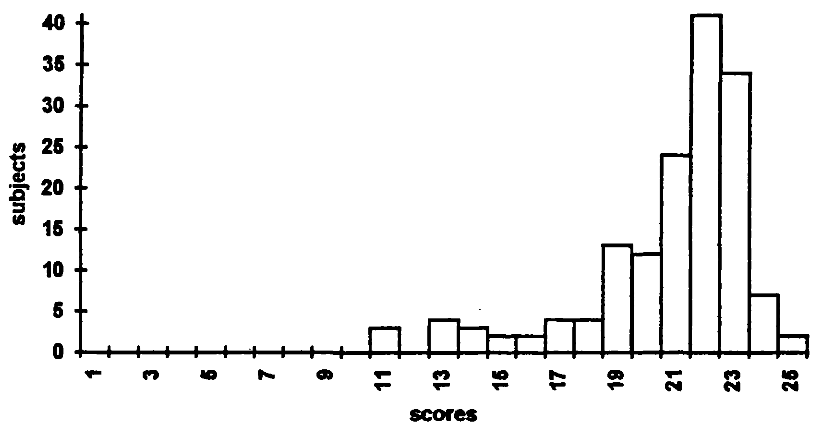
4. Control subjects' scores on non verbal odd one section. n=155.



5. Control subjects' scores on non verbal analogy section. n=154.



6. Control subjects' scores on non verbal series section. n=155.



Inspection of the distributions of the control subjects' scores reveals that the new tests approximate normal distributions. The multiple choice format has resulted in the predictable shift of the curves such that they tend to start around the chance score of 6 and an adequate range against which to evaluate test scores. The easier items of section 6 result in a higher mean score for the controls on this section, as can be seen in Table 8.

The effects of age on the control subjects' scores on the new test will now be considered in detail. A multiple regression analysis was described in section 2.3B(i) which demonstrated that age determined a significant proportion of the variance of the control subjects' scores on the verbal and non-verbal problems of the new test. The means and standard deviations of the new test scores for five age bands have been given in Table 7 in section 2.3B(iii).

test	mean	standard deviation
verbal odd one	16.7	3.3
verbal analogy	17.5	3.8
verbal series	17.4	3.8
non-verbal odd one	16.6	2.3
non-verbal analogy	18.4	3.9
non-verbal series	20.8	2.9

Table 8. Means and standard deviations of control subjects on the six sections of the new test.

Examination of these descriptive statistics revealed that, with one exception, the means for each section of the new test decreased with every age band. Inspection of these suggested that three age bands would capture the main effects of age, and the means and standard deviations for the three age bands used to intercorrelate the tests, with the intercorrelations, have been discussed in the same section.

Because the purpose of the normal sample was to provide a comparison for the scores of people with brain damage, account had to be taken of these age effects. The scores that lay on the 5th, 25th and 50th percentile of the cumulative frequency curves for the three age groups for each section of the new test were calculated and are given in Table 9. Consideration of these cut offs allows the score distributions of each age band to be compared. The overall impression is of a coherent data set which demonstrates consistent and regular age effects. Two minor adjustments were made to smooth the data. The first was at the 5th percentile of the middle age band for the verbal series section, which was increased from 8 to 9. The second was the 50th percentile of the elder age band for non-verbal odd one, which was reduced from 18 to 17.

age		18-39	40-55	56-70		18-39	40-55	56-70
pc								
	verbal odd one				**non-verbal odd one**			
5		13	10	10		13	12	9
25		16	15	13		16	15	14
50		18	17	16		17	17	17*(18)*
	verbal analogy				**non-verbal analogy**			
5		12	9	9		12	11	9
25		17	14	12		19	15	14
50		19	18	17		20	19	18
	verbal series				**non-verbal series**			
5		12	9*(8)*	9		19	14	13
25		17	14	14		21	19	17
50		19	18	17		22	21	21

Table 9. Age cut off scores for three age bands of the control sample, for each section of the new test. Two minor adjustments to smooth the data are indicated by the original figures being given in italics after the amended figure.

(v) ITEM ANALYSIS

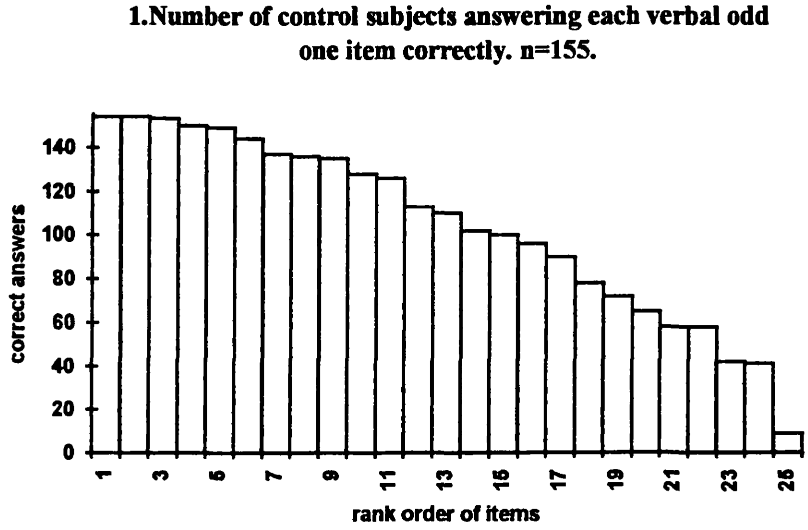
For each of the six sections, the number of control subjects getting each item correct was calculated. These totals allowed the order of the items by difficulty to be refined. The original piloting was found to have been largely correct. Only a handful of items were moved further than four places away from the rank order they had for the normal sample. Once the rank order had been refined, split half correlations were calculated for each of the six sections. They are given in Table 10. Although the split half correlation is to some extent a rough approximation of the true reliability of a test (in that only one split is used), the alpha coefficient (which calculates all possible splits) only offers a minute improvement in accuracy which is "of no practical or theoretical interest" (Kline, 1993, p11). The Spearman–Brown correction has been used to compensate for the fact that the split–half coefficient is always an underestimate of a test's reliability, by virtue of the reduced length of the halves in comparison to the complete test (Kline, 1993, p11).

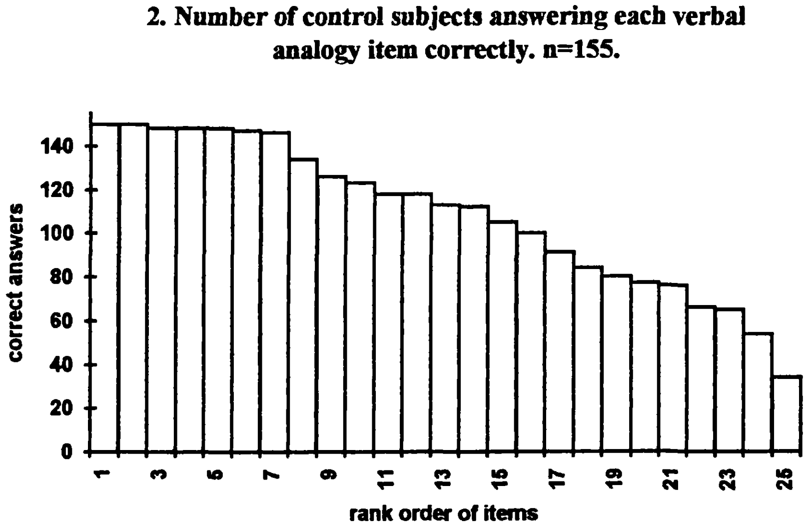
test	split half correlation	p value
verbal odd one	0.64	<0.001
verbal analogy	0.76	<0.001
verbal series	0.83	<0.001
non-verbal odd one	0.48	<0.001
non-verbal analogy	0.82	<0.001
non-verbal series	0.78	<0.001

Table 10. Split half correlations for the six sections of the new test, including the Spearman-Brown correction.

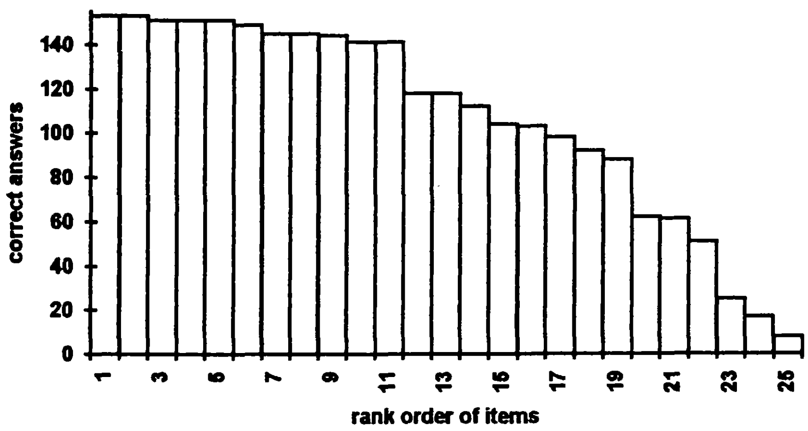
After the rank order by difficulty of the items had been refined, it was possible to construct item difficulty distributions for each section of the new test. These are given in Figure 5. The item difficulty curves show the graded difficulty of the items in each section. The easiest items are admittedly close to 100% correct in the normal sample, but it must be remembered that all scores are affected by the multiple choice format, which will inflate the number of correct answers to any item. In addition, the test is designed for use with a brain damaged population and a section of easy items might be necessary to avoid the problem of floor effects in the target group. The final version of the new test is given in Appendix VI.

Figure 5. The item difficulty distributions from the control sample for each section of the new test.

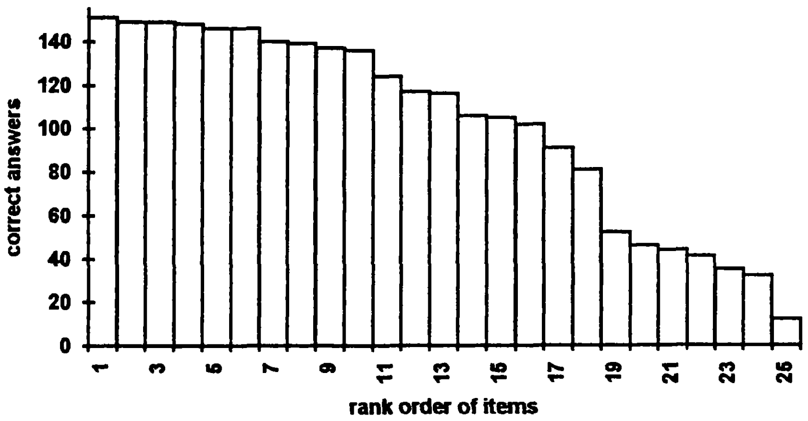




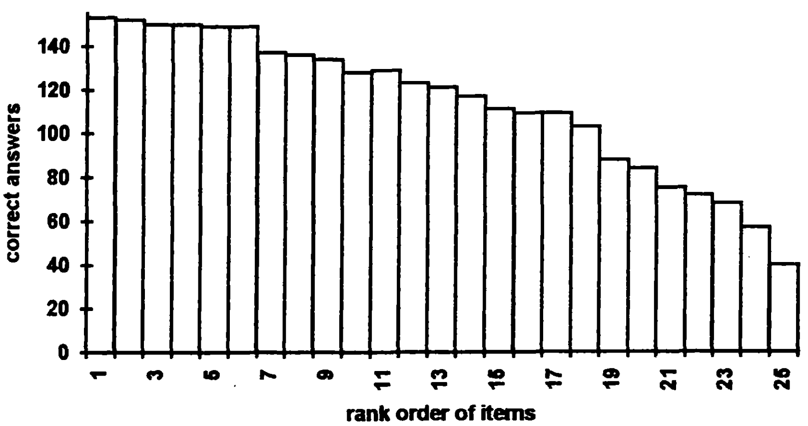
3. Number of control subjects answering each verbal series item correctly. n=155.



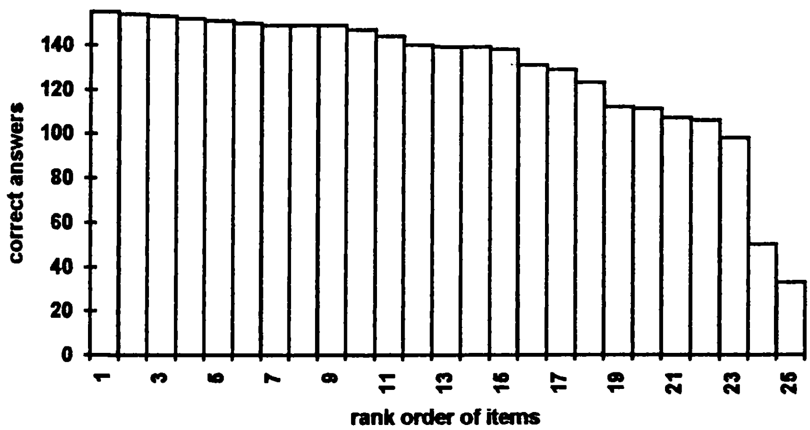
4. Number of control subjects answering each non verbal odd one item correctly. n=155.



5. Number of control subjects answering each non verbal analogy item correctly. n=154.



6. Number of control subjects answering each non verbal series item correctly. n=155.



2.3C CONCLUSIONS

Each section had to meet several constraints in order to serve the eventual purpose of evaluating reasoning in brain damage, and it was not clear at the outset whether the constraints might render the new test untenable for control subjects. For example the required accessibility of the stimuli, in that all words were very high frequency and all non-verbal stimuli were easily distinguished, meant that the normal range of adult ability had to be tested purely in terms of how simple stimuli related to each other. The multiple choice format, considered essential to minimise the handicap that physical disability might confer on a brain damaged person, meant that the answer had to given alongside easily distinguishable alternatives. Finally, these constraints had to be met by twenty five problems of the same inductive reasoning type, presented as exclusively verbal or non-verbal stimuli.

However each section of the new test produced a range of scores which approximated the normal curve and item difficulty distributions indicated that a fair spread of difficulty had been achieved by the test problems. The results showed that it might be possible to meet both the requirements of a brain damaged population and the demands of a validation sample of control subjects.

It has been demonstrated that the control sample covers the normal range of adult intelligence and approximates a normal distribution across five age bands. The internal reliability was demonstrated by very significant split half correlations for each section. All six sections of the new test have been shown to relate in a logical and coherent way to established tests of cognitive function, in line with the findings of other researchers. These sets of results validate the test and its control sample as a standard set of control data against which the scores of people with brain damage can be evaluated.

The effects of age on the new test have been demonstrated, which is typical of conventional reasoning tests. The age effects appear to be coherent and consistent. The robustness of the age effects in reasoning in the context of especially clear and accessible stimuli is interesting. In the past, there was no way of knowing whether the decline of reasoning scores with age reflected subtle declines in linguistic or visual spatial skills. Two aspects of the control sample data suggest this was not a significant factor. Firstly, the control sample produced marked age effects on each of its six sections. Secondly, the correlations of the new test with established tests of reasoning did not differ across the age bands, which would have been the case if the older subjects were less disadvantaged by the more accessible stimuli of the new test than by the more complex presentation of the established tests.

Because each section has been validated separately across a wide age range, and has been demonstrated to have a similar distribution of control subjects' scores to the other sections, the possibility arises of being able to evaluate separately the effects of both the type and presentation mode of reasoning problems in people who have suffered organic brain disease.

2.4 THE LESION SERIES

A sample of people with organic brain disease had to attempt the new test for the next stage of the validation process. It was decided to assess people who had suffered unilateral focal cerebral lesions. There were several reasons why this particular group of patients was particularly suitable. Firstly, they would present the opportunity of evaluating performance on reasoning problems presented in both verbal and non-verbal format, in the context of acquired deficits in language or visual perceptual functions. Secondly, the circumscribed nature of their brain damage would allow an attempt to assess the contributions of various cortical areas to reasoning. Thirdly, there was an extensive literature documenting the effects of focal cortical lesions on reasoning and other cognitive functions. Some of this has been discussed in the introduction to this thesis and it provides a corpus of established findings against which the study can be evaluated.

2.4A METHOD

(i) THE TEST BATTERY

For comparison purposes all tests in the control sample battery, except the NART and Schonall reading tests, were included in the lesion study. In addition some focal tests of left and right hemisphere function were selected, to provide an indication of the integrity of the right and left hemisphere functions of the patients. Finally, two tests of early visual processing were selected, to ensure a minimum visual ability. In fact no lesion cases were excluded on the basis of the early visual criteria, but the tests and scores are reported to indicate the visual competence of the patients. The lesion battery comprised:

1. Four WAIS subtests (Wechsler, 1955): Similarities, Digit Span, Picture Completion and Block Design.
2. The Graded Arithmetic Test (Jackson and Warrington, 1986).
3. The new test of reasoning in organic brain disease.
4. The Object Naming Test (McKenna and Warrington, 1983).
5. The Token Test (Coughlan and Warrington, 1978).
6. The Unusual Views Test (Warrington and Taylor, 1973).

7. The Efron Squares (as adapted by Warrington, 1986).
8. The Ffook Visual Acuity Test. In fact, all patients had at least 6/18 corrected visual acuity.

(ii) ADMINISTRATION OF THE BATTERY

A Individual tests

All the published tests were given in accordance with their authors' insructions, with the following minor exception: if a patient obtained a score above 16 on the Unusual Views Test, then only the items they failed were presented as Usual Views.

The administration of the new test of reasoning in organic brain disease was the same as that explained in the methodology of the control sample, in section 2.3A(ii). The rank order of items within each section of the new test was the same as that given to the control subjects, before the final refining of the order. This was done so that data from this scarce group of patients could be collected before the control series had been finished and analysed. All patients attempted all items, apart from the few exceptions detailed under missing data. Because there was no cut off after a specified number of errors and because there were only minor adjustments to the rank order after analysis of the control data, it is not thought that this will have influenced the patients' scores to any significant degree

B Order of tests

The battery of tests was arranged in two orders which were given alternately to patients in each of the two unilateral series. The two orders were constructed to reverse the order in which new and established tests of similar cognitive skills were attempted by the patients, to reduce practise effects. The two orders of tests for lesion patients are given in Appendix VII.

All patients were tested individually alone with the experimenter across a desk in an office. A handful of patients had been assessed on the previous day as a matter of clinical urgency, by other members of the psychology department of the National Hospital. This meant that the WAIS subtests, Graded Naming Test, Token Test and Unusual Views Test had already been given. It is not thought that this will have prejudiced the results to any significant degree, because a standardised administration is adopted by all members of the department.

Several test sessions were sometimes necessary for patients; most were completed within 48 hours, and the maximum time span over which patient data was collected was 5 days. The testing was organized such that the patients underwent no procedures involving a general anaesthetic between testing sessions for this battery. The purpose of the study was explained at the start and the patient's verbal consent obtained. After the first test, the experimenter checked that the patient was happy to continue.

(iii) THE TEST SUBJECTS

Two consecutive series, each of forty patients, with unilateral right or left cortical lesions were collected. Patients were identified by regular inspection of In Patient medical notes at the National Hospital for Neurology and Neurosurgery. The following selection criteria were adopted:

1. A unilateral cortical lesion on head CT scan. Details of the localisation and pathology of the eighty patients are given in Appendix VIII.
2. Within the age range 18 to 70 years.
3. Right handed, defined as not reporting use of left hand in preference to right for any activity.
4. Born and educated in Great Britain.
5. No evidence of any generalised cerebral pathology (e.g. head injury, long standing epilepsy).
6. No evidence of systemic disease (e.g. diabetes).
7. No evidence of either significant or recent psychiatric disease (e.g. a woman who had

spent six months in a psychiatric hospital after the birth of her first child thirty years ago, who had since been healthy and employed, was included. In contrast any current counselling or other similar specialist input meant exclusion, in part because it was an indication that the patient was feeling under considerable strain).

Permission to test the patient was obtained from the consultant and the ward sister was asked whether the patient was well enough to leave the ward. In fact all identified patients were able to leave the ward.

A Refusals

There were no refusals to take part in the research at initial contact. Two left hemisphere and two right hemisphere patients declined to complete the battery when approached for a second session and these four cases were not included in the final analysis.

B Unfinished and excluded cases

Six left hemisphere cases and two right hemisphere cases either went for craniotomy or were discharged from hospital before testing could be completed. One patient with a left hemisphere lesion emigrated to America directly from hospital before completing the battery. The psychologist discontinued testing a twenty year old man with a left frontal lesion, because he was judged to be too unpredictable and aggressive. Testing was also discontinued with two right hemisphere cases who became tearful during the testing session and were obviously distressed.

C Missing data

Of the eighty patients included in the series, two with left hemisphere lesions and one with a right hemisphere lesion did not attempt the complete test battery. All of these three attempted five of the six sections of the new test, which was a minimum criterion for inclusion in the final analysis. They all missed the verbal series section, the Graded

Arithmetic Test and the four WAIS subtests. In addition one of the left hemisphere cases missed the Token Test. These data could not be collected because the patients were unavailable as a result of clinical contingencies. The numbers of patients attempting each test in the battery are given in Table 11. Inspection of this table leads to the conclusion that the small amount of missing data is unlikely to have influenced the results.

test	left lesions	right lesions
verbal odd one	40	40
verbal analogy	40	40
verbal series	40	40
non-verbal odd one	40	40
non-verbal analogy	40	40
non-verbal series	38	39
WAIS Similarities	38	39
WAIS Digit Span	38	39
WAIS Picture Completion	38	39
WAIS Block Design	38	39
Graded Arithmetic	38	39
Standard Progressive Matrices	40	40
Unusual Views	40	40
Graded Naming	40	40
Token Test	39	40

Table 11. Numbers of patients attempting each test to show effect of three cases who did not attempt the complete battery. For each series, total n=40.

Consideration of the datasets from the two lesion series led to the conclusion that the number of refusals, number of lost cases and amount of missing data were acceptable for a research project based on a clinical population of seriously ill patients. It was decided to move to the next phase of analysing the data and the first task was to describe the demographic parameters of the samples.

2.4B RESULTS

(i) DEMOGRAPHIC CHARACTERISTICS

The demographic characteristics of the lesion series were considered. The age and sex distributions of the two series are given in Table 12 along with the control data for comparison. The age distributions are very similar for the control and lesion groups. A one way analysis of variance of age by case type resulted in an F value of 0.97 ($p=0.38$). Multiple regressions indicating that sex was not a significant variable in determining scores on the new test are given in Appendix IX.

	age mean	age sd	females	males	n=
controls	45.1	14.9	97	58	**155**
left lesions	47.4	14.2	11	29	**40**
right lesions	48.7	13.7	15	25	**40**

Table 12. The age and sex distributions of the control and patient subjects.

The SES distributions are detailed in Table 13.

	SES	1	2	3	4	5	6	HW	missing	n =
controls %		5	39	44	3	8	0	2	0	**155**
left lesions %		8	25	45	18	3	3	0	0	**40**
right lesions %		13	25	25	20	5	0	3	10	**40**

Table 13. Social economic status distribution of lesion series, with control figures given for comparison. HW = housewife.

Initial inspection of the SES distributions suggests that they were similar. SES 5 and 6 were collapsed to give acceptable frequencies in each cell and then three chi squares for linear trend were performed (Epi-stat, 1984). Firstly the comparison of the control and left lesion series gave a chi square of 2.1 (p=0.15). Secondly the comparison of the control and right lesion series gave a chi square of 0.18 (p=0.67). Thirdly the comparison of the left and right lesion series gave a chi square of 0.73 (p=0.39). Thus there was no significant differences among control and lesion series in their age and SES distributions.

(ii) LOCALISATION AND PATHOLOGY OF LESIONS

The details of each individual case are given in Appendix VIII. The frequencies of the localisation and extent of lesion are given in Table 14. Initial inspection suggested that there were no important differences between the localisation or extent of the lesions ocurring in the left and right hemisphere groups. Statistical confirmation of this is detailed in Appendix VIII. The frequencies of the various pathologies are given in Table 15.

lesion	lobes involved:	frontal	temporal	parietal	occipital	missing
left		22	17	16	2	0
n=40						
right		17	13	20	5	0
n=40						
	number of lobes involved:	1	2	3	4	total
left		26	12	2	0	40
n=40						
		27	11	2	0	40

Table 14. Localisation and extent of lesions in right and left hemisphere lesion series.

lesion series	cerebral tumour	meningioma	vascular	metastases	abscess	granuloma	unclear
left	18	8	9	3	1	0	1
right	21	12	3	1	2	1	1

Table 15. The frequencies of different pathologies in the two lesion series.
One right hemisphere case had both a right frontal abscess and previous excision of a right frontal meningioma and is recorded in both categories.

Initial inspection suggested that the range and frequencies of the various pathologies were similar in the two groups. This was confirmed statistically and details are given in Appendix VIII. Thus there were no significant differences between the types or locations of lesions ocurring in the right and left hemisphere series.

(iii) PERFORMANCE OF PATIENTS ON ESTABLISHED TESTS

A Level of performance

The means and standard deviations of the lesion groups' scores on established tests are given in Table 16.

	controls mean (s.d.)	left lesions mean (s.d.)	right lesions mean (s.d.)
WAIS			
Similarities s.s.	11.6	8.3	11.1
	(2.3)	(3.7)	(2.2)
Digit Span s.s.	12.2	7.8	11.0
	(3.2)	(3.8)	(2.6)
Block Design s.s.	12.7	10.2	10.5
	(2.9)	(3.2)	(3.3)
Picture Completion s.s.	12.3	10.4	11.6
	(2.2)	(3.2)	(2.3)
Matrices r.s.	26.4	22.8	19.4
	(6.5)	(7.5)	(7.9)
Graded Arithmetic r.s.	14.4	6.9	11.2
	(5.6)	(6.1)	(5.5)

Table 16. Means and standard deviations of scores of control, left hemisphere lesion and right hemisphere lesion groups on established tests that all three groups attempted.
s.s. = scale score; r.s. = raw score.

The scale scores of the WAIS subtests were used for this table, because the values are an international reference set and allow the subtests to be compared one with another initially by visual inspection. The means and standard deviations of the raw scores of the lesion series on the WAIS subtests are given in Appendix X for information. The same descriptive statistics for the control series have already been presented (Table 7).

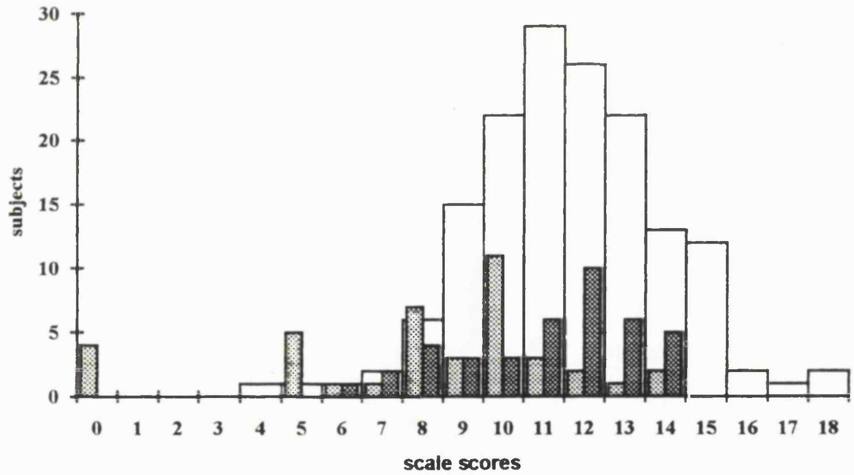
The published control data for the established tests were not considered appropriate for any statistical evaluation of the lesion patients' performance. First, the WAIS subtest normative data were collected nearly 50 years ago in America. Secondly, adult normative data on the Standard Progressive Matrices are only published in terms of percentile bands, for all five sections attempted together. Thirdly, although the Graded Arithmetic test has a recent normal sample, its 100 subjects are a small group in comparison to the Wechsler normative sample. In order to avoid the inaccuracy of using control data collected from samples of different sizes, at different times, in different countries, the data from the control sample described in Section 2.3 were used. It is contemporaneous with the lesion series and the age and SES distributions do not differ significantly from those of the lesion series, as has been demonstrated in Section 2.4B(i).

In order to compare the left and right hemisphere lesion patients' scores to the control group's on established test, bar charts were constructed to allow inspection of how the distributions related to each other. In preparation for a statistical comparison, cut off scores were calculated. For the four WAIS subtests, the WAIS scale scores were used. The scale scores which corresponded to the 5th, 25th and 50th percentiles of the control group's cumulative frequency curves were calculated. These cut off scores were then applied to the two lesion series score distributions, to ascertain what percentage of the patients had scored at or below the control cut off scores. A similar procedure was followed for the Matrices and Graded Arithmetic, except that the raw scores were used. The bar charts and percentages of patients scoring at or below the control cut off scores are given in Figure 6.

Inspection of the distributions of the lesion and control groups' scores on the WAIS subtests suggests that the left hemisphere lesion group is performing at a lower rate than the other two groups on Similarities and Digit Span, but there seems little difference between the two lesion groups on Block Design or Picture Completion. Raven's Matrices appear to have been difficult for both lesion groups. In contrast the Graded Arithmetic Test seems to have been especially difficult for the left hemisphere lesion group.

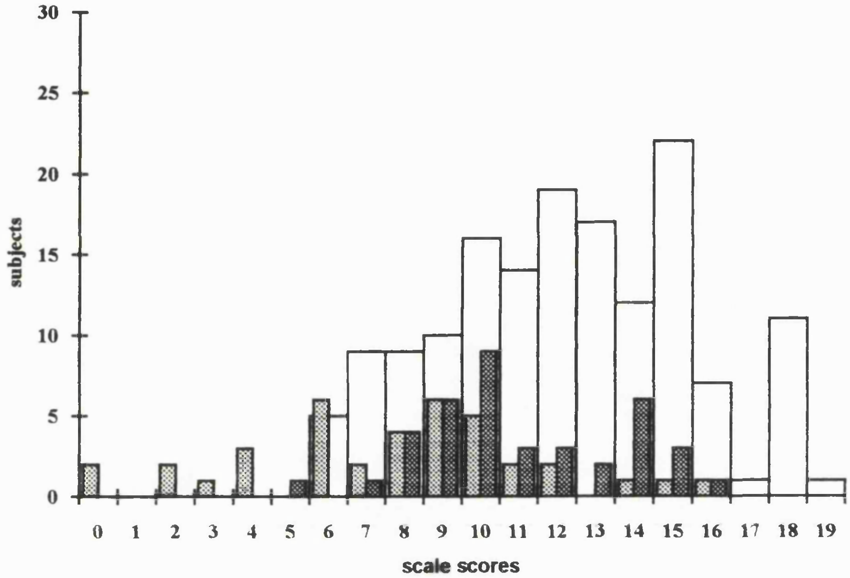
Figure 6. Bar charts of control and lesion groups' scores on established tests and tables of percentages of patients scoring at or below control group cut offs.
The control bars are white, the left hemisphere group are mid grey and the right hemisphere group are dark grey.

1. WAIS Similarities scale scores.



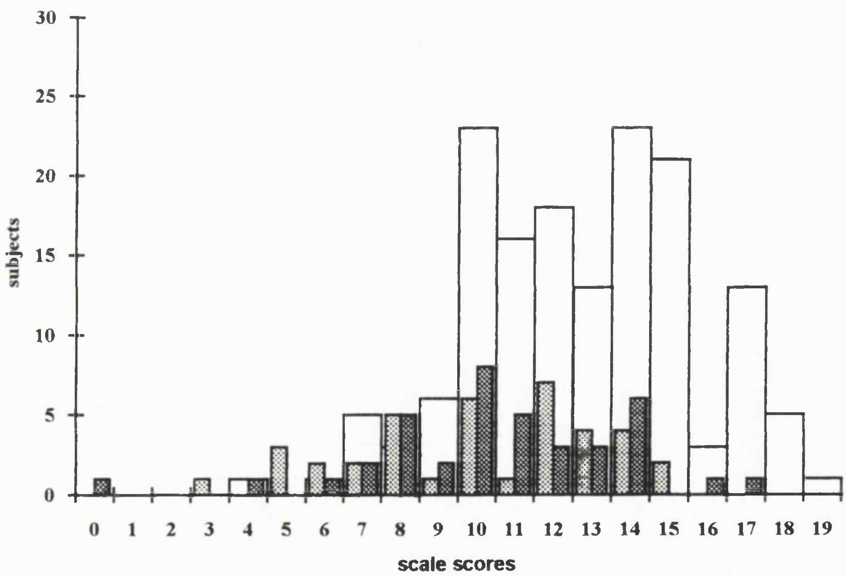
cut off scores	7	10	11
controls %	**5**	**25**	**50**
left lesions %	28	80	88
right lesions%	8	33	48

2. WAIS Digit Span scale scores.



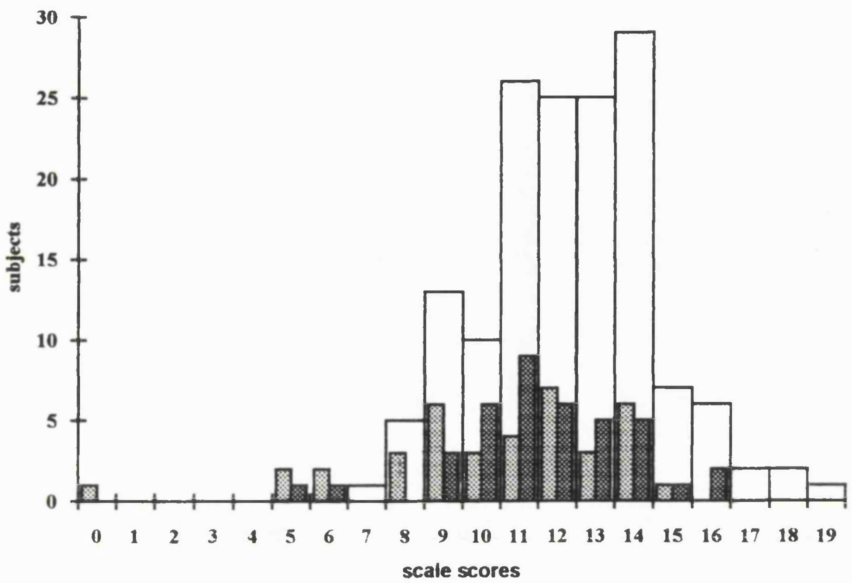
cut off scores	6	9	12
controls %	**5**	**25**	**50**
left lesions %	37	68	92
right lesions%	3	31	69

3. WAIS Block Design scale scores.



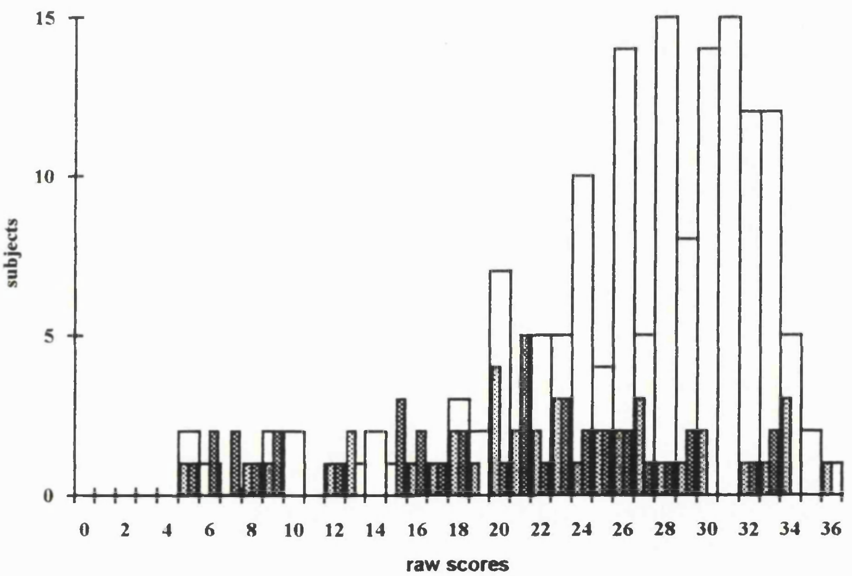
cut off scores	7	10	18
controls %	**5**	**25**	**50**
left lesions %	21	53	74
right lesions%	13	51	72

4. WAIS Picture Completion scale scores.



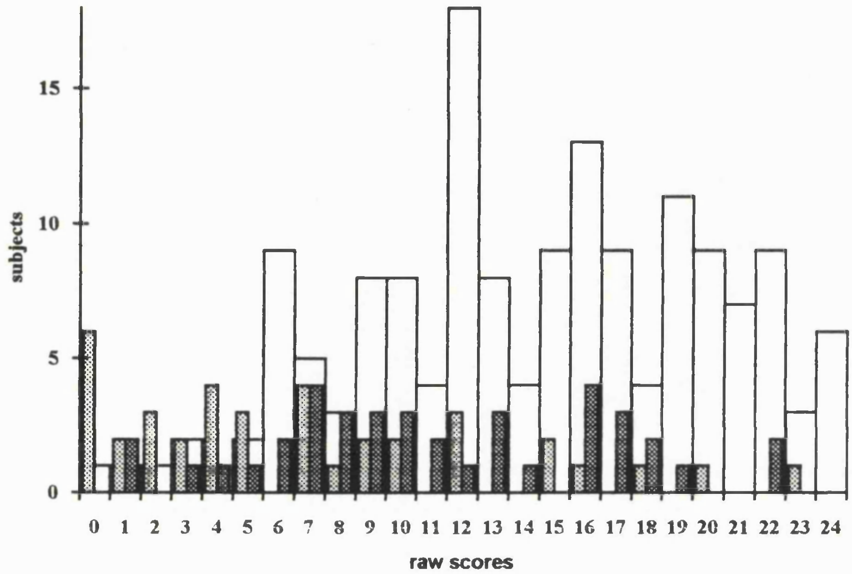
cut off scores	8	10	12
controls %	**5**	**25**	**50**
left lesions %	21	45	74
right lesions%	5	28	67

5. Raven's SPM (BCD) raw scores.



cut off scores	12	23	27
controls %	**5**	**25**	**50**
left lesions %	10	55	75
right lesions%	23	68	85

6. Graded Arithmetic Test scores.



cut off scores	5	10	14
controls %	**5**	**25**	**50**
left lesions %	53	76	84
right lesions%	13	51	69

B Effect of laterality of lesion

The chi square test for linear trend was considered to be the most effective means of determining whether the lesion patients' scores were statistically different either from the control sample frequencies or the other unilateral lesion series. Whereas a conventional analysis of variance would take account of the whole of each distribution and thus emphasise the similarities arising as a result of overlapping distributions, comparison of percentile cut-offs focussed on the areas where the differences between the distributions might lie. The linear trend analysis would be particularly sensitive to patients' scores being increasingly impaired the further down the ranked order their position.

Using the cumulative frequencies detailed in Figure 6, the numbers of the lesion patients scoring at or below the 5th, 25th, or 50th control percentile, or above the 50th control percentile, were calculated. Chi squares for linear trend were performed to compare the two lesion series firstly with the control group and secondly with each other. The tables of observed and expected frequencies used to compute the chi-squares are given in Appendix XII. The chi square values and their levels of significance are given in Table 17.

	left hemisphere lesions compared with controls	**right hemisphere lesions** compared with controls	**right and left hemisphere lesions** a comparison
WAIS			
Similarities	22.05***	0.12	18.37***
Digit Span	18.28***	1.00	14.12***
Picture Completion	4.91*	0.73	2.36
Block Design	6.24*	5.27*	0.10
Matrices	7.18**	15.85***	2.50
Graded Arithmetic	19.86***	5.30*	6.88**

Table 17. Chi squares for linear trend comparing lesion and control series on established tests. * $p<0.05$. ** $p<0.01$. *** $p<0.001$.

In addition to the chi square analyses of frequencies of subjects' scores falling below certain percentile cut offs, the more traditional analysis of variance tests was used to compare the distributions of the lesion patients' raw scores with the control subjects' scores on established tests. This analysis covaried age, so that any possible differential effects of age on test scores achieved by lesion patients were eliminated. The two lesion series were also compared using analysis of variance, with age as covariate. This and all further statistical analyses, except for chi squares by linear trend, were performed using SPSS/PC+ (1988). The results are given in Table 18.

	left hemisphere lesions compared with controls ANOVA F	**right hemisphere lesions** compared with controls ANOVA F	**right and left hemisphere lesions** a comparison ANOVA F
WAIS			
Similarities	**55.94*** **	1.88	**19.09*** **
	(p<0.000)	(p=0.172)	(p<0.000)
age t-level	*-3.99****	*-3.19***	*-2.94***
Digit Span	**49.47*** **	**5.21***	**15.57*** **
	(p<0.000)	(p=0.24)	(p<0.000)
age t-level	*-3.42****	*-3.05***	*-2.70***
Picture Completion	**23.74*** **	**4.30***	**4.17***
	(p<0.000)	(p=0.39)	(p=0.045)
age t-level	*-2.30**	*-3.03***	*-2.23**
Block Design	**29.42*** **	**16.07*** **	1.30
	(p<0.000)	(p<0.000)	(p=0.258)
age t-level	*-6.40****	*-6.82****	*-4.04****
Matrices	**11.67*** **	**32.00*** **	2.25
	(p=0.001)	(p<0.000)	(p=0.135)
age t-level	*-5.84****	*-6.04****	*-4.39****
Graded Arithmetic	**55.50*** **	**8.84** **	**14.39*** **
	(p<0.000)	(p=0.003)	(p<0.000)
age t-level	*-2.64***	*-3.19***	*-2.85***

Table 18. Comparison of the two lesion series with control series, and of the two lesion series, on established tests by analysis of variance with age as covariate.
* p<0.05. ** p<0.01. *** p<0.001.

Inspection of Table 18 reveals a broadly similar pattern of statistical significance to that produced by the analysis by chi square for linear trend, detailed above in Table 17. However, three more comparisons reached significance: the right hemisphere lesion group compared with the control group on Digit Span and Picture Completion; the right hemisphere group with the left hemisphere lesion group on Picture Completion. In addition six comparisons reached a higher level of significance.

The increased numbers of comparisons reaching significance with ANOVA's, as compared to the chi squares reported above, probably reflects the more general effects of brain damage. That is, the lesion patients' scores are likely to be slightly depressed overall and this small but general shift in their scores influences the ANOVA results, whereas the chi square for linear trend takes more account of the most impaired cases.

Table 18 confirms that the covarying of age does not substantially alter the pattern of results and the chi squares for linear trend will be referred to in further discussions, because their highlighting of the subjects who were especially impaired on cognitive tests is particularly useful in determining the theoretical basis of reasoning.

In addition to the six tests detailed above, which were attempted by both the lesion patients and the control group, three established tests of focal dysfunction were included in the lesion patients' battery. They were the Graded Naming Test (hereafter "GNT", McKenna and Warrington, 1983), a short form of the Token Test (Coughlan and Warrington, 1978) and the Unusual Views Test of visual perception (Warrington and Taylor, 1973). The means and standard deviations of the raw scores obtained by the lesion series on the Graded Naming and Token tests are given in Table 19.

The difference score between the Unusual and Usual Views was calculated for each patient, in an attempt to reduce the impact of aphasia in left hemisphere cases on scores on this test of right hemisphere function. For example, a severely aphasic patient who could not communicate recognition of an object photographed from an atypical angle would be just as impaired when presented with objects photographed from a typical angle. The differing levels of complexity required of the visual processing system by the two sets of stimuli should hardly affect the left hemisphere cases. In contrast, the increased visual processing demands of the Unusual Views over and above that required by the Usual Views, should produce different levels of performance between the two sets of stimuli in a group of right hemisphere lesion cases. The means and standard deviations of the Unusual Views difference scores for the two lesion series are also given in Table 19.

	Left Lesion Group mean (s.d.)	Right Lesion Group mean (s.d.)
Graded Naming	13.8	21.1
raw score.	(8.0)	(5.3)
DeRenzi	9.6	13.1
raw score.	(5.7)	(2.0)
Unusual Views	2.3	3.0
difference score	(3.3)	(2.8)

Table 19. Means and standard deviations of lesion patients' scores on established focal tests.

Inspection of the means reveals the weakness of the left hemisphere lesion group on the two language tests, the GNT and DeRenzi, and the poorer performance of the right hemisphere group on the more complex visual processing task. No contemporaneous control data was collected for these tests, because they have already been validated in recent unilateral lesion series (McKenna and Warrington, 1983; Coughlan and Warrington, 1978; Warrington and Taylor, 1973). The scores of the two lesion series were compared to show that they were statistically different. As has been previously demonstrated, the patients' score distributions on these tests did not approximate a normal curve and the Mann Whitney U test was therefore used to compare the scores of the two lesion series. The results of these comparisons are given in Table 20.

	Comparison by Mann Whitney
Graded Naming Test raw scores	-4.23***
Token Test raw scores	-2.54**
Unusual Views Test difference scores	-1.97*

Table 20. Comparison of lesion series on established tests of focal dysfunction by Mann Whitney U Test.
*p<0.05 **p<0.01 ***p<0.001

c Effect of lesion quadrant on established tests

Next the effects of lesion location on scores on established tests were considered. Patients were grouped according to the quadrant in which their lesion occurred. Patients with frontal, fronto-temporal and fronto-parietal lesions on CT scan were designated "anterior". All other patients were designated "posterior", with the exception of two patients from each lesion series who had suffered lesions involving three lobes. The extensive nature of their disease meant that they were unsuitable for inclusion in a detailed localisation study and their data were excluded from the localisation analysis. The means and standard deviations of the four lesion quadrant groups are given in Table 21.

There appears to be a trend for the left hemisphere lesion groups to be weaker on the WAIS verbal subtests, and on both the Graded Naming and the Graded Arithmetic Test.

	Left anterior	Left posterior	Right anterior	Right posterior
WAIS				
Similarities	12.14	8.33	14.83	13.92
	(3.48)	(7.00)	(4.15)	(4.81)
Digit Span	10.23	8.13	12.09	10.73
	(2.28)	(4.07)	(2.34)	(1.97)
Block Design	33.58	26.13	33.55	27.35
	(9.04)	(11.18)	(9.18)	(10.55)
Picture Completion	13.58	12.09	15.55	13.46
	(3.6)	(4.91)	(2.54)	(3.95)
Matrices	23.79	22.46	21.08	18.50
	(7.52)	(7.87)	(7.18)	(8.52)
Graded Arithmetic	8.38	6.39	12.64	10.46
	(5.91)	(6.37)	(6.77)	(4.96)
Graded Naming	18.43	11.71	23.83	19.85
	(4.87)	(8.35)	(3.46)	(5.78)
Token Test	12.38	8.33	13.25	13.00
	(2.72)	(6.40)	(2.05)	(2.04)
Unusual Views d.s.	1.50	2.92	2.42	3.20
	(2.10)	(3.79)	(2.20)	(3.10)

Table 21. Means and standard deviations of patients' raw scores on established tests, by lesion site. d.s. = difference score.

	LA vs LP	**RA vs RP**	**LA vs RA**	**LP vs RP**
WAIS	ANOVA F	ANOVA F	ANOVA F	ANOVA F
Similarities	1.31	0.40	**7.11***	**11.40*****
	(p=0.260)	(p=0.533)	(p=0.014)	(p=0.001)
age t-value	*-3.09***	*-1.29*	*-2.62**	*-2.41**
Digit Span	0.83	3.59	**4.87***	**8.64****
	(p=0.370)	(p=0.067)	(p=0.039)	(p=0.005)
age t-value	*-2.20**	*-1.64*	*-1.08*	*-2.64**
Block Design	1.16	4.10	0.63	0.06
	(p=0.290)	(p=0.051)	(p=0.436)	(p=0.805)
age t-value	*-3.16***	*-3.36***	*-2.59**	*-3.91****
Picture Completion	0.14	3.20	2.66	1.04
	(p=0.709)	(p=0.082)	(p=0.118)	(p=0.313)
age t-value	*-1.58*	*-2.45**	*-0.73*	*-2.90***
Matrices	0.19	1.43	0.11	**4.90***
	(p=0.662)	(p=0.240)	(p=0.740)	(p=0.032)
age t-value	*-3.53****	*-3.41***	*-2.20**	*-4.64****
Graded Arithmetic	0.07	1.65	3.65	**6.76***
	(p=0.791)	(p=0.208)	(p=0.070)	(p=0.012)
age t-value	-1.77	-2.86**	-1.07	-3.37**

Table 22. Comparison by ANOVAs of lesion quadrant groups' raw scores on established tests, with age as covariate.
L = left, R = right, A = anterior, P = posterior.
* = p<0.05 ** = p<0.01 *** = p<0.001.

The right posterior group appears to be weak on the Matrices. In order to determine statistically the effect of lesion location on established tests, analyses of variance were performed to compare each lesion quadrant group's scores on the WAIS subtests, the Graded Arithmetic and Matrices. All of these test score distributions approximated a normal distribution (see Figure 6). ANOVA's were chosen for these comparisons because the numbers in each group were small and chi square comparisons could not be performed on sufficient numbers of score frequency bands to be useful. The ANOVA results are given in Table 22.

Significant differences were demonstrated between the two posterior groups and the two anterior groups. The comparisons of the two posterior groups evinced four significant differences. Only Block Design and Picture Completion were not significantly different. Inspection of the group means in Table 21 shows that for the Matrices, it is the right posterior lesion group that performed most poorly. It is the left posterior group that was the weaker on both the WAIS verbal subtests and the Graded Arithmetic. The comparison of the two anterior groups demonstrated two significant differences, on WAIS Similarities and Digit Span; inspection of the group means reveals that the left anterior lesion group were weaker than the right anterior lesion group on these two WAIS subtests.

(iv) PERFORMANCE OF PATIENTS ON NEW TEST

A Level of performance

As was explained in the control methodology section 2.3A(ii), only subjects who correctly answered at least one of the two practice items at the beginning of each of the new tests progressed to attempt the twenty five graded items. Only one control subject on one section failed to pass this screen. However, eight left hemisphere cases and three right hemisphere cases failed both practise items on at least one section. The numbers in each series failing both practice items in each section are given in the following Table 23.

Inspection of the Table 23 reveals that left hemisphere cases are more than twice as likely to fail both practise items on a section of the new test and also that the non-verbal analogy practise items were as likely to catch out a patient as the practise items of all the other five sections put together.

		lefts	rights
test			
verbal	odd one	2	0
	analogy	4	0
	series	1	1
non-verbal	odd one	1	0
	analogy	5	3
	series	1	0

Table 23. Numbers of patients failing both practice items on each section of the new test.

The numbers of sections on which individual patients failed both practice items is given in the following table.

	sections	1	2	3	4	5	6
group							
lefts		4	3	0	1	0	0
rights		2	1	0	0	0	0
all patients		6	4	0	1	0	0

Table 24. Numbers of patients failing both practice items of one or more sections.

Inspection of the above table reveals that, with one exception who failed both practice items of three sections, all of the lesion cases were able to solve correctly at least one practice item from at least four sections of the new test. For the eleven patients who failed both practice items on one or more sections, their test scores on these sections were entered as six, which would be the most likely chance score on a test of twenty five items each with four response alternatives.

	Control group	**Left lesion group**	**Right lesion group**
Verbal			
odd one	16.7	13.3	15.4
	(3.3)	(4.8)	(3.7)
analogy	17.5	12.7	15.3
	(3.8)	(4.8)	(4.0)
series	17.4	13.6	14.2
	(3.8)	(4.6)	(4.1)
Non-verbal			
odd one	16.6	14.8	15.2
	(2.3)	(3.0)	(3.2)
analogy	18.4	15.0	14.1
	(3.9)	(5.3)	(5.0)
series	20.8	18.3	17.5
	(2.9)	(4.7)	(4.4)

Table 25. Means and standard deviations of patients' and controls' raw scores on new test.

The general impression is of both lesion series tending to be weaker than the control group. The left hemisphere lesion group appear to be especially weak on the three verbal sections. Interestingly, the two unilateral lesion series seemed to differ least on the two comprising series completion problems. Three composite scores were calculated. First, verbal odd one and Verbal analogy were added to give a composite verbal reasoning score, with a maximum score of 50. Secondly, non-verbal odd one and non-verbal analogy were added to give a composite non-verbal reasoning score, again with a maximum score of 50. Thirdly, the composite verbal and the composite non-verbal reasoning scores were added to give a total composite reasoning score, this time with a maximum score of 100. The means and standard deviations of these three composite scores are given in Table 26.

	Control group	**Left lesion group**	**Right lesion group**
Verbal odd one + analogy (50 items in total)	34.2 (6.4)	26.0 (9.1)	30.7 (6.9)
Non-verbal odd one + analogy (50 items in total)	35.0 (5.5)	29.8 (7.5)	29.3 (7.3)
Verbal odd one + analogy + Non-verbal odd one + analogy (100 items in total)	69.3 (10.9)	55.8 (15.5)	60.0 (13.2)

Table 26. Means and standard deviations of composite reasoning scores.

Bar charts were constructed to show the distributions of the left and right hemisphere groups' scores on each section of the new test. The raw scores for the six individual sections and the three composite score distributions are given in Figure 7, with the control distributions for comparison.

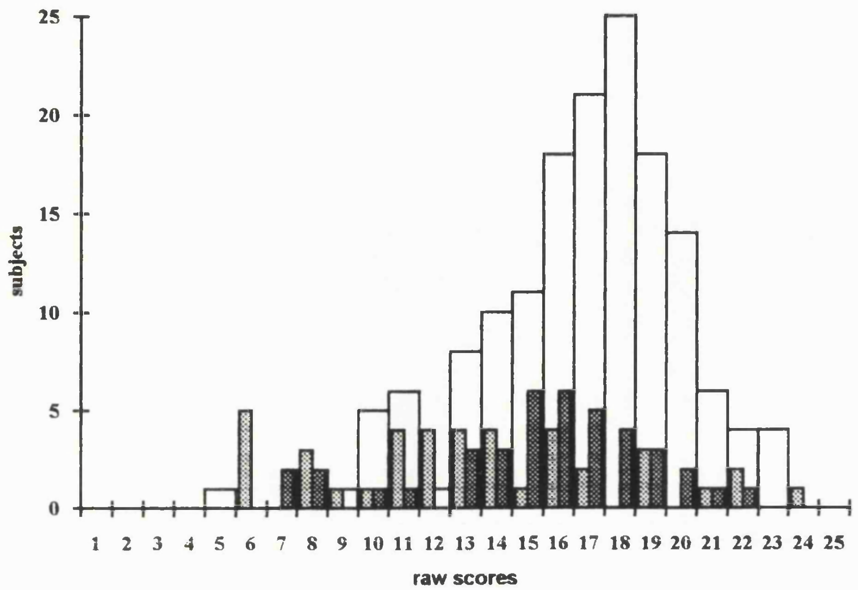
An examination of the distributions plotted in Figure 7 leads to a general impression of the lesion patients obtaining a range of scores on each section of the new test that at least equals the control sample and which, on occasion, extends below the controls' range of scores. The means of the control samples on each section and composite appear to be higher than those achieved by the lesion patients. In addition the score distributions of the lesion patients appear to be flatter than the rather peaked distributions of the control scores, which is to be expected if the smaller lesion series of 40 patients are each equalling the ranges of the larger control group of 155 subjects.

The left hemisphere lesion group appears to be impaired on all the reasoning sections, whereas the right hemisphere lesion group does not appear to differ from the controls on the verbal odd one and verbal analogy sections. This impression is not obviously contradicted by an inspection of the percentages of subjects from each series falling within each specified band.

Figure 7. Bar charts of control and lesion groups' scores on each section of the new test and tables of percentages of patients scoring at or below control group cut offs.

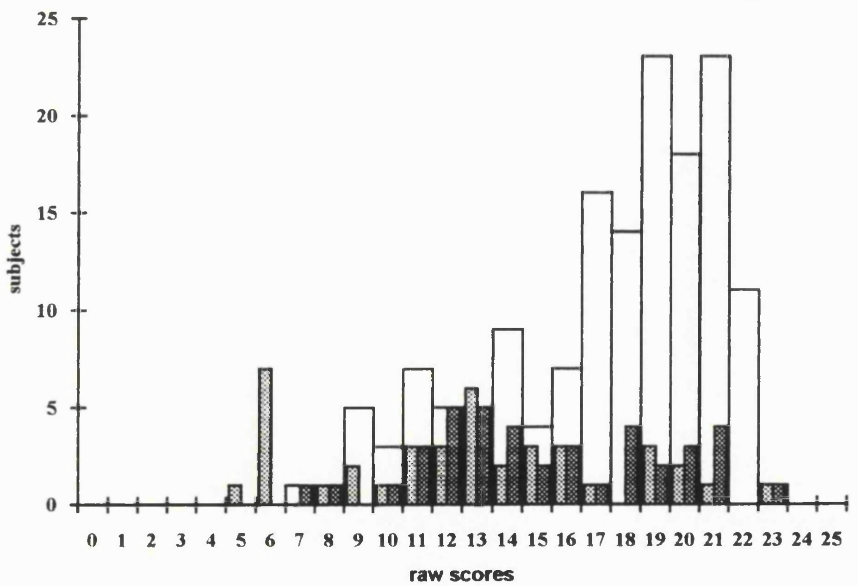
The control bars are white, the left hemisphere group are mid grey and the right hemisphere group are dark grey.

1. Verbal odd one



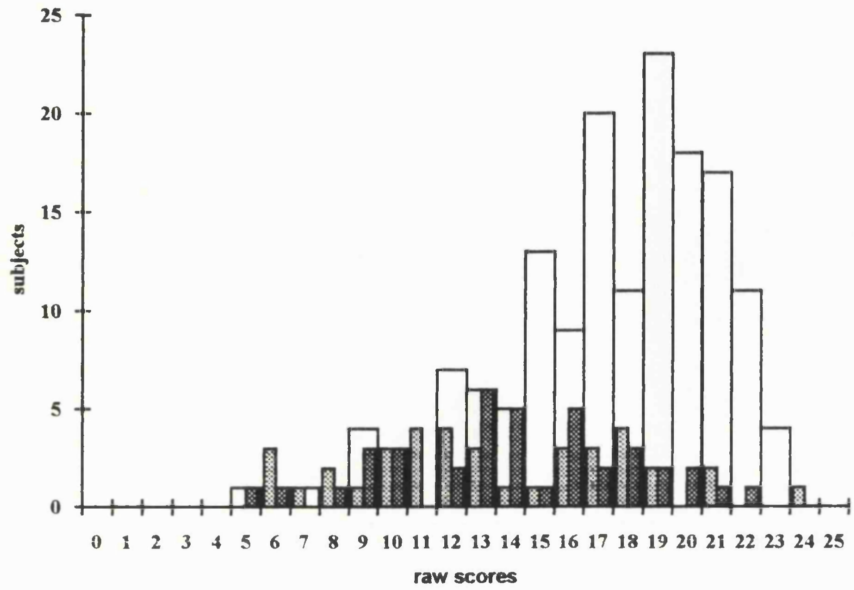
cut off scores	10	15	17
controls %	**5**	**25**	**50**
left lesions %	25	68	83
right lesions%	13	45	73

2. Verbal analogy



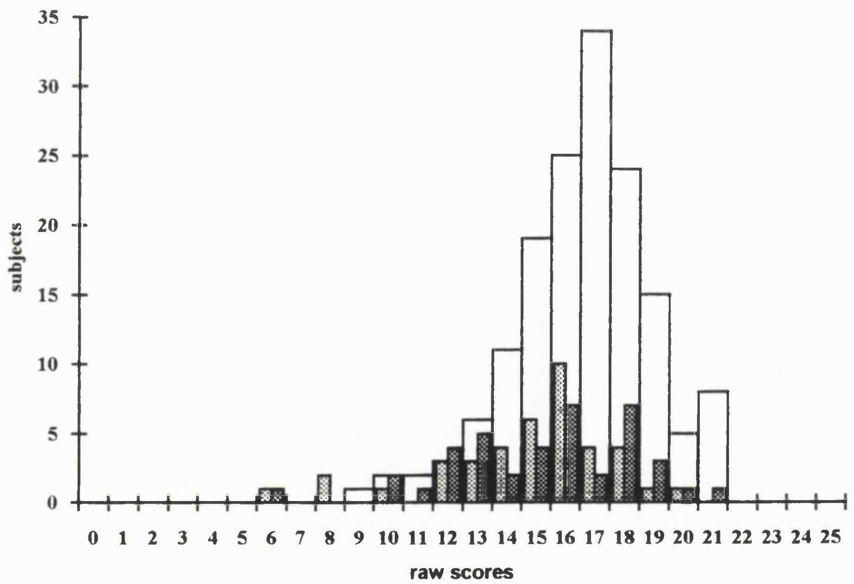
cut off scores	10	15	19
controls %	**5**	**25**	**50**
left lesions %	30	73	90
right lesions%	08	55	80

3. Verbal series



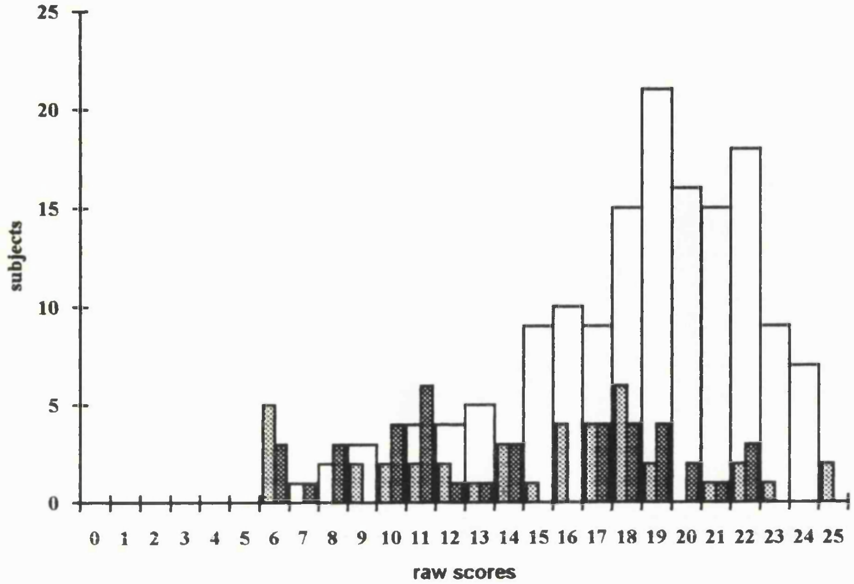
cut off scores	9	15	18
controls %	**5**	**25**	**50**
left lesions %	18	61	87
right lesions%	15	59	85

4. Non verbal odd one



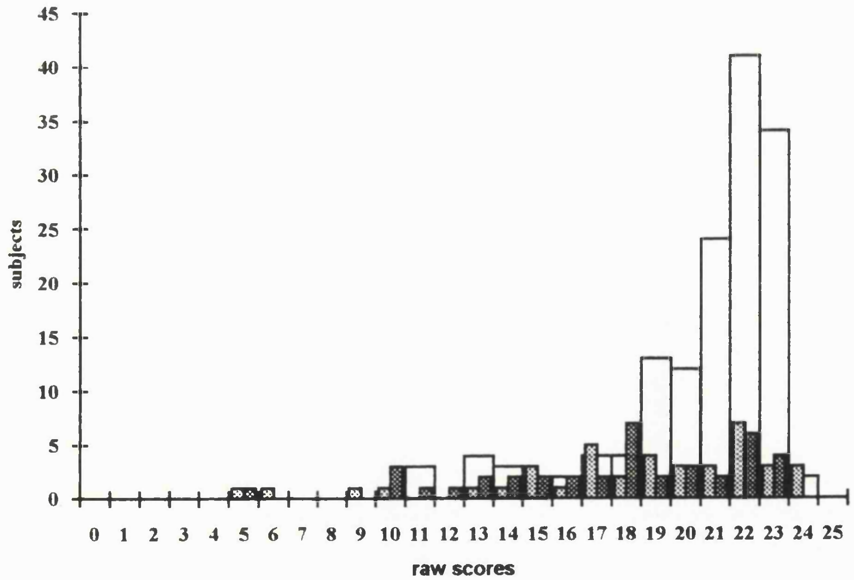
cut off scores	12	15	17
controls %	**5**	**25**	**50**
left lesions %	18	50	85
right lesions%	20	48	95

5. Non verbal analogy



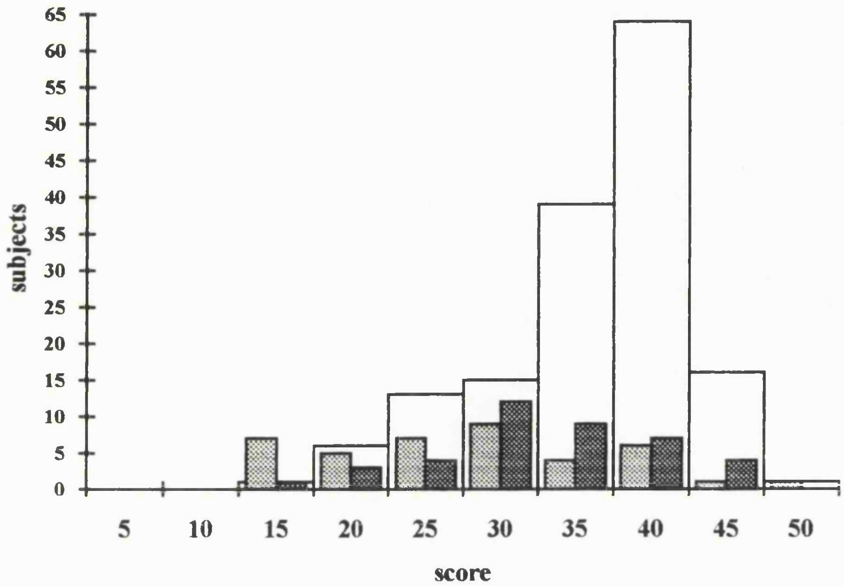
cut off scores	11	16	19
controls %	**5**	**25**	**50**
left lesions %	28	55	85
right lesions%	43	55	85

6. Non verbal series



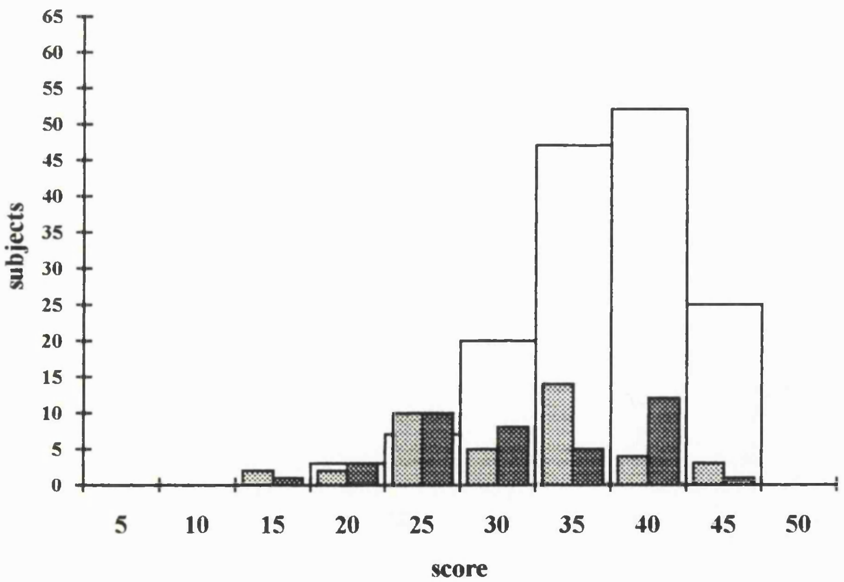
cut off scores	14	20	22
controls %	**5**	**25**	**50**
left lesions %	15	60	85
right lesions%	25	70	90

7. Composite Verbal Reasoning Score



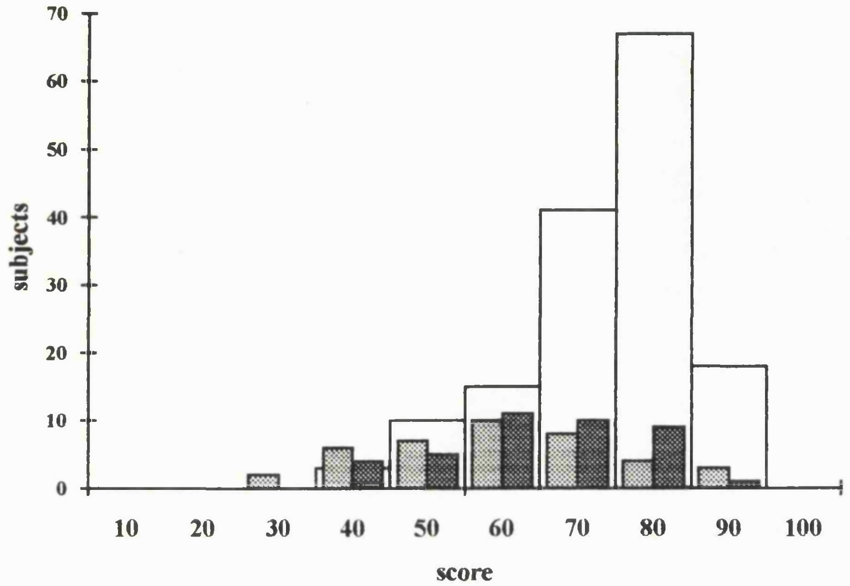
cut off scores	20	31	35
controls %	**5**	**25**	**50**
left lesions %	30	73	80
right lesions%	10	58	73

8. Composite Non Verbal Reasoning Score



cut off scores	24	32	35
controls %	**5**	**25**	**50**
left lesions %	25	60	83
right lesions%	30	58	68

9. Total Composite Reasoning Score



cut off scores	47	63	71
controls %	**5**	**25**	**50**
left lesions %	30	68	85
right lesions%	15	55	78

B Effect of laterality of lesion on new test

The next task was to compare the frequencies within each cut off band across experimental series. Again the chi square test for linear trend was selected, for the reasons discussed in the preceeding section. The tables of the observed and expected frequencies used to calculate the chi squares are given in Appendix XIII. The chi square values and their probability values are given in Table 27.

Inspection of Table 27 reveals that whilst the left hemisphere lesion group were significantly impaired on all six sections of the new test, the right hemisphere lesion group were not impaired on verbal odd one or verbal analogy. Following from these statistics, comparisons of the left and right lesion series only demonstrated significant differences on verbal odd one and analogy. The significantly impaired performance of both lesion series on the non verbal and total composite reasoning scores is predictable from the two lesion series scores on the individual sections of the test. The impairment of both lesion series on

test	left hemisphere lesions compared with controls	right hemisphere lesions compared with controls	right and left hemisphere lesions a comparison
1. Verbal odd one	15.68***	2.74	6.61*
2. Verbal analogy	19.04***	3.61	4.94*
3. Verbal series	14.74***	12.68***	0.20
4. Non-verbal odd one	10.53**	5.40*	0.84
5. Non-verbal analogy	12.69***	16.82***	0.71
6. Non-verbal series	9.71**	11.77***	0.10
7. Composite verbal score	16.41***	7.01**	3.20
8. Composite non-verbal score	11.14***	8.42**	0.04
9. Total composite score	17.08***	8.62**	2.30

Table 27. Chi squares for linear trend comparing the lesion and control groups on the six sections of the new test and the three composite scores. * $p<0.05$ ** $p<0.01$. *** $p<0.001$.

the composite verbal reasoning score is less congruent with their performance on the individual verbal odd one and verbal analogy sections, where there was no demonstrated impairment of the right hemisphere lesion group. The apparent discrepancy was probably due to the control group achieving a better average over more items, whilst the lesion patients in general were more likely to experience difficulty over a range of problems, which exposed the patchiness and inconsistency of their cognitive function.

In addition to the chi square analyses of frequencies of lesion and control subjects' scores falling below the specified cut offs, traditional analyses of variance were used to compare the score distributions on the new test, with age as covariate. The results are given in Table 28.

	left hemisphere lesions compared with controls	**right hemisphere lesions** compared with controls	**right and left hemisphere lesions** a comparison
	ANOVA F	ANOVA F	ANOVA F
1. Verbal odd one	**28.60*** **	3.62	**6.83***
age t-value	*-3.56****	*-3.87****	*-2..63**
2. Verbal analogy	**48.08*** **	**9.03** **	**10.53** **
age t-value	*-4.32****	*-4.37****	*-3.54****
3. Verbal series	**28.95*** **	**19.93*** **	1.02
age t-value	*-2.32**	-2.69**	*-2.53**
4. Non-verbal odd one	**16.58*** **	**7.59** **	1.27
age t-value	*-3.66****	*-3.81****	*-3.57****
5. Non-verbal analogy	**21.43*** **	**31.11*** **	0.07
age t-value	*-4.33****	*-5.11****	*-3.82****
6. Non-verbal series	**19.66*** **	**32.37*** **	0.05
age t-value	*-6.00****	*-6.20****	*-5.32****
7. Composite verbal score	**48.34*** **	**7.63** **	**10.04** **
age t-value	*-4.42****	*-4.59****	*-3.34****
8. Composite non-verbal score	**27.61*** **	**26.51*** **	0.09
age t-value	*-4.49****	*-5.23****	*-4.23****
9. Composite total score	**46.11*** **	**18.86*** **	**3.95***
age t-value	*-4.91****	*-5.22****	*-4.10****

Table 28. Comparison of the two lesion series with control series, and of the two lesion series, on new tests by analysis of variance with age as covariate. * p<0.05 ** p<0.01. ***p<0.001.

The ANOVA results describe a similar pattern of significant differences to the chi-square analyses, with three additions. The first is that the ANOVA produces a significant difference for the right lesion series on the verbal analogy section. The remaining two additional significant differences are between the right and left hemisphere lesion patients on the verbal composite score and the total composite score. The weakness of the right hemisphere group on verbal analogy was exposed by giving equal weight to all parts of the score distribution. However, when the more impaired sections of the distribution are emphasised, by the chi square method, then the right lesion patients are not significantly different from control subjects. The significant differences between the two lesion series on the composite scores led to an exploration of the pattern of these scores obtained by lesion patients.

Next the differential effect of unilateral cerebral lesions on each type of reasoning was considered. Sternberg and Gardner's 1983 findings with normal subjects were discussed in section 1.4B. Briefly, the investigators interpreted the differing response times of their subjects to three types of reasoning problems as evidence that classification tasks require less cognitive processes than series completion tasks, which require less processes than analogy tasks. If the lesion patients in this study could be shown to be most impaired on the analogy section, less impaired on the series section and least or not impaired on the odd one section, then the results could be taken to support Sternberg and Gardner's work.

The pattern of varying impairment could be explained in terms of brain damage being more likely to affect at least one of the seven cognitive processes Sternberg suggests are required for analogy problems, slightly less likely to disrupt one or more of the six processes required for series completion, and least likely to disrupt one or more of the five processes required for classification tasks. Taking this as a prediction from the Sternberg and Gardner theory, the following hypotheses were generated:

H1 For left hemisphere lesion patients,

Verbal odd one > Verbal series > Verbal analogy

and therefore Verbal odd one > Verbal analogy

H2 For left hemisphere lesion patients,

Non-verbal odd one > Non-verbal series > Non-verbal analogy

and therefore Non-verbal odd one > Non-verbal analogy

H3 For right hemisphere lesion patients,

Verbal odd one > Verbal series > Verbal analogy

and therefore Verbal odd one > Verbal analogy

H4 For right hemisphere lesion patients,

Non-verbal odd one > Non-verbal series > Non-verbal analogy

and therefore Non-verbal odd one > Non-verbal analogy

Using the frequencies detailed in Appendix XII, of lesion patients scoring at or below the 5th percentile, at or below the 25th percentile, at or below the 50th percentile and above the 50th percentile on each section of the new test, according to the control subjects in their age group, chi squares for linear trend were performed to see if the hypotheses were supported by this study.

	Left lesion group	**Right lesion group**
verbal odd one cf. series	p=0.06	p=0.05*
verbal series cf. analogy	p=0.02*	p=0.05*
verbal odd one cf. analogy	p=0.75	p=1.00
non-verbal odd one cf. series	p=0.91	p=0.20
non-verbal series cf. analogy	p=0.67	p=0.35
non-verbal odd one cf. analogy	p=0.06	p=0.03*

Table 29. Comparison by chi square test for linear trend of different sections of the new test of reasoning.

The chi square for linear trend test was thought to be the most sensitive for detecting different "hit rates" among the sections of the new test of reasoning. The results are summarised in Table 29. Using the analyses summarised in Table 29, we can reconsider the hypotheses.

H1 For left hemisphere lesion patients,

Verbal odd one (NS) Verbal series > Verbal analogy

and therefore Verbal odd one (NS) Verbal analogy

H2 For left hemisphere lesion patients,

Non-verbal odd one (NS) Non-verbal series (NS) Non-verbal analogy

and therefore Non-verbal odd one (NS) Non-verbal analogy

H3 For right hemisphere lesion patients,

Verbal odd one > Verbal series < Verbal analogy

and therefore Verbal odd one (NS) Verbal analogy

H4 For right hemisphere lesion patients,

No- verbal odd one (NS) Non-verbal series (NS) Non-verbal analogy

and therefore Non-verbal odd one (NS) Non-verbal analogy

Of the 12 predicted relations, 2 were confirmed, 9 did not differ significantly and 1 differed significantly in the opposite direction. These results will be discussed in the lesion study discussion.

Because the composite scores failed to differentiate between the left and right hemisphere groups, the discrepancy between the composite verbal and composite non-verbal scores was examined. It seemed likely that the increased variability of lesion patients' performance was influencing the summation of scores within groups. The discrepancy between the total score on verbal odd one and verbal analogy, and the total score on nonverbal odd one and non-verbal analogy for each case was calculated. Thus subjects whose scores were the same for both composite totals achieved a discrepancy score of 0. Subjects whose verbal composite score was greater than their non-verbal composite score, achieved a positive discrepancy score. Conversely, subjects whose verbal composite score was less than their non-verbal composite score, achieved a negative discrepancy score. The individual discrepancy scores were considered in three groups: the control sample, the left hemisphere lesion group and the right hemisphere lesion group. The distributions of the discrepancy scores for each group are given in the following Figure 8.

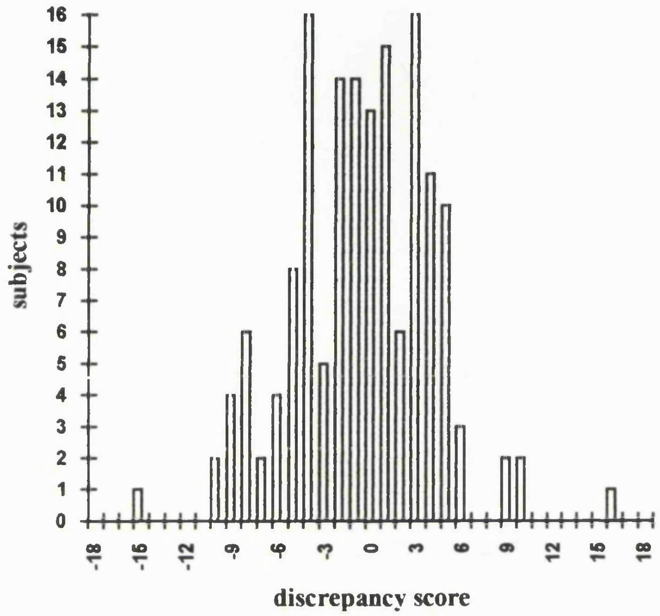
Inspection of the graphs reveals that, whereas the control group were evenly distributed around 0, the lesion groups' discrepancy distributions were apparently skewed. The left hemisphere group had rather more negative discrepancies, that is their verbal composite scores were more often less than their non-verbal composite score. In contrast, the right hemisphere lesion group had more positive discrepancies, that is their verbal composite scores were more often greater than their non-verbal composite scores. Table 30 summarises these differences.

	Discrepancy<0	**Discrepancy>0 or =0**
Control group n=155	75	78
Left lesion group n=40	30	10
Right lesion group n=40	13	26

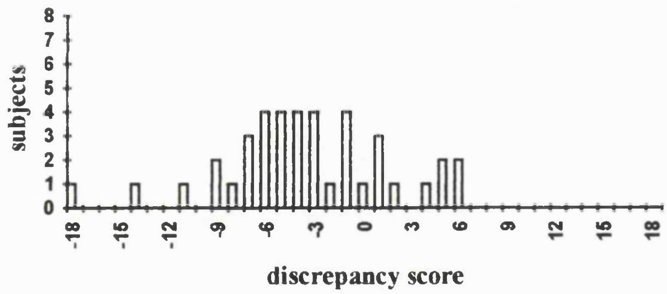
Table 30. Numbers of control, left lesion and right lesion groups with positive or negative discrepancies. Two control subjects and one right hemisphere subject had not attempted all four of the component tests and were therefore excluded from this analysis.

Figure 8. The distributions of the discrepancies between verbal and non-verbal composite scores. The control group data is at the top, the left hemisphere lesion group data is in the middle and the right hemisphere lesion group data is given in the third graph.

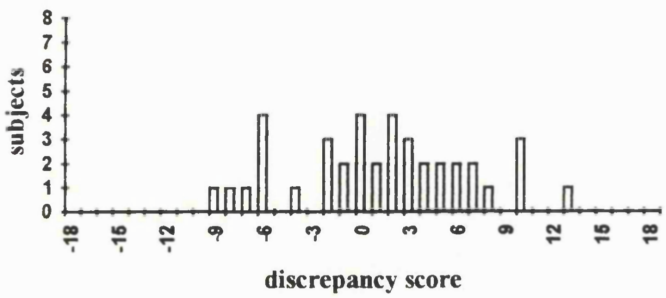
1. Control group. Range –15 to 16.



2. Left lesion group. Range –14 to 6.



3. Right lesion group. Range –9 to 13.



To determine the statistical significance of these trends, two chi squares were performed using the frequencies from the two lesion groups with expected frequencies of 20 for the other two cells. The left hemisphere group's frequencies were significantly different from the expected frequencies ($p=0.021$), but the right hemisphere group's frequencies were not significantly different from the expected scores ($p=0.133$). A chi square comparison of the left and right lesion series' frequencies produced a highly significant result ($p=0.0002$).

c Effect of lesion quadrant on new test

	Control group	Left anterior	Left posterior	Right anterior	Right posterior
1. verbal odd one (maximum score 25)	16.7 (3.3)	13.7 (3.6)	13.1 (5.6)	16.8 (2.3)	14.7 (4.1)
2. verbal analogy (maximum score 25)	17.5 (3.8)	14.1 (3.3)	12.2 (5.6)	16.8 (3.6)	14.5 (4.1)
3. verbal series (maximum score 25)	17.4 (3.8)	14.3 (5.1)	13.3 (4.6)	15.2 (3.6)	13.5 (4.3)
4. non-verbal odd one (maximum score 25)	16.6 (2.3)	15.6 (2.4)	14.3 (3.3)	16.3 (2.3)	14.6 (3.5)
5. non-verbal analogy (maximum score 25)	18.4 (3.9)	16.2 (4.3)	14.5 (5.9)	15.6 (3.7)	13.5 (5.5)
6. non-verbal series (maximum score 25)	20.8 (2.9)	19.8 (3.2)	17.5 (5.4)	18.2 (3.9)	16.9 (4.8)
7. composite verbal score (maximum score 50)	34.2 (6.4)	27.9 (6.0)	25.3 (10.7)	33.7 (5.1)	29.2 (7.5)
8. composite non-verbal score (maximum score 50)	35.0 (5.5)	31.9 (6.1)	28.8 (8.3)	31.8 (5.2)	28.2 (8.0)
9. total composite score (maximum score 100)	69.3 (10.9)	59.7 (11.5)	54.1 (17.7)	65.5 (8.7)	57.4 (14.4)

Table 31. The means and standard deviations of the four quadrant groups on each section of the new test.

The data of the two lesion series were examined. Patients were grouped according to the quadrant in which their lesion ocurred. As in the analysis of the effects of lesion location on 142 scores on established tests, patients with frontal, fronto-temporal and fronto-parietal lesions on CT scan were designated "anterior". All other patients were designated "posterior", with the exception of two patients from each series who had lesions involving three lobes. The extensive nature of their disease meant that they were unsuitable for inclusion in a detailed localisation study. The means and the standard deviations of the four groups are given above in Table 31.

In general, the right posterior group means appear to be less than the right anterior group means. The trend for the posterior group to be weaker seems to be less pronounced in the left lesion groups. The left hemisphere lesion groups perhaps have marginally greater standard deviations on average. A set of analyses of variance was performed to compare the scores of patients with lesions in different quadrants. Age was covaried as part of the analysis. A summary of the findings is given in Table 32.

An examination of Table 32 reveals very few significant differences between the comparisons of the four lesion quadrant groups on the new reasoning test. Among the single test comparisons, only verbal odd one and verbal analogy were significantly different and only in the comparison of the left and right anterior lesion groups. The left anterior group performs most poorly in both cases. Interestingly, these were the only two single sections of the new test to discriminate between the two unilateral lesion series (see Table 25). The results from the quadrant ANOVA's summarised above suggests that most of the difference between the two unilateral series resulted from the scores of the anterior cases, because when analysing individual sections of the new test, neither the comparison of the two posterior groups nor the two within hemisphere comparisons showed any significant differences.

	LA vs LP	**RA vs RP**	**LA vs RA**	**LP vs RP**
	ANOVA F	ANOVA F	ANOVA F	ANOVA F
Verbal odd one	0.01	3.82	**7.63***	1.30
age t-value	*-1.55*	*-2.65**	*-1.06*	*-2.72***
Verbal analogy	0.11	3.44	**9.32****	3.09
age t-value	*-3.50****	*-2.22**	-2.98**	*-3.20***
Verbal series	0.00	1.64	0.66	<0.00
age t-value	*-1.86*	*-2.12**	*-1.08*	*-2.75***
Non-verbal odd one	0.37	2.84	1.63	0.06
age t-value	**	*-2.40**	*-2.12**	*-3.10***
Non-verbal analogy	0.04	2.27	<0.00	0.88
age t-value	*-2.67**	*-3.49****	*-1.20*	*-4.72****
Non-verbal series	0.26	1.19	0.07	0.37
age t-value	*-4.16****	*-3.70****	*-4.23****	*-4.35****
Composite verbal score	0.02	**4.58***	**11.55****	2.38
age t-value	*-2.59**	*-2.72*	*-2.34**	*-3.16***
Composite non-verbal score	0.16	3.34	0.23	0.29
age t-value	*-3.05***	*-3.53****	*-1.72*	*-4.71****
Composite total score	0.07	**4.96***	**4.53***	0.46
age t-value	*-3.04***	*-3.51****	*-2.27**	*-4.24****

Table 32. Summary of analyses of variance comparing new test scores of patients with right and left, anterior and posterior cortical lesions, with age as covariate. The significant differences between groups are printed in bold.
LA = Left Anterior, LP = Left Posterior, RA = Right Anterior and RP = Right Posterior.

In addition, there were significant differences demonstrated between the composite verbal and total composite scores. These differences ocurred both when left and right anterior lesion groups were compared, as in the two verbal sections when considered singly, and also in the comparison between anterior and posterior right lesion cases. The left anterior lesion group was more impaired than the right anterior lesion group. Intriguingly, it is the right posterior group who are weakest on both the verbal composite score and on the total composite score, in comparison with the right anterior group.

(v) EFFECT OF FOCAL DEFICITS ON NEW TEST

Having established that the three focal tests distinguished between the left and right hemisphere lesion groups (see Table 19), the effect of verbal and perceptual focal skills on performance on the new test could be considered. In order to evaluate the effects of focal brain damage on the new test, it was necessary to examine systematically how such acquired deficits as aphasia and perceptual disorders affected patients' performance.

Multiple regression was chosen as a method of assessing how much of the variance of the new test scores was attributable to functional compromise of either hemisphere. The Graded Naming Test and the Unusual Views test were selected from the battery as indicators of the integrity of dominant and non dominant hemisphere function. Age was also included as a variable because of its importance in determining the scores of the control subjects,which was discussed in section 2.3B(i). In addition the sex of the patients was included in the analysis for the reasons outlined in section 2.4B(i). In summary, twelve multiple regressions were performed, one on each of the six sections of the new test for both left and right hemisphere lesion groups separately. The variables examined were age, sex and the scores on Unusual Views and the GNT.

The variables found to contribute to the variance of the new test scores with a probability level of less than 0.05 are given below:

1. Left hemisphere lesions		2. Right hemisphere lesions	
a) Verbal odd one			
1st Variable	GNT	1st Variable	GNT
Significance of F	0.0002	Significance of F	<0.0001
R Square	0.31	R Square	0.44
2nd Variable	Age	2nd Variable	Age
Significance of F	0.0001	Significance of F	<0.0001
R Square	0.39	R Square	0.60
b) Verbal analogy			
1st Variable	GNT	1st Variable	GNT
Significance of F	0.0001	Significance of F	0.0001
R Square	0.32	R Square	0.35
2nd Variable	Age	2nd Variable	Age
Significance of F	0.0001	Significance of F	<0.0001
R Square	0.41	R Square	0.46
c) Verbal series			
1st Variable	GNT	1st Variable	GNT
Significance of F	0.0225	Significance of F	0.0006
R Square	0.14	R Square	0.27
2nd Variable		2nd Variable	Age
Significance of F	p>0.05	Significance of F	0.0002
R Square		R Square	0.38
d) non-verbal odd one			
1st Variable	GNT	1st Variable	GNT
Significance of F	0.0029	Significance of F	0.0119
R Square	0.21	R Square	0.16
2nd Variable	Age	2nd Variable	Age
Significance of F	0.0016	Significance of F	0.0021
R Square	0.29	R Square	0.28
e) non-verbal analogy			
1st Variable	GNT	1st Variable	Unusual V
Significance of F	<0.0001	Significance of F	<0.0001
R Square	0.36	R Square	0.40
2nd Variable	Age	2nd Variable	Age
Significance of F	<0.0001	Significance of F	<0.0001
R Square	0.44	R Square	0.47

Inspection of the results of the multiple regression analyses reveals that for the left hemisphere group, the GNT score is responsible for the largest amount of variance on five of the six sections. The exception is non-verbal series, where age is the most significant variable and the first variable on this section was the Unusual Views score. Age is the second variable for four of the sections. The remaining section, verbal series, did not have a second variable reach significance. Apparently, the scores of the left hemisphere lesion group on the new test were generally best determined by the GNT, a test of the integrity of the dominant hemisphere and by age.

Turning now to the right hemisphere group, the most important variable on both the three verbal sections and non verbal odd one was the GNT score. For the non verbal analogy and series sections, Unusual Views was the most significant variable. Age was the second variable on all six sections of the test for the right hemisphere group. The GNT reached significance as a third variable on non verbal analogy and series, for the right hemisphere group.

Interestingly, the sex of the patient was a never a significant variable and age was never the most important variable in determining the variance of the new test scores. Clearly it is the patients' acquired cognitive dysfunction that is the major determinant of their scores on the new test and not demographic variables.

(vi) COMPARISON OF ESTABLISHED TESTS WITH NEW TEST

The sensitivity of the new test to right and left hemisphere functional impairments was considered in comparison with established tests of reasoning. First, the "hit rate" of an established test of reasoning was compared with the "hit rate" of the six sections of the new test of problem solving, by considering the number of patients from each unilateral lesion series falling at or below the 5th, 25th and 50th percentile, or above the 50th percentile. The first table in this section lists the frequencies of scores for WAIS Similarities, WAIS Block Design, the Matrices and the new test of problem solving, obtained by the left hemisphere lesion group.

The frequencies detailed in Table 33 give an initial impression of the verbal odd one and analogy sections being at least as sensitive to left hemisphere damage as the WAIS Similarities

	below 6th %	6th-25th %	26th-50th %	above 50th %	significance of O x E ^
Expected	**2**	**8**	**10**	**20**	
WAIS Similarities	11	21	3	5	***
WAIS Block Design (age scale scores)	8	12	8	12	*
Matrices	4	18	8	10	**
Verbal odd one	13	13	7	7	***
Verbal analogy	12	16	7	5	***
Verbal series	9	13	12	4	***
Composite verbal	12	17	3	8	***
Non-verbal odd one	6	15	13	6	**
Non-verbal analogy	9	15	9	7	***
Non-verbal series	9	13	9	9	**
Composite non-verbal	10	11	12	7	***
Total composite	12	15	7	6	***

Table 33. Frequencies of left hemisphere lesion patients' scores on WAIS Similarities and Block Design, the Matrices and the new test of reasoning, using cut offs derived from control sample.
^ Significance of chi square for linear trend tests detailed previously in Tables 17 and 24.

and perhaps more sensitive than the Matrices. The composite verbal score appears more sensitive than Similarities. The non-verbal sections appear to have a similar sensitivity to the WAIS Block Design, and the Matrices to left hemisphere damage.

Patients who scored at or below the 5th percentile score of the control sample were of particular interest in determining the efficiency of the new test. Interestingly, of the 13 patients who were impaired on either Similarities or the composite verbal section of the new test of reasoning, 10 were impaired on both.

Turning now to compare the scores of right hemisphere lesion patients on the new and established tests of reasoning, a summary table similar to that given for the left hemisphere cases was constructed. Table 31 details the frequencies of right hemisphere lesion patients scoring within the same percentile ranges, described above. WAIS Similarities was not included in this table as it would not be expected to detect right hemisphere involvement and indeed did not do so in this study's group comparisons, described in Table 34.

Initial inspection of Table 34 suggests that the three non-verbal sections of the new test of problem solving, and the number series section, were all at least as sensitive as the WAIS Block Design, to right hemisphere damage. Non-verbal analogy appears to be especially sensitive. However first impressions suggest that the Matrices and the composite non-verbal score may be similarly sensitive to right hemisphere damage.

Comparing the groups of patients whose scores fall at or below the 5th percentile score of the control sample on either the Matrices, the composite non-verbal reasoning section, or both, once again the most striking feature is the number of cases in common. Of the 13 cases who were impaired on either the Matrices, the non-verbal reasoning score, or both, 8 were impaired on both.

	below 6th %	6th-25th %	26th-50th %	above 50th %	significance of O x E ^
Expected	**2**	**8**	**10**	**20**	
WAIS Block Design (age scale scores)	5	15	8	12	*
Matrices	9	18	7	6	***
Verbal odd one	3	12	15	10	NS
Verbal analogy	3	12	15	10	NS
Verbal series	7	15	12	5	***
Composite verbal	4	19	6	11	**
Non-verbal odd one	5	14	10	11	*
Non-verbal analogy	15	10	9	6	***
Non-verbal series	9	15	8	8	***
Composite non-verbal	12	11	4	13	**
Total composite	6	16	9	9	**

Table 34. Frequencies of right hemisphere lesion patients' scores on WAIS Block Design and new test of problem solving, using cut offs derived from control sample.
^ Significance of chi square for linear trend tests detailed previously in Tables 17 and 24.

In summary, a comparison of the sensitivity of the new test of reasoning to unilateral cerebral disease with established tests demonstrated that the new test was at least equal to, and perhaps better than, traditional tests.

2.4C DISCUSSION OF LESION STUDY

The results of the lesion study are discussed in the following two sections. Section A considers matters relating to the lesion study as a validation sample for the new test. First the construction of the two lesion samples will be reviewed. Secondly, the suitability of the new test for people with aquired brain damage will be assessed. Thirdly, their typicality as unilateral lesion series will be assessed by summarising their scores on established tests of cognitive function. Fourthly, the sensitivity of the new test and established tests will be compared. Section B of the discussion will focus on the anatomical considerations that arise from the results of the lesion study: first, the implications of the overall pattern of results for the lateralization of inductive reasoning processes and secondly, with respect to verbal number series.

(i) VALIDATION OF NEW TEST

A Validation of sample

It has been established that the two series of patients with unilateral cerebral lesions do not differ significantly from the control sample with respect to either age or SES. All comparisons and evaluations based on the control series can therefore be treated with a measure of confidence. In addition, the localisation and pathology of the lesions of the two unilateral series were demonstrably similar and therefore the two lesions series' test scores could be compared .

B Suitability of test for target population

In order to avoid patients who were beyond the range of normal test procedures being forced to endure a relentless stream of items that they could not comprehend, two screen items had been included at the beginning of each section of the new test. However, remarkably few patients did not proceed to tackle the 25 graded problems (see Table 23). Interestingly, all except one patient were able to tackle at least four sections in full. Thus it seems likely that most patients from this population could be assessed using the new test.

c Cognitive profile of lesion groups

The performance of the lesion patients on established tests was analysed in Section 2.4B(iii). Predictably, the left hemisphere group was especially impaired on the WAIS Similarities and Digit Span and on the Graded Arithmetic Test. In comparison and equally predictably, the right hemisphere group was not impaired on these tests. However the right lesion patients were especially impaired on the Matrices. Both right and left lesion groups were equally impaired on Block Design. So far the reported results in this section present no anomalies, but there was one: the left lesion group was impaired on the WAIS Picture Completion whilst the right hemisphere group was not.

Multiple regression revealed that the major variable determining Picture Completion scores for both the left and right lesion groups was the GNT score, normally regarded as a test of left hemisphere integrity. However the Unusual Views test did figure as the second variable in the regression analysis of the right lesion group's scores. Why should a naming test be a better predictor of a right lesion group's scores on a test of pictorial material that requires the subject to recognise what item is missing from a line drawing? First, it might be that the right lesion group's functional impairments were not pertinent to the Picture Completion task. Fine spatial discriminations or the ability to recognise objects from perceptually complex or degraded presentations are not essential to a logical analysis of an incomplete line drawing. It is not necessary to count dots or distinguish similar shapes in order to spot a missing eyebrow.

Secondly, the GNT is closely related to intelligence and it may be that the members of the right lesion group who performed the least badly were those able to generate strategies to cope with the task despite their difficulties. Whereas excellent spatial skills cannot compensate for aphasia on Similarities, good verbal intelligence might help organize a disordered perceptual input or generate a search for likely missing items. Lastly, there was a similar finding in the large retrospective analysis of patients with cerebral lesions mentioned in the Introduction. Warrington, James and Maciejewski (1986) suggested that the patients with left hemisphere lesions who had difficulties on Picture Completion had some degree of agnosia.

D Comparison of new test with established tests

A comparison of "hit rates" of the new test and established tests (see Tables 33 and 34) revealed that the new test picked up slightly more unilateral lesion cases as impaired, using a 5th percentile cut off derived from the control sample. For example, whilst the WAIS Similarities "failed" 11 left hemisphere patients on this criterion, both the composite verbal reasoning test and the total composite reasoning test "failed" 12 left hemisphere patients. The results with right hemisphere lesion patients were more impressive: whereas the WAIS Block Design "failed" 5 right hemisphere patients and the Matrices "failed" 9, the composite non verbal reasoning test "failed" 12 right hemisphere patients. The general impression from this qualitative comparison was of at least equal efficiency to established tests and probably better, with the added advantage of being suitable for patients with damage to either of the cerebral hemispheres.

(ii) ANATOMICAL CONSIDERATIONS

It has been established that the two lesion series can be considered as satisfactory validation samples for the new test of reasoning. In this section, the anatomical implications of the overall pattern of results will be considered in the following order. The performance of the two unilateral lesion series on the odd one and analogy sections presented in verbal format will be discussed first with regard to the possible lateralization of inductive reasoning processes and then their more precise localization.

Secondly, the performance of the two unilateral lesion series on the odd one and analogy sections presented in non verbal format will be discussed first with regard to the possible lateralization of inductive reasoning processes and then their more precise localization. Thirdly, the relationship of scores on the GNT to reasoning will be highlighted. Fourthly, conclusions about the rôle of the left hemisphere in inductive reasoning will be drawn. Fifthly, the localization of reasoning processes will be discussed, with particular reference to the frontal lobes. Sixthly, the lack of differential effects of localization of lesion on types of inductive reasoning will be summarised. Seventhly, the performance of the two unilateral lesion series on verbal number series will be considered.

The non verbal series section will not be considered in detail in this section for the following reasons. The effects of presentation of reasoning problems in a non verbal format are fully discussed in relation to the other five sections of the new reasoning test. Secondly, the difficulty of series problems to unilateral lesion groups is fully discussed in relation to the verbal series section of the new test of reasoning. The right hemisphere involvement in performance on the verbal series section means that the results of both lesion groups being impaired on the non verbal series section does not add to the anatomical implications of this study, because the left hemisphere lesion group was impaired on all sections and the right hemisphere group would be expected to be impaired on tests requiring visual spatial analysis.

A Laterality effects on verbal odd one and analogy

Applying cut offs obtained from the normal sample and performing chi-square tests for linear trend resulted in significant differences between the lesion groups on the verbal odd one and verbal analogy sections. For a summary of these results, see Table 27. Whereas the left hemisphere lesion group was very impaired ($p<0.001$) on both of these sections, the right hemisphere lesion group did not differ significantly from the control sample. In addition, the left and right hemisphere lesion groups differed significantly ($p<0.05$) on these two sections when they were directly compared.

It seems likely that the left hemisphere lesion group was impaired by aphasic difficulties and this may explain its weak performance on these two sections. In contrast, the right hemisphere lesion group showed no demonstrable difficulty on these sections and thus unilateral right hemisphere damage does not apparently interfere with deductive reasoning problems presented in a verbal format.

B Localization effects on verbal odd one and analogy

The results of more precise localization details were summarised in Table 32. Verbal odd one and verbal analogy both only differed significantly in comparisons of right anterior and left anterior lesion patient groups. Although examination of the group means given in Table 31 suggests that the right anterior lesion group was particularly competent, these results also raise the possibility that the left anterior region of the brain is implicated in these particular reasoning processes. However this can only be a tentative conclusion because the relevant comparisons of left anterior and left posterior lesion groups (detailed in Table 32) did not reach significance, possibly because of the overriding effects of aphasia.

C Laterality effects on non verbal odd one and analogy

Whereas the left hemisphere lesion group's poor performance on the two verbal format tests could be arguably attributed to focal aphasic deficits, it is harder to argue the same cause for their failures on the non verbal format sections. Table 17 detailed the statistical comparisons of the left and right lesion series with the control sample on established tests. The right hemisphere lesion group tended to be more impaired on the Matrices. It seems unlikely that the left lesion group were handicapped by aphasia on the non verbal sections of the new test, which included a number of practice and trial items and all items were of the same reasoning type; and that the same left lesion group were less handicapped by their aphasia on the Matrices, which have no practice items, allow no explanation beyond the initial instructions and require constant changes and recombination of deductive reasoning types for their solution.

The trend towards poorer performance by the right lesion group on the Matrices argues against the impairment of the left hemisphere lesion group on all six sections of the new test being attributable to the left lesion group being generally more cognitively impaired than the right lesion group. The reverse is more probable, that the right hemisphere lesion group are likely to be more impaired, because typically right hemisphere lesions are on average clinically silent for longer before detection than left hemisphere lesions and patients presenting for treatment have more advanced disease if they have suffered lesions of their non-dominant hemisphere.

D Localization effects on non verbal odd one and analogy

Statistical comparisons revealed no significant differences between lesion quadrant groups' scores on non verbal odd one and analogy (see Table 32).

E Relationship of GNT to reasoning scores

Further evidence for the role of the left hemisphere in not only verbal but also non verbal presentations of reasoning items was provided by additional statistical analysis. Multiple regression analyses, detailed in 2.4B(v), were used to investigate which variables were most significant in determining patients' scores on the new reasoning test. The model used the GNT as an indicator of the functional integrity of the left hemisphere and Unusual Views as an indicator of the functional integrity of the right hemisphere. The age and sex of the patients were also included in the regression model. The GNT score was the most significant variable for the left hemisphere lesion group's score on five sections of the new test of reasoning. Four of these sections were linked to a second variable in the model: age. Age was the first variable for the left hemisphere lesion group's score on the non-verbal series section, with the GNT score being the second variable.

Turning now to the multiple regression analysis of the right lesion series, the verbal odd one and verbal analogy sections both have the GNT score as their first variable. It has been discussed above that right hemisphere pathology would not be expected to compromise performance on the verbal odd one or analogy sections and demonstrably did not do so in this study (see Table 17). GNT was the first variable in the non verbal odd one regression analysis.

One explanation would be in terms of the right lesion patients, in an effort to overcome their compromised right hemisphere function, being forced into using a verbal encoding strategy where possible. Non verbal odd one, which has a perceptual categorization component, may be the only section that it is feasible to code verbally. The more spatially complex relations of non verbal analogy are more likely to defy verbal coding and indeed, this section has Unusual Views at the top of the multiple regression analysis and the GNT is third. Interestingly, the proposed verbal coding strategy cannot completely compensate for the poor right hemisphere functions, because the right lesion group is impaired on these non verbal odd one and analogy sections. However it may be that, in the context of impaired right hemisphere function, the natural endowment of verbal skills determines to some extent how great the impairment on non verbal problem solving will be.

F Role of left hemisphere in reasoning

The findings are broadly consistent with the theory discussed above in the section on new test scores: that is, that the integrity of the left hemisphere influences all reasoning processes, whatever their presentation format. Not only did the comparisons of the unilateral lesion series support this (see Table 17), but also the finer grain multiple regression analysis (see section 2.4B(v)) showed that the GNT, used as an index of left hemisphere functional integrity, best predicted left lesion patient's scores on both odd one and analogy sections presented in either verbal or non verbal format.

The finding of left hemisphere damage resulting in impaired performance on all types of reasoning is in line with the findings discussed in the Introduction, section 1.7B. Early work on the Weigl sorting task (Weigl, 1927) showed that left hemisphere patients were more impaired than right hemisphere patients. McFie and Piercy's (1952) study also showed that patients with left hemisphere lesions did less well than patients with right hemisphere lesions on the Weigl sorting task. A similar finding by Costa and Vaughan (1962) led them to conclude that internal verbalization might be necessary to mediate the solution of the Weigl problems. Russo and Vignolo (1967) found that both right hemisphere cases and aphasic left hemisphere cases were significantly impaired at locating a geometric shape masked by an abstract pattern.

The current findings extend previous work that attempted to describe the role of the left hemisphere in reasoning processes by exploring the relation of abstraction to language. For example McFie and Piercy's 1952 study, discussed in section 1.7B, used the Weigl test as a measure of abstract reasoning. They found that, whilst left hemisphere lesion patients were less competent on the Weigl than right hemisphere lesion patients, the presence of aphasia in a left hemisphere patient's test profile was unrelated to their competence on the Weigl. Apparently, language competence was unrelated to abstracting ability, although both faculties can be reduced by left hemisphere lesions.

In contrast, some experiments have shown a link between language competence and abstract reasoning. For example De Renzi *et al* (1966), also discussed in section 1.7B, found a link between aural comprehension and abstract reasoning. Aphasic patients' scores on a variant of the Weigl varied with the severity of their comprehension deficit. Gainotti *et al* (1986) demonstrated that severity of language impairment did not affect aphasic patients' performance on the Coloured Matrices, but the presence of a "semantic-lexical" disorder at the receptive level significantly influenced scores.

The new test of reasoning allows us to extend the discussion of these contradictory observations. Previously, the possibility that the patient with left hemisphere damage had failed to grasp the task and therefore could not attempt to solve it, could not be discounted. With the graded set of problems that comprise each section of the new test of reasoning, we know whether the left hemisphere patient has passed the screen items and performed above chance on the first few items. It cannot be, therefore, that they have failed to comprehend the task demands. In addition the use of A and AA words (Thorndike and Lorge, 1936) throughout ensures that the comprehension of the final items' stimuli is no harder than the comprehension of the preliminary items' stimuli. The new test provides firmer evidence for the previous speculation that the dominance of the left hemisphere for abstract reasoning is not necessarily functionally related to it's dominance for language.

G Role of the frontal lobes in reasoning

It might have been expected that the anterior lesion quadrant groups would have been more impaired than the posterior lesion quadrant groups, in view of the abstract reasoning problems that have been described and demonstrated in patients suffering from frontal lobe damage (for a review, see McCarthy and Warrington, 1990a). However, this study's findings are not unduly perturbing.

First, the frontal lobe deficits are notoriously elusive to formal testing. A typical account would be Wang's 1987 chapter *Concept formation and frontal lobe function: The search for a clinical frontal lobe test.* Secondly, whilst classical tests of frontal lobe function appear to test concept formation by requiring the subject to organize materials into groups and categories, recent work suggests that it is concept shift that is the true test of competent frontal lobe function and the new test of problem solving involves sets of 25 problems of identical type.

For example Stuss *et al* (1983) compared the performance of patients with frontal lobe lesions on the WAIS, tests of metaphor, a test of concept formation and concept shift, and the Wisconsin Card Sorting Test. The frontal lesion group did not differ from controls on either the WAIS or identification of metaphor. The third test, of concept formation and shift, required the subjects to tell how three of the four figures on a card were alike in some way and then to generate another rule to categorise three of the same four figures, this second time in some other way. Stuss' frontal lobe lesion group was able to manage the first abstraction, but were impaired at shifting to a second different conceptual categorization of material they had just classified. The frontal lesion group was also impaired on the Wisconsin Test, which of course requires concept shift.

Stuss' work suggests that an initial reasoning problem does not typically defeat a patient with a frontal lobe lesion. It is certainly very rare to observe at clinical testing a patient with a frontal lobe lesion who cannot manage to generate one rule by which to sort the Wisconsin cards (although it is typically only frontal lesion cases who will choose the least obvious rule, to sort by numbers, as their first attempt). Given the relatively low demands on planning and attention that the new test makes, it may be that the task requirements of concept formation and manipulation of symbolic representations are not especially difficult for patients with frontal lobe lesions. It is their impairments in their cognitive supervisory and executive functions that may cause them to fail conventional tests of abstraction and these supervisory and executive impairments may not be exposed by sets of 25 reasoning problems of the same type.

Thirdly, Duncan (in press) mentions the striking mismatch, often observed in patients who have suffered frontal lobe lesions, between their verbal report of a task requirement and their behaviour in response to task demands. He terms this impairment "goal neglect". Drawing on his experimental demonstration of the phenomenon, he concludes that there are three conditions which produce goal neglect: novelty, lack of feedback or verbal prompting, and multiple concurrent goals. As discussed above, the sets of identical problem types in the new reasoning test would reduce the effects of novelty and number of concurrent goals. The training items at the start would provide a certain amount of feedback. On all three conditions, the new test should not produce goal neglect and therefore patients with frontal lobe lesions would not be expected to be especially impaired on the new test of reasoning.

Fourthly, Mesulam (1981) has suggested that the frontal lobes' role in attentional systems is to explore, monitor, fixate and shift the direction of attention. Clinical studies have supported this (eg Stein and Volpe, 1983). The new test of reasoning was designed to be easy to assimilate so that peripheral deficits will interfere less with patients' performance, and perhaps at the same time efficient direction of attention has become easier to achieve. A more general model of the programming and monitoring functions of the frontal lobes is the Supervisory Attentional System, which was first described by Norman and Shallice in 1980.

Later developments (described by Shallice, 1988) describe lower level "contention scheduling", the routine selection of routine actions, and the Supervisory Attentional System ("SAS"), monitoring and modulating the contention scheduling. If we apply this model, the initial practice and explanation of the screen items might be sufficient to orientate the compromised SAS to each new type of reasoning problem. Each item then becomes a "routine operation", repeatedly activating the triggered schema for the appropriate reasoning type. In this model, it is only when the presenting problem does not initiate sufficiently strong activation of the routine schema that the SAS is sidetracked by unhelpful and irrelevant information.

The new test of reasoning validated in this study has been pared down to be predictable and accessible and it seems by so doing, it has been rendered suitable for solution by an inefficient SAS. It may even be that rigidity and perseveration of reasoning type could confer an advantage, although this was not demonstrated by the statistical analysis. Clearly, Shallice's SAS is a more general treatment of the theories of Stuss *et al* (1983) discussed above, with Stuss' concept shift being perhaps one aspect of the SAS' modulation of the routine schema envisaged by Shallice. It could be argued that once past the training items of the new test of reasoning, a patient is only performing a routine operation to solve each subsequent item of the same reasoning type. The SAS is not implicated to any great extent and therefore its deficiencies are not exposed by the new test of reasoning.

Fourthly, the frontal lobes' role in language has been described as an initiating, directive one (eg Luria, 1973; Stuss and Benson, 1987). The new test of reasoning, with its high frequency verbal stimuli and forced choice response format, requires comparatively little initiation or direction by the patient.

The few significant differences demonstrated among the lesion quadrant groups on the new test of reasoning could be viewed as encouraging, in view of its aim to reduce the effects of focal dysfunction, and compares well with the greater number of significant differences demonstrated by the same patients on conventional tests (see Table 22). In addition to the two anterior groups differing significantly on WAIS Similarities and Digit Span, the two posterior groups differed on the same subtests. In addition, the posterior groups were also significantly different on the Matrices and Graded Arithmetic.

H Laterality effects on reasoning types

The Sternberg and Gardner (1983) theory of increasing numbers of cognitive processes required by classification, series and analogy problems (discussed in section 1.4B) failed to find support from this study, in that there were only two significant differences demonstrated out of the twelve predicted. Negative results are always disappointing, but not disheartening in this case because the proposed proceses themselves could be differentially sensitive to brain damage and the five core processes necessary for classification tasks might be the most vulnerable. This vulnerability might result from anatomical location, perhaps close proximity to each other, or simply be numerical. That is, if one or more of five processes are damaged then all forms of reasoning are compromised and in that case it would be hard to demonstrate the differential effects of incremental changes in processing requirements of just one extra process for each of the two other reasoning types.

I Laterality effects on verbal number series

The process of applying cut offs obtained from the control sample and then performing chi-squares for linear trend was carried out for both lesion groups' scores on verbal number series. The results are summarised in Table 27. Both unilateral lesion groups were very impaired on the verbal number series section of the new test ($p<0.001$), when compared with the control sample. A direct comparison of the left and right hemisphere lesion series revealed no significant difference.

The left hemisphere lesion group's impairment on the number series section was predictable and could be explained in terms of their failures to perform simple calculation. Previous work supporting this conclusion has been discussed in the Introduction, section 1.8A. Jackson and Warrington (1986) found that right hemisphere cases all scored within the control range on the Graded Arithmetic Test, whereas the left hemisphere group was significantly more impaired. This study has not replicated these findings, in that the current right hemisphere lesion group was impaired on the Graded Arithmetic Test (see Table 17). Interestingly, the right hemisphere lesion group was as equally impaired as the left hemisphere lesion group on the number series section of the new test of reasoning (see Table 27). This is a somewhat unexpected but not inexplicable finding.

Other investigators have considered the possibility of the right hemisphere being involved in some processes that underlie the solution of various arithmetic problems. Henschen (1926) is credited with one of the first discussions on this topic, in which he suggested that the right hemisphere could act as a substitute for damaged left hemisphere processes in simple, automatic arithmetic. His analysis of cases led him to conclude that the "visual factor" was important.

In an important attempt to identify the processes that might underlie arithmetic functions, Hecaen (1962) tested large groups of unilateral lesion patients for three types of impairment. The first he termed "figure alexia", which was an inability to read or write digits; the second "anarithmetria", which was an impairment of simple calculation; the third was "spatial discalculia", where the patient failed not because of calculation deficits but because of neglect, or wrong positioning of the figures or other similar visual perceptual impairments. Hecaen's results are given in Table 35.

Process impairment	Left hemisphere lesion cases	Right hemisphere lesion cases
Figure Alexia	37%	2%
Anarithmetria	87%	20%
Spatial Discalculia	2%	31%

Table 35. Impairments of arithmetic component processes in unilateral lesion cases, after Hecaen (1962).

Hecaen notes that the accompanying deficits for each of these process impairments underline the heterogeneity of the patients impaired on "pure" calculation tasks. Whereas the figure alexics tended to also suffer from alexia, aphasia and other traditionally left hemisphere impairments, and the spatial discalculics tended to also suffer from spatial agnosias, dressing apraxia and other conventional right hemisphere impairments. Intriguingly the patients displaying anarithmetria suffered from either aphasia or dressing apraxia. Hecaen states that "This last association, according to our data, indicates that injury of the minor hemisphere can also cause anarithmetria". He goes on to suggest that a plurality of mechanisms underlies calculation. The current finding of a right hemisphere lesion group being slightly impaired on a calculation test and the left hemisphere lesion group being more severely impaired is thus in line with Hecaen's findings.

Cohn (1961), in a qualitative account of 40 patients presenting with disturbances in calculation ability, describes how his subjects performed written multiplication problems and drew simple geometric figures. He noted that whenever arithmetic functions were markedly disturbed, geometric ability was also profoundly affected. A later quantitative study of written addition, subtraction, multiplication and division problems also found that both right and left hemisphere lesion patients were impaired when compared to control subjects, although the left posterior lesion group was especially weak (Grafman, Passafiume, Faglioni and Boller, 1982).

Warrington, James and Maciejewski (1986), in their large retrospective analysis of 656 patients with localised unilateral lesions, found that left hemisphere cases were more impaired than the right hemisphere cases on the WAIS Arithmetic subtest. Interestingly, 25 of their 281 right hemisphere cases obtained an impaired score on the WAIS Arithmetic with reference to a standardized population, which contrasts with the performance of the right lesion group on the Graded Arithmetic Test, described above. One difference between the two arithmetic tests is that the Jackson test is almost pure calculation, whereas the WAIS Arithmetic requires some problem solving by the subject to determine which arithmetic procedures to apply.

The verbal number series section of the new test is not just a test of mental arithmetic; it requires in addition that the subject solve an arithmetic reasoning problem. The subject must determine how the numbers given in the series relate to each other and use the relation to calculate the next item. We have seen how the right hemisphere group in this study was impaired on this section. It seems to be that the larger the reasoning component in an arithmetic test, the more vulnerable it is to right hemisphere damage.

Although it is obvious how right hemisphere dysfunction might compromise reasoning problems presented in a non verbal format, why should right hemisphere damage impair arithmetic reasoning? There is considerable evidence from both child (Hermelin and O'Connor, 1986) and student (Benbow *et al,* 1983; Casey *et al,* 1990) studies that mathematical talent is linked to spatial reasoning skills. Mathematical talent, of course, is distinct from arithmetic competence. The role of the right hemisphere in spatial processing has been discussed in the Introduction, section 1.8B. Hecaen (1962) and Cohn (1961), in the papers discussed above, emphasised the importance of spatial skills to some arithmetic problems. It seems plausible that arithmetic reasoning should be at least as vulnerable to spatial skills as written calculation problems. Therefore it may be that the current right hemisphere lesion group has reduced spatial skills and that this is the mechanism of their impairment on the reasoning problems of the verbal number series section of the new test.

2.4D CONCLUSIONS

The new test of reasoning in organic brain disease has been demonstrated to be suitable for patients with unilateral cerebral lesions. Despite being constructed of simple stimuli, it produced broadly similar results to established tests and its sensitivity to brain damage was demonstrated to be at least as good as any of the established tests in the battery.

The clinical significance of the effects of laterality could be expressed as follows. A failure of a right hemisphere lesion patient on the number series or non verbal sections can not be taken (in isolation) as an indication of anything more than an impairment in visual-spatial skills. Similarly, a failure of a left hemisphere lesion patient on the verbal sections can not be taken (in isolation) as an indication of anything more than aphasic difficulties. However, a failure of a right hemisphere lesion patient on the verbal odd one or verbal analogy sections of the new test could indicate dominant hemisphere involvement. Similarly, a failure of a left hemisphere lesion patient on the non verbal sections of the new test could indicate a reasoning deficit.

Theoretical considerations from this study include the indication that left hemisphere damage compromises all forms of inductive reasoning tested by the new test, whilst right hemisphere damage did not affect verbal odd one or verbal analogy. A multiple regression analysis found that naming skills best predicted the left hemisphere lesion group's scores on most sections of the new test, which provided further support for the theory that the left hemisphere makes a crucial contribution in reasoning, whatever their mode of presentation. Because this study included matched sets of reasoning problems presented in verbal and non verbal formats, which had not been available to previous investigators, it adds confidence to the conclusion that the integrity of the left hemisphere is important for the solution of reasoning problems presented in any format. In addition, the finding that right hemisphere lesion patients are impaired on arithmetic reasoning problems thought to have a geometric or spatial component extends previous work on discalculia which had documented right hemisphere involvement in arithmetic functions.

3. GENERAL CONCLUSIONS

The general discussion is divided into two sections. Section 3.1 will summarise and evaluate the development and validation of the new test that has been attempted according to Mapou's 1988 model. Section 3.2 will discuss theoretical considerations arising from the current study concerning theories of general intelligence.

3.1 EVALUATION OF METHODOLOGY

In the overview of methodology (Section 2.1), the model of Mapou (1988) for test development was described and adopted. He carefully identified the steps needed for initial development of a neuropsychological test that is not designed to detect brain damage *per se* but rather a specific deficit in an identified cognitive skill. These will now be considered in sequence and the success of the current study in fulfilling each of these prescriptions will be discussed.

1. "The focus of the test should be a specific cognitive function."

   The new test of reasoning in organic brain disease was conceived and designed as a specific test of reasoning. The load of other focal cognitive skills was kept to a minimum. The requirements for intact motor and sensory function were reduced, in comparison with other tests.

2. "Content validity should be established by reviewing relevant literature and obtaining expert judgement on items prior to data collection."

   Factor analyses of large normal samples of adult scores on cognitive tests had repeatedly revealed a number of factors considered to represent reasoning of various types. Inductive reasoning problems had proved to be a particularly robust means of eliciting the purest measure of reasoning.

Aquired brain damage had been an acknowledged factor in reducing reasoning ability since at least the beginning of the century. However the lack of matched verbal and non verbal presentations and the high demands on motor and sensory functions placed by established tests meant that the relationship between the functional integrity of the brain and reasoning ability was far from precisely understood.

3. "A large number of items must be included on the initial measure, to ensure that there are enough items after selection to meet statistical criteria."
   To select a final 25 items for each section, 76, 50, 35, 52, 54 and 50 items were piloted for sections 1-6 respectively.

4. "An appropriate normal sample must be collected, especially in terms of age and ability spread."
   The data from 155 normal controls were used to construct the normative sample. The age range was 18-70 years. There were between 28 and 32 control subjects in each decade group. The 12 year spread of 18-30 years included 36 subjects. The two estimates obtained for general ability level, the National Adult Reading Test and Full Scale IQ pro-rated from four WAIS subtests, gave similar means and normal distributions for each age range.

5. "Initial pilot testing should be performed by administering the test to a normal subset of the target population. Item selection should be made with considerations of item consistency and an adequate distribution of total scores."
   The pilot study took account of the performance of a minimum of 50 control subjects on all of the pilot items of each of the six sections of the new test. The age and sex distributions of the pilot subjects were satisfactory. Item selection took account of the validity and discriminability of each item. Distributions approximating the normal curve

were obtained when the data from the 25 selected items were plotted and an adequate spread of scores was evident.

6. "The revised measure and other measures should be used to assess construct validity." The six sections of the new test of reasoning were given to the control subjects in conjunction with Raven's Matrices, four WAIS subtests, the Graded Arithmetic Test, and two adult reading tests. The lesion subjects attempted the same battery, with the omission of the reading tests and the addition of three tests of focal dysfunction to demonstrate their specific cognitive deficits.

7. "Item responses and overall test scores must be analyzed to assess internal consistency and discrimination, an adequate spread of ability and, where possible, reliability." Face validity has been confirmed to a large extent by the very small numbers of subjects who failed to complete the rather lengthy experimental batteries.The levels of performance and distributions of test scores supported the new test as a measure of discrimination at least equal to others assessed in the study. Good internal consistency was demonstrated by the item difficulty curves constructed from the control sample data and highly significant split half correlation coefficients. A satisfactory spread of ability was described by the distributions of both control and lesion subjects. Test reliability was increased by choosing novel inductive reasoning items, to reduce the effects of education on performance. Items were presented in a the multiple choice format, a simple and unequivocal scoring system which reduces the tester's judgement in the scoring process to a minimum and thus reduces variability.

In addition the items of the new test of problem solving have been shown to meet Sternberg's (1982) four criteria of quantifiability, reliability, construct validity and empirical validity, as discussed in section 1.3.

8. "Construct validity can be formally assessed by showing the new test's relationship to test which are thought to measure similar functions and tests which measure less similar functions."

The scores of control subjects on both the new test of problem solving in organic brain disease and appropriate established tests of cognitive function were compared statistically, and the correlations and similarities supported the construct validity of the new test. Correlations of sections of the new test with other sections were demonstrated to be satisfactory. The scores of two series of 40 patients with unilateral cerebral lesions on both the new test of problem solving and appropriate established tests of cognitive function were compared statistically and additional support for the construct validity of the new test was obtained.

In summary, at this stage in its development, we have a matched set of reasoning tests presented in a verbal and non verbal format. They have been developed to be suitable for patients with a measure of motor and sensory impairment and also cognitive impairments that affect visual perception and language. Validation samples have been collected from the normal population and from unilateral left and right hemisphere lesion patients. They discriminate at least as well as established tests. They provide a useful tool for examining the pattern of difficulties that individual patients or groups experience in solving inductive reasoning problems.

Having completed the control series and the first validation sample of patients with unilateral cerebral lesions, future work is under consideration. Following the demonstration that the new test is as sensitive as conventional tests to unilateral cerebral lesions, it would be important to ascertain if the new test is more resistant to focal deficits than conventional tests. A more detailed exploration of how severe focal deficits affect performance on established tests, in comparison with performance on the new test, would be required. Another validation study of interest would be to investigate patients who had suffered diffuse brain damage and possibly to assess the new test as a predictor of outcome in rehabilitation, where it might provide an index of residual processing capacity relatively uncontaminated by focal deficits and unrestricted by sensory and motor deficits.

3.2 THEORETICAL CONSIDERATIONS

In this section, the implications of the current study for theoretical models of reasoning, and in particular for *g*, will be discussed. After a brief review of the evidence that the new test of reasoning does measure *g* to some extent, the first theoretical model of *g* as frontal lobe function will be considered. Secondly, the model of *g* as a single entity will be examined. Thirdly, the notion of *g* as a measure of efficiency will be assessed. Fourthly, *g* will be considered as pattern matching ability.

The new test of reasoning described in this study comprises six sections, each of which contain matched sets of inductive reasoning problems. The item types, odd one, analogy and series, have all been traditionally associated with *g* since Spearman's work. Standard tests of general intelligence usually incorporate some induction items (most markedly, Raven's Matrices). In addition the large study of 57 tests by Hakstian and Cattell (1974, discussed in section 1.2C) demonstrated that inductive reasoning, with speed of closure, yielded the highest *g* loadings.

The correlations derived from the three age groups in the current study's control sample demonstrated a good level of significance when the sections of the new test of reasoning were compared with established tests of *g*. Examining the six sections' correlations with the Matrices, WAIS Similarities and WAIS Block Design, for all three age groups, gives a total of 48 correlations, of which only six were not significant (see Appendix V). In addition each section produced a normal distribution of scores in the control sample, which is another feature of *g*. The age effects noted on the sections of the new test were similar to those demonstrated in established tests of *g*.

Finally, the demonstration in the lesion study that left hemisphere lesion patients failed matched sets of reasoning problems presented in both verbal and non verbal format (see Table 25), makes it very unlikely that aphasia can entirely explain their reasoning impairments. Previously, the role of focal deficits in mediating the failures of patients with cerebral lesions on reasoning tests could not confidently be discounted. As mentioned in section 1.11, it was a logical possibility that such failures could be entirely attributed to aphasia, apraxia or agnosia. The results on the new test of reasoning comprising matched sets of verbal and non verbal problems point to the conclusion that there is a specific reasoning ability, which relies in some way on left hemisphere integrity. In the light of these observations, it seems reasonable to consider the new test of reasoning as a measure of *g* and to consider theoretical models of *g* in the context of the results of the current study.

(i) *G* as a single entity

Various candidates for the processes underlying inductive reasoning have been mentioned in the Discussion to the lesion series. First, the role of primary aphasia has been discounted because the left hemisphere lesion cases were impaired on both the verbal and non verbal fomat sections and it seems unlikely that their aphasia could prejudice their performance on the non verbal presentations. Secondly the role of spatial skills, although implicated in the right hemisphere lesion patients' impairment on verbal number series, can not be employed to explain the left hemisphere lesion patients' difficulties.

The precise localization of reasoning processes has been similarly elusive, with very few statistically significant differences between scores on sections of the new test produced by comparisons of left and right (and more especially by anterior and posterior) lesion groups. In addition the different types of reasoning, odd one, analogy and series, demonstrated no differential sensitivity to lesion location.

There was very little systematic effect of localization demonstrated across the six sections of the new reasoning test, which suggests that the integrity of several systems is required for efficient reasoning. Risberg and Ingvar's 1973 work with PET, which was discussed in section 1.6A, demonstrated that the succesful participation of many cerebral regions was necessary to solve odd one problems. Although many systems may be involved, successful reasoning seems to require all of their contributions. For example Sternberg and Gardner's 1983 work with undergraduates, which suggested that differing numbers of processes are required for odd one, analogy and series problems, received no support from this study (see Table 29). They used response times to varying stimuli in an attempt to isolate elementary units of intelligence. The current study, using error rates to varying stimuli, did not produce similar differences. It could be argued that because the cognitive processes subserving reasoning overlap closely, either anatomically or functionally, an experiment using error rates in brain damaged subjects would be likely to fail to demonstrate a separation.

Further evidence for the close coupling of the component processes of reasoning comes from the discrepancy scores calculated between the verbal and non verbal composite reasoning scores (see Figure 8). Inspection of the ranges of the discrepancy scores for the control group, the left hemisphere lesion group and the right hemisphere lesion group reveals that the unilateral lesion groups have a smaller range of discrepancy scores than the control group. Although their pattern of discrepancies differ significantly (that is, the left lesion group have more negative discrepancies and the right lesion group have more positive discrepancies), the range of discrepancy scores was no greater for the lesion groups. Thus the verbal and non verbal composite scores were just as tightly yoked for the lesion patients as for the control group, suggesting that, although brain damage can slightly alter the efficiency of different types of problem solving, it does not typically selectively disable the processes required to solve a specific sort of problem.

Although this is negative evidence, and must therefore be treated with caution, it fits well with much of the theoretical work that has attempted to explain and define *g* and later work that models cognitive processes. For example Sternberg's 1988 review of inductive reasoning, which was discussed in section 1.4B, concluded that many information processing components overlap across a range of induction problems. The ability to solve problems seems to be close to the idea of energy or efficiency of cerebral action, as expressed by Spearman in 1923, rather than a process or area dedicated to a specific function.

This formulation is supported by the very few significant differences between lesion location and group performance on the new test of reasoning. It raises the possibility that the documented failures of patients with frontal lobe lesions on conventional tests of reasoning may be the result of how the problems are presented, rather than a specific failure to grasp and manipulate logical relations. As discussed in the Introduction section 1.4, it is the eduction of logical relations and correlates that Spearman proposed as a definition of reasoning.

(ii) *G* as frontal lobe function

Duncan (in press) argues for a close relation between the functions of the frontal lobes and Spearman's *g*. He considers that theoretical models of both frontal lobe function and *g* implicate cognitive processes which are concerned with active goal selection, especially in the context of novel events, poor feedback and many goal options. In this last situation of many goal options, failing to select the right goal could be viewed as failing to inhibit a wrong goal response. He contends that the failure of neuropsychologists to identify a litmus test of frontal lobe function results from two facts. First any cognitive test has a *g* component at the same time as having a non *g* component, and it can therefore be failed for many different reasons. Secondly there is enormous variability in *g* and therefore pre morbid frontal lobe function is difficult to estimate.

The current study demonstrated no systematic impairment of the patients with anterior lesions on the new test of reasoning. Patients with left frontal lesions were significantly impaired on verbal odd one and verbal analogy, when compared to patients who had suffered right anterior lesions (see Table32). However comparisons of patients who had suffered anterior lesions with patients who had suffered posterior lesions, for each hemisphere respectively, did not produce evidence of any clear detrimental effect of having suffered a frontal lobe lesion on any of the six sections of the new test. In contrast there was a clear detrimental effect of having suffered a left hemisphere lesion on all sections of the new test (see Table 27). The systematic effect of left hemisphere lesions rather goes against the argument that a mixture of *g* and non *g* components confounds the reliable demonstration of the true frontal lobe deficit. The use of a carefully matched control sample in this study goes some way towards reducing the need for an accurate estimate of the individual patients' pre morbid *g*.

It has been suggested that intelligence cannot be understood without reference to inhibitory processes, which are a manifestation of the efficiency of the frontal lobes. Dempster (1991) concludes that inhibitory processes appear to define a basic cognitive dimension that enters a broad spectrum of intellectual phenomena. They have been neglected because frontal lobe patients tend to perform adequately on global measures of intelligence; because computers have dominated theoretical models of intelligence and computers are technically poor sources of inhibition and suppression; and because inhibitory processes operate at the lower levels of consciousness and are thus less accessable to experimental investigation.

Shallice's SAS (1988) has been implicated in frontal lobe dysfunction and it's relevance to this study has been discussed in section 2.4B. It was concluded that a set of reasoning problems of the same type, which are initially presented in a training format, would not stress the SAS unduly but rely on the implementation of routine operations. If this is the case, then it seems that frontal lobe function can not be equated with *g*, but rather that some tests of *g* can be disrupted by frontal lobe dysfunction. An extreme position would be that the deficits demonstrated by patients with frontal lobe lesions on conventional tests of *g*, such as the Matrices or WAIS Block Design, are artifactual: they result from the format in which the test is presented. The observed frontal lobe dysfunction results from an inability to switch between types of reasoning problems, not from a primary inability to solve reasoning problems.

It seems that although the current study did not demonstrate any fractionation of different types of reasoning, it does seem to have pared down the encoding and supervisory demands of the reasoning task to a minimum. For example Spearman's 1923 description of *g* as the apprehension of experience, the eduction of relations and the eduction of correlates could be interpreted to define the new test as being mainly concerned with the eduction of relations. Similarly, Sternberg's (1988) information processing model describes information-acquisition components, performance components and meta components. The new test of reasoning would seem to stress the performance components, because the type of reasoning problem is described and practised (hence little for the metacomponents to process) and there are explanations and training items to ease acquisition. To implement all three levels of reasoning process might require the functional integrity of several cognitive systems.

Another way in which the new test of reasoning reduces task demands is that it offers very little information that is irrelevant or insignificant. Only the stereotyped multiple choice format requires a selection on the part of the subjects and even then they are not required to generate one answer from a large universe of possibilities, merely to choose one from four proffered options. If Holyoak and Nisbett's 1988 paper is considered (previously discussed in section

1.4A), then an important aspect to the solution of induction problems is the capacity to avoid being overwhelmed by fruitless hypotheses. The subject attempting the new reasoning test arguably has only four hypotheses to consider, all helpfully cued by the test's possible answers.

It could be argued that *g* must reflect a basic notion of intelligence. Is being able to change cognitive set within normal limits of performance (e.g. Milner,1963) an essential prerequisite for intelligent behaviour. Is the capacity to respond to Duncan's multiple goals (in press) a minimum requirement for an adult to be considered intelligent, however efficiently an adult may be able to solve sets of reasoning problems of the same type. At the heart of this debate is the philosophical nature of *g*. Can we accept a test of *g* which fulfils the psychometric requirements of validity and reliability but which requires no large scale switching of strategies, no responding to novelty without copious explanation and prompts? Should we expect factors evinced from the statistical analyses of large groups of healthy people to inform research with people who have suffered brain lesions?

The strong psychometric arguments for the new test of reasoning must carry the day, but there is a strong pointer for future work: could patients who have suffered frontal lobe functions manage three sets, each of the same type of reasoning problem, but fail a mixed set of equal difficulty with no training items?

(iii) *G* as a measure of neural efficiency

Whilst it should be remembered that Spearman (1927, discussed in section 1.6) thought it impossible that any physiological correlate could be linked to *g*, there is some evidence from PET work (Haier *et al*, 1988; Parks *et al*, 1988) that subjects with higher intelligence not only solve more complex problems, but expend less energy in the process (discussed in section 1.6A). There are also correlations between standard intelligence tests and nerve conduction velocity, a peripheral measure (Vernon and Mori, 1989, discussed in section 1.6D). These physiological experiments would fit with the notion of neural efficiency, as would Cattell's (1943) model of fluid intelligence.

Whereas there were considerable numbers of significant differences among groups with differently localized lesions on established tests of calculation and verbal and non verbal reasoning, which it could be argued are more dependent on knowledge stores, or cystallized (and apparently localised) intelligence, the new test was less susceptible to lesion location within the cerebral hemispheres. It could be argued that this indicates a test that is more reliant on fluid intelligence in patients with cerebral lesions, and further work could be directed to exploring this possibility.

Fluid intelligence recognizes complex relationships, but has small information content. It is thought of in terms of processing power, rather than as a store of problem solutions. This notion of a capacity to form bonds among ideas and concepts, described by Thorndike, Bregman, Cobb and Woodyard in 1927, fits well with the current study's results of little systematic localisation data and no demonstrable fractionation of reasoning types.

The data from the current study would support the view that fluid intelligence is the eduction of correlates, an ability to abstract relations among separate items. It is not tied to any single location in the brain, other than the crucial role of the left hemisphere. In addition types of reasoning have not been demonstrated to fractionate, which further supports the hypothesis of reasoning ability as processing power rather than as a store of problem solutions.

(iv) *G* as pattern matching

The fourth model is in line with recent work that attempts to explain cognitive processes in terms of parallel distributed processing models, which describe how patterns of connectivity within neural networks store information. Most connectionists think of the representational states of the system as not essentially associated with the manipulation of symbols. Instead, states of the networks that represent cognitive events are associated with the activity of grouping similar things into categories or "frames". Sometimes the analogy of iron filings reacting to a magnetic field is given to explain how information can be conceived of as structured patterns of energy.

In a theoretical paper that considers how this model might be applied to reasoning, Rumelhart (1989) rejects the explanations of problem solving in terms of symbol processing. Instead, he believes a better account to be in terms of pattern matching and generalization. He suggests that some of his postulated large number of processing units might represent the relational aspects of a situation, giving the example of the abstract relation of "same shape". He describes excitatory and inhibitory processes that correspond to familiar and unfamiliar patterns. The system tries to fit novel inputs to previous input patterns by distorting the novel stimuli to fit familiar events. The mechanism of similarity can work if a number of similar patterns have been stored, regardless of whether the common logical relation has been stored with the events, or even been recognised at the time. Rumelhart contends that the system will respond strongly to the central tendency and thus is able to respond to prototypes, even when no prototype has ever been registered by the system. This last property might explain why subjects can solve analogical reasoning problems far more quickly than they can provide an explanation of how to solve analogical reasoning problems.

Rumelhart's vision has far reaching implications, but to confine the discussion to the relevance of his model to the current study, the main issues are the failure of reasoning to fractionate in acquired brain damage and the role of the left hemisphere. Rumelhart's description of a pattern matching process, rather than the recall and application of stored rules, would fit well with both the lack of fractionation of inductive reasoning types and the lack of a systematic effect of lesion location in this study. It is also close to the notion of fluid intelligence, which has been described as a measure of processing efficiency.

The evidence reviewed in the previous section that supports the notion of *g* as efficiency would also be consistent with a theoretical model of *g* as a set of processes whose primary functions rely on the matching of patterns. The PET work (for example Haier *et al*, 1988) which was mentioned in this context, appeared to demonstrate that not only could more intelligent subjects solve more complex problems, but also that they required less energy to do so. An efficient pattern matching system would not only be able to achieve more complicated matches, made more difficult either as a result of the stimulus items being more different or as a result of the match relying on obscure features, but also to achieve those matches in a more streamlined way. Less energy would be spent on irrelevant features.

The connectionist paradigm has taken account of a reasoning system's need to avoid energy being wasted on unnecessary details. Smolensky (1986) has described a principle of least commitment, which means that the system only encodes sufficient information to explain the observed contingencies. A more detailed exposition of this processing model suggests that the system requires both an input vector and a knowledge representation vector. Smolensky suggests an exponential relationship between the consistency holding between the input and knowledge vectors on the one hand, and the probability of detecting the input, given the knowledge vector.

To some extent this is stating the obvious. If an individual can always correctly identify an input, and thus alert the representation of the relevant knowledge on every exposure to that stimulus, there will be a perfect correspondence between that input and that knowledge representation. If the individual can only correctly identify that stimulus on half of the occasions that he experiences that input, then the consistency of the input to the knowledge vector falls sharply. Smolensky's insight has been to demonstrate that a reduction in the probability of correct stimulus identification by 50% results in a much more dramatic drop in consistency than just half, as a result of the network of connections that can magnify and enhance an error.

Smolensky's description of the principle of least commitment and the relationship between the input and knowledge vectors could be employed as processing principles which mediate abstracting ability. For example the Gottschaldt test, a complex geometric figure discussed in section 1.7B, was thought to require a general capacity to isolate a coherent concept from an irrelevant context (Goldstein, 1927). The correct solution requires the subject to link the input vector, that is the sensory stimulus, to the knowledge vector, that is the goal shape. To make this link, the distractor lines must not be considered at the identification stage.

To return to the solution of reasoning problems, it can be seen how a perfect individual, who can always input an analogy problem correctly and alert the appropriate knowledge pattern to determine the solution, will achieve a perfectly consistent relation between input vector and knowledge vector. In contrast, a less perfect individual who rarely inputs an analogy problem correctly will substantially more rarely activate the knowledge vector to reach a correct solution.

To consider this in the light of the physiological evidence mentioned above (Haier *et al*, 1988), an individual who is competent at organising the input and therefore solving analogy problems will use less energy to answer a reasoning problem. In addition the importance of inhibiting unnecessary information, which has been stressed by cognitive theorists (Holyoak and Nisbett, 1988) and those speculating about the role of the frontal lobes (Dempster, 1991), is characterised as a mechanism to improve efficiency by Smolensky's principle. Not only does the failure of patients with frontal lobe lesions to ignore irrelevant stimuli lead to gross behavioural distortions such as perseveration on the Wisconsin Card Sorting Test, it could be allied to a much lower level processing impairment: disruption of Smolensky's principle of least commitment.

Another aspect of the pattern matching model which seems to provide a plausible account of the solution of reasoning problems is the interactive nature of the proposed process, instead of the rather stilted division into three or more processing levels. An example of this would be Sternberg's 1988 specification of encoding, comparison and combination (summarised in section 1.4).

Encoding that is independent of the semantic knowledge that automatically leads to solution, can only be of the most basic, sensory kind. For example, consider the example "grape is to vine, as apple is to bark, leaf, tree, worm". It seems unlikely that "grape" and "vine" could be read, without the semantic knowledge that a grape grows on a vine being accessed. In this example, the comprehension of the words leads to solution.

For a more testing problem, for example in the categorisation problem "gas, glass, iron, coal," the words can be read and possible candidates for categorisation considered out loud by the subject, for example "fuels, composite substances, clear substances." But the instant of reaching the categorisation of "gas, because it is not a solid", seems to be the same as finding the solution. An iterative method would test each generated hypothesis against the original stimuli. The process of correctly encoding an inductive reasoning problem, seems to be indivisible from arriving at the answer. Subjects can only be certain that they have encoded a reasoning problem correctly, that is attended to the relevant parts of the stimuli, when those parts lead to the selection of an acceptable answer.

The consideration of relations and comparisons is all part of the encoding and testing that takes place en route to the solution of a reasoning problem. A model of pattern matching fits with this plausible account and is probably close to the "aha!" experience. It should be remembered that the two tests with the highest loadings on *g* in Hakstian and Cattell's 1974 study were speed of closure and inductive reasoning. The solution of a reasoning problem could be viewed as a closure of one set of activations.

The theoretical shift of the encoding stage of an inductive reasoning problem away from basic sensory processing and into a larger iterative process involving combinations and comparisons is consistent with the findings of the lesion study reported in this thesis. Not only does it lead to the prediction that types of reasoning typically would not fractionate, because there is no crystallized store of inductive problem prototypes or rules, but it also explains why so little effect of precise localisation was demonstrated, because several processes are repeatedly and integrally involved in achieving encoding, combination and comparison.

In contrast, a systematic effect of lateralisation was demonstrated: the left hemisphere appears to have a crucial role in the solution of reasoning problems. Why should this pattern matching process rely on the left hemisphere for its efficient working? The answer to this is not clear. It may be that the left hemisphere has a crucial role in organizing and evaluating the pattern matching. There is considerable evidence that the left hemisphere is crucial in the operation of the stores of both visual and verbal semantic knowledge (McCarthy and Warrington, 1990, chs 2 and 6). In the speculative model regarding the solving of inductive reasoning problems discussed above, which argued that the perception of the problem stimuli is in itself the problem solution, semantic knowledge stores are clearly implicated. The right hemisphere alone may not be able to decide among competing solutions (which would mean selecting which semantic features best categorised or related the stimuli). Or the right hemisphere may not be able to "settle" effectively on an interpretation of the input, which would possibly place its failure at a different stage.

As a final conclusion, it seems that the connectionist model of reasoning gives the best explanation of the results of the current study. It does particularly well at offering a physiological model that is consistent with the failure of reasoning subtypes to fractionate in organic brain damage and of the lack of any systematic within hemisphere localisation effects of cerebral lesions on reasoning. The importance of the left hemisphere, which is so closely in line with previous work, is not so easily explained by a radical connectionist model. Some aspects of the apprehension or coordination of reasoning problems seem to rely on the left hemisphere, rather than the right. It seems especially fitting that many aspects of the connectionist model are consistent with early theories of reasoning, in particular Cattell's fluid intelligence and Thorndike's identification of the capacity to form bonds.

We have seen how workers since the beginning of the century searched for underlying mental structure by correlating, and later factor analysing, the scores of large groups of healthy subjects on a number of tests of cognitive skill. More recent trends have led to cognitive models of reasoning processes, often couched in terms of component procedures. Work with both healthy subjects and people who have suffered brain damage implied that the integrity of the cerebral hemispheres was necessary for efficient reasoning, but current tests were confounded by associated deficits. The development of matched sets of reasoning problems in verbal and non verbal format has led to a more precise assessment of the contributions of the two cerebral hemispheres to reasoning and increased our understanding of the reasoning process. The current study would support the concept of *g* and its continuing use as a psychological construct. Its definition remains remarkably close to Spearman's original *g*.

APPENDIX 1
INSTRUCTIONS TO SUBJECTS ATTEMPTING NEW TEST

I. VERBAL ODD ONE

Here are some sets of words. There are four in each group. I would like you to look at the first set of four words. Three of them go together in some way and one is the odd one out. The answer is to do with the meanings of the words, not how they are spelt or what sort of word they are. This is a practice item. Which one do you think is the odd one out?

Repeat as necessary for the rest of the training items, with prompts and help given as specified in the administration instructions.

Now you have done the five practice items, there are 25 items in the main test. For each item, just pick the word that you think is the odd one out. If you are not sure, have a guess.

2. VERBAL ANALOGY

This test is asking you to decide how words go together. These are practice items. First there are two words "up-down", which go together in some way. Then there is one word "come". Your job is to find a word, from these four given on the right, that fits with "come" in just the same way as "down" fits with "up". So "up" is to "down", as "come" is to ....

Repeat as necessary for remainder of training items, with prompts and help offered as specified in the administration details.

Now you have done the five practice items, here are the 25 items of the main test. Remember that each time you will see two words that are linked together in some way, followed by a single word. You must choose a word from the four given on the right that goes with this single word in the same way as the first two words go together. If you are not sure, have a guess.

3. VERBAL SERIES

Here are three numbers followed by a blank. On each of these practice items, your job is to look at the first three numbers, on the left, and then choose a number, from the four on the right, to fit on the end of the first three. For the first one, 7, 8, 9, ...

The instructions are repeated as necessary for each of the five practise items. Help and prompts are given according to the specified administration details.

Now you have finished the practice items, here are the 25 main items. As you have practised, you must choose one of the four numbers on the right, to complete the series given on the left. If you are not sure, just have a guess.

4. NON VERBAL ODD ONE.

Here are four shapes. Three of the shapes go together in some way. One of them is different from the other three. This is a practice item. Which one do you think is the odd one out?

The instructions are repeated for the remaining practise items and help given as specified in the administration details.

Here are the 25 items of the main test. Just like the practice items, there are four shapes. Three go together in some way. One is the odd one out. If you are not sure, just have a guess.

5. NON VERBAL ANALOGY

This is another test which uses shapes. At the top are two shapes. Something happens to the first shape, to make it into the second. Next we have a single, third shape. Last we have a choice of four shapes to go with the single third shape. This is a practice item. Which one of these four shapes at the bottom go with the third shape in the same way that the first two shapes go together?

Repeat as necessary for the remaining practise items, giving help and prompts as specified in the administration details.

Here are the 25 main items. Each one will have a pair of shapes at the top, and then a third single shape. Your job is to find which of the four bottom shapes goes with the third single shape, in the same way as the top two shapes go together. If you are not sure, just guess.

6. NON VERBAL SERIES

Here are three shapes across the top of the page, and then a question mark. The three shapes along the top form a series and your job is to find which one of the four lower shapes fits on the end to complete the series at the top. Something happens with each step across the top and the shape you choose from the bottom to complete the top row must be the third step in the series. This is a practice item. Which shape will you choose to complete the top row?

Repeat as necessary for the rest of the practise items, with help and prompts given according to the administration details.

Here is the first of the 25 main items. Each time there will be three shapes across the top. your job is to work out what is happening at each step and then choose one of the four shapes across the bottom to fit on the end of the top row. If you are not sure, just have a guess.

APPENDIX II
ORDER OF TEST ADMINISTRATION FOR CONTROL SUBJECTS

Odd numbered subjects	Even numbered subjects
WAIS Similarities	Verbal odd one
Verbal odd one	Verbal analogy
Verbal analogy	WAIS Similarities
Matrices	Non verbal odd one
Non verbal odd one	Non verbal analogy
Non verbal analogy	Non verbal series
Non verbal series	Matrices
Graded Arithmetic Test	Verbal series
Verbal series	Graded Arithmetic Test
Schonell	Schonell
NART	NART
WAIS Digit Span	WAIS Digit Span
WAIS Picture Comp[letion	WAIS Picture Comp[letion
WAIS Block Design	WAIS Block Design

APPENDIX III
TEXT OF LETTER SENT TO RECRUIT COMPANY SUPPORT AND LIST OF ORGANISATIONS SUPPORTING THIS RESEARCH

I am writing to ask if you would consider allowing me access to members of your organisation as part of the development of a new reasoning test for use in hospitals. The study is registered as a PhD with the University of London and it is supervised by Professor E.K.Warrington FRS.

The new test is designed to assess the problem solving abilities of people who have suffered brain damage. Over a hundred patients with brain damage have already completed the test to ascertain its suitability for this group.

The next stage is to find out how the average person does on the test so that the patients' scores can be calibrated.

The test consists of a range of short puzzles and problems and takes a maximum of an hour to complete. The only personal information that I would require from the volunteer would be their age and a brief indication of their occupation. I would not need to know their names and any data obtained would of course be completely confidential.

I realise that if you did feel able to help, then there would be a cost to your company in time and effort. I would be very happy to offer something in return that was mutually acceptable, for example a seminar on stress management or "how to survive a dual career marriage".

Yours sincerely,

Dawn Langdon MA MPhil
Senior Neuropsychologist.

Shell UK plc	Royal Bank of Scotland plc	The Salvation Army
Unilever plc	Smiths Industries plc	University of the Third Age
Abbey National plc	London Borough of Barnet	Mary Ward Centre
Lloyds Bank plc	Oxfam	

APPENDIX IV
TEXT OF LEAFLET GIVEN TO CONTROL SUBJECTS AFTER TESTING

Thank you very much for your help. You have just taken part in a study which is designed to show how ordinary people score on a new reasoning test.

Eventually the test will be used to identify which aspects of a person's thinking have been affected by a brain injury, for example after a car crash or a stroke.

We can do this by conparing a patient¦s scores with the normal range. Your test results, with those of hundreds of other volunteers, will be used to calculate the normal range.

All details are completely confidential and used only in the statistical analysis of the standardisation sample.

APPENDIX V
MEANS, STANDARD DEVIATIONS AND INTER CORRELATIONS OF CONTROL SUBJECTS' RAW SCORES, CALCULATED FOR THREE AGE BANDS.

	18-40 years		41-55 years		56-70 years	
	mean	s.d.	mean	s.d.	mean	s.d.
Nart errors	17.9	8.6	17.6	8.1	17.5	9.4
Matrices	29.3	4.6	25.1	6.7	23.7	7.0
WAIS Similarities	16.6	3.5	15.1	3.5	14.4	4.9
WAIS Digit Span	12.6	2.7	12.3	2.5	11.6	2.4
Digits forward	7.4	1.4	7.0	1.7	7.0	1.4
Digits backward	5.3	1.6	5.1	1.5	4.6	1.4
WAIS Block Design	40.4	6.7	35.0	8.6	31.6	8.8
WAIS Picture Completion	16.0	2.5	15.1	2.7	14.6	3.6
Graded Arithmetic Test	15.2	5.5	15.0	5.6	12.9	5.6
Verbal odd one	17.5	2.7	16.8	3.5	15.6	3.6
Verbal analogy	18.9	2.9	16.9	4.0	16.3	4.1
Verbal series	18.0	3.1	17.3	4.0	16.5	4.2
Non-verbal odd one	17.1	2.3	16.6	2.0	15.8	2.5
Non-verbal analogy	19.7	3.2	18.0	3.8	17.0	4.3
Non-verbal series	21.9	1.9	20.7	2.6	19.4	3.5

Table A. Means and standard deviations of control subjects' raw scores, calculated for three age bands.

TEST	NART errors	SPM	Similarities	Digit Span forwards	backwards	DS total	Block Design	Picture Completion	GAT
Matrices	-0.39**								
WAIS									
Similarities	-0.52***	0.47***							
Digit Span									
forwards	-0.15	0.25*	-0.02						
backwards	-0.30*	0.32**	0.18	0.61***					
total	-0.26*	0.33**	0.10	0.88***	0.91***				
Block Design	-0.33**	0.54***	0.41***	0.31*	0.46***	0.44***			
Picture Completion	-0.42***	0.33**	0.48***	0.22	0.29*	0.29*	0.34**		
Graded Arithmetic	-0.28*	0.47***	0.42***	0.44***	0.56***	0.57***	0.44***	0.41***	
Verbal odd one	-0.43***	0.49***	0.48***	0.24*	0.31**	0.31**	0.45***	0.44***	0.39**
analogy	-0.51***	0.68***	0.48***	0.26*	0.30**	0.33**	0.48***	0.27*	0.42***
series	-0.31**	0.64***	0.45***	0.25*	0.46***	0.41***	0.53***	0.37**	0.62***
Non Verbal odd one	-0.26*	0.38**	0.20	0.19	0.28*	0.27*	0.22	0.04	0.19
analogy	-0.45***	0.69***	0.48***	0.28*	0.41***	0.39***	0.42***	0.35**	0.46***
series	-0.24*	0.59***	0.24*	0.155	0.15	0.17	0.30*	0.22	0.25*

Table B. Correlation table of raw scores of control subjects, aged 18 to 40 years, on established tests. n=63.
Tests are of two tailed significance. *p=0.05. **p=0.01. ***p=0.001

TEST	NART errors	SPM	Similarities	Digit Span forwards	backwards	DS total	Block Design	Picture Completion	GAT
Matrices	-0.63***								
WAIS									
Similarities	-0.50***	0.60***							
Digit Span									
forwards	-0.41**	0.20	0.28						
backwards	-0.46**	0.40**	0.45**	0.60***					
total	-0.48***	0.34*	0.41**	0.89***	0.90***				
Block Design	-0.46**	0.56***	0.57***	0.24	0.24	0.27			
Picture Completion	-0.50***	0.62***	0.56***	0.27	0.29	0.31*	0.51***		
Graded Arithmetic	-0.50***	0.65***	0.43**	0.41**	0.52***	0.52***	0.57***	0.59***	
Verbal odd one	-0.62***	0.57***	0.62***	0.08	0.28	0.20	0.57***	0.57***	0.47**
analogy	-0.66***	0.67***	0.50***	0.15	0.33*	0.27	0.59***	0.59***	0.70***
series	-0.52***	0.74***	0.59***	0.17	0.25	0.24	0.60***	0.59***	0.65***
Non Verbal odd one	-0.177	0.25	0.32*	0.07	0.11	0.10	0.40**	0.40**	0.17
analogy	-0.42**	0.77***	0.57***	0.12	0.33*	0.25	0.67***	0.67***	0.62***
series	-0.55***	0.65***	0.53***	0.14	0.34*	0.27	0.67***	0.67***	0.49***

Table C. Correlation table of raw scores of control subjects, aged 41 to 55 years, on established tests. n=43.
Tests are of two-tailed significance. *p=0.05 **p=0.01 * **p=0.001

TEST	NART errors								
Matrices	-0.50***	SPM							
WAIS									
Similarities	-0.53***	0.45**	Similarities						
Digit Span									
forwards	-0.44**	0.47***	0.12	Digit Span forwards					
backwards	-0.30*	0.33*	0.11	0.49***	backwards				
total	-0.43**	0.46***	0.14	0.87***	0.86***	DS total			
Block Design	-0.42**	0.71***	0.32*	0.33*	0.35*	0.39**	Block Design		
Picture Completion	-0.32*	0.29*	0.33*	0.03	0.18	0.12	0.34*	Picture Completion	
Graded Arithmetic	-0.36**	0.43**	0.33*	0.47***	0.55***	0.59***	0.44**	0.19	GAT
Verbal odd one	-0.50***	0.73***	0.45**	0.42**	0.39**	0.47***	0.67***	0.48***	0.53***
analogy	-0.64***	0.57***	0.45**	0.45**	0.41**	0.50***	0.57***	0.49***	0.40**
series	-0.59***	0.56***	0.42**	0.45**	0.42**	0.51***	0.59***	0.41**	0.44**
Non Verbal odd one	-0.26	0.57***	0.16	0.27	0.08	0.21	0.58***	0.07	0.19
analogy	-0.63***	0.70***	0.44**	0.51***	0.40**	0.53***	0.73***	0.28	0.52***
series	-0.54***	0.67***	0.51***	0.41**	0.33*	0.43**	0.59***	0.20	0.45**

Table D. Correlation table of raw scores of control subjects, aged 56-70 years, on established tests. n=49.
Tests are of two tailed significance.

	Verbal odd one	Verbal analogy	Verbal series	Non verbal odd one	Non verbal analogy
Verbal analogy	0.44***				
Verbal series	0.53***	0.49***			
Non verbal odd one	0.36**	0.31**	0.42***		
Non verbal analogy	0.48***	0.54***	0.51***	0.49***	
Non verbal series	0.20	0.51***	0.41***	0.25*	0.53***

Table E. Correlations of control subjects[1] raw scores on six sections of the new test for the age group 18 to 40 years.
* $p<0.05$ ** $p<0.01$ *** $p<0.001$

	Verbal odd one	Verbal analogy	Verbal series	Non Verbal odd one	Non verbal analogy
Verbal analogy	0.78***				
Verbal series	0.65***	0.64***			
Non verbal odd one	0.41**	0.23	0.16		
Non verbal analogy	0.61***	0.70***	0.76***	0.40**	
Non verbal series	0.50***	0.60***	0.60***	0.21	0.67***

Table F Correlations of control subjects' raw scores on six sections of the new test for the age group 41-55 years.
* p<0.05 ** p<0.01 ***p<0.001

	Verbal odd one	Verbal analogy	Verbal series	Non Verbal odd one	Non verbal analogy
Verbal analogy	0.63***				
Verbal series	0.62***	0.744***			
Non verbal odd one	0.51***	0.42**	0.42**		
Non verbal analogy	0,69***	0.74***	0.72***	0.58***	
Non verbal series	0.59***	0.61***	0.62***	0.45**	0.79***

Table G. Correlations of raw scores on new test sections for controls, aged 56-70 years.

*p=0.05 **p=0.01 ***p=0.001

APPENDIX VI

ITEMS 0F NEW TEST GIVEN IN FINAL ORDER, CORRECT ANSWERS EMBOLDENED.

N.B. The verbal stimuli were presented typed in Letter Gothic 12 pitch, 12 point size.

1. VERBAL ODD ONE

a BRIGHT SHADOW DARKNESS **OPINION**
b STATEMENT **WHISPER** ACCOUNT REPORT
c **SPEND** CASH MONEY COIN
d AMERICA GERMANY **COUNTRY** ENGLAND
e TEACHER MINISTER **LAMP** POET

1. WIND RAIN SNOW **SKY**
2. VEGETABLE FRUIT FLOWER **SEASON**
3. SEPARATE INDEPENDENT INDIVIDUAL **BESIDES**
4. MUTTER MURMER REMARK **UNDERSTAND**
5. **CHICKEN** GOAT SHEEP COW
6. HOTEL CHURCH **TOWN** HOSPITAL
7. THOUSAND **QUARTER** FORTY HUNDRED
8. **FORCE** HARD FIRM STRONG
9. PORTION SECTION CHAPTER **PRODUCE**
10. KITCHEN **TABLE** HALL PASSAGE
11. CITY COLONY BUILDING **TOWN**
12. FIGHT **ARMY** BATTLE WAR
13. DIVISION **DISTRICT** COMPANY TROOP
14. **SALT** WASH SWELL WAVE
15. ICE **MILK** WATER STEAM
16. **LESS** MAJORITY MANY MOST
17. COOK **PIE** FEED BAKE
18. EXPENSE DEBT SPEND **SAVING**
19. ISLAND HILL **LAKE** PLAIN
20. TEA COTTON **SILK** CORN
21. **GAS** GLASS IRON COAL
22. ENTIRE **MANY** ALL ALWAYS
23. NAIL HORN **SKIN** HAIR
24. COMPLETELY ALWAYS **TOGETHER** EVERYWHERE
25. **STEEL** DIAMOND WINDOW AIR

2. VERBAL ANALOGY

a. UP—DOWN	COME—	ON **GO** IF TO
b. VAST—HUGE	LITTLE—	THIN **TINY** NONE SEVERAL
c. BEE—HONEY	COW—	SUGAR **MILK** HORSE FARMER
d. BRANCH—TREE	TOWER—	**CASTLE** CITY STAIR STATION
e. TEETH —MOUTH	FINGER—	**HAND** SKIN SHOULDER PIE

1. MONEY—RICH	HEALTH—	FARM FIRE FAST **FIT**
2. CAPTAIN—SHIP	EDITOR—	**NEWSPAPER** PRINT NEWS PRESS
3. WORKER—FACTORY	MERCHANT-	TEMPLE **MARKET** HOSPITAL KITCHEN
4. HARD—SOFT	ABOVE—	**BELOW** RISE DROP HIGH
5. WATER—SEA	FLAME—	**FIRE** HOT BURN GRAVE
6. ONE—ONCE	NUMEROUS-	SOMETIMES EARLY **OFTEN** TIME
7. TEA—BUSH	ORANGE—	**TREE** FLOWER FIELD FARMER
8. STEEL—METAL	UNIFORM—	SOLDIER POLICE **CLOTHING** FASHION
9. BIRD—NEST	SAILOR—	CAPTAIN **CABIN** WIFE SAIL
10. SHOP—PURCHASE	SCHOOL—	**LEARN** TEACHER FREEDOM COLLEGE
11. TRAIN—STATION	SHIP—	LAND SEA HOME **PORT**
12. OAK—TREE	ROSE—	GARDEN **FLOWER** FRUIT GRASS
13. PAINT—PICTURE	WRITE—	PAPER **LETTER** PEN MENTION
14. TAKE—PULL	PUT—	PICK THROW **PUSH** VISIT
15. LEG—ARM	ROOT—	GROUND FOOT **BRANCH** SEED
16. CURTAIN—WINDOW	PAPER—	**WALL** JOURNAL STRING BOOK
17. WALL—HOUSE	BARK—	DOG **TREE** CAT COVER
18. CIRCLE—SQUARE	ROUND—	FIGURE SHAPE **STRAIGHT** LINE
19. MILK—CHEESE	WHEAT—	GRAIN **BREAD** BUTTER FLOUR
20. SYSTEM—METHOD	PLAN—	PICTURE **MAP** PRACTICE TRACE
21. AGAINST—BESIDE	ON—	AWAY BELOW BEYOND **ABOVE**
22. YESTERDAY-TODAY	FLOWER—	ROSE HONEY BUSH **FRUIT**
23. ICE—MELT	WATER—	WASH FLOW RIVER **BOIL**
24. SAND—DESERT	WORD—	WRITER READ **LIBRARY** POEM
25. NEAR—LOCAL	FAR—	AWAY COUNTRY VAST **FOREIGN**

3. VERBAL SERIES

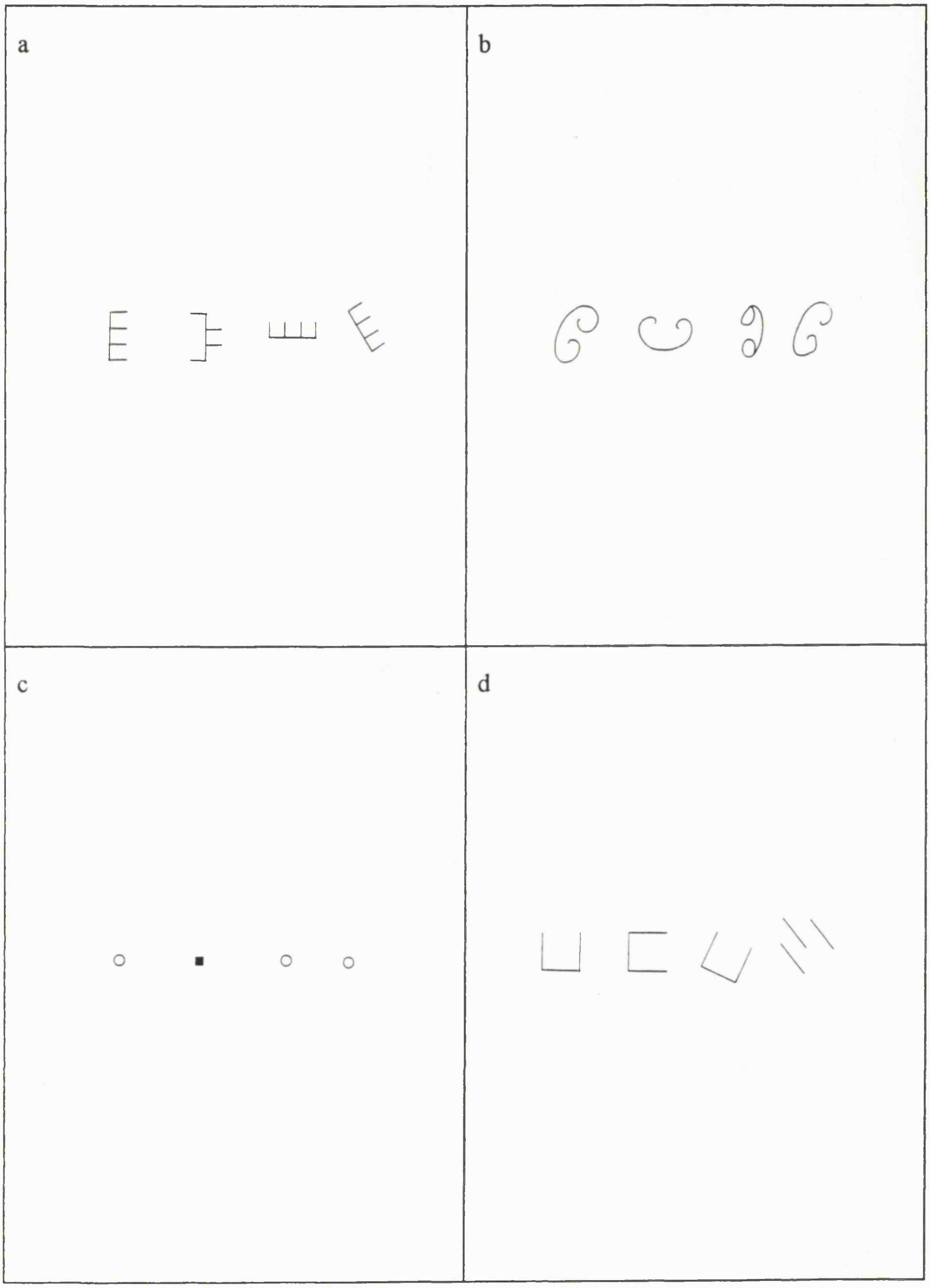
a.	7	8	9	_	6	**10**	12	23
b.	2	4	6	_	**8**	5	7	0
c.	5	4	3	_	1	**2**	10	0
d.	1	2	3	_	7	**4**	9	8
e.	5	10	15	_	1	25	**20**	18

1.	3	6	9	_	10	**12**	15	7
2.	97	98	98	_	**100**	101	110	109
3.	3	5	7	_	14	10	8	**9**
4.	20	16	12	_	**8**	4	2	1
5.	28	21	14	_	0	**7**	10	8
6.	8	11	14	_	35	22	**17**	16
7.	9	7	5	_	2	1	**3**	4
8.	7	5	3	_	14	6	**1**	2
9.	1	5	9	_	**13**	14	10	15
10.	1	4	7	_	**10**	9	11	12
11.	20	17	14	_	7	10	**11**	12
12.	10	7	5	_	3	**4**	1	0
13.	2	4	8	_	**16**	10	12	20
14.	1	3	7	_	7	16	10	**15**
15.	15	7	3	_	2	**1**	0	3
16.	1	9	13	_	16	20	**15**	18
17.	2	5	11	_	15	**23**	22	16
18.	1	3	9	_	18	15	**27**	10
19.	3	5	8	_	10	11	**12**	9
20.	5	6	4	_	3	2	**8**	**7**
21.	1	1	2	_	**3**	4	1	5
22.	1	3	6	_	9	**10**	12	8
23.	5	6	9	_	16	15	**18**	10
24.	1	2	6	_	8	10	14	**22**
25.	1	2	5	_	9	11	15	**26**

3. NON-VERBAL ODD ONE

The items are given here at 25% of their actual presentation size.

The position of the correct answers (a, b, c, or d) is given on page 230.



non-verbal odd one continued

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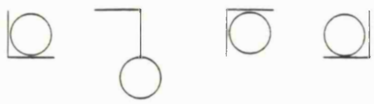
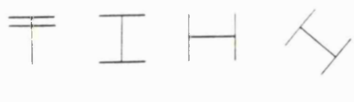


1

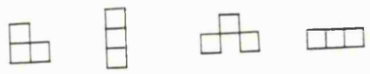
2



3

non-verbal odd one continued

4



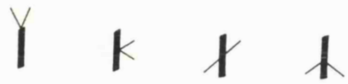
5

6

7

non-verbal odd one continued

8



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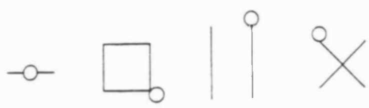

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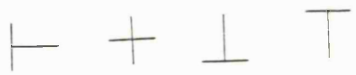

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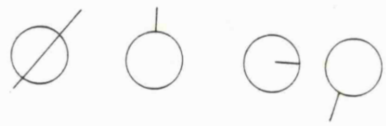

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15

non-verbal odd one continued

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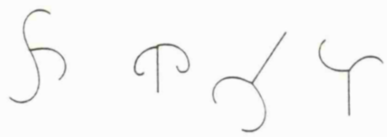

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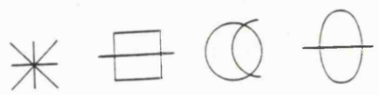

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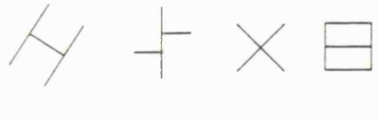

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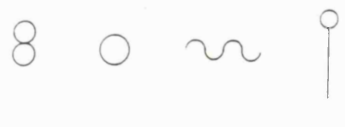
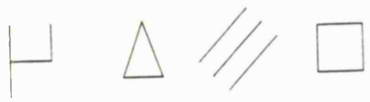


non-verbal odd one continued

20



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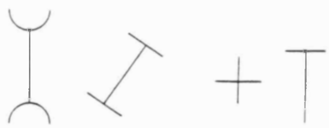


non-verbal odd one continued

24

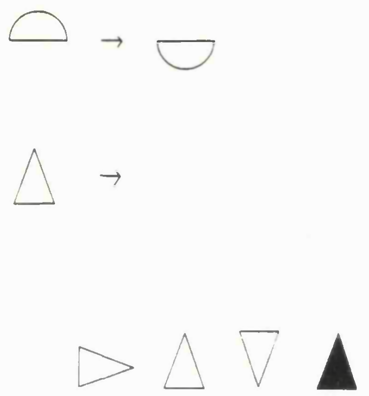
25

4. NON-VERBAL ANALOGY

The items are given here at 25% of their actual presentation size.

The position of the correct answers (a, b, c, or d) is given on page 230.

a



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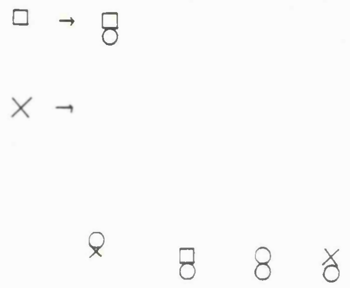
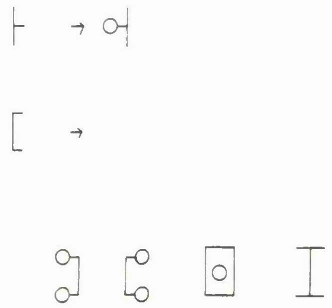
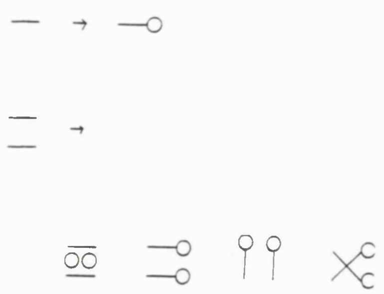


c

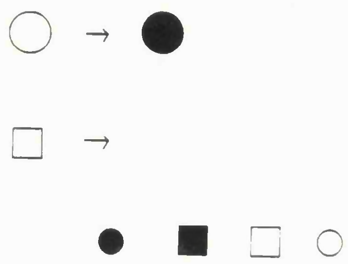


d



non-verbal analogy continued

e



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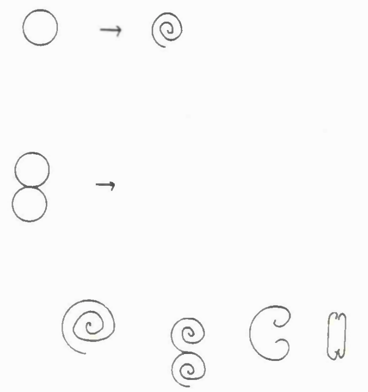

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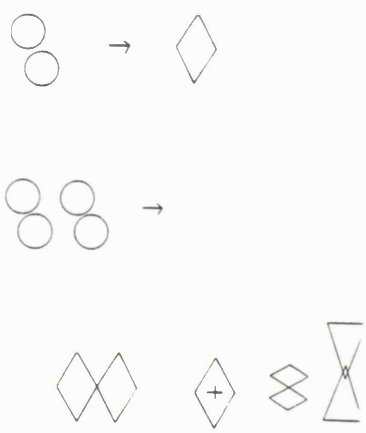

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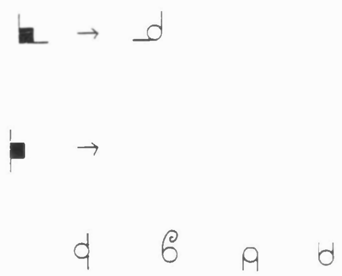
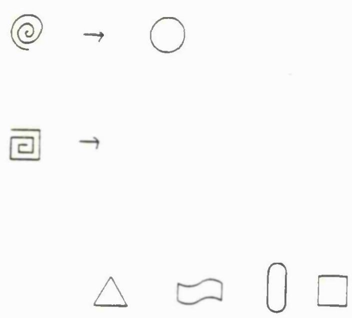


non-verbal analogy continued

4



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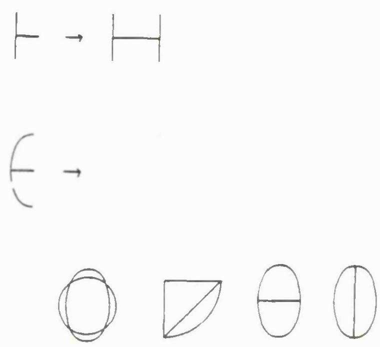

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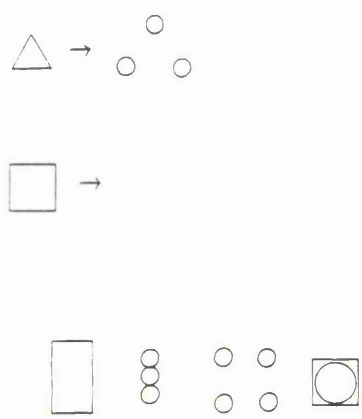

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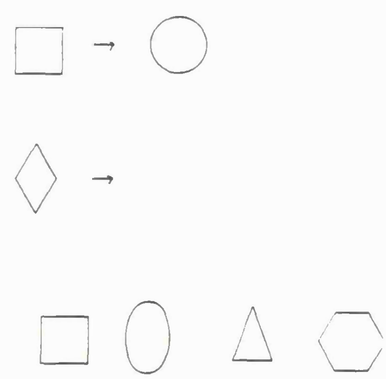
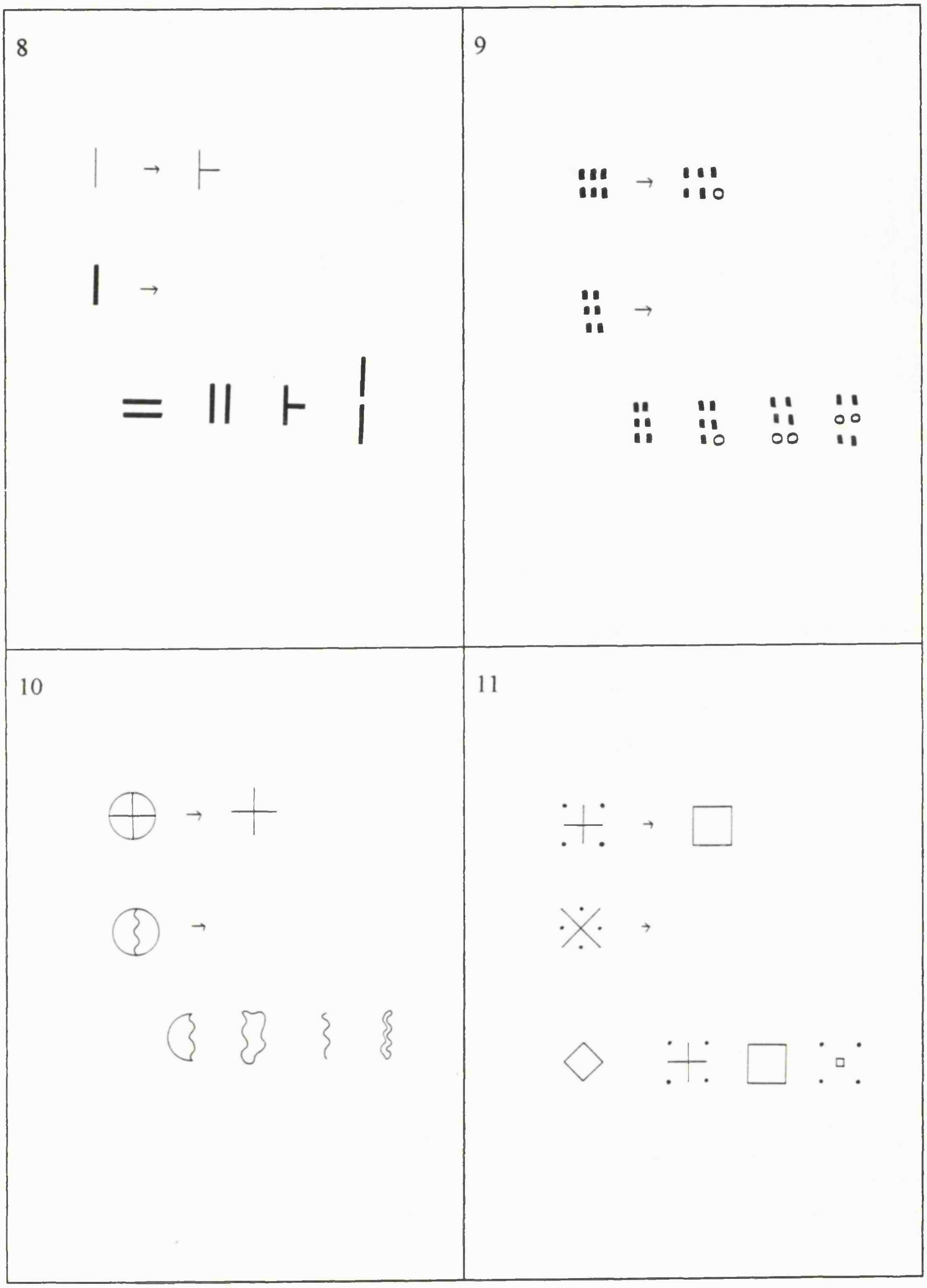
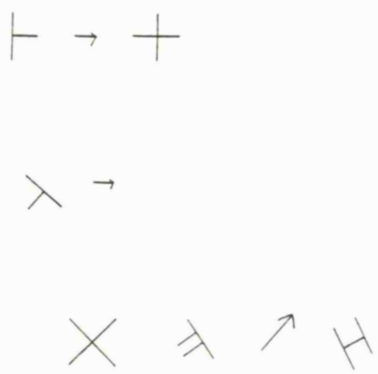


non-verbal analogy continued



non-verbal analogy continued

12



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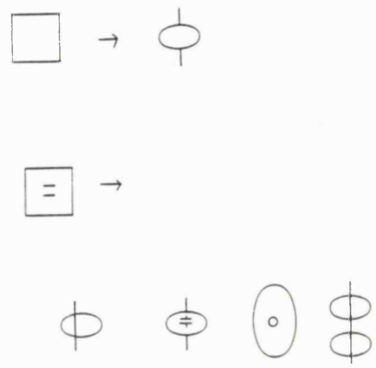

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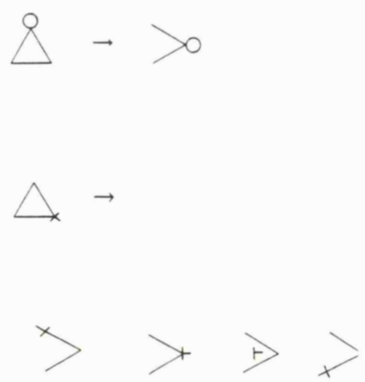

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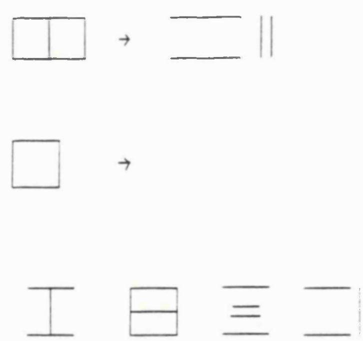

non-verbal analogy continued

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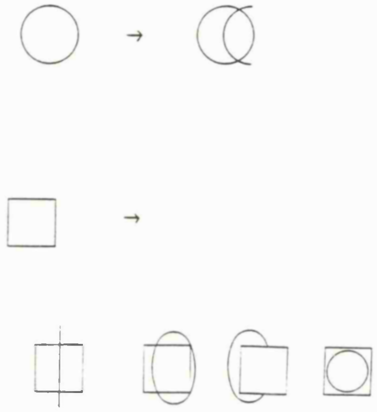

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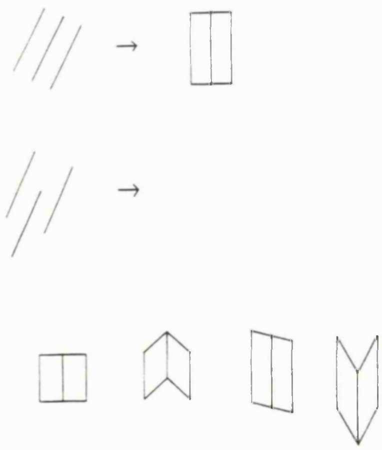

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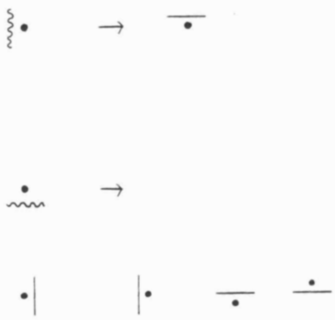

non-verbal analogy continued

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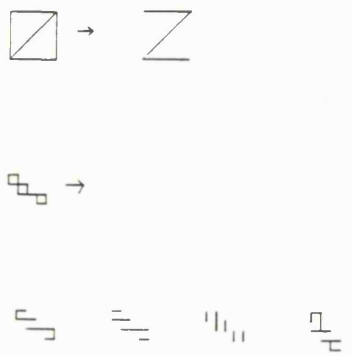

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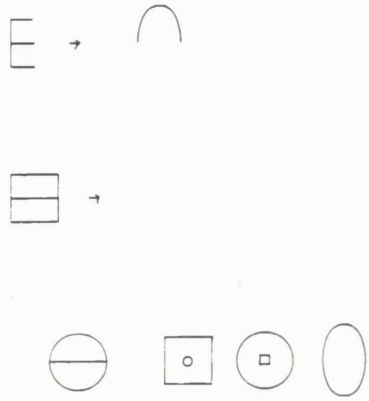

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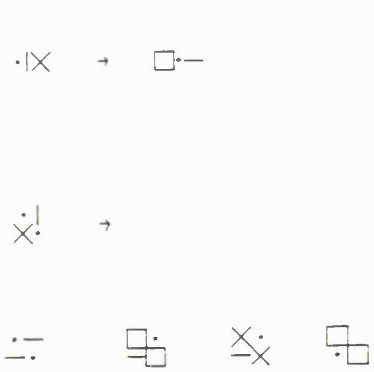

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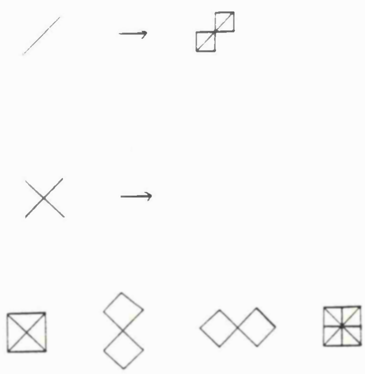
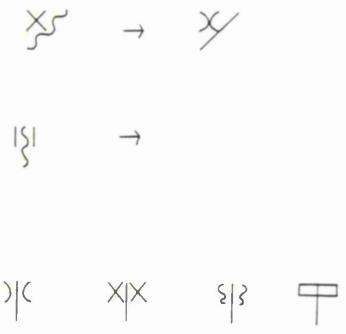


non-verbal analogy continued

24



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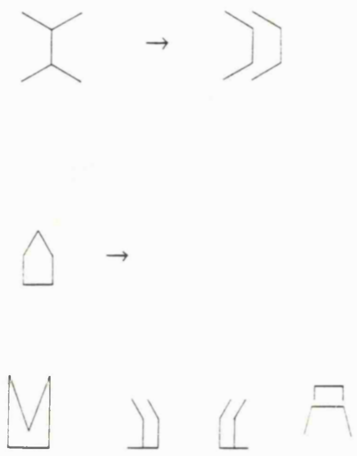
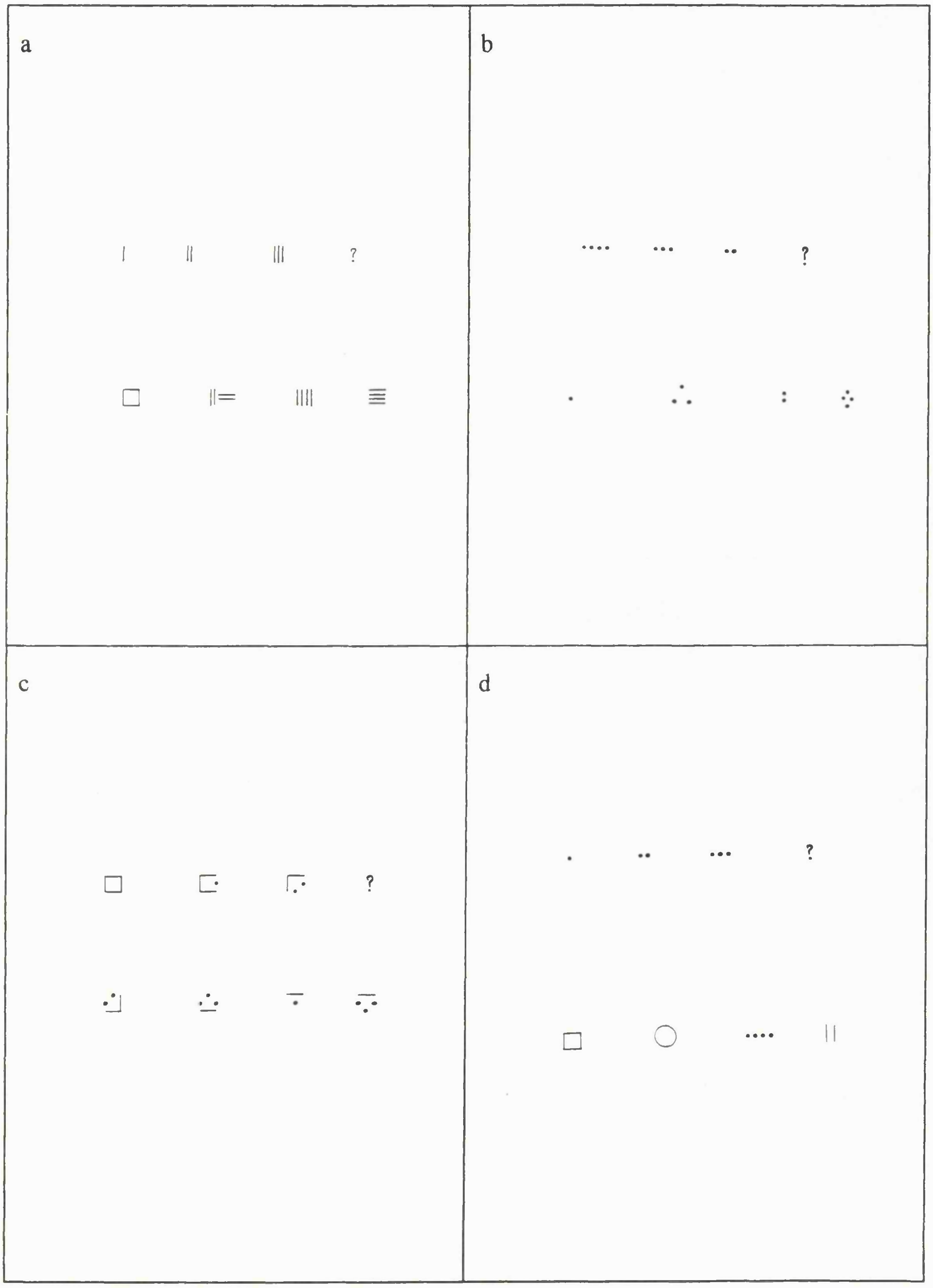


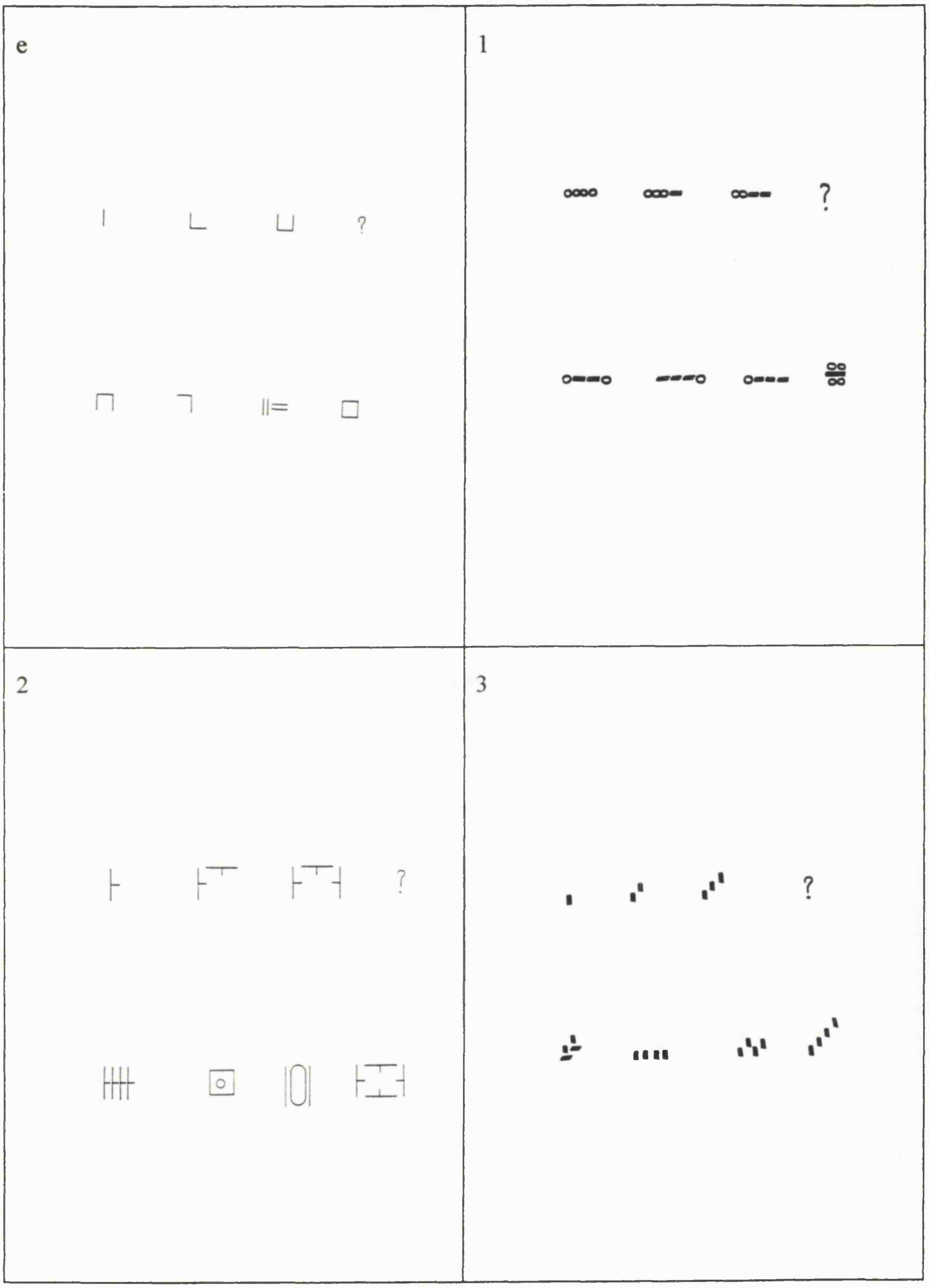
4. NON-VERBAL SERIES

The items are given here at 25% of their actual presentation size.

The position of the correct answers (a, b, c, or d) is given on page 230.



non-verbal series continued



non-verbal series continued

4

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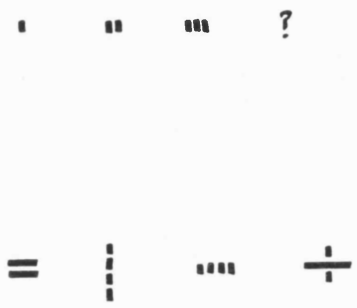

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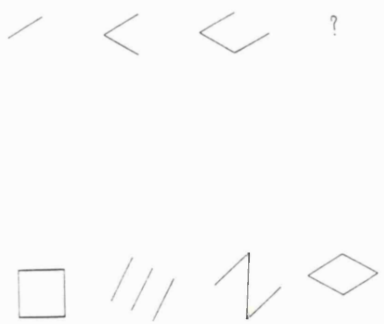

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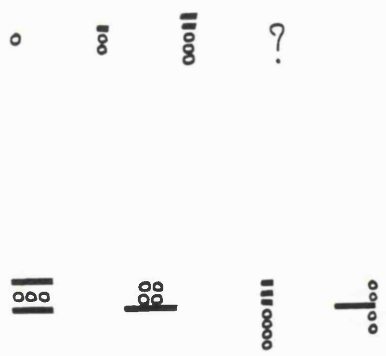

non-verbal series continued

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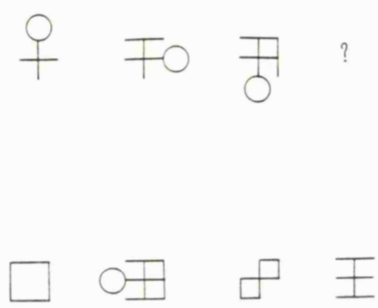

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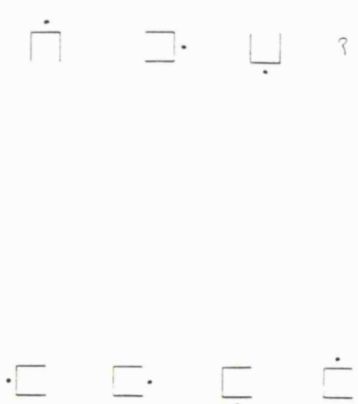

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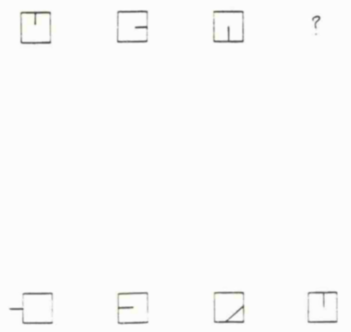
non-verbal series continued

12



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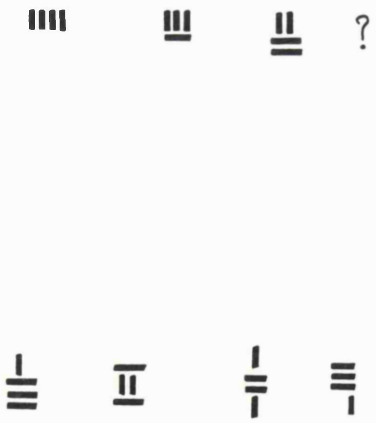

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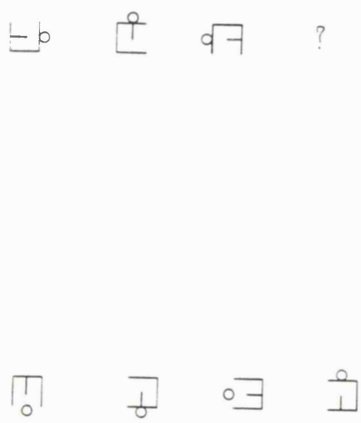
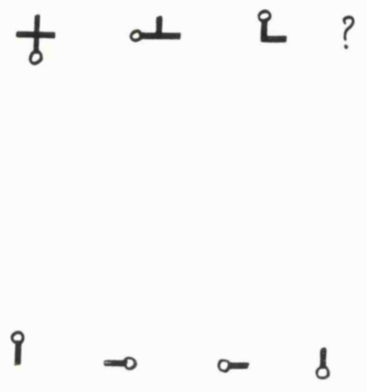


non-verbal series continued

16



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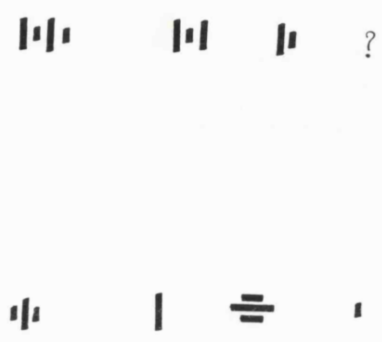

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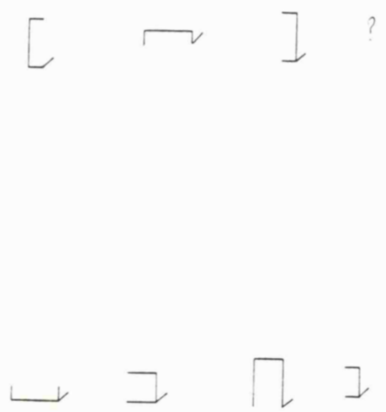

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non-verbal series continued

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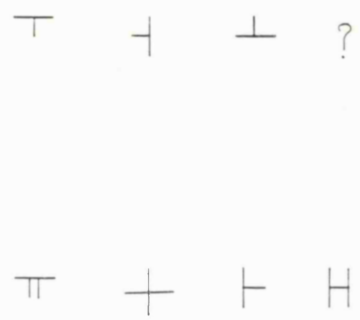

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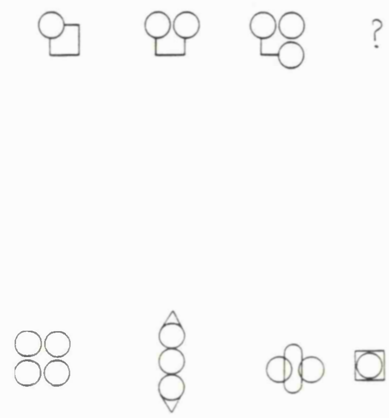

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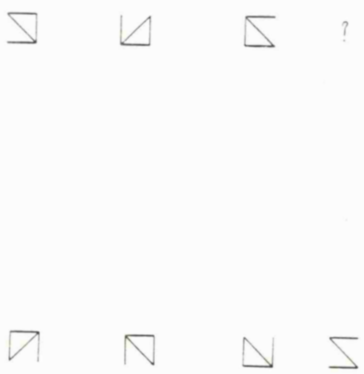

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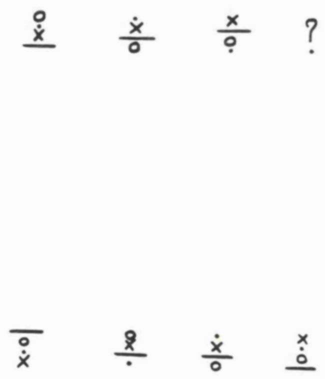

non-verbal series continued

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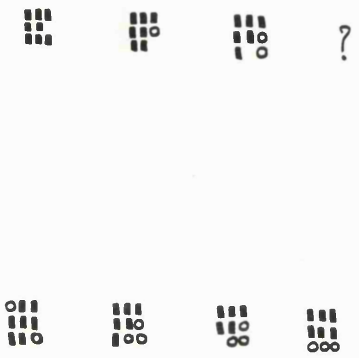

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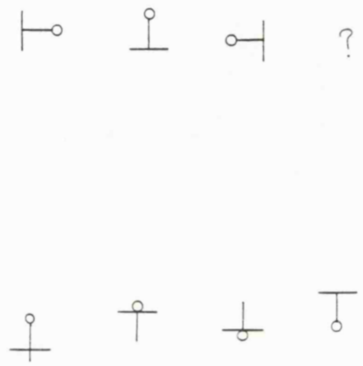
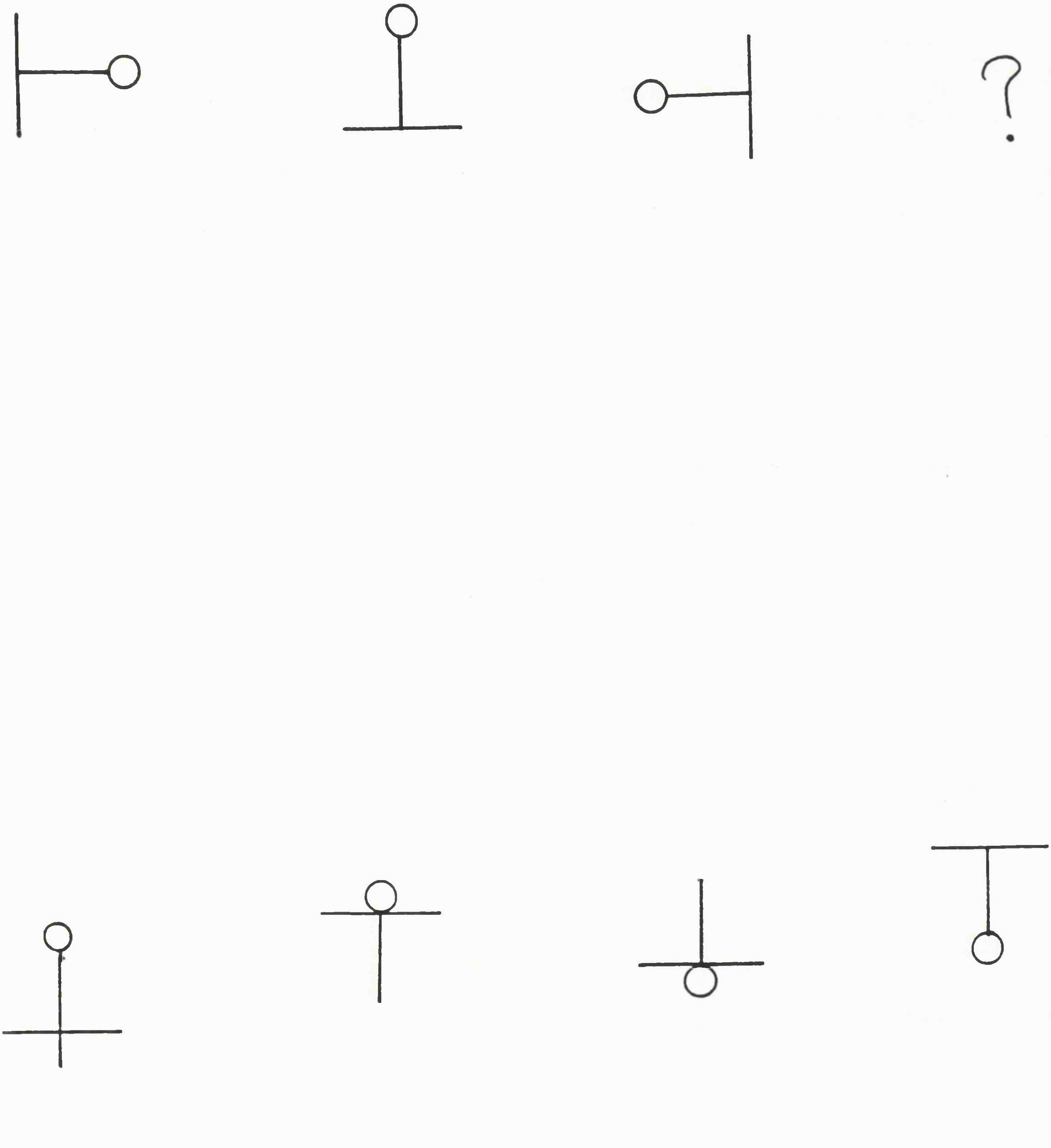


Sample non-verbal test item at full size



Correct answers to non verbal sections of new test:

Non verbal odd one		Non verbal analogy		Non verbal series	
item	answer	item	answer	item	answer
a.	b	a.	c	a.	c
b.	c	b.	d	b.	a
c.	b	c.	a	c.	d
d.	d	d.	b	d.	c
e.	b	e.	b	e.	d
1.	a	1.	b	1.	c
2.	a	2.	a	2.	d
3.	c	3.	a	3.	d
4.	c	4.	d	4.	c
5.	b	5.	c	5.	c
6.	d	6.	c	6.	d
7.	d	7.	b	7.	c
8.	c	8.	c	8.	b
9.	b	9.	b	9.	d
10.	d	10.	c	10.	a
11.	a	11.	a	11.	a
12.	b	12.	a	12.	b
13.	a	13.	b	13.	b
14.	b	14.	d	14.	a
15.	b	15.	d	15.	b
16.	a	16.	a	16.	b
17.	a	17.	c	17.	b
18.	c	18.	d	18.	a
19.	d	19.	b	19.	d
20.	d	20.	b	20.	c
21.	d	21.	d	21.	a
22.	b	22.	b	22.	a
23.	a	23.	d	23.	a
24.	a	24.	a	24.	c
25.	c	25.	c	25.	d

APPENDIX VII
ORDER OF TEST ADMINISTRATION FOR LESION SUBJECTS

Odd numbered subjects	Even numbered subjects
Ffook	Ffook
Efron Squares	Efron Squares
WAIS Similarities	Verbal odd one
Graded Naming Test	Verbal analogy
Token Test	WAIS Similarities
Verbal odd one	Graded Naming Test
Verbal analogy	Token Test
Fragmented Letters	Non-verbal odd one
Unusual Views	Non-verbal analogy
Matrices	Non-verbal series
Non-verbal odd one	Matrices
Non-verbal analogy	Fragmented Letters
Non-verbal series	Unusual Views
Graded Arithmetic Test	Verbal series
Verbal series	Graded Arithmetic Test
WAIS Digit Span	WAIS Digit Span
WAIS Picture Completion	WAIS Picture Completion
WAIS Block Design	WAIS Block Design

APPENDIX VIII

SITE AND PATHOLOGY OF LESIONS BY INDIVIDUAL CASE

I. LEFT HEMISPHERE LESION CASES

Sex	Age	Lesion Site	Pathology
M	42	left frontal	grade IV astrocytoma
F	57	left fronto-parietal	recurrent meningioma
M	67	left temporo-parietal	grade IV astrocytoma
M	70	left fronto-temporal	grade I-II protoplasmic astrocytoma
M	56	left frontal	aneurysm
M	52	left temporal	middle cerebral artery aneurysm clipped
M	58	left temporal	glioblastoma multiforme, indeterminate grade
F	44	left parietal	arterio-venous malformation
M	62	left fronto-parietal	oligodendroglioma
F	58	left parietal	infarct
M	67	left temporo-parieto-occipital	metastasis
M	59	left frontal	recurrence of previously excised meningioma
M	32	left temporal	grade IV glioblastoma mutiforme
M	59	left temporal	meningioma
M	22	left fronto-parietal	intracerebral haematoma
M	30	left frontal	pathology unclear
M	28	left fronto-temporo-occipital	glioma (CT and MRI only)
M	42	left temporal	cerebral vasculitis
M	29	left frontal	grade I astrocytoma
M	55	left temporal	infarct
M	54	left fronto-parietal	metastasis from renal cell carcinoma
M	47	left temporo-parietal	abscess
F	60	left temporo-parietal	meningioma
M	39	left frontal	grade II astrocytoma
F	64	left frontal	metastasis from adenocarcinoma
M	28	left frontal	meningioma

Sex	Age	Lesion Site	Pathology
M	31	left fronto-temporal	grade III astrocytoma
F	35	left frontal	venous angioma
M	34	left fronto-temporal	glioma (CT only)
F	63	left temporal	malignant glioma, grade indeterminate
F	68	left fronto-parietal	meningioma
M	50	left frontal	grade IV glioblastoma multiforme
F	43	left parieto-occipital	meningioma
M	28	left fronto-temporal	glioma (CT only)
F	38	left fronto-temporo-parietal	oligodendroglioma
M	24	left fronto-parietal	middle grade oligodendroglioma
M	39	left frontal	grade III astrocytoma
M	55	left parietal	subdural haematoma
F	42	left parietal	grade I-II oligodendroglioma
F	66	left frontal	meningioma

II. RIGHT HEMISPHERE LESION CASES

Sex	Age	Lesion Site	Pathology
M	49	right parieto-occipital	meningioma
F	49	right fronto-temporal	glioblastoma
F	53	right temporo-parietal	meningioma recurrence
M	61	right frontal	oligodendroglioma
F	66	right temporal	grade IV glioma
F	59	right frontal	grade I-II astrocytoma
M	40	right temporal	grade III astrocytoma
M	67	right frontal	glioblastoma multifotme
M	64	right parietal	grade III-IV astrocytoma
F	62	right frontal	grade IV oligodendroglioma
F	53	right occipital	meningioma
M	54	right frontal	glioma (CT only)
F	60	right temporo-parietal	meningioma
M	50	right parietal	meningioma

Sex	Age	Lesion Site	Pathology
F	23	right parietal	? granuloma ("non specific inflammatory changes")
M	31	right temporo-parietal	meningioma
M	51	right frontal	grade III astrocytoma
M	69	right occipital	infarct
F	43	right fronto-temporo-parietal	meningioma
M	55	right parietal	infarct
M	21	right temporal	abscess
M	20	right fronto-temporal	grade III astrocytoma
M	44	right parietal	grade IV glioblastoma multiforme
M	32	right parietal	pathology unclear
F	57	right fronto-temporal	meningioma
M	42	right parieto-occipital	astrocytoma, indeterminate grade
M	62	right parieto-occipital	grade IV astrocytoma
M	34	right fronto-temporal	glioma (CT only)
M	59	right parieto-occipital	grade III mixed oligoastrocytoma
F	22	right temporo-parietal	arterial venous malformation
M	61	right fronto-parietal	metastasis
F	37	right frontal	abscess, meningioma excised 4m previously
M	68	right temporal	meningioma
M	61	right fronto-parietal	grade II oligodendroglioma
M	41	right temporal	meningioma
F	41	right fronto-parietal	grade II astrocytoma
M	51	right frontal	grade II oligodendroglioma
F	40	right temporo-parietal	meningioma
M	44	right frontal	grade II-III oligodendroglioma
F	55	right frontal	glioma

STATISTICAL COMPARISON OF LOCATION EXTENT AND PATHOLOGY OF LESIONS IN EXPERIMENTAL SERIES.

As an indication of the similarity of the pattern of lobe involvement in the two lesion series, a chi-square was performed, on the top set of data in Table 14. The analysis gave a chi-square of 2.87 and a non significant probability of p=0.41. Turning to the lower set of data in Table 14, after first collapsing the categories of patients who had two, three and four lobe involvement, a 2 x 2 chi square was performed, to indicate whether the extent of the damage differed between the two groups. The chi square obtained from this analysis was 0.06 , giving a non significant probability of 0.81. Thus there is no significant difference between either the location, or the extent of lesions in the left and right hemisphere lesion groups.

As an indication of the similarity of the patterns of pathology in the two lesion series, the last four categories were collapsed to avoid too many frequencies being below six and a chi square was performed on the pathology frequency data (see Table 15). The analysis gave a chi square of 4.0, giving a non significant probability of 0.26. Thus there is no significant difference in the distribution of various pathologies between the left and right hemisphere lesion group.

APPENDIX IX

EFFECT OF AGE, SES AND SEX ON NEW TEST SCORES IN LESION PATIENTS

In section 2.3D(i), sex was demonstrated to be an unimportant variable in determining control subjects' scores on the new test. The lesion patients' scores on verbal odd one, analogy and series were added together to give a total verbal score. Similarly, the lesion patients' scores on non-verbal odd one, analogy and series were added together to give a total non-verbal score. For completeness, two multiple regressions were performed on the patients' total verbal reasoning score and total non-verbal reasoning score, to examine the effects of age, SES and sex.

1. y = total verbal score		2. y = total non-verbal score	
1st variable	AGE	1st variable	AGE
Significance of F	0.031*	Significance of F	0.0004**
R Square	0.12	R Square	0.20
2nd variable	SES	2nd variable	SES
Significance of F	0.008**	Significance of F	0.002**
R Square	0.24	R Square	0.28
3rd variable	SEX	3rd variable	SEX
Significance of F	> 0.05	Significance of F	> 0.05

Sex does not reach the usual 0.05 level of significance, to be counted as a variable influencing the lesion patients scores on the new reasoning problems. As an aside, it is interesting to note that, whereas SES was the first variable for both total scores for the control group, age has come out first for the patients.

SES	CONTROLS	LEFT LESIONS	RIGHT LESIONS
1-2	44	33	38
3-4	47	63	45
5-6	8	6	5

Table H. Chi square table of SES frequencies of control, left hemisphere lesion and right hemisphere lesion groups. For discussion, please see section 3.3D(i).

APPENDIX X

MEANS AND STANDARD DEVIATIONS OF RAW SCORES OBTAINED BY LESION PATIENTS ON WAIS SUBTESTS, CONTROLS GIVEN FOR COMPARISON.

WAIS subtest	left lesions	right lesions	controls
Similarities	9.7	14.3	15.5
	(6.2)	(4.5)	(4.1)
Digit Span	8.9	11.1	12.2
	(3.6)	(2.1)	(2.6
Block Design	28.0	29.3	36.2
	(11.2)	(10.3)	(8.8)
Picture Completion	12.4	14.0	15.3
	(4.5)	(3.6)	(3.0)

Table I. Means and standard deviations (given in brackets) of lesion patients' and control subjects' raw scores on four WAIS subtests.

APPENDIX XI

FREQUENCY TABLES OF OBSERVED AND EXPECTED SCORES ON ESTABLISHED TESTS

1. WAIS Similarities scale scores

a) left hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	11	21	3	5
expected	2	8	10	20

b) right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	3	10	6	21
expected	2	8	10	20

c) left vs right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
lefts	11	21	3	5
rights	3	10	6	21

2. WAIS Digit Span scale scores

a) left hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	14	12	9	5
expected	2	8	10	20

b) right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	1	11	15	13
expected	2	8	10	20

c) left vs right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
lefts	14	12	9	5
rights	1	11	15	13

3. WAIS Block Design scale scores

a) left hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	8	12	8	12
expected	2	8	10	20

b) right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	5	15	8	12
expected	2	8	10	20

c) left vs right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
lefts	8	12	8	12
rights	5	15	8	12

4. WAIS Picture Completion scale scores

a) left hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	8	9	11	12
expected	2	8	10	20

b) right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	2	9	15	14
expected	2	8	10	20

c) left vs right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
lefts	8	9	11	12
rights	2	9	15	14

5. Matrices raw scores

a) left hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	4	18	8	10
expected	2	8	10	20

b) right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	9	18	7	6
expected	2	8	10	20

c) left vs right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
left lesions	4	18	8	10
right lesions	9	18	7	6

6. Graded Arithmetic Test raw scores

a) left hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	20	9	3	8
expected	2	8	10	20

b) right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	5	15	7	12
expected	2	8	10	20

c) left vs right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
left lesions	20	9	3	8
right lesions	5	15	7	12

APPENDIX XII

FREQUENCY TABLES OF OBSERVED AND EXPECTED SCORES ON EACH SECTION OF NEW TEST OF REASONING

1. Verbal odd one

a) left hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	13	13	7	7
expected	2	8	10	20

b) right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	5	11	10	14
expected	2	8	10	20

c) left vs right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
left lesions	13	13	7	7
right lesions	3	12	15	10

Verbal analogy

a) left hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	12	16	7	5
expected	2	8	10	20

b) right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	3	12	15	10
expected	2	8	10	20

c) left vs right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
left lesions	12	16	7	5
right lesions	3	12	15	10

3. Verbal series

a) left hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	9	13	12	4
expected	2	8	10	20

b) right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	7	15	12	5
expected	2	8	10	20

c) left vs right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
left lesions	9	13	12	4
right lesions	7	15	12	5

4. Non verbal odd one

a) left hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	6	15	13	6
expected	2	8	10	20

b) right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
observed	5	14	10	11
expected	2	8	10	20

c) left vs right hemisphere lesion cases

	< = 5th pc	< = 25th pc	< = 50th pc	> 50th pc
left lesions	6	15	13	6
right lesions	5	14	10	11

5. Non verbal analogy
a) left hemisphere lesion cases

	<= 5th pc	<= 25th pc	<= 50th pc	> 50th pc
observed	9	15	9	7
expected	2	8	10	20

b) right hemisphere lesion cases

	<= 5th pc	<= 25th pc	<= 50th pc	> 50th pc
observed	15	10	9	6
expected	2	8	10	20

c) left vs right hemisphere lesion cases

	<= 5th pc	<= 25th pc	<= 50th pc	> 50th pc
left lesions	9	15	9	7
right lesions	15	10	9	6

6. Non verbal series
a) left hemisphere lesion cases

	<= 5th pc	<= 25th pc	<= 50th pc	> 50th pc
observed	9	13	9	9
expected	2	8	10	20

b) right hemisphere lesion cases

	<= 5th pc	<= 25th pc	<= 50th pc	> 50th pc
observed	9	15	8	8
expected	2	8	10	20

c) left vs right hemisphere lesion cases

	<= 5th pc	<= 25th pc	<= 50th pc	> 50th pc
left lesions	9	13	9	9
right lesions	9	15	8	8

REFERENCES

Alajouanine, T. (1960). *Les Grands activites du lobe occipital.* (Paris: Masson).

Alajouanione, T. and Lhermitte, F. (1964). Non-verbal communication in aphasia. In A.V.S De Rueck and M. O'Connor (Eds.), *Disorders of Language.* (London:Churchill).

Albert, M.L.(1973). A simple test of visual neglect. *Neurology.* **23,** 658-664.

Arrigoni, G. and De Renzi, E. (1964). Constructional apraxia and hemispheric locus of lesion. *Cortex,* **1,** 170-197.

Axenfeld, D. (1894). Eine einfache Methode, Hemianopsie zu constatieren. *Neurol.Centralblatt.* **13,** 437–438.

Barrett, P., Eysenck, H.J. and Lucking, S. (1986). Reaction time and intelligence: A replicated study. *Intelligence,* **10,** 9–40.

Basso, A., Capitani, E., Luzzatti, C. and Spinnler, H., (1981). Intelligence and left hemisphere diseases. The role of aphasia, aprxia and size of lesion. *Brain,* **104,** 721-734.

Basso, A., De Renzi, E., Faglioni, P., Scotti, G., and Spinnler, M. (1973). Neuropsychological evidence for the existence of cerebral areas critical to the performance of intelligence tasks. *Brain,* **96,** 715-728.

Benbow,C., Zonderman,A. and Stanley, J. (1983). Assortative marriage and the familiality of cognitive abilities in families of extremely gifted students. *Intelligence,* **7,** 153-161.

Benowitz, L.I., Moya, K.L. and Levine, D.N. (1990). Impaired verbal reasoning and constructional apraxia in subjects with right hemisphere damage. *Neuropsychologia,* **28,** 231-241.

Benton, A.L. (1962). Clinical symptomatology in right and left hemisphere lesions, in V.B. Mountcastle, (Ed.). *Interhemispheric Relations and Cerebral Dominance.* (John Hopkins: Baltimore).

Benton, A.L. (1962). The visual retention test as a constructional praxis test. *Confina Neurologica,* **22,** 141-155.

Benton, A.L. (1968). Differential behavioural effects in frontal lobe disease. *Neuropsychologia,* **6,** 53-60.

Binet, A. and Simon, T. (1905). Methodes nouvelles pour le diagnostic du niveau intellectuel des anormaux. *L'Annee Psychologique,* **11,** 191–244.

Bisiach, E., Luzzatti, C., and Perani, D. (1979). Unilateral neglect, representational schema and consciousness. *Brain,* **102,** 609-618.

Byrne, R.M.J. (1991). The psychology of thinking. *The Psychologist,* **4,** 297–300.

Casey, M. B., Winner, E., Brabeck, M. and Sullivan, K.(1990). Visual-spatial abilities in art, maths and science majors: effects of sex, family handedness and spatial experience. In *Reflections on the psychology of thought. Vol II,* Gilhooly, K.J., Keane, M.T.G., Logie, R.H. and Erdos, G. (eds.)(Chichester: John Wiley and sons).

Cattell, J.M. (1890). Mental tests and measurement. *Mind,* **15,** 373–381.

Cattell, R.B. (1941). Some theoretical issues in adult intelligence testing. *Psychological Bulletin,* **38,** 592 (Abstract).

Cattell, R.B. (1943). The measurement of adult intelligence. *Psychological Bulletin,* **40,** 153-193.

Cattell, R.B. (1978). *The Scientific Use of Factor Analysis in Behavioral and Life Sciences.* (New York: Plenum).

Cattell, R.B. (1987). Fluid and crystallized general intelligence. In .R.B. Cattell (ed.), *Intelligence: Its Structure, Growth and Action* (Amsterdam: North Holland).

Cattell, R.B. and Johnson, R.C. (eds.), (1986). *Functional Psychological Testing.* (New York: Brunner Mazel).

Chase, T.N., Fedio, P., Foster, N.L., Brooks, R., Chiro, G.D. and Mansi, L. (1984) Wechslar Adult Intelligence Scale Performance. Cortical localization by flurodeoxyglucose F18 positron emission tomography. *Archives of Neurology,* **41,** 1244-1247.

Christensen, A.L. (1975a). *Luria's Neuropsychological Investigation.* (New York: Spectrum).

Christensen, A.L. (1975b). *Luria's Neuropsychological Investigation: Manual.* (New York: Spectrum).

Cohn, R. (1961). Dyscalculia. *Archives of Neurology,* **4,** 79-85.

Colombo, A., De Renzi, E.,and Faglioni, P. (1976). The occurence of visual neglect in patients with unilateral cerebral disease, *Cortex,* **12,** *221-231.*

Colonna, A. and Faglioni, P. (1966). The performance of hemispheric damaged patients on a spatial intelligence test. *Cortex,* **2,** 293-307.

Costa, L.D. and Vaughan, H.G. (1962). Performance of patients with lateralized cerebral lesions: 1 verbal and perceptual tests. *Journal of Nervous and Mental Diseases,* **134,** 162-168.

Costa, L.D., Vaughan, H.G., Horowitz, M., and Ritter, W. (1969). Patterns of behavioural deficit associated with visual spatial neglect. *Cortex,* **5,** 242-263.

Costello, A. de L. and Warrington, E.K. (1989). Dynamis Aphasia. The selective impairment of verbal planning. *Cortex.* **25,** 103–114.

Coughlan, A.K. and Hollows, S.E. (1984). Use of memory tests in differentiating organic disorder from depression. *British Journal of Psychiatry,* **145,** 164-167.

Coughlan, A.K. and Warrington, E.K. (1978). Word comprehension and word retrieval in patients with localized cerebral lesions. *Brain,* **101,** 163-185.

Dagenbach, D. and McCloskey, M. (1992). The organization of arithmetic facts in memory: evidence from a brain-damaged patient. *Brain and Cognition,* **20,** 345-366.

Das, J.P., Kirby, J.R. and Jarman, R.F. (1979). *Simultaneous and Successive Cognitive Processes.* (New York: Academic).

Dempster, F.N. (1991). Inhibitory processes: a neglected dimension of intelligence. *Intelligence,* **15,** 157–173.

Denes, F., Semenza, C., Stoppa, E., and Gradenigo, G. (1978). Selective improvement by unilateral brain-damaged patients on Raven Coloured Progressive Matrices. *Neuropsychologia,* **16,** 749-752.

De Renzi, E. (1982). *Disorders of Space exploration and Cognition,* (Chichester: John Wiley).

De Renzi, E. and Faglioni. P. (1967). The relationship between visuospatial impairment and constructional apraxia. *Cortex,* **3,** 327-342.

De Renzi, E. and Faglioni, P. (1978). Normative data and screening power of a shortened version of the Token Test. *Cortex,* **14,** 41–49.

De Renzi, E., Faglioni, P., Savoiardo, M. and Vignolo, L.A. (1966). The influence of aphasia and of the hemispheric side of the cerebral lesion on abstract thinking. *Cortex,* **2,** 399-420.

De Renzi, E., Gentilini, M., Faglion, P. and Barbieri, C. (1989). Attentional shift towards the rightmost stimuli in patients with left visual neglect. *Cortex,* **25,** 231-237.

De Renzi, E., Motti, F., and Nichelli, P. (1980). Imitating gestures: A quantitative approach to ideomotor apraxia. *Archives of Neurology (Chicago),* **37,** 6-10.

De Renzi, E., Scotti, E. and Spinnler, H. (1969). Perceptual and associative dsorders of visual recognition: relationship to the site of the lesion. *Neurology,* **19,** 634–642.

De Renzi, E. and Vignolo, L.A. (1962). The token Test: A sensitive test to detect receptive disturbances in aphasia. *Brain,* **85,** 665-678.

Duncan, J.(in press). "Attention,intelligence and the frontal lobes." in M.Gazzaniga (Ed.), *The Cognitive Neurosciences.* (Boston: MIT Press).

Elithorn, A. (1955). A preliminary report on a perceptual maze test sensitive to brain damage. *J. Neurol. Neurosurg. Psychiatr.,* **18,** 287-292.

Epi-stat (1984). Statistical package for the IBM personal Computer. Version 3.0.

Fechner, G. (1860). *Elemente der Psychophysik.* (Leipzig: Breitkopf and Hartel).

Ffook Acuity Test. (London: Clement Clarke).

French, J.W., Ekstrom, R.B. and Price, L.A. (1963). Kit of reference tests for cognitive factors. (Princeton, N.J.: Educational Testing Service).

Gainotti, G. (1968). Les manifestations de negligence et d'inattention pour l'hemispace. *Cortex,* **4,** 64-91.

Gainotti, G., D'Erme, P., Villa, G. and Caltagirone, C. (1986). Focal brain lesions and intelligence: a study with a new version of Raven's Colored Matrices. *Journal of Clinical and Consulting Neuropsychology,* **8,** 37-50.

Galton, F. (1885). On the anthropometric laboratory at the late International Health Exhibition. *Journal of the Anthropological Institute,* **14,** 205–219.

Golden, C.J., Hammeke, T.A. and Purisch, A.D. (1978). Diagnostic validity of a standardized neuropsychological battery derived from Luria's neuropsychological tests. *Journal of Consulting and Clinical Psychology,* **46,** 1258-1265.

Golden, C.J., Hammeke, T.A., Purisch, A.D. and Moses, J.A. (1984). A manual for the administration and interpretation of the Luria-Nebraska Neuropsychological Battery. (Los Angeles: Western Psychological Services).

Golden, C.J. and Maruish, M. (1986). The Luria-Nebraska Neuropsychological Battery. In D. Wedding, A.M. Horton and J. Webster (Eds.), *The Neuropsychology Handbook.* (New York: Springer).

Golden, C.J., Moses, J.A., Fishburne, F.J., Engum, E., Lewis, G.P., Wosniewski, A.M., Conley, F.K., Berg, R.A. and Graber, B. (1981). Cross-validation of the Luria-Nrbraska Neuropsychological Battery for the presence, lateralization and localization of brain damage. *Journal of Consulting and Clinical Psychology,* **49,** 491-507.

Goldstein, G. and Scheerer, M. (1941). Abstract and concrete behaviour. *Psychological Monographs,* **43,** 1-151.

Goldstein, C., Neuringer, C. and Olson, J. (1968). Impairment of abstract reasoning in the brain-damaged: qualitative or quantitative?. *Cortex,* **4,** 372-388.

Grafman, J., Passafiume, D., Faglioni, P. and Boller, F. (1982). Calculation disturbances in adults with focal hemispheric damage. *Cortex,* **18,** 37-50.

Guilford, J.P. (1956). The structure of intellect. *Psychological Bulletin,* **53,** 267–293.

Guilford, J.P. and Hoepfner, R. *The Analysis of Intelligence.* (New York: McGraw–Hill).

Haier, R.J., Siegal, B.V., Nuechterlein, K.H., Hazlett, E., Wu, J.C., Paek, J., Browning, H.L. and Buchsbaum, M.S. (1988). Cortical glucose metabolic rate correlates of abstract reasoning and attention studied with positron emission tomography. *Intelligence,* **12,** 199-217.

Hakstian, A.R. and Cattell, R.B. (1974). The checking of primary ability structure on a broader basis of performance. *British Journal of Educational Psychology,* **44,** 140-154.

Halstead, W.C. (1947). *Brain and Intelligence.* (University of Chicago Press: Chicago).

Hebb, D.O. (1941). Clinical evidence concerning the nature of adult test performance. *Psychological Bulletin,* **38,** 593 (Abstract).

Hebb, D.O. (1949). *The Organization of Behaviour.* (New York: Wiley).

Hecaen, H. (1962) Clinical symptomatology in right and left hemispheric lesions. In *V.B.Mountcastle* (Ed.) *Interhemispheric Relations and Cerebral Dominance.* (Baltimore: The John Hopkins Press).

Hecaen, H. (1978). Les Apraxies ideomotrices essai de dissociation. In Hecaen, H. and Jeannerod, M. (eds.), *Du controle moteur a l'organisation du geste.* (Paris: Masson).

Hecaen, H. and Assal, G. (1970). A comparison of constructive deficits following right and left hemisphere lesions. *Neuropsychologia,* **8,** 289-303.

Hecaen, H., and Marcie, P. (1974). Disorders of written language following right hemisphere lesions: spatial dysgraphia. In S.J. Dimond and J.G. Beaumont (Eds.) *Hemispheric Function in the Human Brain.* (London: Paul Elek).

Heilman, K.M. and Valenstein, E. (1979). Mechanisms underlying hemispatial neglect. *Arch. Neurol.,* **5,** 166-170.

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

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

Henschen, S.E. (1926). On the function of the right hemisphere of the brain in relation to the left in speech, music and calculation. *Brain,* **49,** 110-123.

Hermelin, B.and O'Connor, N.(1986). Spatial representations in mathematically and in artistically gifted children. *British Journal of Educational Psychology,* **56,** 150-157.

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

Hom, J. and Reitan, R.M. (1982). Effect of lateralized cerebral damage upon contralateral and ipsilateral sensorimotor performances. *Journal of Clinical Neuropsychology,* **4,** 249-268.

Hom, J. and Reitan, R.M. (1984). Neuropsychological correlates of rapidly vs. slowly growing intrinsic neoplasms. *Journal of Clinical Neuropsychology,* **6,** 309-324.

Holmes, G. (1918). Disturbances of visual orientation. *British Journal of Opthalmology,* **2,** 449-468.

Horn, J.L. (1968). Organization of abilities and the development of intelligence. *Psychological Review,* **75,** 242-259.

Horn, J.L. (1985). Remodeling old models of intelligence. In B.B. Woldman (ed.). *Handbook of Intelligence: Theories, Measurements and Applications.* (New York: Wiley).

Horn, J.L. and Cattell, R.B. (1966). Refinement and test of the theory of fluid and crystallized general intelligences. *Journal of Educational Psychology,* **5,** 253-270.

Horn, J.L. and Knapp, J.R. (1973). On the subjective character of the empirical base of Guilford's structure–of–intellect model. *Psychological Bulletin,* **80,** 33–43.

Hunt, E. (1978). Mechanics of verbal ability. *Psychological Review,* **85,** 109-130.

Jackson, M. and Warrington, E.K. (1986). Arithmetic skills in patients with unilateral brain lesions. *Cortex,* **22,** 611-620.

Jensen, A.R. and Figueroa, R.A. (1975). Forward and backward digit span interaction with race and IQ: Predictions from Jensen's theory. *Journal of Educational Psychology,* **67,** 882-893.

Jensen, A.R. (1980). *Bias in Mental Testing.* (New York: Free Press).

Joreskog, K.G. (1969). A general approach to confirmatory maximum likelihood factor analysis. *Psychometrika,* **34,** 183-202.

Kane, R.L., Parsons, O.A. and Goldstein, G. (1985). Statistical relationships and discriminative accuracy of the Halstead-Reitan, Luria-Nebraska and Wechsler IQ scores in the identification of brain damage. *Journal of Clinical and Experimental Neuropsychology,* **7,** 211-223.

Kimura, D. (1963). Right temporal lobe damage: perception of unfamiliar stimuli after damage. *Archives of Neurology (Chicago),* **8,** 264–271.

Kimura, D. (1982). Left hemisphere control of oral and brachial movements and their relationship to communication. *Philosophical Transactions of the Royal Society of London, Series B*, **298,** 135-149.

Kline, P. (1986). *A Handbook of Test Construction.* (London: Methuen).

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

Kline, P. (1993). *The Handbook of Psychological Testing.* (London: Routledge).
Luria, A.R. (1966). *Higher Cortical Functions in Man.* (New York: Basic Books).

Luria, A.R. (1973). *The Working Brain.* (New York: Basic Books).

Mackintosh, N.J. (1989). IQ. in Robbins, T. and Cooper, A. (eds.), *Psychology for Medicine.* (Cambridge: CUP).

Mapou, R.L. (1988). Testing to detect brain damage: an alternative to what may no longer be useful. *Journal of Clinical and Experimental Neuropsychology,* **10 (2),** 271-278.

McCarthy, R.L. and Warrington, E.K. (1987). Understanding: a function of short term memory? *Brain,* **110,** 1565-1578.

McCarthy, R.L. and Warrington, E.K. (1988). Evidence for modality specific meaning systems in the brain. *Nature*, **334,** 428-430.

McCarthy, R.A. and Warrington, E.K. (1990a). *Cognitive Neuropsychology: a clinical introduction.* (San Diego: Academic Press).

McCarthy, R.A. and Warrington, E.K. (1990b). Auditory verbal span of apprehension: a phenomenon in search of a function? in . G. Vallar and T. Shallice (eds.), *Short Term Memory.* (Cambridge:CUP).

McFie, J. and Piercy, M.F. (1952a). Intellectual impairment with localized cerebral lesions. *Brain*, **73,** 292-311.

McFie, J. and Piercy, M.F. (1952b). The relation of laterality of lesion to performance on Weigl's sorting test. *Journal of Mental Science,* **98,** 299-305.

McFie, J., Piercy, M.F., and Zangwill, O.L. (1950). Visual-spatial agnosia associated with lesions of the right cerebral hemisphere. *Brain*, **73,** 167-190.

McGee, M.G. (1979). Human spatial abilities: psychometric studies and environmental, genetic, hormonal and neurological influences. *Psychological Bulletin,* **86,** 889–918.

McGuinness, D. (1976). Away from a unisex psychology: Individual differences individual differences in visual sensory and perceptual processes. *Perception.* **5,** 279-294.

McKay, S.E. and Golden, C.J. (1979). Empirical derivation of experimental scales for localizing brain lesions using the Luria-Nebraska Battery. *Clinical Neuropsychology,* **1,** 19-23.

McKay, S.E. and Golden, C.J. (1981). The assessment of specific neuropsychological skills using scales derived from factor analysis of the Luria-Nebraska Neuropsychological Battery. *International Journal of Neuroscience,* **14,** 183-188.

McKenna, P. and Warrington, E.K. (1980). Testing for nominal dysphasia. *Journal of Neurology, Neurosurgery and Psychiatry,* **43,** 781-788.

McKenna, P. and Warrington, E.K. (1983). *The Graded Naming Test.* (Windsor:Nelson).

Marshall, J.C. and Newcombe, F. (1973). Patterns of paralexia: a psycholinguistic approach. *Journal of Psycholinguistic Research,* **2,** 169-176.

Meier, M.J. (1970). Effects of focal cerbral lesions on contralateral visuomotor adaptation to reversal and inversion of visual feedback. *Neuropsychologia,* **8,** 269-279.

Mesulam, M.M. (1981). A cortical network for directed attention and unilateral neglect. *Annals of Neurology,* **10,** 309-325.

Milner, B. (1963). Effects of different brain lesions on card sorting. *Archives of Neurology,* **9,** 90-100.

Milner, B. (1971). Interhemispheric differences and psychological processes. *British Medical Bulletin,* **27,** 272-277.

Nelson, H.E. (1982). *National Adult Reading Test.* (Windsor: NFER).

Nelson, H.E. and O'Connell, A. (1978). Dementia: The estimation of premorbid intelligence using the new adult reading test. *Cortex,* **14,** 234-244.

Nelson, H.E. and Willison, J. (1992). *Restandardisation of the NART against the WAIS-R.* (Windsor: NFER).

Nunally, J.O. (1978). *Psychometric Theory.* (New York: McGraw–Hill).

Parks, R.W., Loewenstein, D.A., Dodrill, K.L., Barker, W.W., Yoshii, F., Chang, J.Y., Emran, A., Apicella, A., Sheramata, W.A. and Duara, R. (1988). Cerebral metabolic effects of a verbal fluency test: a PET scan study. *Journal of Clinical and Experimental Neuropsychology,* **10,** 565-575.

Picker, W.T. and Schlottman, R.S. (1982). An investigation of the Intellectual Processes scale of the Luria-Nebraska Neuropsychological Battery. *Neuropsychology,* **4 (3),** 120-124.

Piercy, M. (1964). The effects of cerebral lesions on intellectual function: a review of current and research trends. *British Journal of Psychiatry,* **110,** 310–352.

Piercy, M. (1969). Neurological aspects of intelligence. In P.J.Vinken and G.W.Bruyn (eds.), *Handbook of Clinical Neurology. Vol.III.* (Amsterdam:North Holand).

Piercy, M. and Smyth, V.O.G. (1962). Right hemisphere dominance for certain non-verbal intellectual skills. *Brain,* **85,** 775-790.

Penrose, L.S. and Raven, J.C. (1936). A new series of perceptual tests. Preliminary communication. *British Journal of Medical Psychology,* **16,** 97-104.

Poeck, K. and Lehmkuhl, G. (1980). Das Syndrome der ideatorischen Apraxie und seine Localisation. *Nervenartz,* **51,** 217–225.

Ratcliff, G. (1979). Spatial thought, mental rotation and the right cerebral hemisphere. *Neuropsychologia,* **17,** 49-54.

Raven, J.C. (1938). *Standard Progressive Matrices.* (London: H.K. Lewis & Co. Ltd.).

Raven, J.C. (1939). The RECI series of perceptual tests: an experimental survey. *British Journal of Medical Psychology.* **18,** 16-34.

Raven, J.C. (1941). Standardisation of Progressive Matrices. *British Journal of Medical Psychology.* **19,** 137-140.

Raven, J.C. (1962). *Advanced Progressive Matrices.* (London: H.K. Lewis & Co. Ltd.).

Raven, J.C. (1983). *Standard Progressive Matrices.* (London: H.K.Lewis & Co. Ltd.).

Raven, J.C., Court, J.H. and Raven, J. (1985). Manual for Raven's Progressive Matrices and Vocabulary Scales. Section 1. (London: H.K. Lewis & Co. Ltd.).

Ree, M.J. and Earles, J.A. (1991). The stability of *g* across different methods of estimation. *Intelligence,* **15,** 271-278.

Reed, T.E. (1984). Mechanism for heritability of intelligence. *Nature,* **311,** 417.

Reitan, R.M. (1955). Certain differential effects of left and right cerebral lesions in human adults. *Journal of Comparative and Physiological Psychology,* **48,** 474-477.

Reitan, R.M. (1958a). The validity of the Trail Making test as an indicator of organic brain damage. *Perceptual and Motor Skills,* **8,** 271-276.

Reitan, R.M. (1958b). Qualitative versus quantitative mental changes following brain damage. *Journal of Psychology,* **46,** 339-346.

Reitan, R.M. (1959a). The comparative effects of brain damage on the Halstead Impairment Index and the Wechsler -Bellevue Scale. *Journal of Clinical Psychology,* **15,** 281-285.

Reitan, R.M. (1959b). Impairment of abstraction ability in brain damage. *Journal of Psychology,* **48,** 339-346.

Reitan, R.M. (1960). The significance of dysphasia for intelligence and adaptive abilities. *Journal of Psychology,* **50,** 355-376.

Reitan, R.M. (1964). Pschological deficits resulting from cerebral lesions in man. In J.A. Warren and K.A. Ekert (Eds.), The frontal granular cortex and behaviour. (New York: McGraw-Hill).

Reitan, R,M. and Wolfson, D. (1986). The Halstead-Reitan Neuropsychological test battery. In D.Wedding, A.M. Horton and J. Webster (Eds.), *The Neuropsychology Handbook.* (New York: Springer).

Risberg, J. and Ingvar, D.H. (1973). Patterns of activation in the grey matter of the dominant hemisphere during memorizing and reasoning. *Brain,* **96,** 737-756.

Rumelhart,D.E. (1989). Toward a microstructural account of human reasoning. In S. Vosnaidou and A. Ortony (Eds.), *Similarity and Analogical Reasoning.* (Cambridge: Cambridge University Oress).

Russo, M. and Vignolo, L.A. (1967). Visual figure ground discrimination patients with unilateral cerebral disease. *Cortex,* **3,** 113-127.

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

Schonell, F.J. (1945). *The Psychology and Teaching of Reading.* (London: Oliver and Boyd)

Shallice, T. (1982). Specific Impairments in planning. In Broadbent, D.E. and Weiskrantz, L. (eds.), *The Neuropsychology of Cognitive Function.* (London: The Royal Society).

Shallice, T. (1988). *From Neuropsychology to Mental Structure.* (Cambridge: CUP).

Shelly, C. and Goldstein, G. (1982). Psychometric relations between the Luria-Nebraska and Halstead-Reitan Neuropsychological Batteries in a neuropsychiatric setting. *Clinical Neuropsychology,* **4 (3),** 128-133.

Smolensky, P. (1986). Information processing in dynamical systems: foundations of harmony theory. In McClelland, J.L. and Rumelhart, D.E. (eds.) *Parallel Distributed Processing: Explorations in the microstructure of cognition.* (Boston: MIT).

Spearman, C. (1904). The proof and measurement of association between two things. *American Journal of Psychology.* **15,** 72—101.

Spearman, C. (1923). *The Nature of "intelligence" and the principles of cognition.* (London: Macmillan).

Spearman, C. (1927). *The Abilities of Man.* (New York: Macmillan).

Spearman, C. and Jones, L.W. (1950). *Human Ability: A continuation of "The Abilities of Man".* (London: Macmillan.

SPSS (1989) Version 3.1. (Chicago: SPSS Inc.).

Stein. S. and Volpe, B.T. (1983). Classical "parietal" neglect syndrome after subcortical right frontal lobe infarction. *Neurology.* **33,** 797-799.

Stern. W. (1912). *Psychologische Methoden der Intelligenz—Prufung.* (Leipzig: Barth).

Sternberg, R.J. (1977). Component processes in analogical reasoning. *Psychological Review,* **84,** 353-378.

Sternberg, R.J. (1982). Reasoning, problem solving and intelligence, in Sternberg, R.J. (Ed.), *Handbook of Human Intelligence.* (Cambridge: CUP).

Sternberg, R.J. (1988). Toward a unified theory of human reasoning. *Intelligence,* **10,** 281-314.

Sternberg, R.J. and Gardner, M.K. (1983). Unities in inductive reasoning. *Journal of Experimental Psychology: General,* **112,** 80-116.

Stuss, D.T. and Benson, D.F. (1987) The frontal lobes and control of cognition and memory, in Perecman E. (ed.), *The Frontal Lobes Revisited.* (New York: IRBN Press).

Stuss, D.T., Benson, D.F., Kaplan, E.F., Weir, W.S., Neaser, M.A., Lieberman, I. and Ferrill, D. (1983). The involvement of orbitofrontal cerebrum in cognitive tasks. *Neuropsychologia,* **21,** 235-248.

Swisher, L.P. and Sarno, M.T. (1969). Token Test scores of three matched patient groups: left brain-damaged with aphasia; right brain-damaged without aphasia; non-brain-damaged. *Cortex,* **5,** 264-273.

Terman, L.M. (1916). *The Measurement of Intelligence.* (Boston: Houghton–Mifflin).

Terman, L.M. and Merrill, M.A. (1960). *Stanford–Binet Intelligence Scale.* (Boston: Houghton–Mifflin).

Thompson, E.H. (1951). *The factorial analysis of human abilities.* (London: Methuen).

Thorndike, E.L., Bregman, E.O., Cobb, M.V., Woodyard, E., & staff of the Division of Psychology of the Institute of Educational Research of Teachers College, Columbia University. (1927). *The Measurement of Intelligence.* (New York: Columbia University, Teachers College, Bureau of Publications).

Thorndike, E.L. and Lorge, I. *The Teacher's Word Book of 30,00 Words.* (New York: Columbia University).

Thurstone, L.L., (1938). *Primary Mental Abilities.* (Chicago: University of Chicago Press).

Undheim, J.O. (1981). On intelligence II. A neo–Spearman model to replace Cattell's theory of fluid and crystallized intelligence. *Scandanavian Journal of Psyvchology.* **22,** 181–187.

Vega, A. and Parsons, O.A. (1969). Relationship between sensory-motor defigits and WAIS Verbal and Performance scores in unilateral brain damage. *Cortex,* **5,** 229-241.

Vernon, P.A. (1991). Studying intelligence the hard way. *Intelligence,* **15,** 389-395.

Vernon, P.A. and Mori, M. (1989). Intelligence, reaction times and nerve conduction velocity. *Behaviour Genetics,* **19,** 779.

Vilkki, J. (1988). Problem solving after focal cerebral lesions. *Cortex,* **24,** 119–127.

Wang, P.L. (1987). Concept formation and frontal lobe function: The search for a clinical frontal lobe test. In Perecman, E. (ed.) *The Frontal Lobes Revisited.* (New York: IRBN Press).

Warrington, E.K. (1975). The selective impairment of semantic memory. *Quarterly Journal of Experimental Psychology,* **27,** 187-199.

Warrington, E.K. (1982). The fractionation of arithmetic skills: A single case study. *Quarterly Journal of Experimental Psychology,* **34A,** 31-51.

Warrington, E.K. (1984). *Recognition Memory Test.* (Windsor: Nelson).

Warrington, E.K. (1986). Visual deficits associated with occipital lobe lesions in man. *Experimental Brain Research Supplementum,* **11,** 247-261.

Warrington, E.K. and James, M. (1967). Disorders of visual perception in patients with localised cerebral lesions. *Neuropsychologia,* **5,** 253–266.

Warrington, E.K., James, M. and Maciejewski, C. (1986). The WAIS as a lateralizing and localizing instrument: a study of 656 patients with unilateral cerebral lesions. *Neuropsychologia,* **24,** 223-239.

Warrington, E.K. and Rabin, P. (1970). Perceptual matching in patients with cerebral lesions. *Neuropsychologia,* **8,** 475–487.

Warrington, E.K. and Rabin, P. (1971). Visual span of apprehension in patients with unilateral cerebral lesions. *Quarterly Journal of Experimental Psychology,* **23,** 423–431.

Warrington, E.K. and Shallice, T. (1969). The selective impairment of auditory verbal short–term memory. *Brain.* **92,** 885–896.

Warrington, E.K. and Taylor, A.M. (1973). Contribution of the right parietal lobe to object recognition. *Cortex,* **9,** 152-164.

Wechsler, D. (1939). *Wechsler-Bellevue Intelligence Scales.* (New York: Psychological Corporation).

Wechsler, D. (1944). *The Measurement of adult intelligence.* (Baltimore: Williams and Wilkins).

Wechsler, D. (1955). *Manual for the Wechsler Adult Intelligence Scale.* (New York: The Psychological Corporation).

Wechsler, D. (1981). *Manual for the Wachsler Adult Intelligence Scale—Revised.* (New York: Psychological Corporation).

Weigl, E. (1927). Zur Psychologie sogenannter Abstraktionsprozesse. *Zeitschrift fur Psychologie,* **103,** 2–45. (Translated by M. Rioch and reprinted (1948) On the psychology of so called processes of abstraction. *Journal of Abnormal and Social Psychology.* **36,** 3–33.

Weinstein, S. and Teuber, H.L. (1957). Effects of penetrating brain injury on intelligence test scores. *Science*, **125,** 1036-1037.

Whipple, G.M. (1910). *Manual of Mental and Physical Tests.* (Baltimore: Warwick and York).

Whiteley, A. and Warrington, E.K. (1978). Selective impairment of topographical memory: a single case study. *Journal of Neurology, Neurosurgery and Psychiatry,* **41,** 575–578.

Wissler, C. (1901). The correlation of mental and physical traits. *Psychological Monographs,* **3,** 1–62.

Wundt, W. (1862). *Beitrage zur Theorie der Sinneswahrnehmung.* (Leipzig and Heidelberg: Winter).

Wyke, M. (1967). The effect of brain lesions on the rapidity of arm movement. *Neurology,* **17,** 1113-1130.

Yerkes, R.M. (1921) Psychological examining in the United States Army. *Memoirs of the National Academy of Sciences,* **15.**

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