I. MACFARLANE SMITH, Ph.D., M.A., B.Sc., Ed.B.

SPATIAL ABILITY

Its Educational and Social Significance

UNIVERSITY OF LONDON PRESS LTD
Warwick Square, London E.C.4

Dedicated to Joan

PRINTED AND BOUND IN ENGLAND BY
HAZELL WATSON AND VINEY LTD
AYLESBURY, BUCKS

FOREWORD

by Professor P. E. Vernon
PROFESSOR OF EDUCATIONAL PSYCHOLOGY, INSTITUTE OF EDUCATION OF THE UNIVERSITY OF LONDON

THIS is a book which needed writing; and Dr. Macfarlane Smith, who has been closely identified with its subject-matter for over one quarter of a century, is clearly the person to write it. At first sight it would appear to be a highly technical survey of the statistical findings of certain mental tests. But the conclusions which the author draws from his careful weighing of the evidence have very important implications for current educational policy. It is high time, therefore, that educationists should take the trouble to acquaint themselves with this technical evidence, to ponder and act on it. Briefly stated, Dr. Macfarlane Smith's thesis is that British education, particularly that given in grammar schools, while stressing the development of general or all-round intelligence, has over-valued the verbal type of ability at the expense of its psychological opposite—spatial ability. The Crowther Report, Sir Charles Snow and many other public figures have, of course, urged the claims of mathematical, technical and scientific education, together with Britain's need for technologists and scientists. But few of such advocates possess any scientific knowledge of the nature of these abilities they wish to encourage, what is their common essence, nor how this essence is related to other abilities or to temperamental traits and personality qualities. Nor are they, perhaps, sufficiently aware that our current system of selection for secondary and university education actively discriminates against the pupil or student who is most likely to be talented in these directions.

Dr. Macfarlane Smith outlines a large body of work on spatial, performance, mechanical and other non-verbal tests and shows that there is a major underlying factor or type of ability which is best defined as the capacity to perceive and hold in mind the structure and proportions of a form or figure, grasped as a whole. This view reconciles the somewhat divergent results of British and American workers, since the latter have often used less appropriate multiple-choice tests involving recognition of details rather than perception and reproduction of complex wholes. There is ample evidence of the usefulness of such tests in selection for technical courses and training, for geometry and art. But in addition a comprehensive survey of work on mathematical aptitude indicates that, apart from general (preferably non-verbal) intelligence tests, the most predictive tests are also those of the spatial factor. In contrast, mechanical arithmetic tests give very little indication of future mathematical or scientific ability (hence Crowther's advocacy of 'numeracy' is psychologically misleading). It would seem that the perception of form is a general characteristic of the abstract thinking involved in mathematics and science, as distinct from the verbal thinking involved in most school subjects.

A good deal of interesting work is surveyed, also, on defects in spatial ability associated with brain injury, cerebral palsy and leucotomy; and a discussion of the relations of this ability to types of attention (analytic vs synthetic) and to EEG brain waves throws further light on the neurological and mental processes involved. Finally the author makes a strong case for some relation between the ability and temperamental qualities akin to introversion, masculinity and initiative. The lack of understanding between the scientist and the humanist probably arises from the fact that their modes of thinking are intimately bound up with their whole personality organization.

The book covers much controversial ground and not all psychologists will endorse all of Dr. Macfarlane Smith's interpretations. I myself wonder, for example, whether some of the correlations and factor loadings he quotes are not too small to justify some of his more novel conclusions; and I would see more virtues in the verbal type of thinking than he seems to allow. But it is all to the good that his evidence and arguments should be presented and marshalled logically, since this will stimulate others to undertake further badly needed research. I would, then, particularly commend the book not only to educational policy makers, but also to research students in education and psychology who are searching for fresh ideas to explore.

January, 1963 PHILIP E. VERNON

ACKNOWLEDGMENTS

IT is not possible to name individually all those who have helped in connection with the researches which form the basis of the present work.

My first introduction to a test of spatial ability occurred when I was a student at the University of Glasgow. Mr. C. A. Oakley, Lecturer in Industrial Psychology, requested volunteers to take a number of aptitude tests and I offered my services as a guinea pig. One of my fellow students who also took the tests and who has since taken a keen interest in my researches on spatial ability was Dr. A. K. Cairncross, the well-known economist. My long-standing interest in the subject seems to date from this incident and from the discussions to which it gave rise.

I received my initial training in psychology in the department directed by Dr. R. H. Thouless, whose classes were a source of lasting inspiration. My interest in the subject had been aroused by the experience of acting as a subject for Dr. Thouless in his first experiments (1931) on phenomenal regression, now called the constancy effect.

Dr. Thouless was then concerned with the problem of demonstrating the existence of a group factor in the abilities underlying the experiments on constancy. Thus, not only did he direct my interest to the field of shape-perception but he also familiarized me with one of the early techniques of factor-analysis. Some years afterwards, it became apparent that Dr. Thouless' researches were more closely related to mine than we realized at the time. We had in fact been studying different aspects of the same factor.

During my first investigation on spatial ability, I was greatly assisted by Dr. W. Stephenson of the University of Oxford, who responded to a postal request by supplying samples of test-materials, some of which were identical with those used by El Koussy in his well-known investigation (1935).

During the second world war, I served as a R.E.M.E. officer, responsible for servicing radar equipment, and I had little contact with the work of psychologists, but after the war Professor R. A. C. Oliver encouraged me to continue my pre-war investigations. When I joined the staff of the National Foundation for Educational Research as their first officer in charge of Tests Services, Professor P. E. Vernon acted as a supervisor of this research.

My interest in spatial ability has been sustained over the years because of my role as supervisor of the researches of a number of M.Ed. students, many of whom worked in this field and contributed in various ways, notably R. Edwards (now Professor), J. S. Lawes, C. Stewart, C. C. Taylor, F. R. Witty and J. Wrigley (now Professor). I am also indebted for some help to a former colleague, J. J. C. McCabe, and to former students R. Anderson and J. C. Gardener.

In 1959 I was awarded the Research Fellowship of the Institute of Education of the University of Durham and I took the opportunity of carrying out a follow-up study of the validity of secondary school allocation procedures. For help in the collection of data I am indebted particularly to Mr. L. Charnley and Mr. J. Clitheroe, Officers of the City of Carlisle Education Committee, to Mr. T. H. C. Walker, Headmaster of Tynemouth Technical School, and to Mr. T. C. Wonnacott, Headmaster of Higginshaw Secondary Modern School, Oldham.

During my tenure of the Research Fellowship I received valuable assistance from Professor Brian Stanley, Director of the Institute of Education of the University of Durham, and also from the Institute Advisory Committee on Research. It was during this period that the present work took shape.

Subsequently, when I was appointed Director of the Research Unit at Garnett College, Roehampton, Professor P. E. Vernon read the draft of the book and made numerous helpful comments and suggestions. Professor Vernon's influence on the work will be apparent to all who are familiar with his writings.

While the present volume is the direct outcome of my tenure of the Research Fellowship of the Institute of Education of the University of Durham, the views expressed and conclusions reached in it are largely the result of reflections which have taken place from time to time over the last thirty years. For these views I must accept full responsibility, though, of course, they have been fashioned by innumerable circumstances and influences in my educational and family background. In so far as they have merit, much of the credit must go to the teachers who have stimulated and inspired me in the past. It would be ungrateful not to pay tribute to my old University, for it was while I was a student at Glasgow that my interest in the subject was first awakened. Undoubtedly another formative influence was a family tradition which valued technical skill and which fostered a youthful enthusiasm for biography and clan history.

It is scarcely surprising that a student with such a family background and attending a University associated with names such as Watt and Kelvin should become interested in the nature and inheritance of scientific and technical abilities. Thus, it may be deemed not inappropriate if I conclude by quoting an ancient motto of the Clan Macfarlane referring to a traditional interest in the science of astronomy:

Numen lumen, astra castra. (The Lord my light, the stars my camp.)

I. M. S.

GARNETT COLLEGE,
DOWNSHIRE HOUSE,
ROEHAMPTON LANE,
ROEHAMPTON, S.W.15

CONTENTS

ILLUSTRATIONS

LIST OF TABLES

PART ONE

Chapter one

Spatial Ability and the Selection Problem

The shortage of scientific manpower

It has often been said that, in an age of scientific revolution, a nation's economic progress and survival depend largely upon the quality of its scientific, technological and technical education. Hence, it is widely recognized that the present acute shortage of all grades of scientific and technical personnel is one of the most critical problems affecting the future well-being of Great Britain. While the shortage appears to be world-wide,* in Britain it approaches the dimensions of a national crisis. Numerous authorities have estimated that in proportion to the population, both the United States of America and Soviet Russia are producing several times the number of scientists and engineers that are being produced in the United Kingdom. C. P. Snow (1959) has estimated that if we compare like with like, putting scientists and engineers together, Britain is training at a professional level one Briton to every one and a half Americans and to every two and a half Russians. He has given the following figures of graduates trained per year (scientists and engineers combined): United Kingdom 13,000; U.S.A. 65,000; U.S.S.R. 130,000.

Snow states that the Russian output of engineers is now much larger than that of the rest of the world put together, approximately, 50 per cent larger. While only slightly more pure

* C. F. McCrensky (1958) *Scientific Manpower in Europe*. London, Pergamon Press.

scientists of all kinds are being trained than in the United States, in physics and mathematics the balance is heavily in the Russian favour.

Reliable comparative figures are difficult to obtain, however, and the writer has found that estimates vary widely. A British Labour Party statement of policy, dated October 1961, asserts that per head of the population, the United States is educating each year two to three times as many, and the Soviet Union five times as many, highly trained technologists as Great Britain. J. Vaizey (1961), of London University Institute of Education, has estimated that the number of newly qualified scientists and technologists per million of the population is no larger in Britain than in Yugoslavia. It is half that of Canada, a third that of Russia and about a seventh that of the United States. In spite of these differing estimates, there is general agreement that Britain is lagging behind other countries in the production of scientists and engineers. In technological education, Britain lags behind not only great nations like Russia and the United States, but also behind smaller countries like Switzerland, France and Western Germany.

Statements regarding the long-term demand for scientific manpower and Britain's capacity to meet this demand have been even more contradictory. In a report issued by the Stationery Office in London in 1956, estimates were given both of the short-term and long-term demands for scientific manpower in Britain. It was suggested that to maintain an annual rate of growth of 4 per cent in industrial output, it would be necessary to increase the number of qualified scientists and engineers from the 1956 level of 135,000 to somewhere in the region of 220,000 in 1966—an increase of over 68 per cent. A 70 per cent increase in the number of engineers would be needed and a 50 per cent increase in the number of scientists. To produce this increase, the output of trained scientists and engineers would have to have been doubled by 1960. A British Labour Party pamphlet, published in 1961, has suggested, however, that the official target for the output of scientists and engineers in 1970 is quite inadequate. It proposed that Britain should aim to produce a 15 per cent increase in the yearly output, which would mean a doubling in seven years and a three-fold increase in ten. This aim was considered none too high to meet the challenge of the seventies.*

In January 1962, the American National Science Foundation published a report on education in the Soviet Union, which gives comparative figures for the U.S.A. and the U.S.S.R. This 900-page report was compiled by Mr. Nicholas de Witt, an associate of the Russian Research Centre at Harvard. It concludes that the Soviet Union is now turning out twice as many scientists and engineers as the United States.

The current American space programme, according to the report, will absorb the services of all available trained staff. The present (1962) annual total of American science and engineering graduates is 90,000 compared with 190,000 in the Soviet Union. Before 1970 the Soviet total will be expanded to 250,000—over twice the anticipated number in the United States. In 1959, 57 per cent of all B.A. graduates in the Soviet Union were in engineering, science and applied sciences. The comparable percentage in the United States was 24.

The report disposes of the widely held belief that American and West European educational standards are higher than those in the Soviet Union. It maintains that Soviet higher education in science and engineering transmits about as much knowledge as, and at times more than, American or West European higher institutions. The 'time inputs' required in Soviet education, it states, moreover, are invariably higher than in the United States.

A more optimistic view of the situation in Britain was expressed in a report published in October, 1961, by the British Advisory Council on Scientific Policy, which suggested that the country will have a surplus of scientists and technicians by 1970. According to the Council's calculations, by 1965 Britain should have achieved the necessary annual output of qualified men and

* For an exhaustive analysis of data on Britain's scientific and technological manpower, reference should be made to the comprehensive treatise by Payne (Stanford University Press, 1960).

women and from then onwards, production would exceed demand. This forecast arose from an earlier estimate made in 1956 by the Council's Manpower Committee that an annual output of 20,000 qualified people should be achieved between 1966 and 1971.

The 1961 report suggested that this figure would be reached by 1965 and that the output of 30,000 may be achieved by 1972. It recognized, however, that several contingencies might falsify the figures, and that in any case, supply and demand in individual disciplines were less easy to equate.* There was likely to be, for example, a continuing shortage of mathematicians.

In its annual report, published in January 1962, the Council commented that in some quarters the earlier report of its manpower committee has been "seriously misunderstood". Despite a six-fold increase of new qualifications likely in the early 1970's compared with 1938 there will still be a dearth of men and women with scientific education to fill posts in management, administration and other professions generally. A very similar view was expressed by the Institute of Physics and the Physical Society in a memorandum to the committee on higher education (1962). The memorandum stressed that America and Russia were investing heavily in physics to ensure a supply of well-trained scientists.

"We are certain," it stated, "that the supply of such people in Britain will not be remotely sufficient in 1965 or in any period for which it would be worth making a forecast."

The serious shortage of teachers of mathematics might well be one of the contingencies which may falsify the forecast of the

* Since this passage was written, the Advisory Council for Scientific Policy in Britain has reported (October, 1963) that the figures would in fact be falsified. Instead of a surplus of qualified scientific manpower in 1965, there would probably be a shortage of some 28,000. There would be major shortages of mathematicians, electrical engineers and possibly of physicists and mechanical engineers. The report emphasized that the shortage would be mainly one of technologists.

A statistical summary published in 1963 by the United States National Science Foundation has shown that in America specialized manpower in science was growing at the rate of about 4·3 per cent per year. Estimates for 1970 foresaw a total of 4,000,000 persons working as scientists, engineers, technicians or science and mathematics teachers. In these four manpower categories, there would be by 1970 an increase of 1,300,000 over the 2,700,000 estimated for 1963.

Advisory Council's manpower committee. The Labour Party pamphlet from which we have already quoted has described the situation as "desperate" and has called for "desperate measures to relieve it".

With almost monotonous regularity, leading authorities in Britain have been drawing attention to the seriousness of the teacher shortage and have emphasized that the situation is deteriorating. Sir John Cockcroft (1961) has expressed his views in the following passage:

"Part of the reason for our present mathematical deficiencies is the fact that the country is short of mathematicians. Their employment has increased by 50 per cent in the past three years, due partly to the development of computers in industry, and the supply is quite inadequate for industry, Government and the schools. As usual, the schools are taking the brunt of the deficiency. Last year (1960), the direct grant schools were able to fill only 61 per cent of their mathematics vacancies. The teaching of the subject is now in a serious state. The supply of mathematicians coming from the Universities is far too low . . ."

Professor Bryan Thwaites (1961), of Southampton University, made the following comments: "The truth is that the whole profession of mathematics is like a very sick man, a man in a high fever and still restlessly active, but suffering even so from a wasting disease, advancing so fast that one hesitates to speak too loudly of recovery. . . . If no recovery in fact comes about, mathematical education as it exists today is likely to die a natural death within twenty years. So desperate is the situation. . . ."

Summing up, Professor Thwaites said that "for the Universities, the present staffing deficiency was at least one year's total output of Ph.D.s and the maintenance of staffs at their present level required a doubling of the annual output. For the grammar-type schools, the present deficiency equalled at least three years' total output of graduate mathematicians, and the maintenance of staffs required at least a doubling of graduates in departments of education. These figures took no account of the difficulties of secondary modern schools. . . ."

No doubt many factors have contributed to the present difficult situation in Britain, but it seems probable that a vicious circle has already begun to operate and that this will create a more difficult situation in the future. The growing demands of industry for qualified technical personnel are denuding the schools of the normal supply of teachers of mathematics and of science and the shortage thus created will in turn have an adverse effect on the future supply of scientists and engineers to industry. While the shortage of teachers of mathematics and science is particularly serious because of its long-term effects, there are acute shortages in numerous highly essential technological occupations. Draughtsmen, for example, appear to be in short supply, as also are chemical engineers and technicians (Alexander, J., 1959). There is an unsatisfied demand for technicians of all kinds.

The pool of ability

McIntosh (1962) has stressed the fact that there are considerable untapped reserves of talent which ought to be developed and has suggested that there is an urgent need for scientific investigation to discover the factors which prevent this development. In considering the arguments for increasing facilities for higher education, it is necessary to take account of the size of the reserves of talent. But any estimate of the size of the pool of ability must be qualified by the reservation that this figure is valid only for conditions existing at any given time. Under different conditions, the figures might be very different.

Teachers are well aware of the fact that there are limits to the intellectual achievements of their pupils. Some pupils seem to be incapable of mastering Latin, at least when taught by conventional methods, and never reach a level which would enable them to read and appreciate Latin literature in the original. There is a growing awareness that mathematics also presents a stumbling block and many apparently intelligent adults seem to be unable to make progress in abstract mathematics. It is possible, however, that if methods of teaching mathematics could be greatly improved, even at the primary stage, the size of the pool of mathematical ability might be substantially increased.

In McIntosh's view, one of the most urgent educational problems is that of finding out how many people are capable of doing these things, how many are not doing them and what are the factors preventing them from realizing their full potential. He defines a pool of ability as that part of a population which is capable of success in a clearly defined type of higher education. There is not one pool of ability, but a number of pools and they differ according to the criteria by which they are defined. It is a matter of concern in Britain to discover how much greater is the pool of mathematical ability than the present output of mathematicians. McIntosh rightly emphasizes that in studying either a population sample or an age-group, it would be folly to use only one measure to estimate a pupil's potential ability. The size of the pool of ability cannot be estimated from anything as simple as the I.Q. distribution. The I.Q. is merely one of several measures which might be used to estimate potential ability, and it is necessary to make revised estimates based on a pupil's actual progress at school. There is clearly a very great need to devise methods for identifying the different types of ability which are necessary for success in subjects such as mathematics and science.

The criterion by which 'success' is judged must also be considered with care. A distinction must be made between 'being successful' in a course of education and 'benefiting' from it. Some students may benefit from a course in which they may have very little to show in the way of examination results.

The analysis of abilities

Any discussion of the 'pool of abilities' and of the problem of identifying talent necessarily requires some understanding of the structure of human abilities and of the techniques involved in their measurement. Only a very brief reference to the basic principles of mental measurement can be given here and the reader who is not familiar with the field should consult standard works, such as that by Vernon (1950).

The most far-reaching attempt to place the psychology of mental measurement on a sound, quantitative foundation was that of Spearman who claimed that mental abilities could be analysed into factors, a general factor *g* and numerous specific factors ($s_1, s_2, s_3 \ldots$). He believed that for any individual, *g* was a measure of the mind's ability to educe relevant relations between ideas or to educe correlates corresponding to a given relation.

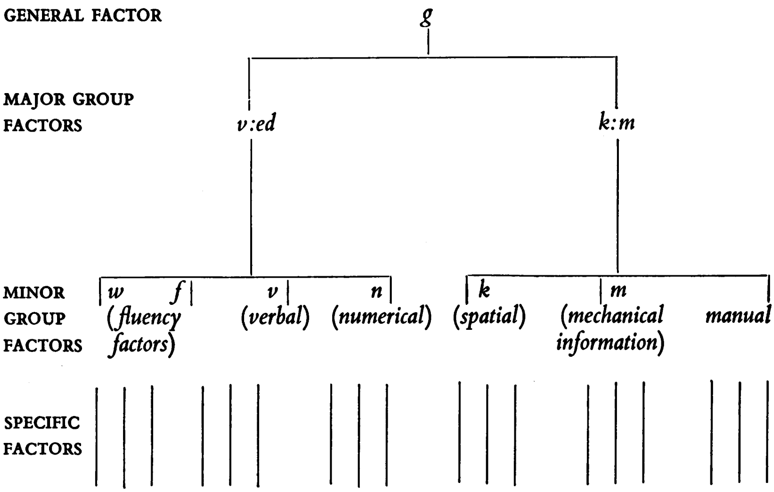
This two-factor theory of Spearman has provided a logical basis for constructing tests for measuring *g* and it has been found to give satisfactory results in practice. By analysing the correlations between tests it is possible to identify those tests which have high saturations in, or loadings of, the general factor *g*. Though each test has its own specific factor, when a number of such tests are combined together to form one test, the various specific factors tend to cancel out so that the total score provides a better measure of *g*.

More recent factorial studies have brought to light the existence of a number of group factors, which enter into some distinct abilities but not into all abilities, and which correspond fairly closely to the more important aptitudes. The evidence for the existence of these group factors is particularly strong in the case of the verbal, spatial and numerical aptitudes and the corresponding group factors are denoted by *v*, *k* and *n*. There is considerable doubt as to the existence of a unique group factor corresponding to mathematical aptitude.

It is possible to analyse mathematically the inter-correlations of a set of test-scores by a process known as factor-analysis. There are now many different methods of factor-analysis, but the results obtained are broadly equivalent. They consist essentially of systematic techniques for removing the effect of each factor in succession from the original table of correlations.

Usually, when the inter-correlations of the scores of a set of mental tests are analysed, the first factor to be extracted corresponds approximately to *g*. After the removal of *g*, the tests tend to fall into two main groups: the verbal-numerical on the one hand (sometimes referred to as the *v:ed*-factor); and the spatial-mechanical-practical on the other (sometimes referred to as the *k:m*-factor). If there are sufficient tests in the battery and the analysis is carried far enough, the two main groups sub-divide into minor groups factors: verbal *v* and numerical *n* on the one hand; and spatial *k*, mechanical information *m* and manual on the other.

Thus, we may think of human abilities as arranged hierarchically like a family tree, as shown in the following diagram.



Hierarchical structure of human abilities

The abilities needed by industry

The technical staff required in modern industry may be conveniently classified into four categories as follows:

1. Research scientists (including mathematicians and statisticians);

2. Technologists (both development and production engineers);

3. Technicians;
4. Skilled craftsmen.

There is a need to find ways of identifying potential abilities for any of these categories of occupations at a sufficiently early age to enable the talents to be developed to the full. Skilled craftsmen and technicians are likely to require among other qualities a high degree of spatial or mechanical ability, called by Vernon *k/m*. Research scientists, mathematicians and technologists will certainly require a high degree of general ability, usually denoted by *g*, but it is possible that they may also require some degree of spatial ability *k*. All four categories will require to have had at least a basic training in mathematics.

Thus, it is particularly necessary to find methods of identifying spatial and mathematical aptitudes at an early age. It has sometimes been said that the bottleneck in the present shortage of technical personnel in Britain is mathematics. There are not enough people studying mathematics. There are reasons for believing, however, that talent for mathematics may involve specialized aptitudes, which may be possessed by pupils who are not gifted in other scholastic subjects. This view has been expressed by McIntosh (1959), who made a number of case studies of such pupils in his follow-up study in Fifeshire. Clearly, the existence of such special aptitudes must be taken into account in the procedures by which pupils are selected both for grammar schools or technical schools or for grammar school courses or technical school courses. The type of secondary school organization, whether tripartite, multilateral, bilateral, or comprehensive, will have to be taken into account in considering selection procedures, but it will not affect the essential problem. Even in a comprehensive school, due account must be taken of a pupil's aptitudes, if he is to derive the maximum benefit from his education.

At the present time, the majority of scientists and technologists receive their secondary education in grammar schools. Many studies have been made of the efficiency of the selection procedures by which pupils are admitted to these schools. But, hitherto few of these studies have investigated the problem in the light of the shortage in the supply of scientific and technical manpower.

McIntosh (1959) has discussed the problems of guidance and selection in the light of the need to increase the production of pupils of university calibre, but he seems to have no radical suggestions to offer. The proportion of pupils who achieved a good Leaving Certificate in his age group of some 4,000 was 6·3 per cent and he estimated that with an ideal allocation procedure and full parental support, the figure might be increased to 11 per cent. These figures, however, relate to the situation in Fife in which 24 per cent of pupils are offered full secondary education. It cannot be concluded that a greater percentage might not reach the same standard with a different type of secondary school organization. Sir Geoffrey Crowther has repeatedly expressed the view that it is among those who fail at the early age of 11 plus that Britain loses most of her latent and badly needed talents.

Tests used in selecting for secondary courses

The tests which are most commonly used are known to be highly efficient for predicting all-round success in grammar-school courses. Thus McIntosh found that the combination of two verbal I.Q.s, semi-objective tests of attainment and scaled teachers' estimates in English and arithmetic yielded a correlation of ·872 with all-round marks in the fifth and sixth years of the senior secondary school. It is less certain, however, that these measures would be equally successful in predicting success in mathematics, physics and technical subjects. McIntosh found that teachers' estimates and the test of ability in English had greater validity for predicting marks in mathematics and science than had the test and estimates in arithmetic. This was true in the senior secondary schools, whereas in the junior secondary schools with their greater emphasis on practical subjects the relationship was reversed.

There is some evidence that some of the tests normally used for grammar school selection in Britain have *negative* value for predicting success in science courses at the university. Nisbet and Buchan (1959) followed-up a group of eleven-year-old pupils, who were eventually admitted to Aberdeen University. They compared the standardized scores obtained in the original selection tests with the results gained in the School Leaving Certificate examinations and in courses at the University (in first, third and final year examinations). The selection procedure employed in Aberdeen City involved the use of two verbal reasoning tests (I.Q.s), and attainment tests in English and arithmetic, as well as teachers' estimates.

Nisbet and Buchan calculated correlations between each of these scores, and the results obtained in the School Certificate examinations and in examinations in arts, science and medicine at Aberdeen University. They found that for the 1953 university entrants who took courses in science, their three criteria of success (first, third and final year) correlated negatively with the 11 plus attainment test-scores in English; two of the criteria (first and third year) correlated negatively with teachers' estimates and one of the criteria (for third year courses) correlated negatively with one of the verbal I.Q.s. Undue reliance cannot, however, be placed on these figures, since the number of students in the 1953 group was only 34, but a similar negative correlation between science and the 11 plus English score was found again in the 1954 group of 27 students, though it was not found in the 1952 group of 31 students. For the 1953 and 1954 entrants, the arithmetic score was a better predictor of success in university science than any of the other test-scores. All the test-scores were found to give positive, though moderate, correlations with criteria of success in university courses in arts and medicine.

It would appear from these findings that the 11 plus selection procedure in Aberdeen seems to operate moderately successfully from the point of view of its long-term validity for selecting potential arts and medical students, but it appears to give preference to pupils who are likely to be *less* successful in university science courses. Since the English tests tend to correlate negatively with criteria of success for science courses and positively for arts courses, there are grounds for suspecting that pupils who might succeed in university science are being rejected by the grammar schools because they lack the linguistic abilities required for success in the 11 plus examination.

University science courses appear to involve abilities which differ from those required for all-round success in the wider range of subjects taught in the grammar schools. Indeed, there is now some evidence that even for predicting success in the grammar school, the test batteries at present in use tend to over-emphasize linguistic abilities.

Nisbet and Buchan found that two of the 11 plus selection tests gave slightly negative correlations, both for science and medical students, with the number of passes in the Leaving Certificate Examination. Yates and Pidgeon (1957) have shown that the predictive value of the selection battery can be improved by including a spatial test in the battery. They studied numerous combinations of tests and estimates to discover the best combination of the predictor variables for predicting all-round success in the grammar school. Their criterion was the scaled estimates by the secondary school headmasters of the success of the pupils after two years in the secondary school. These estimates (based on the results of internal examinations) were scaled against scores in a verbal reasoning test given to all the pupils (876 in number).

The best prediction of all-round success was given by the combination 4 P.H.A + 2E + Sp.I, where P.H.A. is the Primary Head Teachers' Assessment, E is the score in a special English test by A. F. Watts, and Sp.I is the score in N.F.E.R. Spatial Test I (Macfarlane Smith). This weighted battery gave the highest correlation with the criterion, namely ·931.

Commenting on this finding, Yates and Pidgeon write (p. 72 of their Report): "The appearance of a test of spatial ability in this battery is deserving of comment. Such tests are not usually considered as useful predictors of success in grammar schools. It is possible, however, that the abilities that are measured by this kind of test are related to subsequent success in some branches of mathematics and science. It would seem to be desirable for further research to be undertaken to investigate this point."

If it should be confirmed that spatial ability is important for success in some branches of mathematics and science, it would follow that the 11 plus examination, as it is now conducted by most Local Education Authorities, is failing to identify an unknown percentage of pupils with an aptitude for mathematical studies. Pupils with high spatial ability may fall just below the border-line on the conventional combination of test-scores and may consequently be directed into secondary modern schools. There is no doubt that the tendency of current selection procedures (1963) is to reject rather than to select pupils of high spatial ability. Spatially gifted pupils are not represented in the grammar schools to the same extent as pupils of high verbal ability, as was shown by Dempster (1951) in an investigation carried out in Burton-on-Trent. The grammar-technical group of boys usually had higher verbal than spatial scores, whereas the modern school boys almost as frequently had higher spatial than verbal scores (roughly speaking in the ratio 2:1 in each case). Dempster made the following comment on his findings: "This evidence shows, of course, that the tests or examinations which had been used for selecting the grammar-technical group of pupils tended to give more weight to verbal ability than to spatial ability."

A similar result was obtained by J. C. Gardener, who administered verbal and spatial tests to 95 pupils in two Northumberland grammar schools. The only reason for testing this sample was that it could be done conveniently in the two chosen grammar schools.

Since the two tests (verbal and spatial) had been standardized with the same mean (100) and the same standard deviation (15), the standardized scores could be compared directly. In the sample of pupils tested, the numbers having standardized scores greater than or equal to 134, 131 and 128 on the two tests were as shown in Table I.

Table 1

Comparison of numbers of grammar school pupils obtaining high scores on verbal and spatial tests (Gardener)

NUMBERS OF PUPILS	M.H. VERBAL TEST (ADV. I)	N.F.E.R. SPATIAL TEST I
Scoring 134 *or above*	15	1
Scoring 131 *or above*	30	4
Scoring 128 *or above*	49	6

While it cannot be claimed that this sample of grammar school pupils is likely to be representative of all pupils in Northumberland grammar schools the discrepancies between the numbers of pupils obtaining high scores in the two tests is much too large to be ascribed to sampling error. There is no doubt that in these two schools at any rate, pupils with high spatial ability are not represented in numbers approaching those of pupils with high verbal ability. The reason, of course, is that the selection examinations tend to give an advantage to pupils with high verbal ability, because most of the tests are of a linguistic nature. A large proportion of spatially gifted pupils fail to gain admission to the grammar schools because they are handicapped in performing these tests. If it is true that such children are likely to include potential engineers, mathematicians and other scientific workers, then there should be a possibility that the supply of such workers may be increased by means of a suitable modification of the selection procedure. It might be supposed that pupils with high spatial ability who have failed to gain admission to a grammar school would probably be offered a place in a technical school. Such an assumption, however, would not be justified. In Britain as a whole, local authorities have been slow to make use of available tests of spatial ability.

While many authorities, such as Northumberland, have regularly administered both verbal and non-verbal tests of mental ability, true spatial tests have not been used extensively, except occasionally for the testing of relatively small groups of pupils recommended for transfer at 13 plus.

In 1951, the Chief Education Officer for Middlesex sent a letter to the L.E.A.s in 101 counties and county boroughs, enquiring about their methods of selection for secondary technical education. These L.E.A.s were chosen because it was known that they were responsible for at least one technical school in the area. Replies were received from 80 Chief Education Officers. These showed that in the great majority of cases, the usual battery of verbal reasoning, English and arithmetic tests was administered. A few authorities relied on tests of English and arithmetic alone, and a very few on a test of verbal reasoning alone. (In the latter cases, an interview and Primary Head Teacher's report was regarded as an essential part of the procedure.)

Only 18 of the 80 replies mentioned the use of a spatial test. M.H. Space Test I was mentioned 13 times and the recently published N.F.E.R. Spatial Test I was mentioned twice. Nine of the replies stated that some other spatial test had been tried at some time. Thus, Peel's Group Test of Practical Ability was mentioned six times; N.I.I.P. Form Relations twice; Peel's V.S. 17 once; four replies mentioned aptitude tests but gave no name; one mentioned a 'drawing interest and observation' test; and finally Birmingham referred to the very extensive battery of aptitude tests used in their vocational selection studies (Allen, E.P. and Smith P. 1931, 1934, 1939). Four replies stated that a spatial or other special aptitude test had been dropped, two of these mentioning that this was because of their high correlation with the more usual tests. Nine expressed doubt, advised caution or stated that they were using such tests only experimentally. Two stated that Peel's Group Test of Practical Ability appeared to be very satisfactory, and the Authority which used its own locally devised 'drawing interest and observation test' reported that it was very successful.

By 1952, some fifteen Local Authorities had used one or other of the recently published N.F.E.R. spatial tests. Since then, some nine Authorities have been regularly using N.F.E.R. spatial tests at the age of 11 plus as part of the normal selection procedure, though many more include a spatial test in the battery administered to the groups of pupils aged 13 who have been recommended for re-examination and transfer from modern schools to some form of selective secondary education.

In 1960, the National Foundation for Educational Research carried out a survey of the different procedures used by Local Authorities for selection at the age of 11 plus. Further enquiries were made of the nine Authorities who reported that they used spatial tests as part of their procedure. The replies showed that three of the nine no longer used spatial tests, two having based their decision on subjective impression only and the third on the result of statistical and other analyses though no details of this were given. Four Authorities used spatial tests with only part of their group. Two administered them to all children, though one of these made use of the results only in borderline cases.

Two follow-up studies had been carried out in Preston, one study showing that the spatial test was good for predicting success in technical subjects in the grammar school and the other study being less favourable. In a pilot study carried out by the National Foundation for Educational Research (Yates and Barr, 1960) in a county Borough (Wallasey) a variety of types of test were added to the standard battery of Moray House verbal reasoning, English and arithmetic tests. The criterion for the follow-up investigation was the head teachers' assessment based on cumulative records at the end of four years of the technical course. Of the tests used (Non-Verbal Test 3, Spatial Test 2, Watts' Group Performance Test, Clerical Test 1, and the Lambert-Peel and Devon Interest Tests), the spatial test gave the best prediction (·41), the degree of prediction not being significantly improved by any combination of tests.

Differential selection for grammar and technical courses

Reese Edwards (1960) has reported the results of an extensive survey, carried out between 1958 and 1960, of a large number of secondary technical schools. One chapter on the classification and selection of pupils is devoted to a discussion of the evidence for and against attempts at selection by means of psychological tests. He concludes from his investigation that opinion in England does not favour the use of spatial tests, though he quotes with approval statements to the contrary such as that made in a Report (1950) to Southampton Education Committee, to the effect that "where selection is for technical education alone, whether this is carried out at 11 or at a later age, spatial tests have been shown to have considerable value."

At the end of a detailed discussion of the selection problem, Edwards states his conclusions in the following words:

"It is here contended that the boy with a high level of *g* and relatively high verbal ability can successfully undertake either a course in a secondary grammar school or a course in a secondary technical school. . . .

"It can be said that:

1. A number of boys of good ability can take either a secondary grammar school course or a secondary technical course with a prospect of ultimate success.

2. Certain boys will be more successful in a purely secondary technical course than in a purely secondary grammar school course; and

3. Certain boys will be more successful in a purely secondary grammar school course than in a purely secondary technical school course, but that

4. It is exceedingly difficult, if not impossible, in the present state of our knowledge, to differentiate between boys in categories (2) and (3) at the age of 11 or 12.*

"When an age-group of 11 plus children is taken, it is possible, with a fair degree of accuracy, to separate on the basis of their past records in the primary school, the teachers' estimates of their ability and attainment, and of tests of *g* into those who are likely to succeed in a specialized course of secondary education and those who are not. After there has been a classification of pupils into those who can profit from a specialized secondary education course

* A somewhat similar view has been expressed by Gooch, cf. Gooch (1962) and the reply by the writer (1963).

and those who are not likely to succeed in such a course, then the final decision as to whether the grammar school course or the technical school course is to be taken should be made by the parents."

Thus, in Edwards' view, the decision as between grammar and technical school education should be made in *accordance with parents' wishes.* A consideration of aptitude would play no part in this most vital decision. He suggests, however, that it would be advantageous if the years from 11 to 13 should form a diagnostic period, during which all pupils should follow, as far as possible, the same type of course. A review could then be made at the age of 13 before a final decision is made as to which ultimate course, whether grammar or technical, the pupil should enter for the completion of his secondary education. This recommendation implies a postponement of the final decision until the age of 13. There is no mention, however, of the use of aptitude tests during the diagnostic period to facilitate the making of a decision. He does stress the fact that general ability is just as important for technical as for academic courses, and this is a point which has not always been appreciated in the past.

In a later chapter, he states that "Art and technical drawing are, in a sense, the key subjects in the boys' secondary technical school and craft subjects must be closely integrated with these, if the maximum value is to be derived from the teaching of crafts."

There is now abundant evidence that art and more especially technical drawing are subjects which require a high degree of spatial ability, as do most of the craft subjects, such as woodwork, metalwork and building crafts. On the other hand, it has been repeatedly shown that the majority of grammar school subjects, such as English, modern languages and social studies, depend in large measure on verbal ability. Thus, there are grounds for adopting the view contrary to that maintained by Edwards, that grammar school and technical school courses depend to a large extent on different, if not opposing, ability factors. It is true that both groups of subjects also involve the general factor *g* and the greater the contribution of this common factor the more difficult becomes the problem of differential selection. This problem will be discussed more fully in Chapter five.

Our results suggest that pupils who do well in tests of verbal intelligence (i.e. pupils whom Edwards describes as "having a high level of *g* and relatively high verbal ability") do not as a rule distinguish themselves in technical courses. Such pupils appear to advantage when success is judged by written answers to examination questions. When, however, the criterion depends on ability to do an actual job, whether involving an actual construction or its representation by means of a drawing, the possession of high verbal ability confers no advantage.

Edwards quotes statements made by some of the head teachers he interviewed to the effect "that a considerable number of pupils in their schools are found to be incompetent with their hands. Apparently, practical work is beyond them." The cure, Edwards thinks, is to be found by diverting "the energies of these pupils . . . into other channels, since it is inadvisable to let them continue the serious study of these subjects, if they prove to be unfitted to do so." It may be questioned whether the deficiency shown by these pupils is something lacking 'in their hands'. It is more likely to be something lacking 'in their heads' since spatial ability is quite as intellectual as verbal or numerical abilities are. It is very probable that those pupils 'whose energies should be diverted to other channels' have been committed to these courses because of the inadequacies of current selection or guidance procedures, in which undue reliance is placed on parents' wishes and little account is taken of the pupils' aptitudes.

The success of secondary technical schools

In spite of these serious defects in methods of recruitment, technical schools have fully justified their existence by providing a form of education which has satisfied a real need in the great majority of their pupils. It is interesting to find that Edwards reports on the work of the technical schools of 1960 in very much the same terms as the Spens Committee wrote in their report of

1938 of the education provided by junior technical schools. The Spens Committee stated that "we have found in the schools we visited an atmosphere of vitality, keenness and happiness that was not only refreshing, but afforded a sure index that the curriculum and its methods of treatment so appealed to the pupils that the process of education was developing smoothly and unrestrainedly."

Writing of the technical school of 1960, Edwards comments that, in spite of inadequate selection procedures and the general inferiority of accommodation and equipment, "it is everywhere noted for the success that attends its pupils and for the evident satisfaction that so many of its teachers find in their work. . . . Indeed, it has been found that with pupils of comparatively low intelligence, the constructive impulse, if given adequate expression and outlet, can have a remarkably stimulating effect upon other creative faculties, upon the expression of intelligence itself and upon progress in academic studies." (Edwards, 1960.)

Most heads of technical schools would probably interpret the success of their schools as being due to the obvious link between technical subjects and the needs of industry and commerce. They suppose that the technical bias gives a sense of purpose and reality to the work and so engenders a favourable attitude to work and a sense of responsibility.

It is possible, however, that there is an important contributory factor to the success of these schools which is not generally recognized. Many pupils, whose aptitudes are spatial rather than verbal and who have achieved only moderate success in ordinary scholastic subjects will discover on being transferred to a technical school that they can achieve much greater success in technical subjects. It is to be expected that such pupils with hitherto undistinguished records will be stimulated and encouraged and will communicate their enthusiasm to their teachers.

If this is indeed one of the secrets of the remarkable successes of these schools, it behoves administrators to ensure that their selection procedures are as valid as possible. Exclusive reliance on parents' wishes may well cause frustration among the unfortunate misfits as well as denying to many technically gifted pupils an opportunity to develop their talents to the full.

There are some 225 secondary technical schools in England and Wales and 63 bilateral or multilateral schools most of which provide technical courses. Nearly 100,000 pupils attend secondary technical schools and more than 45,000 attend bilateral or multilateral schools. It is likely that the number of pupils taking technical courses will increase very considerably as a result of the drive to increase the output of technically trained personnel.

The validity of the procedures by which pupils are selected for these courses is a matter of considerable national importance. There is a very great need to investigate thoroughly the validity of current selection procedures and in particular to assess what improvement, if any, can be achieved by making use of any of the existing tests of spatial ability or of practical interests. The work of the National Foundation for Educational Research in providing an information service and in providing facilities for the co-ordination of the efforts of research workers in this field is very much to be welcomed.

That there is dissatisfaction with existing methods of selection is illustrated in a letter with the signature H. E. Hopper, which appeared in *The Times Educational Supplement* for 3rd March, 1960. The letter requested advice and information regarding procedures for selecting pupils at the age of 11 plus for the new secondary technical schools and for later transfer of misfits. Only one reply appeared in the subsequent issue. It was a letter from the author in which he suggested that a properly designed spatial test should be included among the selection tests. There was no subsequent published comment on the subject of these two letters. May it be assumed from the absence of comment that no one had any more promising suggestion to offer?

Conclusions

It is difficult to avoid the conclusion from the foregoing discussion that most educational systems, including that in Britain, have been slow to adapt themselves to the rapidly changing needs of a society which is being transformed by the application of scientific discovery. That this conclusion is officially accepted in Britain can be gleaned from statements made by Government spokesmen, e.g., on 6th May, 1963, Lord Hailsham expressed the view that "we need to develop from being a nation of shop-keepers and colonial administrators to become a nation of technologists."

In the light of such pronouncements it is clear that Local Authorities have been slow to make use of spatial tests in their selection procedures. They have tended to rely almost exclusively on tests of linguistic and numerical abilities. While no one would deny that language plays an important part in intellectual development, by facilitating the growth of concepts of increasing complexity, we must beware of supposing that thought can take place only by means of words.

Certainly there are now grounds for believing that linguistic tests are not the most valid tests for selecting candidates for technical courses or for the more advanced courses in mathematics or science. It is, therefore, very probable that most of the existing technical schools are not securing the maximum number of pupils who can make adequate use of the facilities they provide.

It is true, of course, that there is now a tendency to break down the rigidity of the tripartite system and to provide courses with a technical bias in grammar, modern and comprehensive schools. This policy is to be welcomed but it does not absolve authorities from the responsibility for *identifying* technical talents and for ensuring that they are developed to the full. The view expressed as recently as 1962 by a prominent educationist that tests of spatial ability, however valid, are of little more than academic interest, scarcely accords with the needs of the times.

It is a matter of some urgency to ensure that the best facilities for technical education are readily available to *all* pupils who possess the requisite aptitudes. Only when action is taken to make accurate diagnoses of the abilities and aptitudes of pupils can it be claimed that the ideal of education according to ability and aptitude is any nearer to realization than it was in 1944.

Chapter two

The Spatial Factor and its Subdivisions

Early studies using simpler techniques (1917–1935)

THE reluctance of most Local Authorities in Britain to make use of tests of spatial or mechanical ability in connection with their selection procedures is a phenomenon which requires some explanation. To a foreign visitor, it must seem surprising that this attitude should prevail some twenty years after the passing of the Education Act of 1944, which laid it down that pupils should be educated in accordance with age, abilities and aptitudes.

To understand the widespread tendency to regard the verbal test as a measure of a pupil's 'intelligence' and to treat the standardized verbal score as an 'I.Q.', indicating potentiality for any type of secondary education, we must study the history of the evolution of the 'intelligence' test, particularly in relation to its use in educational selection. The original impetus to the development of mental tests arose from the need to improve methods of predicting scholastic success. Thus, the pioneering work of Binet was directed to the construction of tests which would separate successful scholars from those who would be unlikely to succeed in the ordinary school. Since scholastic success depends to a large extent on reading and writing, the tests which were found to be most successful for this purpose consisted, not unnaturally, of verbal material. These tests were called 'intelligence' tests at an early stage in their development and so it became customary to assume that intelligence was best measured by tests consisting of verbal questions. The great majority of the so-called intelligence tests constructed prior to the Second World War were of this type. It is true that many psychologists were fully aware of the fact that these tests tended to give a very great advantage to pupils who were gifted in the use of words. But it was not until 1931 that it was clearly demonstrated by Stephenson that there is a group factor of verbal ability distinct from general ability, and this demonstration gave an impetus to the development of non-verbal tests, such as 'Progressive Matrices', due to Penrose and Raven (1938).

Throughout this period, i.e. prior to the Second World War, technical abilities were conceived to be mainly practical or mechanical and the earliest procedures for selecting pupils for technical education were designed to measure aptitudes for manipulating mechanisms or other concrete materials. Among the many tests of manual dexterity which were devised were those consisting of peg-boards and eye-boards, tests of tapping and aiming, tests of tweezer-dexterity, of wire-bending, tests involving the manipulation of nuts and bolts, and many others.

One of the most successful of the early tests was the Mechanical Assembly Test devised by Stenquist, in which the task was to fit together pieces of familiar objects such as bicycle bells and locks. This test was found to give high validities (·8 to ·9) with boys of secondary school age when assessed against criteria of success in manual subjects. It was later modified and extended and called the Minnesota Assembly Test. It yielded correlations of about ·55 with marks for quality of practical work done in the high school.

During the First World War, it was administered to more than 14,000 recruits in the American Army, to provide a measure of non-verbal intelligence, additional to the verbal score of the Army Alpha test. It is interesting and most significant that the Army psychologists discontinued using the Assembly Test when they found that it yielded low correlations with the Army Alpha.

The latter was devised by Otis and was the first group verbal test to be used on a large scale. In this situation in which both a verbal and a non-verbal score were available, it was assumed that the verbal score provided the more valid criterion. It might have been argued that since the Assembly Test consisted of a miscellaneous collection of 'real-life' problems, it was the more valid test of general ability. The fact that it was the Assembly

Test which was dropped and not the verbal test may be regarded as evidence of 'bias' on the part of the psychologists. The Assembly Test had been shown to be valid when judged by the criterion of quality of work done, but the verbal test was preferred presumably because this type of test was more convenient to administer and was known to be the better predictor of scholastic success.

Clearly, the only valid criterion in this situation was that of efficiency from the military point of view; while the verbal test might be more successful in predicting success in a clerical job, the Assembly Test would almost certainly be a better predictor of efficiency in a purely technical arm.

Though verbal tests were generally described as 'intelligence' tests throughout the period between the wars, a different attitude prevailed from the beginning of the Second World War. It was not automatically assumed that the verbal type of test had the greater validity. Indeed in the British Army, the test used for general grading purposes was a non-verbal test—the 'Progressive Matrices' of Penrose and Raven. It was presumed, following Spearman's principles, that this type of non-verbal test provided a measure of *g*, the general intellectual factor uncontaminated by the verbal factor. But in both the British and American armed forces a very wide range of test-materials was used.

One of the earliest investigations of 'practical' ability was that by McFarlane in 1925. She devised a number of wooden constructional tests, like the wheel-barrow test, in which the parts of a wheel-barrow had to be fitted together. She also used the Cube Construction Test and Healy's Puzzle Box, which was rather like the boxes used by Thorndike in his experiments with cats. McFarlane found some evidence of the presence of a group factor additional to *g*, with her sample of boys, though not with the girls. She wrote that the performance tests "measured an ability whose uniqueness lies in the fact that those persons possessing it in high degree analyse and judge better about concrete spatial situations than do other individuals who perhaps excel in dealing with more highly abstract symbols." Her description suggests that she was referring to the same aptitude which is now more usually measured by paper-and-pencil spatial tests. In 1928, O'Connor devised the O'Connor Wiggly Block Test and claimed that it was highly successful in selecting prospective mechanical engineers. Since it consisted of a single test-item it could scarcely be expected to have high reliability and yet it gave validities of ·62 and ·42 for shopwork with two groups of boys, figures which are remarkably high for a test of low reliability.

In spite of these promising pioneering investigations many psychologists tended to think of performance tests as providing only rather unreliable measures of non-verbal intelligence. This was certainly the view adopted by Spearman. In *Abilities of Man* (1927), he quotes the results of Macrae as evidence that there is no common group factor underlying spatial or performance tests in general. He accounted for McFarlane's finding of a large overlap in her tests with boys, though not with girls, by supposing that this derived from acquired experience rather than from innate ability:

"Daily observation shows that many boys, unlike almost all girls, tend already in their second year of life to play with mechanical instruments in a very thorough way, which can scarcely fail to help them subsequently in all performances of a kindred nature."

Apart from this element of acquired experience in handling mechanical objects, Spearman tended to regard most performance tests as being somewhat unreliable measures of *g*. Kohs (1923) adopted a similar view in putting forward his Block Designs Test as a measure of general intelligence and, as late as 1936, Cattell wrote of performance tests as if they were unrelated to technical abilities.

Only very gradually was it realized that some of these tests measure a very important factor in addition to general intellectual ability. One of the early tests which showed special promise was the elaborate wooden form-board known as the Minnesota Spatial Relations Test, which was found to give a correlation of ·53 with marks in shopwork. Earle and Milner (1929) found some evidence suggesting the presence of a spatial or practical group factor in a number of performance and spatial tests (Cube Construction, Dearborn Form Board, Form Relations (N.I.I.P.), Memory for Designs (N.I.I.P.) and Stenquist Assembly).

Rodger (1937), working with Borstal boys, found that the Cube Construction Test gave the best results for predicting success in the mechanical trades. It was the investigation by Alexander (1935), however, which seemed to establish the fact that some performance tests do measure a factor over and above *g*. This study originated from his work in developing a performance test of nine items which he called the Passalong Test. He included this and other performance tests in a large battery which he administered to several groups of subjects. One group consisted of primary school pupils, another of secondary and technical school pupils and a third of adult women in a delinquent institution. It appears that Alexander was the first to apply Thurstone's recently devised Centroid Method to an investigation involving factor-analysis of abilities. Using this technique, he showed that some of the performance tests involved a factor additional to *g*, which he designated the *F*-factor. Later he developed a performance scale consisting of Passalong, Cube Construction, and Kohs' Blocks for measuring what he called 'concrete' or practical intelligence as distinct from abstract intelligence.

It can now be seen that the terms 'concrete' and 'abstract' to distinguish between spatial and verbal abilities were ill-chosen. This terminology, which had been used by McFarlane in her 1925 study, tended to suggest that pupils with exceptional spatial ability were less likely to be capable of abstract thought than verbally gifted children. Such an assumption, which appears to be quite unfounded, may have been responsible for much of the tardiness with which spatial tests have been considered for use in selection procedures by Local Education Authorities.

While on the subject of performance tests, mention must be made of the cognate tests, designed to measure mechanical ability. Early forms of these, devised by Cox (1928), were very elaborate and were both expensive and time-consuming. They consisted of mechanical models, the mechanism of which was concealed behind a screen, the subject being required to answer questions about the nature of the mechanism. Similar tests which were more easily administered were later devised by Vincent for the N.I.I.P. Brush found that Cox's Mechanical Models were the most useful of the mechanical tests he gave to students for predicting success on engineering courses. A simpler form of this test, originally devised by Stenquist (1922), consisted of pictures of systems of gears or pulleys, the task being to indicate what would happen when any of the wheels were made to revolve. Cox developed the idea in three tests, Mechanical Designs, Mechanical Explanations and Mechanical Completion. These were much more convenient to administer and Brush found that they were also successful in predicting success in engineering courses.

Paper-and-pencil tests of the type which we should now call spatial tests have been in use since about 1917. They seem to have originated as paper-and-pencil versions of wooden form-board tests rather like jig-saw puzzles. They were intended to be tests of general intelligence and were considered suitable for testing the intelligence of persons who had had very little education or who were thought to be poor in expressing themselves verbally. These spatial tests were used in investigations into methods of awarding scholarships to trade schools and technical institutes. A question which naturally arose from these investigations was whether the tests involved a special aptitude (i.e., a group factor over and above *g*), just as verbal tests have been found to involve a large verbal group factor additional to *g*. Much time and energy has been expended in an attempt to answer this question, and different investigators came to opposite conclusions at different times. The existence of such a factor was long denied by Spearman, who claimed (1950) that the spatial type of test was originally devised by him for the very purpose of measuring *g*. However, it seems to be generally conceded that the factor does exist and numerous American psychologists claim to have found several distinct spatial factors.

The history of research on the spatial factor (or factors) is closely bound up with work on the mechanical factor *m* and the practical factor *F*. In his study of mechanical aptitude, Cox (1928) found the mechanical factor present in mechanical models and explanations, in paper-folding and jig-saw tests, in practical trade tests and technical tasks. He identified the *m* factor with the mental activity involved in the comprehension of mechanical relations rather than in manipulative activities. The thinking has to be of the nature of correlate eduction.

At about the same time as Cox's study, Truman Kelley (1928) tested children in the age-range 10 to 16 and identified a spatial factor in the following tests:

1. speed in reading;
2. power in arithmetic;
3. memory for meaningful symbols;
4. memory for meaningless symbols;
5. manipulation of geometric forms.

In another experiment, he obtained evidence that the spatial factor could be separated into two parts which he designated:

ε—an ability involving the sensing and retention of geometric forms;

θ—a facility in the mental manipulation of spatial relationships.

He admitted, however, that the existence of the factor was doubtful in four of his five groups.

Earle, Milner *et al.* (1929), and Earle and Macrae (1929), published two relevant studies in the same year. The conclusion expressed by Earle and his colleagues was that "the special abilities entering into the performance tests under consideration appeared to be unrelated except in the case of those in which spatial elements enter. . . . These are related by a rather small group factor for spatial perception, as well as by the general factor *g*."

There followed a number of studies all tending to cast doubt on the existence of a spatial factor. Thus, Line (1931) concluded from his study of the growth of visual perception in children "that throughout the spatial tests there seemed to be no evidence of a group factor". Similarly, Fortes (1930) concluded from his analysis that "the tetrad difference criterion (two factors) proved that these tests measured only *g* and specific factors".

Stephenson (1931) concluded from a very extensive investigation involving 1,037 girls "that the evidence was against any group factor in the non-verbal sub-tests." In a later study, however, in collaboration with W. Brown (1933) he reported "some slight signs of a group factor on the border of significance". In the same year, Milton Smith (1933) reported having found a small group factor between a form-board test and Kelley's spatial test.

Later studies using more complex techniques (1935–1945)

The next important contribution was that of Alexander (1935) in the related field of performance tests, several of which were found by him to involve a factor *F* in addition to *g*. He called this a factor of practical ability.

In the same year an outstanding contribution was made by El Koussy (1935), in a research carried out under the guidance of Stephenson. In this very comprehensive investigation, 28 tests covering a wide range of abilities were administered to 162 boys aged 11 to 13, attending a central school in Sidcup.

The battery included the following spatial or mechanical tests:

Area Discrimination (El Koussy)
Memory for Designs (N.I.I.P.)
Form Relations (N.I.I.P.)
Fitting Shapes (Stephenson)
Form Equations A (El Koussy)
Form Equations B (El Koussy)
Form Equations C (El Koussy)
Overlapping Shapes (i) (Stephenson)
Overlapping Shapes (ii) (with directions, Abelson)
Pattern Perception (Stephenson)
Spatial Analogies (Stephenson's test modified)

Classification (Areas, directions and lines, Spearman)
Band Completion (El Koussy, after Spearman)
Correlate Eduction A (El Koussy)
Correlate Eduction B (El Koussy, after Spearman)
Mechanical Explanations (Cox)
Mechanical Completion (Cox)

The following reference tests for *g* were used:

Inferences (Verbal)
Alphabet Series (O's and A B C D E F G H)
Visual Perception (Spearman)
Comparison of Greys (Power, Spearman)
Comparison of Greys (Speed, Spearman)
Greys Analogy (El Koussy)
Letter Cancellation
Pitch Discrimination (Seashore)
Loudness Discrimination (Seashore)

To investigate a possible relationship between spatial tests and practical abilities, marks in school examinations in woodwork and drawing were also included.

El Koussy used a modification of Spearman's Tetrad-difference Technique, partialling out the influence of *g* from the table of correlations by means of the scores in the reference tests for *g*. He concluded that there was evidence for the existence of a factor in eight of the spatial tests but not in the others. He stated his main conclusion in the following words:

"There is no evidence for a group factor running through the whole field of spatial perception. . . . Spatial tests are primarily tests of *g*. But some spatial tests involve a group factor over and above their *g*-content. This group factor, called the *k*-factor, receives a ready psychological explanation in terms of visual imagery."

He mentions that the letter *k* was suggested by the first letter of the word 'kurtosis', though Burt (1949) has stated that it was originally applied to the spatial factor because kinaesthetic imagery was formerly believed to be essential for success in such tests.

The contrasting results for the two kinds of spatial test are shown in the following table.

Table 2

Factor loadings of spatial tests with and without significant k-*loadings (El Koussy)*

TESTS HAVING SIGNIFICANT *k*-LOADINGS	loadings g	loadings k	TESTS NOT HAVING SIGNIFICANT *k*-LOADINGS	loadings g	loadings k
Memory for Designs	·66	·58	*Classification (Spearman)*	·76	·22
Form Relations	·43	·49	*Area Discrimination*	·55	·00
Fitting Shapes	·62	·61	*Form Equations B*	·54	·17
Form Equations A	·67	·40	*Form Equations C*	·61	·25
Pattern Perception	·76	·61	*Overlapping Shapes (i)*	·67	·00
Spatial Analogies	·63	·50	*Overlapping Shapes (ii)*	·64	·00
Band Completion	·65	·46	*Classification (Spatial)*	·49	·16
Correlate Eduction A	·50	·62	*Correlate Eduction B*	·65	·01
			Mechanical Explanations	·73	·09
			Mechanical Completion	·55	·26
			Woodwork	·51	·20
			Drawing	·40	·19

El Koussy obtained reports of introspections from many of his subjects concerning the mental processes which occurred during the working of the tests. These subjects reported that in the tests with high *k*-loadings visual imagery was employed in reaching the solutions whereas in tests not involving the *k* factor, success depended on a process of generalization and abstraction without the use of imagery. Thus, when performing the Pattern Perception Test one subject reported:

"I simply look at this shape on the left and when I look on the right I see it straightaway."

El Koussy concluded from these reports that "the explanation of the *k*-factor consists in the ability to obtain and the facility to utilize visual, spatial imagery."

At a much later date Emmett (1949) refactorized El Koussy's table of correlations using Thurstone's Centroid Method. Three factors were found to be significant, by applying McNemar's rough test of significance to the second residual correlations. Axes were then rotated orthogonally to eliminate negative loadings and the second factor was identified as the spatial factor. This factor showed loadings of ·4 or over, not only in the eight tests listed by El Koussy, but also in the following tests:

Table 3

Tests having spatial loadings of ·4 or more (Emmett's analysis of El Koussy's data, after rotation)

TESTS	2ND FACTOR LOADINGS
Visual Perception (Spearman)	·663
Form Equations C (El Koussy)	·612
Greys Analogy (El Koussy)	·606
Alphabet Series	·605
Mechanical Explanations (Cox)	·576
Classification (Spatial)	·556
Mechanical Completion (Cox)	·484
Woodwork Marks	·410
Form Equations B (El Koussy)	·407

Emmett's orthogonal rotation to eliminate negative loadings has resulted in some tests having high spatial loadings though on psychological grounds they might not be expected to have any spatial content at all. Thus, after rotation, the second factor loading of greys analogy is ·606 and of alphabet series ·605.

We might attempt to account for the *k*-loadings of these tests by supposing that *k*-factor is involved not only in the perception of relations between shapes but also in the perception of configurations or patterns of a more general kind (analogies in shades of grey, patterns in sequences of letters). Alternatively, we might invoke the explanation of imagery proposed by El Koussy. An ability to retain an impression of a shade of grey might conceivably assist in performing the greys analogy tests, while a similar ability to retain an image of a group of letters might be of value in doing the alphabet series test (since some of the items require the subject to continue a series of recurring letters).

If we consider the second factor loadings obtained by Emmett before rotation, we find that this bipolar factor contrasts the typical spatial tests (which in this case have high positive loadings) with a somewhat miscellaneous group of tests having high negative loadings. Arranging these loadings in order of magnitude and taking account of sign, they are:

Table 4

Spatial loadings of spatial and other tests
(Emmett's analysis of El Koussy's data, before rotation)

TESTS	2ND FACTOR LOADINGS
Correlate Eduction A (Spearman)	·333
Spatial Analogies	·317
Memory for Designs (N.I.I.P.)	·287
Classification (Spatial)	·233
Form Relations (N.I.I.P.)	·224
Greys Analogy	·188
Alphabet Series	·129
Inferences (Verbal)	— ·240
Pitch Discrimination (Seashore)	— ·256
Area Discrimination	— ·338
Loudness Discrimination	— ·397
Letter Cancellation	— ·413
Comparison of Greys (Speed, Spearman)	— ·444

When the second factor loadings are thus arranged in order, we note that the typical spatial tests, such as Correlate Eduction A (Upside-down Drawing), Spatial Analogies, and Memory for Designs (N.I.I.P), are differentiated in the sign of their loadings from a verbal test such as Inferences and a group of tests involving discrimination between pitches, loudness of sounds, or shades of greys. The fact that the second group includes a number of non-verbal tests suggests that the bipolar factor involves a broader differentiation than that between spatial and verbal abilities. A possible alternative hypothesis is that it represents a differentiation between an ability to perceive and retain 'in mind' spatial patterns (as in Memory for Designs) and an ability to switch attention from one item to another when perceived in temporal succession. In Comparison of Greys, which has the highest negative loading, the subject is presented with a series of circular areas of differing shades of grey. He has to compare each shade in turn with the previous one, crossing it out if it is darker. It is not difficult to make the required discrimination in any particular case, but since the test is speeded, subjects who can make many judgments in quick succession are likely to be most successful. Letter cancellation, which has the second highest negative loading, is rather similar. The difficulty does not lie in deciding which letters to cancel but in making as many cancellations as possible in the time allowed. In these two tests, high negative loadings are associated with rapid switching of attention. The pitch and loudness discrimination tests require the subject to compare or discriminate between sensations presented successively in time. Thus, a tentative interpretation of the bipolar factor may be attempted on the grounds that it differentiates between a group of tests involving the perception and retention of spatial patterns and a somewhat miscellaneous group requiring attention to stimuli perceived in temporal succession.

In the year following the publication of El Koussy's monograph, Clarke (1936) submitted a Ph.D. thesis to London University, reporting a very similar investigation carried out entirely with girls. The main experiment involved the administration of 29 tests to some 200 girls in the age-range 12 to 15. Of these tests, 7 were verbal and 17 spatial, two of them being the same as El Koussy's. Five were devised by Clarke expressly to test El Koussy's hypothesis that visual imagery was the explanation of the *k*-factor.

Two analyses were carried out, one using the Thurstone Centroid method and the other using a Spearman analysis in the light of information obtained from the Thurstone treatment. Her conclusion was that there was *no* extensive group factor in spatial tests, such as the *k*-factor found by El Koussy. She did find a group factor of small extent among the visual imagery tests, but this did not overlap into the spatial tests. She made the interesting observation that according to the analysis by the Thurstone method and perhaps also by the Spearman method, the verbal factor and the imagery factor were inversely related to one another.

One of her imagery tests (Designs) seems to have been similar in principle to the N.I.I.P. Memory for Designs Test, while another (Reversals and Inversions) was very like El Koussy's Correlate Eduction A (or Inverse Drawing). Both Memory for Designs and Correlate Eduction A had been found to have high *k*-loadings (·62 and ·58) so that it appears probable that Clarke's imagery tests were actually *k*-tests.

The following tests had extreme (positive or negative) second-factor loadings:

Table 5

Spatial loadings of tests used by Clarke

TESTS	2ND FACTOR LOADINGS
Imagery Tests	
Noughts and Crosses	·444
Designs	·378
Clockface	·350
Reversals and Inversions	·205
Ball	·195
Spatial Tests	
Line Pattern	·377
Form Relations (N.I.I.P.)	·272
Dot Series	·205
Incomplete Drawings (Street Gestalt Completion)	·198
Fitting Shapes	·196
Non-verbal Selection	·170
Verbal Tests	
Verbal Analogies (Selective)	— ·138
Selection	— ·154
Verbal Analogies (Inventive)	— ·231
Verbal Fours (Inventive)	— ·248
Best Answers	— ·310
Inferences	— ·332
Disarranged Sentences	— ·517

If Clarke's imagery tests were actually *k*-tests, her results did in fact support El Koussy's conclusions, although she claimed that they did not. Since her sample of pupils consisted entirely of girls, the factor would not be expected to show itself so prominently as in a sample of boys. Her conclusion that the verbal factor and the imagery factor were inversely related implies that the *v*- and *k*-factors are inversely related. This observation has been repeatedly confirmed. It does not mean that verbal and spatial tests necessarily correlate negatively. But it does mean that the correlation will be lower than one might expect to result from the presence of the common general factor. The verbal and spatial factors will tend to oppose rather than reinforce one another but the correlation will still be positive because of the general factor.

Though Clarke's results offered some support to El Koussy's findings, the general effect of her work in 1936 was to shed doubt on the existence of the *k*-factor. In 1937, the present writer submitted a thesis on the same topic to the University of Glasgow in part-fulfilment of the requirements of the Ed.B. degree, the title being "The Form-Perception Factor". When the writer embarked on this investigation in 1933, he knew nothing of the work of El Koussy. He had become interested in the possibility that a group factor might exist in tests of spatial ability. At that time the only technique that was generally known was the somewhat laborious method of tetrad-difference analysis originated by Spearman, though the first paper by Hotelling on the method of Principal Components was published in 1933. The writer investigated the factor problem by carrying out a tetrad-difference analysis and by applying Hotelling's method. But the main purpose of the investigation was to construct a spatial test of some hundred items and to make a preliminary study of its validity.

Having read an article by Stephenson (1931) describing an investigation into the existence of a group factor in non-verbal tests, he wrote requesting the loan of samples of test-material. Stephenson very kindly replied, enclosing a number of tests, some of which had been used by El Koussy, who was then a Ph.D.

student working under Stephenson's supervision. The writer proceeded to construct a spatial test consisting largely of items based on materials which had been obtained from this and other sources. He was also indebted to C. A. Oakley, of the Scottish Branch of the N.I.I.P., who supplied a N.I.I.P. spatial test. One sub-test of the new test (Form Recognition) was based on designs from an article by Gottschaldt (1926). (Many subsequent test-constructors, including Thurstone and Witkin, have based tests on these designs.) Another sub-test was modelled on the non-verbal items of Cattell's Test IIIA.

At an early stage in the investigation, the writer had noted that subjects showed very great individual differences in the ability to make recognizable drawings of simple objects. He had been particularly impressed by the fact that some pupils made drawings of objects such as Bunsen burners which were grossly 'out of proportion'. Thus, some pupils drew a burner with a base which was twice as wide as the height. It seemed painfully obvious that an inverse ratio of the dimensions would have been more nearly correct. Yet pupils who produced drawings like this seemed to see nothing amiss with them.

Thus, from the outset of the investigation, the writer had the theory that the special aptitude which he sought to measure, if it existed at all, would be manifested in an ability to perceive and reproduce shapes correctly, i.e. with their dimensions and their relations in due proportion. To test this theory, he included in the battery of tests a drawing test which required the pupils to make drawings of eight familiar objects of standard shape, such as Bunsen burners or milk bottles. These drawings were marked for the correct representation of proportions.

The sub-tests of the spatial test proper were constructed largely on this principle, i.e. that the items should depend *critically* for success on the perception of the correct proportions of a figure or pattern. This has been the writer's guiding principle in his subsequent researches. He has been puzzled by the fact that other research workers in this field seem to be unaware of it, or at least do not refer to it. It was not mentioned in the symposium on hypotheses concerning the nature of the spatial factors, held at the A.P.A. Congress in Washington in 1952.

Altogether, nine spatial tests were constructed and these were duplicated and administered to first and second year pupils in a Scottish grammar school in June, 1934. The ages of the pupils ranged from 12½ to 14½, the average age being about 13. The experiment was carried out, the correlations calculated, a tetrad-analysis completed and the thesis written, before the publication of El Koussy's thesis. When El Koussy's monograph became available late in 1935, it was clear that the findings were substantially the same.

The following tests were used in the investigation:

1. *Area Discrimination.* Three series of forms, having the same shape, but differing in size (circles, squares, triangles), the pupil being required to number the items in order of magnitude.

   This test was a development of part of a similar N.I.I.P. test consisting of a series of circles. It is not the same as the test of that name used by El Koussy.
2. *Completion.* Two pages of the N.I.I.P. Form Relations Test, each page having a series of squares, containing gaps which differed in shape.

   The subject had to select from a number of given shapes, the correct ones to fill the gaps.
3. *Fitting Shapes (A and B).* Similar in principle to tests used by Stephenson and El Koussy. Groups of shapes are shown which, when properly orientated and fitted together, form a larger shape. Lines have to be drawn on the larger shape to indicate how the parts are fitted together.
4. *Form Equations.* Similar to El Koussy's Form Equations B. Each item consists of an 'equation' with spatial terms, the signs being omitted. The pupils were required to insert the signs (+) or (—) required to make the 'equation' true.
5. *Classification.* 'Odd man out'. The pupil is required to indicate which of the five does not belong to the same group as the others.

The items were similar in principle to the non-verbal items in Cattell's Test IIIA, but they were designed to involve an ability to discriminate between more complex gestalt-qualities, such as symmetry, roundness, etc.

6. *Spatial Analogies.* Two shapes are shown in relation to one another. The pupil is required to select from a group of figures the one which bears the same relation to another given figure.
7. *Form Recognition.* The pupil is required to identify a given figure in a set of more comprehensive diagrams, containing the given figure as part of each of them. The test was based on the well-known Gottschaldt figures.
8. *Pattern Perception.* Similar in principle to Stephenson's Cross-Pattern Test, The pupil is required to draw a line round those crosses in a complex pattern, which correspond to crosses in a simpler given pattern.
9. *Drawing.* A drawing test was included, in an attempt to measure memory for visual or spatial form. Drawings of eight familiar objects of standard shape were marked for the correct representation of shape ('correct proportions') by a trained art teacher.
10. *Otis Test* (*Form B*). A well-known intelligence test, containing both verbal and non-verbal items.
11. *School Test.* An objective test consisting of two parts, one emphasizing logical reasoning and the other general information. It was unspeeded and, being intended for administration to all pupils in the school, was somewhat exacting for first and second year pupils.

An analysis of the resulting table of correlations by Spearman's method of tetrad-analysis provided clear evidence of the presence of a group factor in some but not all of the spatial tests. Subsequently, Hotelling's Method of Principal Components, Burt's Method of Group Factor Analysis and Holzinger's Bi-factor Technique were applied.

The factor loadings obtained are shown in the accompanying table, together with the corresponding loadings for somewhat similar tests as obtained by El Koussy. The results, seen in Table 6, show a substantial measure of agreement.

Table 6

Comparison of factor loadings in two studies (Macfarlane Smith and El Koussy)

TESTS	MACFARLANE SMITH 100 PUPILS AGED 12½–14½		EL KOUSSY 162 PUPILS AGED 11–13	
	g	*k*	*g*	*k*
Otis Test (Form B)	·76	— ·02		
School Test	·73	·03		
Fitting Shapes	·66	·43	·62	·61
Pattern Perception	·40	·65	·76	·61
Completion (Form Relations)	·48	·50	·43	·49
Analogies (Spatial)	·55	·26	·63	·50
Form Equations B	·52	·25	·54	·17
Form Recognition (Gottschaldt Figures)	·48	·25		
Classification	·61	·01		
Area Discrimination (Macfarlane Smith)	·47	—·01		
Area Discrimination (El Koussy)			·55	·00

When the writer was preparing his thesis for submission, the Centroid Method of Thurstone, which was first published in August, 1935, was not yet available, and the conclusions of his study were mainly based on the results of the Spearman tetrad-difference analysis.

The thesis was summarized as follows:

1. A variety of types of form-perception test were constructed and administered to first and second year pupils in a secondary school.
2. There is evidence for the presence of a group factor in some of these tests. This confirms the result found by El Koussy.
3. The group factor is present in tests which require an ability to form and retain an exact impression of shape or pattern.
4. The battery of form-perception tests shows a significant sex-difference (boys doing better than girls).
5. The specific correlations between the battery of tests and marks in certain school subjects were calculated. The

specific correlations with art, practical geometry and engineering drawing were significant; that with handwork was not significant.

6. The specific correlations indicate that the ability measured by the test might be useful in certain occupations and that an improved form of the test might be used as a diagnostic test of ability for these occupations and for such school subjects as art, engineering drawing and geometry.

The following year, Thurstone (1938) published the results of a large-scale investigation in which the correlations of a varied battery of 60 tests were analysed by means of his recently invented centroid method. The 218 subjects were students in the age-range 16 to 25. Tetrachoric correlations were calculated and 12 factors extracted and axes rotated to achieve 'simple structure'. Thirteen of the test-variables were found to have loadings in a factor which he identified as the 'visual-spatial' factor.

Instead of following Thurstone's procedure, we shall consider the loadings of the second factor before rotation. Listing these in order of magnitude and considering particularly the extreme positive and negative values, we find that the spatial tests have high negative loadings and the verbal tests high positive loadings (see Table 7).

The first thirteen of the tests in the above list are those given by Thurstone as having loadings in the visual-spatial factor *S*. The relatively poor loading of Form-Board is surprising, since this is similar to Stephenson's Fitting-Shapes which usually has a high *k*-loading. The lower loading in Thurstone's study may be due to the fact that his sample consisted of adult students, for whom this test may have been relatively easy. It is rather surprising that the tests of Syllogisms, Verbal Classification and Sound Grouping had substantial loadings in the visual-spatial factor (viz., ·430, ·411, ·412 after rotation). Thurstone explained this by supposing that these tests must be solved by the use of spatial imagery. Possibly Sound Grouping may involve the perception of sound patterns or configurations.

Table 7

Spatial loadings of tests used by Thurstone (signs reversed)

TESTS	2ND FACTOR LOADINGS (v/k)
Flags	—·53
Block Counting	—·44
Pursuit	—·42
Hands	—·42
Cubes	—·40
Lozenges B	—·38
Figure Classification	—·29
Surface Development	—·29
Lozenges A	—·27
Form-board	—·23
Syllogisms	—·18
Verbal Classification	·11
Sound-grouping	·13
Completion	·36
Reading I	·37
Reading II	·39
Inventive Opposites	·43
Controlled Association	·44
Inventive Synonyms	·46
Vocabulary	·51

Spearman and Wynn Jones (1950) have expressed doubt as to the plausibility of Thurstone's explanation and have quoted this anomaly as an example of the kind of absurdity which has resulted from Thurstone's introduction of the principle of maximizing the number of zero factor loadings in order to achieve 'simple structure'; for "hereby, the theory of two factors is not indeed disproved, but only arbitrarily denied". Other writers, such as Reyburn and Raath (1949), have called in question the advantages which have been claimed for the principle of rotating to 'simple structure'. The present instance provides support for the writer's contention that when the battery contains a varied set of tests, the unrotated second factor loadings can be meaningfully interpreted without resort to rotation. The signs of the loadings differentiate reasonably well between the spatial and verbal tests. Further factors may be interpreted in terms of Burt's hierarchical theory of abilities.

In 1940, Slater reported an investigation in which he administered a battery of spatial and verbal tests to 89 apprentices. He had two main objectives, first to attempt to analyse the spatial factor into components, and second to determine the relationship between spatial ability and mechanical ability. According to El Koussy, the critical psychological process involved in working spatial tests is the identification of a shape seen in one position with the same shape seen in another. Slater believed that this process involved two more fundamental processes, viz. recognition and mental manipulation.

To test this hypothesis, he included four new tests in the battery, two involving recognition and two involving mental manipulation. He described the contrast between these two types of test-material in the following way: "In the recognition problem, all four alternatives are in the correct position, but only one has the correct shape. In the imaginative problem, all four alternatives have the correct shape, but only one has the correct position."

In addition to the tests of spatial recognition and imaginal manipulation, the battery included the verbal Group Test 33 (N.I.I.P.), Cox's Mechanical Models, Form Relations (N.I.I.P.), Squares (after Rybakov), Figure Construction Test, Recognition of Designs, Parallel Lines and Divided Lines. An interesting innovation was the Recognition of Designs Test, which comprised 20 designs, displayed four at a time for 30 seconds. Immediately afterwards, the four designs had to be identified from a set of 16 similar ones. This test differed from the older Memory for Designs Test in that the older form required the subject actually to draw the designs, whereas the new one involved only recognition and identification. Clearly, the new version is much simpler and quicker to mark.

A Spearman-Holzinger bifactor analysis of the resulting table of correlations was carried out, and the following tests were found to have high spatial loadings (Table 8):

Table 8

Spatial loadings of tests used by Slater

TESTS	2ND FACTOR LOADINGS (k)
Vincent's Mechanical Models	·589
Cox's Mechanical Models	·570
Space Perception Tests (Nos. 1 *and* 4, *involving only manipulation)*	·466
Squares (after Rybakov)	·455
Form Relations (N.I.I.P.)	·413
Space Perception Tests (Nos. 2 *and* 3, *involving recognition)*	·410
Figure Construction	·337
Recognition of Designs (Slater)	·252

The fact that the separate space perception tests of manipulation and recognition had roughly similar spatial loadings (·466 and ·410) was taken as an indication that spatial judgment does not necessarily involve either imaginative manipulation or recognition; but both imaginative manipulation and recognition appeared to involve spatial judgment. Slater concluded that spatial judgment depends on mental processes which are simpler than either imaginative manipulation or recognition and which are involved in both.

Probably, the recognition type of test offers greater scope for constructing tests with high *k*-loadings, for in this type the problem of recognition may be made increasingly difficult by making the shapes closely similar. In the manipulation type, in which all the shapes are identical, the maximum angular displacement is a rotation of 180° about any axis. Thus, one might expect the recognition type to be more useful for detecting high spatial ability than the type involving only manipulation. American psychologists claim to have shown that tests involving only manipulation (such as Thurstone's Cards, Figures or Lozenges) measure a different factor, Spatial Orientation, from those tests involving recognition which measure the factor, Spatial Visualization, corresponding to the *k*-factor. Very often both processes are involved in the same test.

Another outcome of Slater's investigation was the lack of any evidence to support the theory that there is a special 'mechanical ability' which can be differentiated from general intelligence and spatial judgment. This conclusion followed from the fact that the residual correlation between Vincent's Models and Cox's Models after g and k were partialled out was only ·076. Thus, Mechanical Ability, as measured by these tests, appeared to depend almost entirely on general intelligence and spatial judgment (i.e. g and k). In passing, it is worth noting that Slater's Recognition of Designs Test has the lowest loading of all the spatial tests used in the investigation. This seems surprising at first sight, in view of the fact that the N.I.I.P. Memory for Designs Test has usually shown a high spatial loading (e.g. ·58 by El Koussy). It would appear that the attempt to make the Memory for Designs Test amenable to objective marking has resulted in a very considerable reduction in its spatial loading. It would almost seem that the baby had been thrown out with the bath water! A study of the two tests, however, suggests that an explanation is to be found in the different psychological processes involved in performing the tests. In marking the Memory for Designs Test according to the marking key, considerable credit is given for the correct reproduction of the proportions of the designs. In the Recognition of Designs Test, however, appreciation of proportions may be relatively unimportant, while an ability to note and remember significant details may be much more important. Four designs are shown simultaneously, and then these have to be chosen from sixteen, there being three variants of each original. Clearly, an ability to switch attention rapidly, noting details on the way, would be of service in this test. Thus, the difference in the spatial loadings of the two tests which are superficially similar may reflect the fact that somewhat different psychological processes are involved.

In 1941, Slater turned his attention to the problem of selecting children differentially for technical and grammar schools. After a preliminary experiment with a group of 82 children, he undertook a larger experiment in which he administered spatial, verbal and non-verbal tests to two large groups of children, 211 aged 11 plus and 161 aged 13 plus.

The following tests were used:

Group Test 70 (non-verbal, four sections)
Progressive Matrices (Raven, non-verbal, given to 13 plus group only)
Squares (N.I.I.P.)
Recognition of Designs (N.I.I.P.)
Shapes Test (N.I.I.P.)
Spatial Test (four sections)
Verbal Test (six sections)

When the correlations for both age-groups were analysed by the Centroid Method, the quite unexpected result was obtained by Slater that there was no trace of the spatial factor, either for the 11 plus or the 13 plus group of children.

Referring to the results of the analysis before rotation, we find that for both groups the second factor which was bipolar had negative loadings in all the verbal tests (averaging —·4) and smaller positive loadings in the non-verbal and spatial tests. Thus, in the case of the 13 plus group, the second factor loading was —·432 for the verbal test (section 3), + ·036 for the non-verbal Progressive Matrices, +·258 for the spatial test (section 4) and +·335 for the spatial test (section 2). The spatial tests seem to be differentiated quite clearly from the non-verbal and verbal tests.

Yet, Slater rotated the axes to eliminate negative loadings and drew the conclusion that the second factor was a verbal one, since the verbal tests had now the highest loadings. But, it would seem that it was the rotation which caused the spatial factor to disappear. Before rotation, the positive loadings of the bipolar factor represented the spatial component and the negative loadings the verbal component and the loading of the non-verbal Progressive Matrices was intermediate, as is to be expected of a non-verbal test which is neither verbal nor truly spatial. Incidentally, Slater's Recognition of Designs Test has again turned out to have a much smaller spatial loading (+ ·024) than would have been obtained with the older Memory for Designs Test.

More recently, Emmett (1949) has re-analysed Slater's table of correlations for the 11 plus group, using Lawley's method. He established a third significant factor, not found by Slater, significant at the P = ·05 level of probability, one spatial test having a highly significant positive loading (P<·001), and a non-verbal test having a highly significant negative loading. The present writer, however, disagrees with Emmett regarding this identification, as the other tests in the battery show irregular loadings in this factor, bearing no relation to their verbal or spatial content. Emmett's solution was to rotate axes orthogonally until all negative loadings had been eliminated (except one of —·001). The rotated orthogonal factors were then identified as *g*, *v* and *k*. This solution does not seem satisfactory, since the Verbal Test (parts 5 and 6) now has a loading of ·288 on the third factor (which Emmett calls *k*) and one of the non-verbal tests appears to have the second-highest *k*-loading of the battery (·379). These loadings are much at variance with previous findings, suggesting that the third factor has been incorrectly identified with *k*.

A more satisfactory solution is to regard the second bipolar factor as the true spatial-verbal factor. If we arrange the loadings, as obtained by Emmett using Lawley's method, in order of magnitude, we obtain the familiar pattern (see Table 9).

Table 9

Spatial loadings of tests used by Slater (Emmett's analysis without rotation)

TESTS	2ND FACTOR LOADINGS (*k*/*v*)
Spatial Test (Parts 2, 3 and 4)	·421
Spatial Test (Squares and Designs)	·390
Non-verbal Test (Part 1)	·313
Non-verbal Test (Part 4)	·296
Spatial Test (Part 1 and Shapes)	·266
Non-verbal Test (Parts 2 and 3)	·241
Verbal Test (Parts 1 and 2)	— ·314
Verbal Test (Parts 3 and 4)	— ·322
Verbal Test (Parts 5 and 6)	— ·372

(It should be noted that to reduce the labour of computation Emmett has grouped some of the tests together, as if forming one test.)

Thus, there is a clear differentiation between verbal tests at one pole and spatial and non-verbal tests at the other, two of the spatial tests having the highest positive loadings. It is certainly incorrect to claim as Slater did that the spatial factor has disappeared, though it is true that the spatial tests are not so clearly differentiated from the non-verbal tests as in other investigations.

This may be partly because, as Emmett has pointed out, the tests as a whole seem to have been unsuited to the children tested, since the intercorrelations at 11 plus averaged only ·345 and those at 13 plus averaged ·479, which are very much lower values than those usually obtained. It is very unlikely that the abilities tested were more specific at the earlier age, so the 11 plus correlations should not have been lower if the tests had been suitable for the 11 plus children.

Slater's explanation of the disappearance of the spatial factor at 11 and 13 years of age was that at these ages the factor is still 'immature'. This explanation can scarcely be reconciled with the positive results obtained by El Koussy, by the present writer and by numerous other investigators from Cox and Alexander onwards. Spearman and Wynn Jones have suggested an alternative partial explanation of the "paradox of Slater" (as they described Slater's claim for the disappearance of the spatial factor). They wrote:

"Herewith we come upon what constitutes perhaps the most serious disturbance in factor-analysis. This is the fact that one and the same cognitive task can often be done in two or more different ways. . . . Subjects are inclined to drop the concrete procedure and take refuge in abstractions when they get into difficulties."

While not accepting the implied dichotomy between concrete and abstract procedures in this context, the writer would agree that many pupils who lack spatial ability may find ways of doing some spatial tests by verbal methods. And some constructors of tests have unwittingly 'conspired' with the pupils to make this possible because they have found that many people dislike marking spatial tests when the process involves some element of spatial judgment. The endeavour to make the marking completely objective (for the sake of those who would otherwise find it difficult) has often had the effect of making it easier for the pupils to find the correct answers without using spatial ability at all. An illustration of this is to be found in the lower spatial loading of the objectively marked Recognition of Designs Test compared with that of the Memory for Designs Test, in which the marking is partly subjective.

A more probable explanation of the "paradox of Slater" would seem to lie in the strong tendency of factorists to prefer to rotate axes to eliminate negative loadings rather than to accept the possibility that the second and subsequent factors may be genuinely bipolar, that for example the verbal and spatial factors are inversely related, when considered apart from *g*.

The reluctance to accept this interpretation arises from the belief that the negative characteristic is inappropriate for factors of ability, which are thought to be essentially positive. Burt (1940), however, has championed bipolar factors, as in the passage where he describes factors "which can vary in opposite or antagonistic directions". While admitting that these occur mostly in such conative cases as "brave-cowardly", he thinks that they may be extended to cognition also, as in the antithesis between tests which are verbal and non-verbal respectively. Holzinger has also made extensive use of the concept of bipolar factors, regarding them as "not essentially different from any other but . . . as measuring the negative aspect of the usual type of factor."

Morrisby has pointed out that "abilities can, in relation to some criteria, be truly negative." He mentions, for example, that "the intelligence tests of the Differential Test Battery commonly show marked negative relationships with university and grammar school (G.C.E.) exams. and other criteria."

In 1944, Thurstone published a monograph giving an account of a very comprehensive investigation of perceptual abilities.

Forty-three sensory and perceptual tests were administered to 170 students, and ten factors extracted by the Centroid Method. Two of these, factors A and E, are of interest in connection with the present investigation. The tests which had highest loadings in Factor A were Shape Constancy (·54), P.M.A. Space Test (·51), Gottschaldt Figures A (·51), Block Designs (·50) and Gottschaldt Figures B (·44). With the possible exception of the first, these are all well-known spatial tests, known to have high *k*-loadings.

Thurstone interprets this factor tentatively, as representing the strength of a configuration as perceived by the subject and this interpretation accords reasonably well with our own conception of the nature of the *k*-factor. In the Shape Constancy Test, which has the highest loading, the subject is required to look at a square piece of cardboard placed on a table across the room and to note the shape of the figure as it would look in a photograph. He is asked to retain this shape 'in mind' and then to look at a large card from which he chooses the one figure which is like the apparent shape of the card.

The more strongly the configuration is held in mind the better should be the subject's choice of figure to represent it. Thus, the high loading of this test in factor A supports the hypothesis that the factor represents the strength of the configuration as perceived by the subject. In some of the tests with lower loadings on factor A, the task is to discover a unified gestalt or configuration in an unorganized perceptual field. Thurstone has tentatively named the factor as 'Facility and Firmness of Perceptual Closure'.

Among the tests with high loadings in Factor E were Two-Hand Co-ordination (·59), Hidden Pictures (·47), P.M.A. Reasoning (·42), Gottschaldt A (·40) and the following tests with lower but still considerable loadings: Gottschaldt B (·34), Block Designs (·33), P.M.A. Space (·32) and Shape Constancy (·21). Thurstone thought that this factor was concerned with the manipulation of two configurations simultaneously or in succession. He suggested the terms 'flexibility' or 'freedom from gestalt-bindung' as being appropriate for designating the factor.

He remarked that these two factors, 'facility and firmness of closure (A)' and 'flexibility (E)', seem to be psychologically the most interesting of his factors. He thought it not unlikely that these two factors will be found to represent parameters which transcend in significance the immediate perceptual content in terms of which they were tentatively identified. Thus, the fact that several non-geometric tests had loadings in factor A indicates that it transcends the abilities represented best by tests with various geometric outlines. It follows that these factors have greater psychological interest. As we have already mentioned, the closure factor A is the same as our spatial factor k. It is possible that the two closure factors correspond respectively to the spatial sub-factors first described by Kelley (1928): perception and retention of geometric forms; and mental manipulation of spatial relationships (cf. p. 46).

The next research to be considered is that carried out by Drew (1944), who administered a battery of paper-and-pencil and performance tests to four groups of subjects:

Group A	181 boys, aged 11 plus
Group B	172 boys, aged 12 plus
Group C	118 boys, aged 13 plus
Group D	88 boys, aged 16 plus

There were nine tests, viz.:

Three Verbal Intelligence Tests (Moray House, Cattell, Simplex)
Spearman's GVK Tests (Non-verbal, Verbal, Spatial—the unpublished Chesterfield Tests)
Alexander's Performance Scale (Passalong, Kohs' Blocks, Cube Construction)

Drew also included among the variables teachers' verbal ratings and teachers' practical ratings.

The resulting four tables of correlations, each for eleven variables, were analysed by the Centroid Method. In groups A and B, three factors were identified, viz. g, v and F; while in Groups C and D five factors were designated, g, v, F, X and k, *F* being Alexander's practical factor, *X* an achievement factor and *k* the spatial factor.

From these results, Drew deduced the following conclusions:

1. There is some evidence to show that the psychological factors which are significant for technical aptitude are *g*, *F* and *k*. Technical aptitude appears to be a slightly wider concept than practical ability, which is held not to include the abstract apprehension in the imaginative sphere of spatial relations. This special aptitude does not emerge until about the age of 13 plus.

2. Technical aptitude is capable of being measured at the age of 13 and later by a performance scale comprising the Passalong, Block Design and Cube Construction Tests.

3. The group test of spatial relations used in the research measures the *k*-factor at 16. Whether it measures this factor at 11, 13, 14 or 15 was not determined. Before the age of 14, the spatial test appears to measure chiefly general intelligence.

4. The performance scale, which has been shown to measure *g* and *F* at 11, correlates substantially with success in the Junior Technical School Diploma Examination and when administered at 16 reveals loadings of the two group factors which are important for technical work. It would not appear to measure *k* earlier than 13.

The analysis on which these conclusions are based has been severely criticized by Slater (1947), by Spearman and Wynn Jones (1950), and others. Drew suggested that while *F*-factor involves mental exercise of a concrete order, *k*-factor appears to be associated with spatial relations of an abstract order.

Emmett (1949) has carried out an independent analysis of Drew's correlations for the 11 plus group using the Centroid Method followed by Lawley's method of maximum likelihood. He extracted three factors and after a suitable orthogonal rotation of axes to eliminate negative loadings, identified these as *g*, *v* and *k*. There was no evidence that a fourth factor such as Alexander's *F* was required to explain the correlations.

Instead of adopting Emmett's interpretation, however, we shall consider the factor loadings before rotation, treating the second as a bipolar spatial-verbal factor differentiating k from v. Following this interpretation, the order of magnitude of the spatial loadings yielded by Lawley's method is as follows (see Table 10).

Table 10

Spatial loadings of tests used by Drew (Emmett's analysis without rotation)

TESTS		2ND FACTOR LOADINGS (k/v)
Kohs' Blocks	*Alexander Performance Scale*	·400
Cube Construction	*Alexander Performance Scale*	·243
Passalong	*Alexander Performance Scale*	·198
Spatial Test (K of Spearman GVK)		— ·016
Teachers' Practical Rating		— ·146
Perceptual Test (G of Spearman GVK)		— ·244
Teachers' Verbal Rating		— ·345
Verbal Test (M.H. Intell. Test)		— ·455
Verbal Test (V of Spearman GVK)		— ·545

Thus, the bipolar factor differentiates between the three performance tests and the spatial test at one pole and teachers' verbal rating and the two verbal tests at the other. The teachers' practical and verbal ratings are in the correct relative positions. Spearman's spatial test has made a relatively poor showing compared with the two performance tests, Kohs' Blocks and Cube Construction. This may be partly explained by the fact that a large part of the spatial test consists of items similar to those in the Squares Test, which, though convenient to mark, was found to have a very moderate spatial loading in investigations carried out in the Services. For this group of pupils in Drew's investigation, there is no doubt that the two performance tests provide better measures of spatial ability than the Spearman paper-and-pencil spatial test.

The publication of Drew's findings in January, 1947, aroused a great deal of interest in educational circles because a solution to the problem of identifying aptitudes for technical education had become a matter of some urgency since the passing of the Education Act of 1944. This Act had placed on Local Education

Authorities the responsibility for ensuring that, so far as possible, all children should receive the type of education best suited to their abilities and aptitudes. The Norwood Report, published in the year prior to the Act, had recommended a three-fold differentiation of curriculum in the post-primary stage. This classification of secondary education into three types had already become established in general educational practice, but the Norwood Committee believed that it corresponded to genuine groupings of abilities and interests.

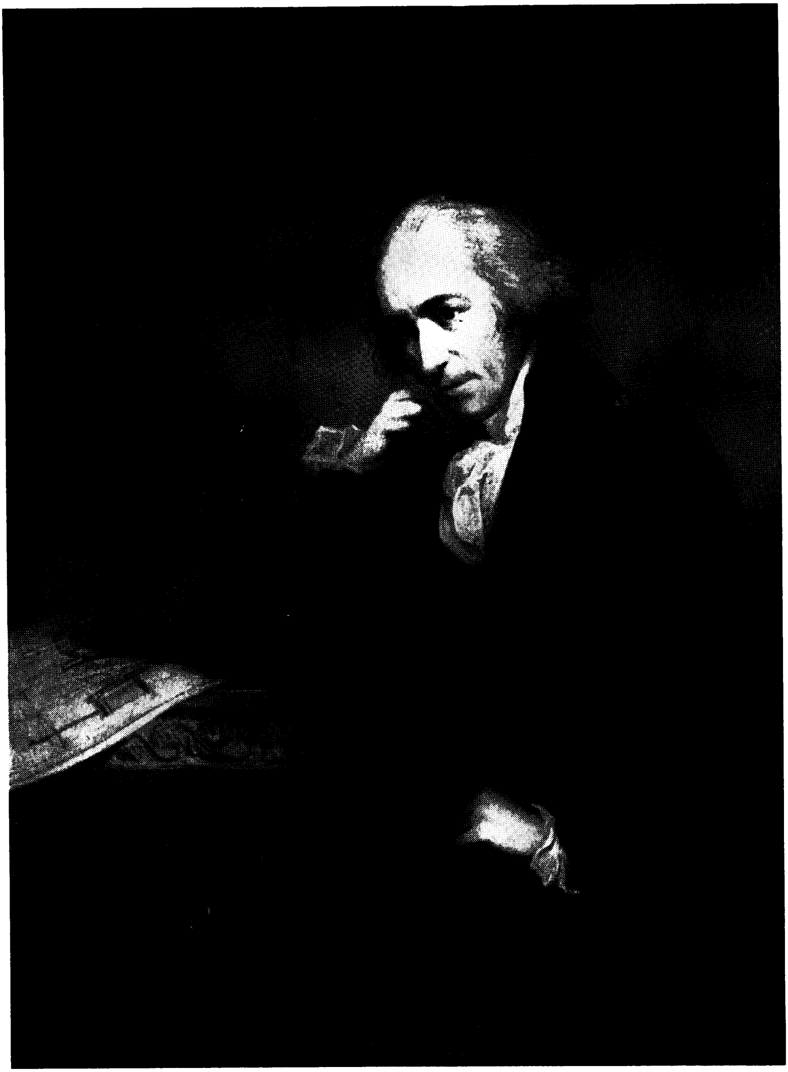
The three types of education were believed to correspond roughly to the following three-fold classification:

1. A group, suited to grammar-school education, who had a high degree of general ability together with facility for reasoning and verbal aptitude. Such pupils were said to be interested in learning for its own sake, were able to follow a piece of connected reasoning and were capable of expressing themselves clearly in words.

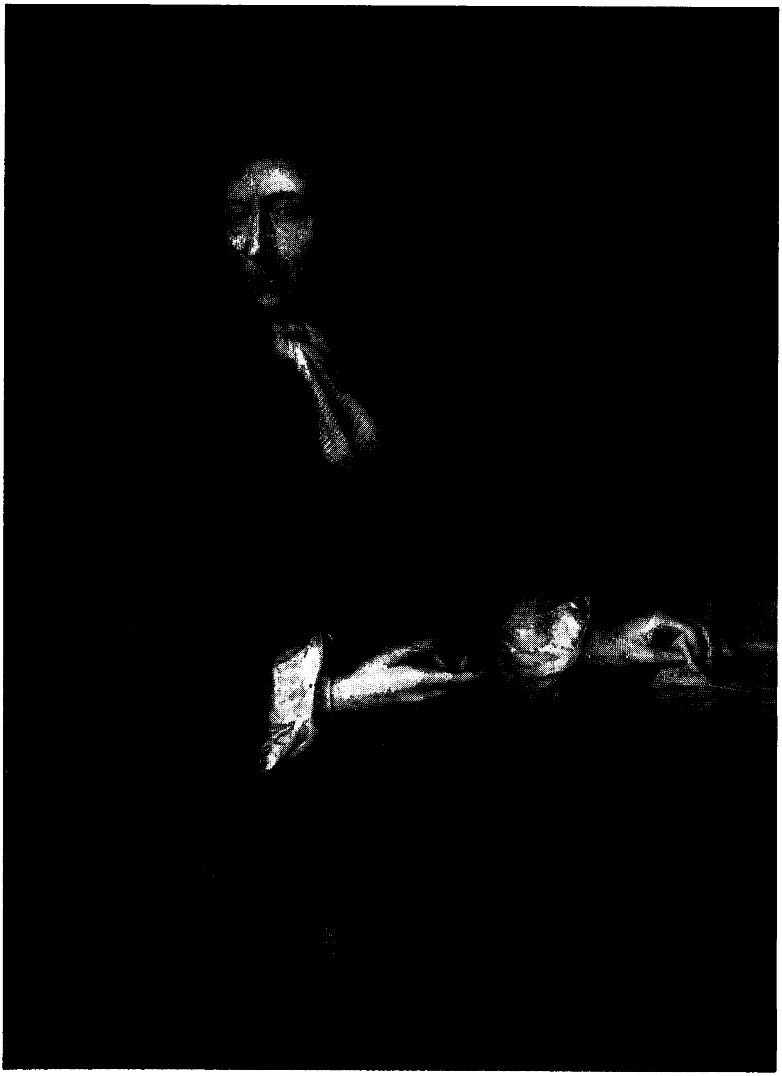
2. A group, suited to technical-school education, who had a high degree of technical ability, which implied insight into mechanisms and capacity to control material things. Such pupils were believed to have interests and abilities, which lay in the fields of applied science or applied art; but they might find difficulty in coping with the subtleties of language construction.

3. A third group, suited to modern school courses, who had practical ability of the concrete order. Such pupils dealt more easily with concrete things than with ideas, and abstractions meant little to them.

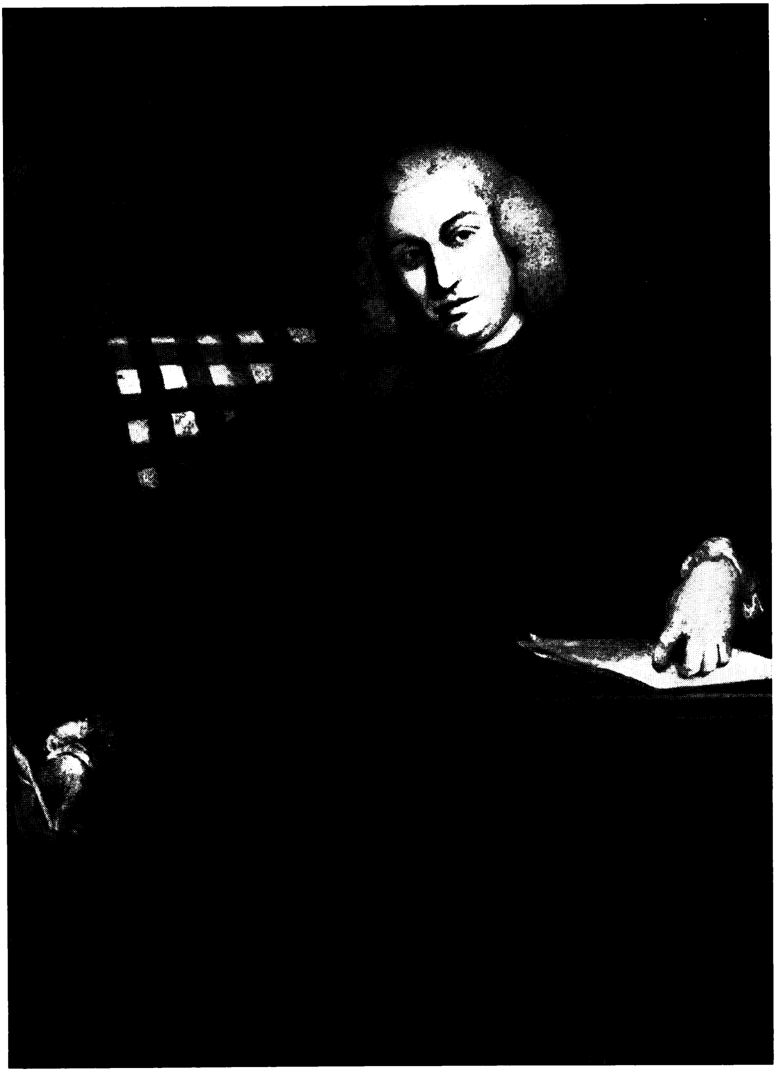
The Norwood Report posed a problem to psychologists. Did this proposed classification, said to have become established in educational practice, have any real basis in psychological reality? Are human abilities actually differentiated in this way, so that the three types described in the Norwood Report are genuinely recognizable or at least identifiable? In particular was it possible to identify by means of psychological tests those pupils who had the kind of aptitudes required for technical education? There was a generally accepted belief among psychologists at this time that



1. James Watt, engineer (1736–1819)
National Portrait Gallery



2. Robert Boyle, physicist (1627–1691)
by permission of The Royal Society



3. Samuel Johnson, man of letters and conversationalist (1709–1784)
National Portrait Gallery

4. G. K. Chesterton, Maurice Baring and Hilaire Belloc, men of letters (1874–1936, 1874–1945 and 1870–1953)
National Portrait Gallery

the spatial factor did not emerge to a measureable extent until about the age of 14 or over. This belief had gained currency largely through the publication of an article by Slater and Bennett in 1943, in which the "disappearance of the spatial factor at 11 plus and 13 plus" was reported.

Early in 1947, the article on Drew's findings appeared in *Occupational Psychology*, giving wide publicity to the view that spatial tests measured only general intelligence until the age of 14, though they did measure the *k*-factor at the age of 16.

Drew also claimed that technical aptitude could be measured at the age of 13 and later by means of a performance scale comprising the Passalong, Block Design and Cube Construction Tests, as advocated by Alexander. At this time, when the need for valid and reliable instruments for the measurement of aptitudes was so apparent, the publication of Drew's paper (and the subsequent criticism by Slater) created a most unfavourable impression. Drew's proposal that performance tests of relatively low reliability should be used for the purpose of selecting children for technical education seemed to be likely to result in serious errors in the placement of pupils.

Post-war investigations (1945 *onwards*)

In a paper read at the Annual Conference of the British Psychological Society at Dartford in April, 1947, the present writer challenged the widespread belief that the spatial factor could not be measured at the age of 11. In his view, there was no foundation for this belief at all and he quoted evidence from his own experiment in 1934 and from El Koussy's very thorough investigation in 1933. It was some time, however, before the scepticism engendered by the negative results of Slater and Bennett, Drew and others was shaken. In June, 1947, L. F. Mills submitted a thesis to the University of Edinburgh, in part fulfilment of the requirements of the B.Ed. degree, in which he presented the results of an analysis of the correlations of the scores for a battery of nine tests including both sections of Moray House Space Test I. Mills had carried out a centroid analysis and found only two significant factors which he identified as *g* and *v*. No significant spatial factor had emerged, and he concluded that neither section of Moray House Space Test I measured the spatial factor at the age of 11. Thus, his results reinforced the negative findings of previous investigators, who had failed to find evidence for a spatial factor at the age of 11.

However, his table of correlations was subsequently re-analysed by Professor Godfrey Thomson, using D. H. Lawley's Method of Maximum Likelihood. Thomson's work was carried further by Z. Swanson and completed by W. G. Emmett. Emmett found four significant factors, three being evaluated by the Lawley method and the fourth by centroid analysis of the resulting residual correlations. The first three factors were tentatively identified as *g*, *v* and *k*.

However, Emmett's reversal of Mills' conclusion was not published until March, 1949. Meantime, the present writer had undertaken a second large-scale investigation of the problem, involving the administration of seven tests and two questionnaires to some 200 pupils in June and July, 1947. At that time all the recent evidence, such as the findings of Slater and Bennett, Drew and Mills, pointed to the conclusion that the spatial factor did not exist to a measurable degree at the age of 11 plus.

At the Twelfth International Congress of Psychology held at the University of Edinburgh in July, 1949, El Koussy himself stated that from the researches carried out in Egypt by Kabbain, Salama, Hana and himself, the existence of the *k*-factor in pupils of from 12 years and upwards had been repeatedly corroborated.

In October, 1948, Adcock published a re-analysis of Slater's spatial judgment research with 13-year-old children. Using three different methods of analysis he argued that the seeming absence of the *k*-factor depends upon the assumption that *g* must always appear in addition to the group factors, and suggested that the resolution of the Spearman-Thurstone controversy by second-order factors seemed to solve the problem. He concluded that there seemed to be no doubt that Slater's data indicated the presence of *k* in the spatial tests. In his reply, Slater (1949) pointed out that the fact that three-factor solutions could be found to fit his data in no way diminished the significance of the finding that a two-factor solution was adequate. Moreover, he argued that Adcock's solutions were psychologically irrational, since all the analyses gave *k*-loadings to one or more of the non-verbal *g* tests and indeed one analysis gave a *k*-loading of ·30 to one of the verbal tests.

The present writer is inclined to agree that Adcock's resolution of the "paradox of Slater" has been achieved only by introducing an interpretation of *k* which would scarcely be acceptable to the great majority of psychologists. He would also agree with Slater that the fact that a two-factor solution fits his data is of very great significance. In a sense, there *are* only two factors. But he would differ from Slater by insisting that the spatial tests are clearly differentiated both from the verbal and non-verbal tests in the bipolar factor and it is this differentiation which entitles us to speak of a spatial factor.

Swineford (1949) has carried out a number of factorial investigations, using the Spearman-Holzinger method of bifactor analysis. Her monograph presents very detailed analyses of the results obtained in nine tests by nearly a thousand pupils in grades *V* to *X*. She constructed three tests to measure general ability, three to measure verbal ability and three to measure spatial ability.

On the average, about 40 per cent of the total variance was accounted for by the general factor which gave positive correlations with school achievement. It increased steadily with chronological age and showed no significant sex-differences.

The verbal factor correlated most highly with the verbal school subjects (reading, English, spelling, civics and history), and least highly with arithmetic, algebra, science, art, handwriting and mechanical drawing. There was some growth in this factor from Grade *V* to Grade *X*.

The spatial factor showed a marked sex-difference, the boys exceeding the girls at all grade levels, and there being no distinction between the normal and the retarded group. The small amount of growth revealed for the period covered by the data suggests that whatever development had taken place must have occurred at a relatively early age. The mean regression coefficients of arithmetic, science and verbal subjects on the spatial factor was —·05, whereas the mean coefficient for art was + ·18. The highest regression coefficient for the spatial factor was with mechanical drawing in Grade *X* (·300).

These coefficients, though in the expected direction, are surprisingly low compared with the results obtained by the present writer. To account for her finding that the group bifactors appeared to be unimportant as predictors of success in the majority of school subjects, Swineford suggests that the evaluations of success were imperfect measures, which failed to include verbal and spatial abilities.

Thus, as in so many other investigations, the factors appeared to be unimportant predictors, not because the abilities they represent are unnecessary for success in the subjects, but because the criteria themselves were inadequate. An alternative possibility, which Swineford herself does not mention, is that the verbal and spatial tests had relatively low saturations in the respective factors.

In a very comprehensive study by Renshaw (1950), six spatial tests (two-dimensional and three-dimensional) as well as other tests were administered to a sample of eleven-year-old children from fourteen different schools in Edinburgh. The correlations were analysed by Thurstone's Centroid Method, and the factor loadings were rotated to 'simple structure' by the method of extended vectors, and second-order analyses were carried out.

Renshaw concluded that the spatial factor was involved in both the two- and three-dimensional tests, but there was some indication, based on averaging the loadings, that the two-dimensional tests are more closely linked with the spatial factor than the three-dimensional tests. The tests with the highest loadings were those in which the subject has to visualize the form of an object when it is moved to an alternative position, irrespective of whether the object is two- or three-dimensional in character.

El Ghareib (1959) administered a large battery of tests to 150 Egyptian pupils of 16 to 17 years of age. The sample consisted of four groups, separate factor-analyses being carried out for each group. Five factors were extracted, but in view of the smallness of the groups, it is unlikely that all of these were significant. El Ghareib concluded that practical ability is complex, consisting of general intelligence and factors F, k and P, i.e., practical, spatial and perceptual speed factors respectively. He also obtained teachers' ratings in certain temperament and personality traits and found a tendency for the practical, spatial and g-loadings to correlate highly with ratings for desirable personality qualities.

This tendency was particularly noticeable with one group of pupils, for whom the personality rating showed fairly high correlations with the performance tests, Carl's Hollow Square, Cube Construction and Passalong. Since these tests are now known to have high k-loadings, El Ghareib's findings suggest that there is an association between spatial ability and certain personality traits, though there is an alternative possibility that the association might be due to the manipulative element common to the performance tests.

Spatial and performance tests

The evidence as to the separate identity of the F- and k-factors, as claimed for example by El Ghareib, is somewhat conflicting.

Watts and Slater (1950) analysed a battery consisting of nonverbal tests, paper-and-pencil spatial tests and the three performance tests which make up the Alexander performance scale. A factor-analysis, using Hotelling's method, showed several factors additional to g, the first two of which were identified as F and k respectively. The identification of these two factors, however, was by no means certain, since the loadings of similar tests appeared to be somewhat irregular.

Williams (1948) found distinctive spatial and mechanical group factors in an investigation with 12- to 14-year-olds, but he seems to be the only one to have found any such differentiation. Slater (1940) found no such distinction. It is interesting also that Williams found no distinction between performance and spatial tests, the Alexander tests having loadings in the same factors as the *k*-tests. Price (1940), in an analysis of a varied set of tests given to 85 University students, found only one significant group factor, apart from *g*, common to both performance and spatial tests. Leff (1949) found similar results for boys of 12. Dempster (1948) found a common factor underlying Alexander's performance scale and paper-and-pencil spatial tests. Watts (1953) administered a battery to a sample of eleven-year-old pupils and found a large group factor additional to *g* present in Alexander's performance scale, the Watts group performance test, and two N.F.E.R. paper-and-pencil spatial tests (Spatial Tests 1 and 2) and having negative loadings in several verbal tests. This is clearly the familiar spatial-verbal bipolar factor. It is interesting to find that the spatial loadings of the paper-and-pencil spatial tests were not very different from those of the performance tests. There was a third factor, which was difficult to interpret, but in the upper half of the table it apparently subdivided the spatial factor into one associated with performance tests and one associated with paper-and-pencil tests.

Burt (1949) and Vernon (1949) have both suggested a possible explanation of the divergent results obtained by different investigators regarding the factors underlying performance and spatial tests. They suppose that there may be a main practical factor which, under suitable conditions, may be subdivided. This would explain why some experiments show a factor common to both types of tests, while others show different factors associated with each type. The majority of the findings tend to favour the view that *F* and *k* are essentially the same. In a summary of the available evidence in 1950, Vernon endorses the view that *F* is identical with *k* and that Cox's *m* is largely composed of *k* also.

The problem of alternative interpretations of factors

A serious source of confusion in many of the researches carried out on spatial ability has been the fact that different workers have tended to interpret factor-loadings in different ways. As an illustration of the different interpretations which can be given to these loadings, we may consider the alternative views which were taken of the factors obtained in the experiment carried out by the writer in 1947.

In a factor-analysis of the correlation matrix of nine variables (two verbal, two non-verbal and five spatial) he had obtained only two significant factors. Using Thurstone's centroid method, he had extracted three factors, put the resulting communalities back into the correlation matrix, and analysed a second time. He had tested the residuals remaining after the extraction of the first two factors, using McNemar's criterion and found the third factor to be of doubtful significance. He then analysed the correlations by Lawley's method of maximum likelihood, using the centroid loadings in the first two factors as first approximations. After two iterations, it was found that the loadings were approximately constant. The residuals resulting from the extraction of these two factors were then tested for significance by Lawley's Test and were found to be non-significant at the 5 per cent level. Thus, the third factor was not significant, and the writer was led to conclude, like Slater, that a two-factor solution was adequate to fit the data. It was apparent, however, that the spatial tests of the battery, especially the writer's experimental Spatial Test and the N.I.I.P. Memory for Designs Test, were clearly differentiated from the non-verbal tests in the bipolar factor (factor II). It was a matter of some surprise to the writer however to find that experts in factor-analysis differed as to the interpretation of these factor-loadings. In the course of a visit, in connection with some other matters, to the department of Education of the University of Edinburgh, he left a copy of the matrix of correlations with Mr. W. G. Emmett. Unknown to the writer, Mr. Emmett arranged for an independent analysis of the correlations to be carried out by members of the staff of the Education Department. Factor-loadings were obtained using Lawley's method which were almost identical with those previously found by the writer, differences occurring only in the fourth decimal place. But the writer was most surprised to learn from Mr. Emmett that there was "no trace of the spatial factor". Apparently it had 'disappeared' again!

The two analyses were in agreement in that there were only two significant factors, but the Moray House experts had then rotated the axes, and given a different interpretation to the rotated loadings.

The figures kindly supplied by Mr. A. E. G. Pilliner (1950) of the Department of Education, University of Edinburgh, are shown in Table 11.

Table 11

Factor loadings obtained by Lawley's method after two iterations (using the centroid loadings in the first two factors as first approximations. Smith's data)

TESTS	UNROTATED LOADINGS		ROTATED LOADINGS	
	I_0	II_0	I_1	II_1
Verbal (i) (M.H.T. 35)	·9087	·1822	·6365	·6737
Verbal (ii) (M.H.T. 35)	·9086	·2500	·5973	·7290
Non-verbal (Jenkins)	·8800	·0981	·6617	·5885
Non-verbal (Raven's Matrices)	·7838	— ·0197	·6512	·4367
Exptl. Spatial Test I	·8845	— ·2937	·8917	·2712
M.H. Space Test I (I)	·9280	— ·0049	·7604	·5321
M.H. Space Test I (II)	·8363	·0163	·6733	·4964
Memory for Designs	·7042	— ·4984	·8628	·0000
Exptl. Drawing Test	·4821	— ·2768	·5534	·0526

1. *Interpretation in terms of bipolar factors*

Since the battery seemed to be reasonably well-balanced containing verbal, non-verbal and spatial tests, the first unrotated factor may be regarded as approximating to *g* and the second as a bipolar factor contrasting verbal loadings, which in this case are positive, with spatial loadings which are negative. The variable with the highest *g*-loading would be the first section of M.H. Space Test I, and that with the lowest loading would be the drawing test. Raven's Matrices, which is usually regarded as a standard measure of *g*, being relatively free from verbal or spatial components, has a near zero loading in the second factor, thus tending to confirm the view that rotation of axes is unnecessary. The test with the highest spatial loading is Memory for Designs, the value being very nearly ·5.

This interpretation may be regarded as corresponding most closely to orthodox British ideas, based on the hierarchical theory of abilities as advocated by Burt and Vernon. On this view, the spatial and verbal factors together constitute a bipolar factor, the spatial and verbal components being inversely related, apart from *g*.

If *g* is defined with reference to a non-verbal test such as Raven's Matrices, two pupils having the same level of general ability (i.e. scoring the same on the reference *g*-test) may show contrasting scores on verbal and spatial tests. One may be relatively good at spatial tests and poor at verbal tests while the other may show the opposite characteristics.

2. *Interpretation after orthogonal rotation of axes to make all loadings positive*

This procedure, illustrated in the foregoing table, seeks to eliminate all negative loadings by a suitable rotation of axes. In the example shown, the first axis was located along the vector for the Memory for Designs Test, giving it a zero loading in the second factor. The first factor was now identified as *g* and the second as *v*. The third factor had been shown to be non-significant by Lawley's Test, so there were no grounds for postulating the presence of a spatial factor in order to account for the correlations. The test which now had the highest *g*-loading was the experimental draft of the writer's spatial test, which had a loading of ·8917.

The next highest *g*-loading (·8628) was that of Memory for

Designs, while the *g*-loadings of the verbal intelligence tests were in the region of ·6. The two non-verbal tests had now considerable loadings on the verbal factor. Thus, Raven's Matrices though hitherto regarded as a *g*-test, now appeared to have a verbal loading of ·4367. We might account for this by supposing that many of the items of Matrices, which are solved by explicit analysis, may actually involve verbal processes, though the content is purely diagrammatic. The Memory for Designs Test, on the other hand, would now be regarded as a relatively pure *g*-test, with the very high *g*-loading of ·8628.

Thus, if we adopt this second interpretation many tests commonly regarded as spatial would really be *g*-tests with considerably higher *g*-loadings than the ordinary verbal or non-verbal intelligence tests. Tests such as Meccano Assembly and Wire-bending, which were found in the Services to have high *k*-loadings (as high as ·76), would be regarded as high *g*-tests. This view, though decidedly unorthodox, has the advantage that it obviates the need to regard ability factors as inversely related.

3. *Interpretation in terms of oblique factors*

In both of the previous interpretations the factor axes were orthogonal. American factorists (following Thurstone) would probably employ oblique axes, passing them through central points in the spatial and verbal clusters. The two factors represented by these oblique axes would probably be identified as *Vz* (spatial visualization) and *V* (Verbal comprehension). The procedure of rotating axes to 'oblique simple structure' automatically excludes the possibility of a general factor among the primary factors, but since these are no longer uncorrelated, a second-order general factor may be extracted from the matrix of correlations of the primary factors.

Of these three interpretations, the first is the orthodox British view and the third has many adherents, particularly in the United States. The second interpretation is unorthodox and is at variance with commonly accepted valuations of spatial as compared with other types of test.

There is some evidence, however, to be discussed at greater length in later chapters, which tends to favour the second view. It is well known that almost any form of severe brain injury is usually associated with gross spatial disabilities, as is reported in studies of cerebral palsy in children. The most typical test-pattern found in brain-injured children shows low spatial achievement and high language achievement, the discrepancy sometimes being very marked. Such children may show great difficulty in thinking conceptually, in spite of having high verbal I.Q.s. (For typical case histories, reference may be made to Strauss and Kephart, 1955.)

Vernon (1950) has noted that spatial ability tends to link up with mathematical abilities at advanced levels, a finding which suggests that spatial ability rather than verbal ability is associated with high-level abstract thinking. The results of a factorial study of creative thinking by Sultan (1962), one of Vernon's research students, gives further support to this view. Sultan administered a varied battery of some 40 tests to 13–14-year-old grammar school pupils and analysed the correlations by various methods. Of the seven factors extracted by the Varimax Method, the largest single factor was clearly a composite of *g* and *k*, with highest loadings in the spatial and flexibility of closure tests, and substantial loadings in non-verbal classification *g*, Shipley abstraction, concept formation and in the mathematics tests and grades. Thus, Sultan's research also suggests that spatial ability rather than verbal ability is associated with abstract, conceptual or mathematical thinking.

As a final argument in favour of the second interpretation of factor loadings, reference may be made to the fact that during the Second World War, army psychologists noted that superior performance in spatial or mechanical tests, such as Squares, Bennett or Assembly, seemed to be associated as much with a kind of general, practical intelligence as with a specifically mechanical aptitude.

If we adopt the second point of view, which the present writer is himself inclined to favour, it would be necessary to modify somewhat our generally accepted notions as to the ways in which high general ability (*g*) manifests itself in everyday life. Such a view would imply that high general ability would be shown not only in a certain versatility but more especially in exceptional capacity for solving problems of a spatial or practical kind. Persons so endowed may not necessarily be distinguished in traditional scholastic subjects, for they may be lacking in verbal facility, but we should not expect them normally to experience difficulty in mathematics.

Leonardo da Vinci is perhaps a good example of a person who exhibited to a superlative degree the kind of high general ability implied in this view. For not only was he remarkable for his versatility, but his achievements were prodigious in many fields requiring a high degree of spatial ability, such as mechanics, engineering, architecture, painting and sculpture.

Galton (1892) has observed that the "foremost engineers are possessed of singular powers of physical endurance and of boldness, combined with clear views of what can and cannot be effected". A high endowment of spatial ability certainly implies an aptitude for dealing with spatial or mechanical problems but it appears to have a greater significance. If this view is correct, high spatial ability provides a surer index or touchstone of high general ability than does an endowment of high verbal ability.

Sub-divisions of the Spatial Factor

Reference has already been made to an early investigation in which Kelley (1928) found evidence for the existence of two sub-factors of spatial ability, which appeared both with samples of kindergarten children and with nine-year-olds. The first sub-factor involved the perception and retention of geometric forms and the second a facility for the mental manipulation of shapes. Similar sub-factors have been reported by subsequent investigators who have tested samples of older pupils or of adults, e.g. Taylor (1960).

Several spatial factors were isolated in the factorial studies carried out by Guilford and Lacey (1947) as part of the American aviation psychology programme in the Second World War. It was claimed that there were three spatial relations factors (S_1, S_2 and S_3), a visualization factor (V_z), a length estimation factor, and a perceptual speed factor P. The first spatial factor S_1 was found in psycho-motor tests of reaction time and complex co-ordination, in instrument and dial-reading and in certain paper-and-pencil spatial tests. The second spatial factor S_2 was involved in Thurstone's Hands and Flags Tests. The Visualization factor V_z appeared in mechanical comprehension tests, in a paper folding test, in a test of surface development and in a test involving the description of painted blocks of cubes.

In later articles, Guilford (1948a, 1948b) identifies the Visualization factor with El Koussy's *k* and relates his first spatial factor S_1 to the appreciation of spatial directions from the body, i.e. an ability to "make discriminations as to the direction of motion such as up and down, left and right and in and out".

Thurstone (1950) listed seven factors, three of these having to do with visual orientation in space, which he labelled S_1, S_2 and S_3. S_1 was interpreted as "the ability to recognize the identity of an object when it is seen from different angles", or as "the ability to vizualize a rigid configuration when it is moved into different positions", as in the Flags test. S_2 was interpreted as representing "the ability to imagine the movement or internal displacement among the parts of a configuration". This second factor S_2 was involved in tests of mechanical movement and surface development. The third spatial factor S_3 was said to represent "the ability to think about those spatial relations in which the body orientation of the observer is an essential part of the problem". Thurstone surmised that kinaesthetic imagery might somehow be involved in his third spatial factor.

In a later study of Mechanical Ability, Thurstone (1951) reported ten factors extracted from the correlations of 32 spatial, mechanical and other group tests given to 350 boys in a technical high school. He identified nine of these factors as follows:

Induction; first, second and third Spatial (S_1 S_2, S_3); second and third Memory; Kinaesthetic; and first and second Closure.

The first spatial factor (S_1) entered into tests in which the subject had to decide whether or not a figure could be made to coincide with a given figure by rotation in the plane of the paper. The second spatial factor (S_2) had moderate loadings in tests involving paper puzzles and surface development, while the third spatial factor (S_3) entered into only two tests and Thurstone did not attempt an interpretation. The second spatial factor (S_2) was found to be most discriminating between two criterion groups of 45 boys, one consisting of boys with high mechanical ability and interest and the other of boys with low mechanical ability and interest, though the first spatial factor S_1, and the second closure factor were also found to be discriminating. The kinaesthetic factor entered into the Hands test and the Bolts test. In the second of these, the direction in which the bolt should be turned to be tightened had to be visualized. It is the second spatial factor (S_2) of Thurstone's investigation which corresponds most closely to the British *k*-factor, though it seems probable that all three factors which discriminated between the two criterion groups of boys would turn out to be sub-factors of the main spatial factor.

In a summary of the findings of a large number of factorial investigations carried out prior to 1951, French (1951) discussed the nature of three spatial factors which had been reported. He called these space, spatial orientation and spatial visualization respectively. He thought the space factor represented "the ability to perceive spatial patterns accurately and to compare them with each other". It appeared to enter into the perception of three-dimensional as well as two-dimensional space. He considered that the interpretation of the spatial orientation factor had not been clarified, but that it seemed "to involve a person's ability to remain unconfused by the varying orientations in which a spatial pattern may be presented". He interpreted the spatial visualization factor as "the ability to comprehend imaginery movement in three-dimensional space, or the ability to manipulate objects in imagination".

It is clear from these descriptions that French had not succeeded in making clear-cut distinctions between the different factors. The next development was the convening of a very interesting symposium on spatial abilities at the Conference of the American Psychological Association held in Washington D.C. in September 1952. The contributions were subsequently published in *Educational and Psychological Measurement* (1954).

The first paper was by Fruchter, who outlined the history and background of the problems involved in the measurement of spatial abilities. He pointed out that while literally hundreds of tests of these abilities had been devised, the question as to whether spatial ability is unitary or whether there are several fundamental types of spatial abilities had not yet been answered to the complete satisfaction of all research workers in this field. The purpose of the symposium was to give some idea of the present status of the problem and to make some suggestions as to what needs to be done to clarify the issues in the future. The problem had seemed much simpler in 1940 when Wolfle (1940) had summarized the results of factorial studies, prior to that year. Wolfle had then stated that the space factor was the second most frequently identified factor, second only to the verbal factor:

"It appeared prominently in tests requiring the subject to react to spatial relations, to read plans or blue-prints, or to tell quickly whether two drawings represent the same or opposite sides of such asymmetrical figures as flags. The same factor seemed to be involved in dealing with both two and three dimensional space."

In the second contribution to the symposium Zimmerman outlined some hypotheses concerning the nature of the spatial factors. Apparently, the trouble had really started with the series of factor-analyses of Army Air Force Tests (1947) carried out under the direct supervision of Dr. L. G. Humphries, where it was demonstrated repeatedly that there were at least two and possibly three or more factors into which the variance of tests formerly appearing on a single factor could be split. The most persistent cleavage appeared to set apart one cluster of tests involving a manipulative visual-imagery process, which was quite satisfactorily described by the label 'Visualization'. There was no appropriate terminology, however, to describe the remaining factor, and the aviation psychologists advanced a number of hypotheses to define the nature of this other factor which was separate from Visualization.

One of these hypotheses was that it involved directional discrimination, but when several tests were devised to measure this ability, none of them were found to measure the original space-factor as it was first recognized when it split away from Visualization. A second hypothesis was that the Space and Visualization factors were differentiated by their relative amounts of complexity or difficulty. It was supposed that merely by varying item-difficulty and complexity, a single kind of test could be made to emphasize each of four factors in succession from Perceptual Speed, through Space and Visualization to Reasoning.

Zimmerman (1954) described how this hypothesis was tested experimentally by administering three different forms of a single test, Visualization of Manoeuvres, in successive months to a group of aviation students. The test required the subject to select from five alternatives the picture which correctly portrayed the position of an aeroplane, after it had completed a given manoeuvre. In the simplest form of the test, a single manoeuvre, such as a turn or a bank, was described and had to be visualized. The moderately difficult form contained two, and the most difficult form, three manoeuvres, which had to be visualized successively.

The students to whom the three tests were administered also took a large battery of classification tests, and this made it possible to identify the factors entering into the three forms of the Visualization of Manoeuvres test. The results were found to support the hypothesis being tested.

It was found that the simplest form of the test had by far the highest loading in the factor of Perceptual Speed. The moderately difficult form was the best measure of the Space factor and the most difficult form proved to be the best measure of the Visualization factor. None of the tests, however, was loaded significantly on the Reasoning factor. Thus, either the Reasoning factor did not belong to the continuum of the spatial factors, or else none of the three forms of the Manoeuvres test was difficult enough to involve it. The three factors Perceptual Speed, Space and Visualization seemed to enter into the same kind of test-material at different levels of difficulty and complexity. The Visualization end of the continuum seemed to be more intellectual as opposed to the non-intellectualized, more automatic, response at the Perceptual Speed end.

Zimmerman made the suggestion that Thurstone's distinction between his space factors S_1 and S_2 may be interpreted in terms of the continuum hypothesis. Thurstone believed that his factor S_1 entered into tests involving the manipulation of total configurations whereas the factor S_2 seemed to be related to the occurrence of movements of the parts within the configuration. Zimmerman advanced the alternative hypothesis that the distinction could be regarded as depending simply on the degree of difficulty and complexity involved.

The third contribution to the Washington symposium was made by Michael (1954), who suggested a possible research programme towards the identification of the psychological processes associated with spatial-visualization factors. This programme would involve the formulation of hypotheses regarding the psychological processes by studying introspective reports given by examinees. Special test items were to be devised to sample the various processes and a research design was proposed, combining both experimental and correlational methods, to test the validity of various hypotheses.

The consensus of opinion expressed at the Washington symposium on spatial abilities seemed to be that spatial ability is complex and still not well-understood.

Undoubtedly, the field had become much more complex during the previous decade because of the development of new types of test-material and also because of the more exhaustive factorizations made possible by the use of modern computing devices. The very great variety of types of test-materials which could now be classed under the heading of spatial ability was demonstrated in the same year, when Anderson, Fruchter, Manuel and Worchel (1952) published a survey, with a bibliography of 157 references and a list of 139 different spatial tests. They described four different factors which they considered to be spatial and four other factors which they felt were not quite in the same category. There was clearly a need for further research, however, to elucidate the nature of these factors.

In 1957, Michael, Guilford, Fruchter and Zimmerman again tackled the problem and in a joint paper attempted to synthesize the findings of research in this field prior to 1957. By comparing the results of several factorial investigations, they sought to describe the similarities and differences in the psychological processes underlying those factors which appeared to have been fairly well established. They formed three groupings of factors which seemed to correspond to the lists by the Army Air Force Psychologists, by J. F. French in Psychometric Monograph No. 5 (1951), and by Thurstone in his series of well-known studies (1938, 1950 and 1951). They then described three types of factors, corresponding to these groups, and identified them as:

1. *SR-O* Spatial relations and orientation;
2. *Vz* Visualization;
3. *K* Kinaesthetic imagery.

(The third type of factor must not, of course, be confused with El Koussy's *k*-factor, though the letter *k* adopted by El Koussy to designate his factor is said by Burt to have been suggested originally by the word kinaesthetic.)

Michael *et al.* suggested that their *SR-O*-factor was "more or less a composite of Thurstone's S_1 and S_3-factors", that their *Vz*-factor was essentially the same as Thurstone's S_2-factor, and that their *K*-factor might be considered identical with Thurstone's tentatively identified *K*-factor.

They also thought that their *SR-O*-factor could be regarded as a composite of French's factors of Space (*S*) and Spatial Orientation (*SO*). To clarify the nature of their three factors they supplied detailed descriptions, summarized in the following notes.

1. *Spatial relations and orientation (SR-O)*

This factor was thought to enter into the ability to comprehend the nature of the arrangement of elements within a visual stimulus pattern, primarily with respect to the examinee's body as the frame of reference. In a typical test of this factor, as the entire configuration, or a principal component of it, is moved into a different position, the objects within the pattern hold essentially the same relationships to one another.

2. *Visualization* (V_z)

Tests of this factor were believed to require mental manipulation of visual objects involving a specified sequence of movements. The objects appear within a more or less complex stimulus pattern.

The individual finds it necessary mentally to rotate, turn, twist or invert one or more objects, or parts of a configuration, according to relatively explicit directions as to what the nature and order of the manipulations should be. The examinee is required to recognize the new position, location, or changed appearance of objects that have been moved or modified, within a more or less complex configuration. In some instances he is required to present a record of his solution by drawing appropriate responses (as in the tests of Punched Holes and Form-Board).

3. *Kinaesthetic imagery (K)*

This highly tentative factor was thought to represent merely a left-right discrimination with respect to the location of the human body. For example, in Thurstone's Bolts test, the examinee has to determine in which of two directions the bolt has to be turned if it is to be screwed into a block of wood.

Having described the factors in this way, the authors admit that though it is convenient to consider them as being conceptually independent, it is likely that a certain amount of correlation exists among them.

That such correlation does exist had already been reported by Thurstone and by Guilford and Zimmerman. The latter reported that their tests of Spatial Visualization and Spatial Orientation gave a correlation of ·5 among college students. Roff (1952) obtained a correlation as high as ·75 between Spatial Visualization and Spatial Orientation. Since ·75 is not far short of the reliability coefficient for some of these tests (·89—in the case of the Guilford-Zimmerman Spatial Orientation Test), there would seem to be a strong case for considering *SR-O* and V_z to be sub-factors of a single, broad, spatial factor rather than separate factors.

Michael *et al.* (1957) list the following tests as representative of the three types of spatial ability.

1. *Tests of the* SR-O-*Factor*

The following were believed to contain substantial amounts of variance in the *SR-O*-factor:

Instrument Comprehension II (A.A.F.)
Complex Co-ordination (A.A.F.)
Aerial Orientation (A.A.F.)
Dial and Table Reading (A.A.F.)
Discrimination Reaction Time (A.A.F.)
Directional Orientation (A.A.F.)
Two-Hand Co-ordination (A.A.F.)
Stick and Rudder Orientation (A.A.F.)
Cubes (Thurstone)
Flags, Figures and Cards (Thurstone)
Lozenges (Thurstone)
Paper-Puzzles (Thurstone)
Spatial Orientation (Guilford-Zimmerman, involving pairs of pictures showing changes in the position of a boat with respect to certain landmarks)

2. *Tests of the Visualization (Vz) Factor*

The following tests were believed to be primarily measures of the *Vz*-factor, though they might have moderate amounts of variance in other factors.

Directional Plotting (A.A.F.)
Spatial Visualization (A.A.F. paper-folding)
Mechanical Principles (A.A.F. An adaptation of Bennett and Fry's Mechanical Aptitude Test)
Mechanical Movements (A.A.F. After Thurstone)
Pattern Comprehension (A.A.F., Thurstone's Surface Development Test, modified)
Punched Holes (Thurstone)
Form-Board (Thurstone. A test of fitting or dissecting shapes)
Spatial Visualization (Guilford-Zimmerman. Pictures of a clock in various positions)

3. *Tests of the Kinaesthetic Imagery Factor (K)*

Only two tests have shown this factor, tentatively identified as the Kinaesthetic Imagery Factor.
Hands (Thurstone)
Bolts (Thurstone)

In 1958, Myers reported an investigation undertaken on the lines of a study by Barrett (1952) to find what information could be gained from more extensive and extended interviewing. The aim was to investigate the nature of spatial abilities and to study the uses of interviewing as an additional technique towards this end. The study consisted of a series of individual interviews in which five college students solved items from spatial relations tests and told how they did the work and what they thought of the tests. These introspections were broad rather than deep. They do not appear to have been very illuminating, though they showed that there were differences in the various individual's approaches to these problems.

In an appendix to the report, Myers included a brief discussion of his views as to the nature of spatial abilities. We quote this passage in full, because it shows very clearly that in 1958, American psychologists had not succeeded in clarifying the distinctions between the factors which have been isolated in this field.

According to Myers, "... the domain of spatial ability has not yet been clearly defined. It verges on the studies of visual depth perception. For this reason the questions of orientation to the environment and of objects to the self have been included.

"It may have some connections with Thurstone's studies of closure and colour-form dominance, with W. Grey Walter's studies of 'brain-waves' or with Witkin's studies of 'field independence'.

"Occasionally, tests of non-verbal reasoning, designed to be measures of Spearman's *g*-factor, have been classed in this domain. The relationship between spatial ability and visual imagery is not well understood. In spite of the fact that the terms 'spatial ability' and 'visualization ability' are occasionally used, sometimes almost interchangeably, as fairly general terms for this ability, the tests that have been devised seem to be mostly concerned with form or shape rather than with intervening space and few tests call explicitly for the formation of visual images. The tests we have used in this study include some that have been used as references for 'Vizualization' and others that seem to be measures of a 'Space' factor. We are not yet prepared to say what this means. Many different hypotheses have been advanced as definitions of spatial factors.

"It does seem fairly clear that 'Vizualization' test items are usually more complicated and difficult than 'Space' test items and there is some indication that they are likely to be more valid for predicting success in such criteria as grades in engineering drawing courses.

"Thurstone (1951) reported that the distinction between the two most important factors was that 'Space' tests dealt with rigid figures, such as those in Identical Block tests, whereas 'Visualization' tests dealt with non-rigid figures, such as those in Surface

Development tests. Unfortunately the distinction does not seem to be quite so simple, since different populations and different conditions of test-administration can produce different factor-loadings in the same spatial tests. In this respect, we use the term 'spatial ability' to represent a complex family of abilities with unknown interrelationships. We do not yet know of a terminology that permits of more precise and efficient language."

A study of the descriptions of these test-materials and of the accounts of the psychological processes involved shows quite definitely that the V_z-factor of Michael *et al.* and the S_2-factor of Thurstone are the same as the *k*-factor familiar to British psychologists. The presence of Paper Form-board, Paper Folding, Surface Development and Punched Holes in the list of tests of factor V_z places this issue beyond dispute.

A remarkable feature of the American research on spatial ability is the difficulty the American psychologists are finding in clarifying the distinctions between the different spatial factors and especially between *SR-O* and V_z. In spite of the numerous studies carried out with large samples of testees and the many discussions, seminars and symposia conducted on the problem since the early investigations by Kelley and Thurstone, it cannot be said that clear-cut distinctions have been established. Michael *et al.* have considered in great detail psychological aspects such as complexity of stimulus, amount of manipulation involved, the examinee's bodily orientation, the movement of parts of the stimulus object versus the movement of the entire object, as well as the relative importance of speed and power. They claim that there are differences between the three factors in each of these respects, but none of the differences seems to be really watertight. For example, it is suggested that tests involving V_z usually involve relatively complex stimulus patterns. Yet some tests with high *k*-loadings (and so presumably involving V_z) consist of relatively simple configurations as in the Block Building Test (of N.F.E.R. Spatial Test 2) in which the examinee has to state how many blocks are contained in a given cube. This test has a *k*-loading of about ·6.

V_z is also said to differ from *SR-O* in that it requires mental manipulation (rotating, turning, twisting or inverting) with a specified sequence of movements, or that it involves displacements of parts within the configuration. Neither of these conditions apply to many tests known to have high *k*-loadings, such as Memory for Designs or Pattern Perception (Cross Pattern), in both of which the pattern is static.

None of the psychological aspects considered by Michael *et al.* seems to be really successful in distinguishing *all* the tests involving V_z from *all* the tests involving *SR-O*. One aspect *not* considered by Michael *et al.* is the view put forward by the writer that the *k*-loading (and therefore the V_z-loading) of a test depends on the degree to which it involves the perception, retention, and recognition (or reproduction) of a figure or pattern in its correct proportions. Success in the item must depend *critically* on an ability to retain and recognize (or reproduce) a configuration as an organized *whole*. This hypothesis would account for the fact that Form-board has a loading in V_z while Flags, Figures and Cards involve only *SR-O*. In both kinds of test, mental manipulation of figures is involved, but in the latter type of test, the configurations about which a decision has to be made are identical though in a different position, so success in the item does not depend *critically* on an ability to distinguish a *particular* configuration from others which differ in shape or form. In the Flags test, for example, which involves *SR-O*, all the subject has to do is to decide whether two pictures represent the same or opposite faces of the same flag.

The high correlation between *SR-O*- and V_z-tests is due to the fact that both types of test involve operations with spatial material and so both depend on the same broad factor. V_z-tests, however, which are the true *k*-tests, differ from *SR-O*-tests in that success or failure in an item also depends *critically* on gestalt- or form-perception. *SR-O*-tests may require only an ability to manipulate the same shape and not an ability to discriminate between this and other different shapes.

In the light of this hypothesis, the suggestion made by Michael *et al.* that tests involving V_z usually include highly complex patterns can be seen to be only partially true. Recognition of a pattern may be achieved in various ways, for example, by observing certain characteristic details or by noting certain properties explicitly (such as the number or equality of the sides of a regular polygon), or by recognizing a shape as a whole, as in the case of an irregular polygon.

Tests which depend on the noting of details usually involve the factor of perceptual speed *P*, and not the V_z- or *k*-factor. A good example is Thurstone's test of Identical Forms. In this test, the first figure in each line is exactly the same as one of five numbered figures following. The subject has to identify the figure which is the same. In this case all the figures from which a choice has to be made have approximately the same form or gestalt as the given figure. The figures differ, however, in certain details. For example, in one item the figures represented the head of a dog and the variants differed in respect of detail, e.g. in one figure the eye was missing, in another the mouth, *etc.* Such tests involve perceptual speed *P* rather than *k*.

Some items may involve highly complex patterns without involving *k* or V_z. If the items require explicit analysis (as in Progressive Matrices) they tend to measure *g* (or *R*) rather than *k* or V_z. *It is only when the complexity is of a kind which compels the subject to rely on the perception of a configuration as a whole that the test involves k.*

It is a relatively simple problem to identify a given square in a series of squares differing both in size and orientation. All one need do is to find one with a side of the required length. Since success in such an item does not depend *critically* on the perception of a *shape*, *k* is not involved.

It is a more difficult task to identify a given quadrilateral in a series of quadrilaterals all differing in shape and where the sides and angles in any figure are not related in any simple way. Such an item *does* involve *k*.

We could set about this problem by measuring the sides and angles of each figure, but it would be some time before we could identify the identical quadrilateral by this procedure. If, however, we can form a mental image of the quadrilateral and superpose it in imagination on each member of the series in turn, the task becomes quite simple. In the writer's view, this is the essential process involved in performing tests of the visualization type (i.e. tests of k or V_z), and persons who have high spatial ability can carry out such processes with ease.

These tests need not be complex in the sense which implies that they contain much detail, but they may be complex in another sense, in the respect that the relations between the parts of a configuration cannot easily be grasped explicitly. The relations must be grasped *implicitly*, and that is what is implied by the statement that such tests involve an ability to perceive and retain in mind a figure as an *organized whole*.

To complete this outline of previous research on spatial ability, it is perhaps appropriate to quote from the communication made by El Koussy (1955) to the International Colloquium of the Centre National de la Recherche Scientifique held in Paris in July, 1955. The theme of the colloquium was 'Factorial Analysis and its Applications' and El Koussy's paper was entitled 'Directions of Research in the Domain of Spatial Aptitudes'.

The following are some of the main points made in the address.

From the point of view of content, spatial aptitude may be subdivided into two-dimensional and three-dimensional, and static and dynamic aspects. From the functional point of view, it may be subdivided into visualization and manipulation sub-factors.

Research has shown that there are differences in spatial aptitude from the kindergarten onwards and that boys show a superiority over girls. This superiority is not due to the effects of apprenticeship, since it exists even when the same education is given to both sexes. It is more marked in three-dimensional tasks than in two-dimensional tasks.

Investigations in schools and colleges have led to the following conclusions:

1. In technical school courses generally, spatial tests and dexterity tests are very important.

2. For shop work, dexterity is more important but for industrial design and practical geometry spatial aptitude *k* is the more important.

3. Among engineering students at the university, spatial and mechanical factors are more marked in advanced students than in the others (Salam).

4. The best *k*-tests for measuring aptitude for engineering are three-dimensional tests and among two dimensional tests, the best are those which depend most on visualization.

Analysis of aptitude for mathematics has shown that it consists of a heterogeneous group of capacities involving the general, numerical, verbal, memory and spatial factors. The numerical and spatial factors have a tendency to be weaker in pupils who are backward at mathematics, though normal in other subjects (Hamza).* The cognitive aspect of geometrical aptitude has been analysed into two distinct factors, two-dimensional and three-dimensional (El Sayed).†

It seems that the factors underlying the mental processes necessary for success with spatial material—considered as a global aptitude to obtain, manipulate and utilize spatial visual imagery—may be differentiated into a visualization factor and a manipulation factor (Salam). The factor of manipulation seems to overlap the spatial domain and merits further investigation. Salam devised thirteen tests involving visualization and manipulation separately or simultaneously. By means of Thurstone's Centroid Method with oblique rotation of axes, he was able to separate the two factors, visualization V_z and mental manipulation M_a.

The possibility of a mental manipulation factor had been suggested in the factorial analyses of Mitchell, Hamza, Barakat, Ormiston and several others, but this was the first time that it appeared clearly and that it was interpreted psychologically. Salam also showed that it is not limited to spatial material in three

* Cf. Hamza, Ph.D. Thesis, Univ. of Leeds, 1951.

† Cf. El Sayed, Ph.D. Thesis, Univ. of Reading, 1951.

dimensions, but that it has a wider extension. He found it in numerical and verbal material.

El Koussy concluded his paper by remarking that he had attempted to show that the spatial factor was a subdivision of a broader factor and that in the course of time this had been subdivided in turn into S_1, S_2, S_3, V_z and M_a. This was an illustration of Burt's theory of hierarchical structure, a point of view which was reassuring, for it allows each to live and others to live as well.

We conclude the chapter with a passage from Myers' study (1958), which expresses a point of view with which the present writer is in full agreement, namely that spatial ability has a wider significance than as a mere aptitude for courses in art and technical subjects.

Myers writes, "We believe that the person with this ability, or these abilities, will characteristically reason in a different manner from people who have little of these abilities. Their interests are likely to differ. They are likely to be more successful in solving certain problems. We believe that these abilities can be developed, that they are partially dependent upon innate characteristics, but that they often remain undeveloped because they are not appreciated. We believe that these abilities are much broader in scope than the limited criteria for which they have thus far been shown to be valid. They may even influence the ways in which one studies philosophy or appreciates literature. . . .

"In our judgment, spatial ability is an important and pervasive trait, affecting our perception of our environment and our style of thinking about it. When better tests are built and a better theory provided for their use, we believe it possible that we will find spatial ability to be similar in importance to such traits as verbal or social intelligence."

Chapter three

Mathematical Ability and its Relationship to Spatial Ability

Outline of earlier research (1910–1945)

MUCH effort has been expended in an attempt to elucidate the nature of mathematical ability. Since most of the early studies were carried out before the advances made possible by methods of factor-analysis, it is inevitable that the pioneer investigations have less importance than more recent enquiries. Nevertheless, it is of some interest to consider the conclusions reached by the early workers and to attempt to relate these to the findings of studies using factorial techniques.

There seems to have been general agreement that there is a fundamental difference between the abilities required for school mathematics and those required for higher mathematics. Thus, Betz (1911) maintained that school mathematics has little to do with real mathematical thinking. William Brown (1913) concluded that "there is good reason for thinking that school mathematics and higher mathematics relate to different forms of ability and should be clearly distinguished from one another". Möbius (1900) went so far as to suggest that "ability in mathematics is a special fundamental capacity independent of other capacities".

Brown (1910) had concluded from one investigation using the method of partial correlation "that geometrical ability was related to algebraical ability only through the mediation of arithmetical ability", but in a later study (1913) he adopted a somewhat different point of view. "The balance of evidence seems to lie in favour of the existence of a special capacity or faculty underlying mathematical ability, distinct from and with no essentially close connection with other forms of intellectual capacity."

One of the early experimental investigations of mathematical ability was that reported by Rogers in 1918. Though carried out before the development of modern methods of factor-analysis, her work broke fresh ground and deserves considerable credit as a pioneer investigation.

She constructed a comprehensive battery of tests, of which thirteen were mathematical, including Algebraic Computation, Geometry, Geometrical Definitions and Interpolation (number series). In addition there were several spatial tests, such as Superposition and Symmetry (similar to Thurstone's Lozenges Test) and Matching Solids and Surfaces. She also included four verbal tests (analogies, opposites, sentence completion and the Thoındike Reading Test).

Using the technique of partial correlation, she found that the three groups of abilities algebraic, geometrical and verbal, measured by her tests were equally important in mathematical ability. She concluded that mathematical abilities were a complex resultant of a number of loosely connected capacities. She wrote, "Our results thus confirm those obtained by Brown that algebra and geometry demand activities of different kinds, although algebraic and geometrical abilities are positively related as is usual in the case of desirable traits. They lend no support to the view that there is a special capacity or faculty underlying mathematical ability, distinct from and with no essentially close connections with other forms of mental capacity."

Spearman (1950) carried out a factor analysis of Rogers' table of correlations using the method of tetrad differences and corroborated her conclusions. He could find no evidence for the existence of a group factor additional to *g*, entering into arithmetic and geometry.

More recently Werdelin (1958) has also carried out a factor-analysis of Rogers' data, using Thurstone's centroid method with rotation to oblique simple structure. He too obtained results confirming Spearman's and Rogers' conclusion, so that there can now be no reasonable doubt that there is no group factor in Rogers' data corresponding to 'mathematical ability'.

Collar (1920) investigated the existence of a unitary ability underlying the different aspects of arithmetic, namely mechanical (computation), knowledge (rules) and intelligence (problems). He concluded that there was evidence for the existence of a single factor *g*, operating in all kinds of arithmetical work, but that there was no support for the view that there were two main sub-divisions of arithmetical ability additional to *g*, a lower one for computation and a higher one for rules and problems. The only factor genuinely characteristic of arithmetic appeared to lie in its computational aspect.

Fouracre (1926) obtained results leading to the same conclusion. After eliminating the contribution of the general factor, he found insignificant residual correlations both between arithmetic and geometry and between algebra and geometry. His geometry tests appear to have been of a kind which we should now call spatial, e.g. Thurstone's spatial relations test, Thurstone's hand test (requiring the subject to differentiate between diagrams of the right and left hands), a symmetry test and a figure-dissection test. He also included several memory tests of the nonsense syllable type. In his conclusion, he wrote of the spatial tests, "This group of tests was the most successful in classifying the pupils regarding their mathematical ability". Of the memory tests, he reported, "The memory tests showed no significant correlation with mathematical achievement, except in the case of trigonometry".

The belief that spatial tests were indicative of mathematical ability seems to have been current at this time, for Rogers (1918), Cameron (1925) and Fouracre (1926) all used them extensively in their studies of mathematical ability. Ballard expressed the opinion in 1922 that tests of spatial orientation were useful for indicating mathematical ability, for this was the reason he gave for including a test of spatial orientation in his Chelsea Tests. He wrote, "Mr. Hugh Gordon, in a valuable series of experiments, has shown that the power to distinguish rapidly the right hand from the left, in any person and in any position, is connected closely with general intelligence and more closely still with mathematical ability. Hence the inclusion of dextrality questions among both the Chelsea Tests and the Picture Tests."

Wilson (1933) carried out two factor-analyses of school-certificate marks to discover which subjects of the school curriculum are related by involving common group factors. He investigated marks of a sample of 371 pupils in English, history, geography, French, arithmetic, algebra and geometry. His analysis showed that the correlations could not be accounted for by means of a single, general factor and that there were specific correlations between subjects in various groups, one of these being the group of three mathematical subjects.

He also analysed marks in English, algebra, geometry, botany, art, needlework and French for a sample of 110 pupils and again found a group factor with high loadings in the mathematical subjects. He concluded that there is a mathematical group factor, having loadings of about the same magnitude as those of *g*.

This conclusion means, in effect, that pupils who are good at one branch of mathematics should tend to be good at others and that the special aptitude involved is distinct from the general factor *g*. It does not follow, however, that the broad group factor is necessarily the expression of an hereditary or innate superiority. It may well be the result of teaching through the building up of interconnections (in the pupils' minds) between the separate branches of mathematics. Thus, an effect of teaching the principle of proportionality might be improved marks in algebra and geometry as well as in arithmetic.

Hamley (1935), who was both a mathematician and a psychologist, has recorded his views on the nature of mathematical ability in a chapter of a book on intelligence testing published in 1935. He wrote, "Mathematical ability is probably a compound of general intelligence, visual imagery, ability to perceive number and space configurations and to retain such configurations as mental patterns. Each of these could be subdivided into simpler components."

This definition emphasizes the importance of both visual imagery and ability to perceive spatial configurations. It would lead to the expectation that the two factors, *k* and *g*, might constitute a large part, if not indeed the essence, of what is generally understood by mathematical ability. Hamley's ideas are of some importance, since a number of investigations on the nature of mathematical ability and on related topics were carried out by his students under his inspiration.

One of these students was Mitchell (1938) who carried out an investigation based upon Hamley's idea that the mathematical concept of functionality has four main components—class, order, variable and correspondence. Mitchell assembled a battery of tests to measure seven processes, which he thought might emerge as factors, viz.,

1. classification, 2. eduction or abstraction, 3. ability to understand and use symbols and words, 4. ordering, 5. eduction of the correspondence between elements of classes, 6. operations in imagery, and 7. deduction or inference.

He applied Thurstone's centroid method to the resulting table of correlations and rotated the axes graphically to positions believed to have psychological significance. The first factor extracted was common to all the tests and was identified as Spearman's *g*. The second factor was found to involve the ability to manipulate spatial materials. It was most clearly present in certain spatial tests requiring "the manipulation, transposition, utilization and recognition of geometrical figures".

Mitchell thought that this factor might be the same as the *k*-factor, but it seemed to enter into certain verbal and reasoning tests and to involve operations with imagery, so he preferred to call it the O-factor. A third factor was found to be common to the verbal tests and was identified as the verbal factor, and a fourth factor was only tentatively identified.

Mitchell concluded that mathematical ability is complex, including a number of group and specific factors. The analysis showed that Spearman's *g* was an important component. The second factor, called by Mitchell the O-factor, was most probably the *k*-factor and it is worthy of note that this factor was found to be important for success in mathematics. That the identification with *k* is probably correct is suggested by the fact that there was also a separate, distinct verbal factor. Also subsequent research has failed to confirm clearly the existence of a separate O-factor entering into spatial tests as well as into certain verbal and reasoning tests.*

Oldham (1936) undertook a somewhat similar investigation, involving the administration of a battery of tests to large groups of boys and girls in the age-range 9 to 15. The battery included tests of arithmetic, algebra, geometry and intelligence and in addition a spatial test was given to some of the pupils. After partialling out intelligence and other variables from her correlation matrix, she found the residual correlations were always positive, some of them being moderately high. In spite of this evidence of the existence of a common factor additional to *g* she concluded that there was no group factor entering into the different branches of mathematics and thus no psychological reason for combining arithmetic, algebra and geometry as a common school subject.

Oldham's conclusions have been criticized by many writers. Vernon, for example, has shown that her results have a common factor which covers some 57 per cent of the variance, very little of this being attributable to *g*. He pointed out that Oldham's figures demonstrated the great amount of variation in correlations in different school classes due to the different ways in which the subjects were taught. The fact that differences in teaching may affect correlations so markedly makes it more reasonable that a mathematical group factor might appear as a result of stress being laid by the teacher on the interrelations of the different branches of the subject.

Blackwell (1938, 1940) carried out two factor-analyses of the correlations of batteries of tests including three tests of mathematical abilities, a number series test, a spatial test and five verbal tests. Applying Thurstone's centroid method to the resulting tables of correlations, she extracted four factors in the case of the

* Salam has claimed that the spatial manipulation sub-factor M_a identified by him is the same as Mitchell's O-factor.

girls and three in that of the boys. The first factor, after rotation of axes, had positive loadings in all the tests, but highest in the mathematics and number series tests. The second factor had its highest loading in the spatial test and was probably the *k*-factor, though Blackwell interpreted it as similar to the corresponding factor in Mitchell's study, i.e. as involving operations in imagery and entering into the manipulation of verbal as well as spatial material. The third factor was a verbal factor and this was found only in the sample of boys. No overlap was found between the spatial test and geometry apart from *g*. Vernon (1950) has pointed out that while the rotation of axes has produced factors in which all types of measure are represented, a study of the unrotated factors suggests that the mathematics marks, the spatial tests and the verbal tests fall into relatively distinct clusters.

Parslow (1942) tested pupils of different ages in the hope of discovering a law of development in the factors entering into mathematical attainment. He found, however, as had previous investigators, that the factor-patterns differed for different age-groups and showed little continuity. Using examination marks in arithmetic, algebra and geometry, he found a large group factor running through all of these, being associated in the case of the boys with verbal tests and number tests, but in the case of the girls with the number tests only. He also found a factor (presumably *k*) associating geometry with the spatial tests in the case of the boys, though the same factor did not appear in the girls' results.

Dahlgren (1944, 1947) analysed correlation tables for several batteries including mathematical and other tests and school marks. Since he did not include tests of spatial ability, his analysis could not be expected to provide evidence of a spatial factor or of its relation to mathematical abilities. He did find, however, the usual general, verbal and numerical factors.

Post-war investigations (1945 onwards)

Holzinger and Swineford (1946) studied the predictive value of the spatial and general factors in forecasting the achievement of high-school pupils in plane geometry. From the results of a bi-factor analysis, they found that a test of spatial ability correlated with teachers' grades in geometry to the extent of ·23, while the correlation with shopwork was ·46 and with drawing ·69. They also found that the test of the general factor gave a higher correlation with geometry grades (·584) than did the test of the spatial factor (·23). This finding suggests that the spatial factor has little importance in geometry, but the evidence cannot be regarded as in any way conclusive, since there may be considerable differences of opinion as to the validity of the criterion (geometry grades). It is possible too that the spatial test used in the study may not have had a very high *k*-loading.

The importance of having a valid criterion of geometrical achievement has been demonstrated by Murray (1949) who investigated the nature of geometrical ability by studying the performance of first year pupils in geometry in three high schools in New York City. Two criteria of geometrical ability were available, firstly a score in an objective achievement test and secondly the terminal grade at the end of the first semester. Other abilities were measured by means of well-known tests—for example, the Reasoning Test of the Chicago Primary Mental Abilities Battery, and the Minnesota Paper Form-Board Spatial Test.

When the terminal grades were used as the criterion of success in geometry, the contributions of the spatial, reasoning and verbal factors were found to be closely similar, but the numerical factor showed a relatively higher contribution. On the other hand, when the achievement test in geometry was used as the criterion of success in geometry, the verbal factor had the highest contributing value. Thus, the respective contributions of the variables differed according to the criterion. The terminal grades were based on the results of examinations which were probably highly loaded with problems of a numerical nature. The geometry achievement test was composed of questions couched in verbal form and this was reflected in the fact that it had a higher correlation with the verbal test than with any of the other tests. Thus, there was a marked contrast between the geometry achievement test and the terminal grades in geometry, the former being highly loaded in the verbal factor and the latter in the numerical factor.

Murray's findings drew attention to the complexity of the problem of finding an adequate criterion of geometric achievement. They also emphasized the importance of differing methods of work which may not be apparent from a casual observation of the task. Problems which appear on the surface to involve spatial and reasoning abilities may actually be solved by means of verbal and numerical techniques.

It seems likely that Murray's specially constructed test of geometric achievement was not well suited to the measurement of geometrical ability, being probably overweighted with questions of a verbal nature and requiring answers to be formulated in verbal terms. Attainment tests in geometry are available which consist entirely of geometrical riders in diagrammatic form, and the writer has shown that such a test correlates more highly with a spatial test than with a verbal test. (Cf. data for Walton's (1947) Geometry Attainment Test reported by Smith (1960).)

The correlation between geometry attainment and a spatial test will also depend on the spatial loading of the spatial test, and it is possible that the Paper Form-Board used by Murray may not have been entirely satisfactory in this respect. (The Revised Minnesota Paper Form-Board consists entirely of selective response items which are probably less loaded with the spatial factor than inventive response items.)

Webb (1949) investigated the nature of geometrical ability by studying its relationship to certain factors of imagery and immediate memory. He administered a battery of memory tests, imagery tests and reference *g*-tests and correlated the scores with marks in geometry. He extracted three factors from the matrix of correlations and after rotation identified them as *g*, *m* (memory) and *k* (spatial). He concluded that geometrical ability is highly dependent on the general intellectual factor and that it also involves an ability to apprehend and manipulate spatial relations and to utilize visual, spatial imagery. He identified the latter ability with the factor isolated by El Koussy (*k*-factor).

Barakat (1950 and 1951) carried out a large-scale investigation with samples of boys and girls in grammar schools. Since this study represents a very considerable advance on previous investigations, we shall discuss his results in some detail. He applied an extensive battery of tests, including a non-verbal test, a test of verbal reasoning, a letter series test, several memory tests (for nonsense syllables and numbers), some numerical tests, two spatial tests (N.I.I.P. Memory for Designs and Group Test 81) and four tests of mathematical attainment (algebra, geometry and mechanical and problem arithmetic). He employed Burt's (1950) method of group factor analysis with numerical, orthogonal rotation of axes, comparing the results with those obtained from a graphical rotation.

He concluded from his analysis that "After eliminating the effect of the general factor of intelligence, there was a significant tendency for the mathematical, symbolic and numerical tests to cluster together and further that the three mathematical achievement tests formed a possible subdivision of their own".

He also noted that the results showed that verbal facility is not necessarily needed in mathematical thinking, and in fact, may have an adverse effect. "The appearance of the negative signs in the verbal factor, in the case of the numerical and mathematical tests, indicates that mathematical thinking may be hindered when accompanied by language and verbalisation" (Barakat, 1950, pp. 157–8). He also found that the geometry test had an appreciable loading on the spatial factor. He suggested that the mathematical factor could be subdivided into two components, mechanical arithmetic (associated with memory), and mathematical thinking (closely related to the manipulation of schemes and relations). He also suggested that there is a cross-division distinguishing geometry (which had a high loading on the spatial factor, probably because of the role of visual imagery in spatial thinking) from problem arithmetic and algebra (which seemed to depend on facility for dealing with 'formal' variables).

Barakat carried out separate analyses for boys and girls, the results being broadly similar with some minor differences. The factor-loadings of his centroid factors for the sample of girls are shown in Table 12, which lists the tests in a slightly different order from that given by Barakat.

Table 12

Factor loadings obtained by Barakat

TEST	UNROTATED CENTROID FACTORS		
	I_0	II_0	III_0
Geometry	·704	·086	·269
Problem Arithmetic	·691	·173	·217
Algebra	·669	·243	·033
Memory (Numbers)	·373	·098	— ·088
Mechanical Arithmetic	·637	·149	— ·144
Numerical Addition	·419	·461	— ·287
Analogies (Verbal)	·478	— ·056	— ·063
Reasoning (Verbal)	·432	— ·061	— ·137
Letter Sequences	·576	— ·092	— ·155
Memory (Nonsense Syllables)	·355	— ·137	— ·202
Non-verbal	·671	— ·196	·116
Spatial (Memory for Designs, N.I.I.P.)	·675	— ·260	·156
Spatial (Group Test 81, *N.I.I.P.)*	·537	— ·408	·285

Barakat carried out group factor analyses into non-overlapping and rotated factors, but a simple interpretation may be given to the unrotated centroid factors, when the tests are grouped as shown in the table. Since the battery contains a very varied selection of tests, verbal, non-verbal and spatial, it may be regarded as fairly evenly balanced and the first centroid factor may be considered as approximating to the general factor *g*.

The second factor (or first bipolar) differentiates the tests into two groups, separating those which are essentially tests of attainment from those which are tests of ability. The third factor (or second bipolar) provides a further differentiation, separating tests involving verbal abilities from those involving spatial abilities. Thus, among the tests of abilities, the non-verbal and spatial tests have positive loadings in the third factor, while the verbal tests have negative loadings. This same factor differentiates the attainment tests into two corresponding groups, the mathematical tests having positive loadings and the purely numerical tests having negative loadings. Thus, for the girls spatial ability is associated with attainment in mathematics, particularly in geometry but also in problem arithmetic, while verbal ability seems to be associated with attainment in mechanical arithmetic.

The results of the analysis of the matrix of correlations for boys are not quite so clear-cut. Again, however, the first bipolar factor differentiates roughly between the tests of ability and those of attainment. The second bipolar factor also differentiates the ability tests into a verbal group and a spatial group, but in this case the verbal tests are associated with algebra and problem arithmetic and the spatial tests with letter sequences and memory for nonsense syllables.

The results of Barakat's own rotated group-factor analysis are in agreement with this interpretation, suggesting that for girls spatial ability is important for success in both geometry and algebra, while for boys it is important mainly in geometry. This interpretation accords well with the experience of test-constructors, who have repeatedly found that tests which have no spatial loading when administered to boys sometimes have considerable spatial loadings when administered to girls.

Barakat makes some interesting observations regarding the nature of the broad factor common to the mathematical subjects. He agrees with Burt (1939) that the difference between this broad factor and the spatial and verbal factors is essentially a difference in the mental content, not in the mental operations or activity required.

"What, then, is the specific nature of this content?

"To the psychologist it scarcely seems sufficient for factorists to declare that the content of the number factor is 'numbers' and that of the verbal factor is 'words'. A 'number' is not an elementary or simple mental unit any more than a 'word' is. Words certainly are related to the distinctive human power of speech; but we cannot suppose that biological evolution has equipped us with a further power for using and understanding numbers." Barakat (1951) argues "that the distinctive peculiarity of numbers (as of certain other concepts used in mathematics) consists in the fact that they are formal variables; and this must constitute a psychological as well as a logical distinction. A mathematical 'expression' is an abstract scheme; it is not the 'expression' of anything concrete. It is a grin, without a cat, and arguing about schemes, formulas, or expressions that are entirely schematic, is altogether different from arguing about verbal expressions or about concrete objects (Burt, 1939). What makes mathematical thinking different from other modes of thought, therefore, is a difference, not so much in the relations to be analysed out or re-applied, but rather in the Gestalt-qualitäten that have to be apprehended and compared. But although from a logical standpoint these Gestalt-qualitäten (like their constituent relations) are 'formal' characteristics, we must not make the mistake of supposing that they are 'formal' processes from a psychological standpoint; they imply special mental contents, not special mental processes."

Thus, according to Barakat, the distinctive characteristic of mathematical thinking lies in the Gestalt-qualitäten that have to be apprehended and compared. And this point of view seems to involve the acceptance of something like the Gestalt school's doctrine of forms or configurations. It would seem to follow that the apprehension of configurations is an essential characteristic of mathematical thinking, if not indeed the essence of it.

Lee (1955) claimed to have shown that the specifically mathematical abilities form a sub-group in the total field of non-verbal abilities, but it is not clear from the published account of her research to what extent this subgroup differs from the general factor *g* or from established group factors. It is unfortunate that she excluded spatial tests from her study, in view of the considerable body of evidence now available which suggests that spatial ability is involved in mathematical, as distinct from numerical or computational, abilities.

Wrigley (1958) has carried out an investigation on the structure of mathematical ability in pupils attending grammar and technical schools. He extracted five factors, identifying four of these with the usual general, numerical, spatial and verbal factors, but he also found a fifth factor entering into the tests of mathematical attainment, though its variance was considerably less than that of the other factors. In his centroid analysis, the first bipolar (factor II) separated the numerical tests from the rest, thus providing evidence for a numerical group factor. The second bipolar (factor III) separated the verbal and numerical tests from the spatial and mathematical, the loadings of the spatial and mathematical tests being closely similar. The third bipolar (factor IV) separated the mathematics tests from the spatial tests, providing the evidence on which Wrigley based his claim to have established a mathematical group factor. It is clear, of course, as Wrigley himself points out, that this factor might well be the result of teaching, the three branches of mathematics being taught in such a way that there is a certain overlap in the basic knowledge acquired. Since the four numerical tests (addition, subtraction, multiplication and division) had loadings in this factor which were almost as high as those of the three tests of attainment in mathematics, it seems probable that it is essentially a factor of arithmetical attainment. The test with the highest loading in this factor was in fact mechanical arithmetic, and arithmetical skill may well have entered into the mathematics attainment tests.

Wrigley points out that the verbal tests (vocabulary and reading comprehension) had negative loadings on the mathematical group factor and draws the conclusion that verbal ability, as represented by the *v*-factor, has little connection with mathematical ability as represented either by the mathematics attainment tests or by the mathematical group factor. He states that special care was taken to allow the mathematics tests used in the experiment to have a higher verbal content than usual. In spite of this, all three tests had negative loadings in the verbal-spatial factor (the second bipolar), a result which is very similar to that obtained by Barakat.

A negative verbal loading on this factor is, of course, equivalent to a positive spatial loading and this is perhaps the most striking outcome of Wrigley's research. There is a remarkable similarity between the loadings of the three spatial tests and of the four mathematical tests on this verbal-spatial factor (the second bipolar). The geometry and mechanical arithmetic tests had spatial loadings almost equal to that of the Moray House Space Test and the loading of the algebra test was not very different from that of the N.I.I.P. Spatial Group Test 81.

The third bipolar certainly separates the spatial from the mathematical tests, presumably because of the attainment element in the latter, but the overlapping group factor analysis suggests that Wrigley's mathematical group factor is largely a factor of attainment in arithmetic, rather than a true factor of mathematical ability. Mathematical ability, as distinct from arithmetical skill, appears to be more closely related to spatial ability.

Werdelin (1958) has carried out an extensive investigation into the nature of mathematical ability as shown in school marks. He prepared a battery of 36 tests, some of them mathematical, and administered them to large samples of pupils in the age range 14 to 15 years. He extracted five factors by the centroid method and after rotation to simple structure, interpreted them as follows:

1. The numerical factor, *N*, was found in the numerical tests, in a test of equations and in several tests not involving computations. He interpreted it as the ability to automatize reasoning, a view similar to that of Coombs (1941).

2. The verbal factor, *V*, similar to that found in numerous previous studies.

3. The spatial factor, *S*, found in tests requiring the manipulation of spatial materials. Though the spatial tests were very varied in content, Werdelin found only one spatial factor. In this respect, his results differed markedly from those obtained by American factorists.

4. The deductive factor, *D*, found in tests, such as quantitative reasoning ('syllogisms'), number series and number analogies.

5. A general mathematical reasoning factor, *R*, which entered into the mathematical tests, including equations and numerical judgment and also into two of the spatial tests (Form-Boards I and Plane Geometry). Werdelin states that it is not a pure mathematical factor.

He also extracted a second-order general factor *g*, which had highest loadings in the mathematical tests, the verbal tests, the number series tests and the form series tests. He attempted to define the ability underlying each of the factors, e.g. the ability underlying the spatial factor was described as "visual plasticity, i.e. the ability to effect purposeful changes in the properties of visualized, imagined but concrete objects and structures".

He put together a battery of tests for measuring the different factors, taking three tests for each of them, and correlations between the estimated factor scores and school marks in mathematics were calculated. The results showed that the general mathematical reasoning factor *R* and the second order general factor *g* were closely related to mathematical ability as measured by school marks.

The factors *D*, *S* and *N* were also important in some classes. Factor *V* had the lowest correlations of all.

Hamza (1951 and 1952) assembled a comprehensive test battery and applied it to two equal groups of 136 boys (age range 12–14), one group being retarded only in mathematics and the other group being normal. This investigation has been discussed by El Koussy (1955).

Factor analyses of test-scores were carried out for both samples, general, numerical and spatial factors being identified. In agreement with many other researches, this study stresses the importance of the general intelligence factor in mathematical ability. The importance of the spatial or 'visual imagery' factor in mathematics and the fact that it was deficient in the sample of pupils retarded in mathematics emphasizes the great need for the use of 'visual aids' in teaching the subject. The spatial factor was clearly present in the analysis for the sample of normal boys, but it was absent in the group of retarded boys. Also the numerical factor was less marked in the retarded group than in the normal group. Hamza claims that his results show that both the spatial and numerical factors are important for success in mathematics since pupils retarded in mathematics appear to be deficient in these abilities.

Myers (1957 and 1958) has made a factorial study of eight variables, one of these being grades in mathematics, another grades in engineering drawing and the remaining six being scores in a varied set of spatial tests. He carried out a factor-analysis of scores for 254 subjects, using Thurstone's centroid method and rotating orthogonally to eliminate negative loadings.

The factor loadings are shown in Table 13.

Table 13

Factor loadings of spatial, mathematical and engineering drawing scores (Myers)

VARIABLES	CENTROID LOADINGS			ROTATED LOADINGS		
	I	II	III	I^1	II^1	III^1
Identical Blocks	·712	·234	·096	·728	·112	·155
Surface Development	·729	·160	— ·013	·676	·156	·269
Hidden Blocks	·566	·119	— ·259	·450	·062	·439
Paper Folding	·748	·153	— ·021	·686	·168	·284
Similar Rotations	·579	·321	·196	·688	·027	·006
Intersections	·781	— ·078	— ·184	·557	·341	·468
Mathematical Grades	·504	— ·522	·146	·213	·700	·102
Engineering Drawing Grades	·844	— ·386	·042	·528	·694	·312

Since all eight variables are likely to involve some degree of spatial ability and since there are no verbal or other non-spatial tests in the battery, it is scarcely to be expected that the obtained factors will permit of a clear separation of the spatial factor (or factors) from other familiar factors. Thus, it is not surprising that the interpretation of the loadings is difficult, and Myers himself does not appear to have offered a possible solution.

It is to be expected that the first centroid factor would involve *g*, as well as a certain amount of *k*, since all variables are likely to contain at least some of both. However, Myers may have succeeded in separating *k* from *g* by means of his rotation to new orthogonal axes, making all loadings positive. Among the test-variables, Intersections and Hidden Blocks would probably have the highest *k*-loadings, with Paper-Folding and Surface Development next in succession. Similar Rotations, however, appears to involve little or no *k* at all. It is rather like Thurstone's Flags, Figures and Cards, which are tests in which a given shape has to be identified in a new position, and thus might be expected to involve Spatial Orientation (or Space I). The figures may require to be oriented in any position in three dimensions, but it is not necessary to distinguish between one shape and other different shapes. Thus successful performance in the test does not depend *critically* on the perception or apprehension of form and so in the light of the writer's hypothesis may only involve *k* to a very small extent. Thus, the writer would tend to favour the interpretation (which must necessarily be tentative) that the first of the rotated factors is *g*, the second is a factor of attainment (like Alexander's *X*) and that the third is *k*.

Whichever interpretation of the factors we adopt, we must conclude that both mathematics and engineering drawing, especially the latter, involve some degree of spatial ability, for they have loadings on all three factors.

Hills (1957) has reported a validity study on the relationship between a number of aptitude tests and success in college mathematics. He administered a varied battery of nine tests to 148 students in three college-level institutions. One hundred of the subjects were junior and senior engineering students. Others were junior, senior or graduate students of mathematics or physics.

Three types of criteria were used. For the engineering and physics students, grades in calculus courses constituted one criterion; for the undergraduate mathematics students, grades in all mathematics courses provided the criterion; for the graduate mathematics students, ratings of proficiency or promise in mathematics constituted the criterion; while for one group of engineering students, scores were obtained in an objective test of proficiency in mathematics.

The nine tests had been devised by Guilford *et al.* in connection with several factor-analytic studies. Each test was intended to measure a single factor. The titles of the tests with the names of the appropriate factors were as follows:

1. *Circle Reasoning* (to measure Eduction of Patterns, *EP*). The subject has to find a principle and apply it.
2. *Plot Titles* (to measure Originality, *O*). The subject has to invent and write as many titles as he can for each plot.
3. *Numerical Operations* (to measure Numerical Facility, *N*). The subject has to carry out operations requiring numerical facility.
4. *Vocabulary* (to measure Verbal Comprehension, *V*). The subject has to find synonyms for words given in a brief context.
5. *Match Problems* (to measure Adaptive Flexibility, *AX*). The subject has to remove lines from line drawings so as to leave a drawing with a certain number of squares or triangles.
6. *Ship Destination* (to measure General Reasoning, *GR*). The subject has to solve simple problems including addition and subtraction.
7. *Syllogisms I* (to measure Logical Evaluation, *LE*). The subject has to answer true-false questions based on syllogisms.
8. *Spatial Visualization Test* (*Form B*) of the Guilford–Zimmerman Aptitude Survey (to measure Spatial Visualization V_z). The subject has to examine a series of items showing pictures of clocks. Instructions are given pictorially as to the rotations required, the subject's task being to decide which of five given alternative positions depicts the way the clock would look after the rotations. Since this test is intended to measure the Visualization factor V_z, it is presumably a *k*-test, a presumption which is borne out by its reported validity coefficients (e.g. a validity of ·41 has been reported for predicting grades in engineering drawing and descriptive geometry).
9. *Spatial Orientation* (*Form A*) of the Guilford–Zimmerman Aptitude Survey (to measure Spatial Orientation, *SO*). Each

item shows pictures across a boat's prow, as seen from the cockpit. The pictures are paired, and the subject is required to locate in the second picture, the 'aiming point' towards which the prow was pointed in the first picture.

Hills calculated correlation coefficients between each of the nine test-scores and criteria of success for some 23 different groups of engineering, physics and mathematics students (junior, senior and graduate). The correlations varied very much from one group to another, but the trends may be studied by comparing the average correlations with each test for nineteen of the groups, for which comparable figures were available.

Though not all the groups were mutually exclusive so that it is not strictly correct to average the correlations, this procedure is perhaps sufficiently accurate to give an approximate estimate of the order of the validities of the nine tests. Arranged in order of magnitude, the mean correlations for 19 groups of students were as follows:

Table 14

Validities of nine tests for predicting mathematical grades (based on Hills' data)

TESTS	MEAN CORRELATION WITH CRITERIA
Match Problems (*Adaptive Flexibility*, AX)	+ ·27
Numerical Operations (*Numerical Facility*, N)	+ ·23
Spatial Visualization (V_z)	+ ·23
Spatial Orientation (SO)	+ ·22
Syllogisms I (*Logical Evaluation*, LE)	+ ·15
Circle Reasoning (*Eduction of Patterns*, EP)	+ ·06
Vocabulary (*Verbal Comprehension*, V)	+ ·06
Ship Destination (*General Reasoning*, GR)	+ ·01
Plot Titles (*Originality*, O)	— ·08

The table shows that the spatial tests have relatively high validities compared with the vocabulary, reasoning and originality tests. Match Problems, the description of which indicates clearly that it is a type of spatial test, shows the highest mean correlation, while Spatial Visualization and Spatial Orientation take third and fourth place respectively.

Spatial Orientation gave rise to a larger number of high validity coefficients than any of the other tests, the correlations with several mathematics courses for engineers being consistently in the region of ·55, though with physics and mathematics students it had very much lower validities. The Spatial Visualization Test had higher validities than Spatial Orientation for the physics students, while the order was reversed for the engineering students.

The Spatial Visualization Test showed fairly uniform correlations of about ·30 with calculus grades in the majority of the groups, but showed lower correlations with the objective test of proficiency in mathematics, probably because the latter placed greater emphasis on technical skills. The Numerical Operations Test showed somewhat similar correlations with the calculus grades and lower correlations with the objective test of proficiency in mathematics. Its validities were higher for engineering students than for physics students, probably because of the greater importance of numerical calculations in engineering courses.

The nine factors believed to be measured by the tests had been judged to be of importance in mathematics by a number of mathematicians with the Ph.D. degree. Although the mathematics professors were in fair agreement as to the relative importance of the factors studied, the results of the investigation led Hills to conclude that "there is no particular ability or set of abilities or traits which is universally associated with success in mathematics. . . .

"Those who believe that there is an entity such as mathematical aptitude should be surprised at the significant differences in correlations for the same test with different groups. Although their number is not impressive considering the possible number, certain of the significant differences are quite striking." (Seventy-one pairs of correlations were significantly different out of 2,113 differences between pairs involving the same factor measure.)

The test measuring the factor of originality O was found to give more negative than positive correlations, but it gave a statistically significant correlation only in the one school where it had been considered to be of importance by the professors. It had not been considered important in the two other schools. Similarly, a significant correlation for the factor of adaptive flexibility occurred in only one institution, and this circumstance led Hills to suggest the hypothesis "... that there is some aspect of teaching method, some approach to the subject matter of mathematics or emphasis in examining at this institution that makes this sort of flexibility an asset."

Hills (1955) drew two conclusions from his study:

"First, for selection and guidance purposes validity data must be collected for the particular curriculum-criterion-institution context under consideration.

"Second, there may be many more potential scientists and technicians, as far as the mathematical requirements are concerned, than would be the case if there were a unique mathematical aptitude."

On considering the relatively high validities of the spatial tests in Hills' study, it might be supposed that the figures merely reflect the facts that spatial ability is involved in geometrical thinking and that geometry must constitute a substantial part of the college course in Mathematics.

Many workers, including the present writer (1948, 1954), have obtained evidence that spatial tests have higher correlations with examinations in geometry than with marks in arithmetic and algebra. Siegvald (1944) found strong evidence that there is a connection between ability to visualize and geometrical ability. Gästrin (1940) found that high school girls are inferior to boys in solving problems in solid geometry and he attributed this to the well-known fact that girls are inferior to boys in visualizing ability. Similar observations have been reported by many others.

But it is perhaps significant that this male superiority is not confined to geometry, though it is most striking in this branch of mathematics. It also occurs in arithmetic and algebra.

Saad and Storer (1960) investigated the question of sex-differences in mathematics in their study of the errors made by fourth and fifth year grammar school pupils in arithmetic, algebra and geometry. They were particularly concerned with the pupils' understanding, and two aspects were studied, the understanding of concepts and of principles.

The results showed a significant sex-difference in mean score in favour of boys most marked in geometry, but also present in arithmetic and in algebra. This difference, which was apparent in nearly all the questions, occurred in mixed classes in the same school, so that it seemed to depend on differences in cognitive, rather than in purely cultural, factors. It is possible that this difference in the ability to understand concepts and principles may be another manifestation of the sex-difference in spatial ability, reflecting a greater capacity on the part of the boys to perceive, recognize and assimilate patterns within the conceptual structure of mathematics.

There has been some difference of opinion in the past as to the relative importance of the verbal factor in mathematical ability, but this has been clarified by the findings of recent researches. Kelly (1928) had held that arithmetical ability involves a considerable amount of the verbal factor in pupils of the third grade but not of the seventh grade. Vernon (1950) drew a somewhat similar conclusion from a study of the mathematical abilities of college students and army cadets. He wrote, "Among children and dull or average adults, *k*- and *n*-tests are strongly opposed apart from *g*. But at high-grade levels an interesting alteration occurs (as Brigham seems to have realised in 1932). Both *k*- and non-verbal *g*-tests tend to link up with mathematical ability, and *n* becomes detached from the *V:ed* cluster."

He gives the following examples of the relationship found at high-grade levels.

"Among training college students, Stephenson's non-verbal *g*-test correlated more highly with arithmetic and science subjects, and a verbal *g*-test with education, geography and history. Similarly, among Army engineering cadets, the correlations of advanced mathematics and physics were greater with Matrices, while the more elementary arithmetic and algebra correlated more highly with the verbal Group Test 33. Also, among candidates for the higher Civil Service, the bipolar factor contrasted verbal tests and academic examinations with spatial tests and arithmetic."

Vernon has attempted to account for the linking up of spatial and non-verbal abilities with arithmetic and mathematics by supposing that training in science improves both spatial and mathematical abilities. This explanation, however, is scarcely adequate since it is not at all obvious why training in ordinary science courses should improve performance on spatial tests.

It is less difficult to understand how a training in engineering drawing might affect a person's score on a spatial test, yet it is very doubtful if any such effect occurs.

Most of the available evidence suggests that scores on spatial tests are not significantly affected by training in engineering drawing. One such study by Faubian *et al.* (1942) found apparently no change after a six weeks course. A second study by Churchill *et al.* (1942) found only a slight gain on a Surface Development Test after a nine-week training course in engineering drawing. On the other hand, a third study by Blade and Watson (1955) reported marked gains on a Spatial Visualization Test during an engineering course. In a well-controlled study by Myers (1958), however, negative results were again obtained. Myers included a spatial relations test in a battery of tests given to two groups of 425 U.S. Naval Academy candidates, one of which had had previous training in mechanical drawing and the other of which had had no such training. Myers found no significant difference in the mean performance of the two groups. This finding could not be explained by inequalities in the two groups prior to training since the two groups were well matched in the other parts of the aptitude test.*

Thus the general conclusion to be drawn from these studies of

* It is true that McFie (1961) found clear gains on Block Designs and Memory for Designs after two years' technical training for various occupations, but his subjects were African youths whose upbringing had lacked the toys and constructional games which are usual in European cultures.

the effects of training is that the gains in performance on a spatial test are likely to be small, if in fact they are measurable at all, after limited amounts of training. Hence, it is necessary to find some explanation other than the effect of training in mathematics or science to account for the increasing importance of spatial ability for success on courses in mathematics and science as these courses become more advanced.

An alternative explanation may perhaps be found in the increasing importance in advanced work of an understanding of the conceptual structure of these subjects. Spatial abilities may be involved in the perception and assimilation of patterns, either in the structure of geometrical figures or in the more general structure of mathematical symbolism. Conceptual thinking may involve abstraction and generalization in terms of configurations or gestalt-qualitäten rather than in terms of words. Hills' (1957) results provide strong evidence that spatial abilities (both spatial visualization and spatial orientation) are important in college courses in mathematics and that verbal reasoning (syllogisms) and vocabulary (verbal comprehension) are relatively unimportant.

Discussion and conclusions

Nearly all investigators have found that the general intellectual factor is important for success in tests or examinations in mathematics. Whenever a method of analysis has been used which permits the extraction of a general factor, high *g*-loadings have been demonstrated, e.g. by Spearman in his analyses of Rogers' and Collar's findings and in investigations by Wilson, Alexander, Mitchell, Blackwell, Sutherland, Barakat, Wrigley and Werdelin. In Rimoldi's study (1951) a test of mathematical reasoning had the highest loading in the general factor.

Other factors which have been reported from time to time are the numerical, spatial, reasoning, deductive and verbal, and some investigators claim to have demonstrated a mathematical group factor in addition to the other well-established group factors.

The numerical factor has usually been identified in tests of addition, subtraction, multiplication and division. Spearman claimed that this was the only factor common to arithmetic over and above *g*. Kelley found it important both in tests of computation and in problems.

Numerous workers, such as Thorndike (1921), Schneck (1929), Schiller (1934), and Holzinger and Harman (1938), found that there was a numerical factor common to numerical tests and tests of arithmetical abilities. Barakat (1951) found a mechanical factor in tests of addition and mechanical arithmetic. For boys it had negative loadings in problem arithmetic, algebra and geometry, while for girls it had a slight positive loading in algebra and near-zero loadings in problem arithmetic and geometry. Wrigley's (1958) numerical factor had a positive loading in mechanical and problem arithmetic, near zero loading in algebra and a negative loading in geometry. Werdelin (1958) found that his factor score for the numerical factor had very variable correlations with school marks in mathematics in some classes being near zero (·08 and ·09) though in two classes it was quite high (·60 and ·59). Hills' Numerical Operations Test was one of the best tests for predicting success in college mathematics courses.

It is clear, however, from the trend of the results in the majority of the studies mentioned that the numerical factor has little in common with what is normally understood by 'mathematical ability'.

The spatial factor appears to have a greater claim for consideration as an essential basis for aptitude for mathematics. Spatial tests have been included among the tests studied in the earliest researches on mathematical ability, such as that by Rogers (1918). It is not correct to suggest, however, as Wrigley has done, that all of Rogers' geometry tests were spatial tests of the kind which would now be used to measure the *k*-factor. It is true that she included spatial tests in her battery, but she had also a test of deductive geometry and one of geometrical definitions.

Rogers stated her conclusion regarding the nature of mathematical ability in the following sentence: "... the experimental evidence we have obtained suggests that a marked degree of the power to analyse a complex and abstract situation and to seize upon its implications is the most indispensable element in mathematical proficiency." Among the six tests which she selected for diagnosing mathematical ability were a geometry test and a superposition test (Thurstone's spatial relations test modified). Many subsequent investigators claimed to find evidence that spatial ability was important in mathematics. Thus, Mitchell and later Blackwell found a visual factor (called by them O) present in spatial tests and having small loadings in the mathematical tests. Since this factor apparently also entered into the verbal tests there is some doubt as to its identification with the *k*-factor.

Holzinger and Swineford (1946) found a correlation of ·23 between their composite test of spatial ability and school marks for plane geometry. Since the composite test of the general factor gave a correlation of ·584 with geometry, the spatial factor seemed to have little importance in geometry. There may be some doubt, however, as Holzinger and Swineford themselves point out, as to the validity of the criterion and as to the adequacy of the spatial content of the composite test of spatial ability.

Barakat (1951) found a spatial factor which had positive loadings in geometry, to a less extent in algebra, a near-zero loading in problem arithmetic and negative loadings in mechanical arithmetic and numerical addition. This pattern was essentially the same for both boys and girls. Wrigley (1958) found closely similar results with his sample of boys. There was a spatial factor which had a positive loading in geometry, a smaller positive loading in algebra and negative loadings in mechanical arithmetic and in the four numerical tests. Werdelin (1958) extracted a spatial factor which had positive loadings in plane geometry and number series and negative loadings in arithmetic and numerical tests. Thus, there are several studies which indicate consistently that spatial ability is important in tests which are genuinely mathematical as distinct from those which involve purely mechanical or computational processes. Werdelin's results are particularly interesting since they suggest that spatial ability enters, not only into tests involving the perception of spatial patterns, but also to some extent into tests not usually considered spatial at all, such as number series (presumably because they involve the perception of numerical configurations or patterns). The factor seems to be negatively related, however, to tasks involving reasoning processes which have become automatized (as in mechanical computation or the solution of simple equations).

As to the question whether or not the abilities which together constitute mathematical ability form a group factor over and above *g*, there is some conflict of views. Most of the earlier workers found no evidence for the existence of such a group factor. Brown Rogers, Spearman, Cameron, Fouracre, Mitchell, Blackwell and Oldham all came to a negative conclusion. American opinion also tends to favour this view. Hills, for example, considered that his results did not support the theory that a unique mathematical aptitude exists. On the other hand, Wilson, Hamza, Barakat, Lee, Wrigley and Werdelin found evidence to support the positive view.

Wilson's findings cannot be regarded as conclusive, since they were based on an analysis of school certificate marks in arithmetic, algebra and geometry. In the usual examinations in algebra and geometry there is frequently an admixture of arithmetical calculation and in geometry algebraic methods and symbols are sometimes used, so that a group factor might easily arise from the presence of common elements in the three papers.

Hamza tested two groups of 136 boys, one retarded in mathematics and the other normal and found evidence from a study of the retarded group that there is a unitary factor of mathematical ability. Retardation usually occurred in all three branches of the subject, especially if taught by the same teacher. Clearly, the factor might be an artefact of the teaching rather than a true group factor of mathematical aptitude. The fact that the spatial factor did not appear in the factor analysis of the intercorrelations for the retarded group may indicate that some degree of spatial ability is necessary for satisfactory progress in mathematics.

Barakat found a factor which he identified as mathematical in addition to the usual general, numerical, spatial and verbal factors. This supposed mathematical factor had its highest loadings for the boys in mechanical and problem arithmetic and for the girls in problem arithmetic. Its variance was very small in relation to that of the general factors and it may well be a factor of arithmetical skill.

Werdelin (1958) carried out several factor analyses using the Thurstone and Lawley methods and extracted a number of factors, including a general mathematical reasoning factor (*R*) as well as the familiar spatial, numerical, verbal and other factors. He recognized, however, that the mathematical reasoning factor was closely connected with the general factor *g* defined by Spearman and he showed that it had a very high correlation with a second-order general factor *g* extracted from the intercorrelations of the factors. He notes that the tests which are high in *R* have characteristics usually associated with the general factor. Thus, he writes: "The mathematical tests are typical examples of tests which involve a combination of noegenesis and abstractness. The visual or spatial tests which are loaded on *R* involve noegenesis, and the process of breaking down a structure into simpler elements, which occurs with these, has been characterized as involving 'abstract attitude' and conceptual thinking (cf. Rapaport 1950, p. 273)."

Thus, Werdelin's general mathematical reasoning factor *R* seems to be closely related to Spearman's general factor *g*. It is interesting to find, moreover, that the battery of four tests which he selected to provide the best measure of *R* included Form-Board I and Plane Geometry, both of which tests had been shown in his own analysis to have high *k*-loadings. (This conclusion bears a strong similarity to that of Rogers, who in 1918 selected a battery of six tests for diagnosing mathematical ability, one of these being a spatial relations test and another a test of geometry.) Since Werdelin's battery for measuring his mathematical reasoning factor *R* includes two spatial tests, there are grounds for suspecting that *R* is a composite of *k* and *g*. Also, Werdelin's description of the nature of the abilities involved in the mathematical tests (for his factor *R*), viz. a combination of noegenesis and abstractness, is very similar to the writer's view of the nature of spatial ability, which is discussed in a later chapter.

The results of Wrigley's factor-analysis requires a somewhat different interpretation. The mathematical group factor which he identified can scarcely be regarded as a true group factor of mathematical aptitude and is more likely to be an artefact of the effects of teaching, i.e. it is an attainment factor. It seems to be largely a reflection of acquired arithmetical skills, for the test which had by far the highest loading on this factor was Mechanical Arithmetic and the loadings of the mathematical tests were closely comparable to those of the numerical tests. As one would expect, the four mathematical tests had highest loadings on the general factor *g*, but it is interesting to find that their loadings on the spatial factor (spatial-verbal bipolar) were almost identical with the loadings of the three spatial tests (in the centroid analysis).

In the first bipolar factor (Factor II of the centroid analysis) the spatial and numerical tests were very strongly opposed. Wrigley has offered as a possible explanation of this the fact that his numerical tests were highly speeded whereas the spatial tests were generously timed.

This explanation implies that the first bipolar factor is essentially a speed factor, and should perhaps be discounted. However, it should be mentioned that a similar opposition between numerical and spatial abilities was found to occur in several independent studies by Werdelin. It has also been reported by Botzum (1951) and it showed up in Barakat's factor-analysis.

A possible explanation of these findings might be sought in Werdelin's theory of the nature of numerical ability. He has shown that the numerical factor is not restricted merely to computations, but also appears in tests requiring the manipulation of letters according to simple rules. He suggests that from the functional point of view, numerical ability may be characterized as an ability to automatize reasoning. Such an interpretation would lead us to expect that it might be extensively involved in tests or examinations in mathematics which emphasize acquired technical skills. The spatial factor might have quite a different role, perhaps entering particularly into processes involving the perception of patterns, configurations and gestalt-qualitäten. It is understandable that tests involving such very different abilities might give rise to a bipolar factor in an analysis by the centroid method and would show loadings of opposite sign.

Most of the investigations with which we have been concerned so far have been carried out with pupils at the secondary school stage. To a large extent, these pupils have been acquiring the elementary technical skills, which are necessary before advanced study becomes possible. The foregoing discussion would lead to the expectation that spatial ability might become increasingly important (and numerical ability decreasingly important) in mathematical studies at more advanced levels. Vernon has pointed out that such a change does in fact take place at high grade levels, spatial ability tending to link up with mathematical ability, where previously it was opposed to the more elementary arithmetical ability (apart of course from *g*).

The linking up between spatial ability and mathematics at college level is illustrated in the validity study by Hills (1957). Hills found that two spatial tests, Spatial Visualization (V_z or *k*) and Spatial Orientation (*SO*), showed correlations of the order of ·3 with criteria of success in several mathematics courses for students of engineering, physics and mathematics some coefficients being as high as ·55. The highest validities were given by the Match Problems Test, which is probably also a spatial test. The Numerical Operations Test gave validities of the same order as Spatial Visualization and Spatial Orientation. The continuing importance of numerical ability may indicate that calculation and computation are still important even in examinations in advanced mathematics. This view is given some support by the fact that the Numerical Operations Test had much higher validities for the engineering students than for the physics students. A striking finding of Hills' study was the poor showing of the Vocabulary, Reasoning and Originality Tests, all of which had negligible validities.

Hill's results suggest that spatial tests may be more valuable for predicting success in advanced courses of mathematics (such as calculus) than they have hitherto been found to be in the grammar school. They also tend to confirm at an advanced level the finding of Barakat, Wrigley and others at a less advanced stage that apart from the influence of general ability, mathematical and verbal ability are independent.

Such a conclusion is scarcely surprising when one considers the nature of the psychological processes involved in 'doing' mathematics. Mathematics can be regarded as a language only in a highly specialized sense. It is certainly not a spoken language. We communicate mathematical ideas in writing, either on paper or on a blackboard or by means of models or diagrams. Formulae and equations have to be read; only the most elementary expressions can be communicated orally. In order to follow an exposition in algebra, we must be able to compare one expression with another, or to relate one part of a formula to another. Thus, a mathematical discussion is usually conducted with the help of a blackboard, often with frequent reference to diagrams. Furthermore, many apparently purely algebraic analyses presuppose a background of geometrical thinking very often in terms of a graph or diagram or of a three-dimensional model. Reference to any standard text-book of college mathematics will show that the contents (calculus, co-ordinate geometry, complex variable, etc.) are largely concerned with ideas that are basically geometrical.

It is sometimes said that the most able mathematicians can think entirely in abstractions and have no need of diagrammatic props. But, this may be because these gifted individuals have their own internal 'blackboards' and can visualize complicated structures without being aware that they are doing so.

Certainly many mental calculators, such as Buxton, Colborn and the Bidders, reported that their calculations always proceeded in a visible form in their minds. Some of these calculating prodigies later became distinguished mathematicians, such as Wallis, Ampère, Euler, Gauss and Ramanujan. George P. Bidder, a notable calculating boy, gained first prize in mathematics in the University of Edinburgh in 1822 and subsequently became a distinguished professional engineer. It has been said of Professor A. C. Aitken,* who is a well-known mental calculator as well as an accomplished mathematician, that "he does not need multiplication tables, but sees them with his mind's eye" (Max Born). Many mathematicians, including no less an authority than Einstein, in a letter to Hadamard (1945), have borne witness to the fact that they relied largely on visual imagery in their thinking. Professor M. H. A. Newman (1959), a well-known mathematician, has referred to this in an article entitled 'What is Mathematics?'.

"How can mathematicians work and make discoveries if they are to abstain from any geometrical intuition? Of course, they don't abstain. The double life of mathematicians is a familiar fact to all who have been exposed to ε analysis. They know that diagrams and graphs are the life-line by which we survive amid the rough seas of hard inequalities. . . . One of our purposes is to use some of our geometrical notions . . . as a guide, as we grope our way towards the proof of a new theorem. When it is found, we shall carefully remove all traces of geometry or mechanics from our strictly axiomatic proof; and the man who reads it will probably put them in again as he grapples with the arguments."

It would appear that mathematics is a special kind of 'language', in which we communicate by means of written signs or symbols ideas which are essentially geometrical or spatial. It is perhaps helpful to think of it as a 'visual' rather than a 'verbal' language. Bronowski (1947) has defined it as the language for describing those aspects of the world which can be stated in terms of 'configuration', and this definition is perhaps more satisfactory than that given in the Oxford dictionary, viz. "the abstract science of space or number". According to either definition, however, it should follow that this is a subject in which spatial concepts are of fundamental importance.

Much of the difficulty in teaching mathematics may arise from the need to communicate abstractions relating to configurations to many pupils (particularly girls), who do not think readily in terms of mental or visual imagery. Even in quite elementary

* Professor Aitken's talent has been fully discussed by Hunter (1962).

mathematics, many such spatial concepts have to be assimilated, e.g. length, squareness, area, angle, direction, congruence, parallelism, volume, similarity, gradient, vector, symmetry, dimensions; and many other abstract concepts may be conveyed most conveniently by means of geometrical illustrations, e.g. continuity, maximum and minimum, limit, functionality, variation.

It is scarcely accidental that the growing volume of criticism of current methods of teaching mathematics has been contemporaneous with an increasing interest in visual aids for teaching mathematics. An Association for Teaching Aids in Mathematics* was founded in 1952 and its membership has been growing rapidly. In recent years, many teachers and psychologists and in one case a professional engineer have devised special sets of apparatus such as coloured rods for assisting pupils to make mathematical abstractions. Numerous articles on these aids have appeared in journals such as *Educational Research* and *Mathematics Teaching*. There has been a growing awareness of the value of mathematical models and certain firms have specialized in the production of beautiful and elaborate models in perspex. All these developments, which have occurred mainly within the past ten years, suggest that there is a growing awareness that mathematics is primarily concerned with spatial, geometrical or configurational concepts. In this chapter, an attempt has been made to assemble evidence from many sources in support of the hypothesis that spatial ability is important for success in mathematics, especially at advanced levels. A decision on this issue will affect not merely methods of selecting pupils and students for courses on mathematics but will also have an influence on methods of teaching. At least one worker (Hamza, 1951, 1952) has concluded from a factorial investigation that the evidence calls for a greater use of visual aids in teaching mathematics.

* Now called The Association of Teachers of Mathematics.

Chapter four

The Validity of Spatial Tests for Predicting Success in Technical Occupations and Courses

IN this chapter, a brief account will be given of the evidence available from various sources as to the value of spatial, performance or mechanical tests for selection and guidance for technical occupations or courses. As the main interest of the present study is in the prognostic value of spatial tests, we shall not deal in full detail with the evidence for the usefulness or otherwise of the many types of mechanical, performance and dexterity tests which have been devised for similar purposes.

However, it is clearly desirable that an evaluation should be made of these types of test material when used for selection or guidance in connection with technical courses. As excellent published accounts of the work done in the field of mechanical, performance and dexterity tests are readily available, e.g. Vernon and Parry (1949), Vernon (1950), Super (1949), Anastasi (1954), only an outline will be given in this chapter.

The pioneering work on mechanical ability was done by J. W. Cox (1928, 1934), who reported correlations of ·40 and ·51 between his mechanical tests and marks obtained by trained R.A.F. Mechanics in a passing out technical examination and in a test of trade knowledge and practical skill. The corresponding correlations with a verbal intelligence test were only ·21 and ·42. With a group of elementary school-boys, estimates of 'ingenuity' in woodwork and technical drawing gave an average correlation of ·42 with Cox's mechanical tests but only ·08 with school marks.

Stenquist's (1922) Mechanical Assembly Test was originally devised for boys of 11 to 15 years of age. This test gave excellent validity coefficients against criteria of success in manual training as assessed by school instructors, the correlations sometimes being as high as ·8 or ·9. It was modified and incorporated in the Minnesota Mechanical Ability Tests, which yielded correlations of about ·55 with quality of work done in the junior high school.

Assembly tests based on Meccano were extensively used in the services during the second World War and were found to give very promising validity coefficients with training course marks for certain classes of technical personnel, such as Driver Mechanics.

In Rodger's (1937) research on 400 inmates of the Feltham Borstal Institution, the Cube Construction Performance Test gave the best results of any in the mechanical trades. But two paper and pencil spatial tests (N.I.I.P. Form Relations and Memory for Designs) constructed by Earle and Macrae in 1925 were found to be among the best tests for vocational guidance and selection in this experiment. These tests were found to show larger differences in mean score between satisfactory and unsatisfactory groups of fitters, plumbers and woodworkers than differences found for similar groups of farmers, labourers, cooks and bakers.

Allen and Smith (1931, 1934, 1939) carried out several investigations on selection of skilled apprentices for the engineering trades. These researches, which were carried out on behalf of the Birmingham Education Committee, included studies of the validity of a large number of selection tests. In the first of these studies, the most satisfactory tests were found to be Nuts and Bolts, Cox's Mechanical Models and Memory for Designs (N.I.I.P.). In the second study, the same series of tests were validated against performance in Mathematics, Machine Drawing, Applied Mechanics, Woodwork and Metalwork. In this case, the most satisfactory tests as shown by the percentage agreement with the criterion were the following: Cox's Test D (Diagrams) 74 per cent, Verbal Intelligence Test 74 per cent, Cox's Test M (Models) 72 per cent, Form Relations Test 71 per cent, Cox's Test E (Explanations) 68 per cent, Cube Construction 68 per cent, Memory for Designs 65 per cent, Variable Adjustment 65 per cent. In a third study, Allen and Smith showed that their test battery gave higher correlations with success in engineering school subjects than does the ordinary academic entrance examination. The test battery consisted of the following tests: N.I.I.P. Tracing and Variable Adjustment, Cox's Mechanical Models and Explanations, Verbal Group Test 33 (N.I.I.P.), Form Relations and Memory for Designs and Cox's Mechanical Diagrams. A possible criticism of the proposed procedure is that, while the test battery has greater validity than the conventional procedure, it is somewhat elaborate and cumbrous for use in routine practice.

Holliday (1940) administered a battery of eight N.I.I.P. spatial and mechanical tests to groups of trade apprentices, engineer apprentices and shop boys. The battery of specialized tests gave a correlation of ·659 with technical drawing whereas the corresponding correlation of the verbal test (Group Test 33) was only ·067. On the other hand, the test battery gave a correlation of ·258 with mathematics while the verbal test gave a corresponding correlation of ·553.

In a later investigation, Holliday (1943) administered a number of spatial and mechanical tests as well as Group Test 33 to six groups of apprentices (numbering from 30 to 90). There were two groups of engineering apprentices, two groups of trade apprentices (toolmakers) and two groups of trade apprentices (mixed). He found that while the verbal Group Test 33 was useful for predicting mathematical and theory work, spatial and mechanical tests gave better correlations with mechanical drawing and with practical assessments of skills made by a foreman a year or two later. His mean correlations for the six groups of apprentices are shown in Table 15.

Table 15

Validity of spatial and other tests for engineering apprentices (Holliday)

TESTS	CORRELATIONS
Vincent Models (N.I.I.P.)	·421
Figure Construction (N.I.I.P.)	·445
Form Relations (N.I.I.P.)	·379
Space Perception (N.I.I.P.)	·358
Group Test 33 (*Verbal, N.I.I.P.*)	·415

Thus, the verbal Group Test 33 correlated just as well as the spatial and mechanical tests with instructors' assessments among engineering apprentices. It correlated less well, however, among trade apprentices. Holliday made the significant comment that boys who do better on verbal intelligence tests impress their assessors as being 'bright', but do not make as good craftsmen. Thus, it appears that verbal ability tends to create a favourable 'halo' effect. This phenomenon may have some importance, and selection and follow-up procedures should be devised to counteract or eliminate it. There are two possible explanations. The ability to express thoughts readily in words may impress instructors as being a manifestation of general intelligence and may lead to the unconscious assumption that pupils so gifted are likely to perform better in crafts. Alternatively, high verbal ability may be linked with certain personality traits (e.g. sociability) which are considered socially desirable and may create a favourable impression, so disposing the instructors to make more generous assessments of the boys' performance.

Shuttleworth (1942) found that spatial tests had higher validities than other tests for predicting marks obtained by 13-year-old boys attending a junior technical school. The validity coefficients are shown in Table 16.

Table 16

Validity of spatial and other tests for predicting marks of pupils in a junior technical school (Shuttleworth)

TESTS	VALIDITY COEFFICIENT
Entrance Examination (6 hours)	·40
Simplex Intelligence Test (Verbal)	·20
Manual Dexterity Test	·10
Cox Mechanical Models	·40
Vincent Mechanical Models	·36
Cox Mechanical Explanations	·29
Space Perception Test (N.I.I.P.)	·46
Memory for Designs Test (N.I.I.P.)	·45
Form Relations Test (N.I.I.P.)	·44
Squares Test (N.I.I.P.)	·28

It will be noted that three of the spatial tests show higher validities than the six hours' entrance examination. They are also superior to the much more elaborate mechanical models tests as well as the mechanical explanations and dexterity tests. The only spatial test which has not turned out well is the Squares Test which was found to have relatively poor validity in many investigations in the Services.

Brush (1941) obtained scores for groups of university students in a large number of mechanical, spatial and other tests. The numbers ranged from 77 to 160, but it is not clear how far the groups are comparable. Also no information is given as to whether the criterion is based on an assessment of theoretical or practical ability.

Table 17

Validity of spatial and other tests given to groups of university students (Brush)

TEST	CORRELATIONS	
	GROUP A	GROUP B
Minnesota Assembly (Short Set)	·274	
Minnesota Spatial Relations	·056	
O'Connor Wiggly Block	·273	
MacQuarrie's Mechanical Aptitude	·219	
Minnesota Interest Analysis	·192	
Minnesota Paper Form-board	·426	·214
Cox Mechanical Models	·394	·406
Cox Mechanical Explanations	·336	
Cox Mechanical Completion	·323	·351
Thorndike Intelligence Test		·434
Columbia Achievement Tests (Algebra)		·513
(Physics)		·500

The table shows that the Minnesota Paper Formboard, which is a *k*-test, has been particularly successful with Group A. The Minnesota Interest Analysis and the manipulative tests show rather low correlations, and the O'Connor Wiggly Block Test, for which somewhat exaggerated claims had been made by its author, also shows relatively poor validity. For Group B, the Thorndike verbal intelligence test and the achievement tests in algebra and physics give the highest correlations. The high validities of the achievement tests strongly suggest that the criterion was based on a theoretical rather than a practical assessment.

Harrell (1940) administered 32 tests to 91 cotton-mill mechanics. Though all the tests showed insignificant correlations with assessments of mechanical skill, the spatial tests gave higher correlations than the others and the highest single coefficient (+·17) was given by the Thurstone's Spatial-Relations Test A. The means for the different groups of tests were:

Table 18

Mean correlations of groups of tests given to cotton-mill mechanics (Harrell)

GROUPS OF TESTS	MEAN CORRELATION
Six Spatial Tests	+ ·08
Four Verbal and Educational Tests	− ·03
Three Assembly and Form-board Tests	+ ·01
Sixteen Manual Dexterity Tests	+ ·01

Slater (1940) has correlated the scores on a number of tests with two criteria:

1. An estimate of ability in engineering drawing, and
2. An estimate of general apprenticeship ability.

He employed seven spatial tests, a test of discrimination of lines and a test of verbal intelligence. Comparable correlations are shown in Table 19.

Table 19

Validity of spatial and other tests given to engineering apprentices (Slater)

TEST	ENGINEERING DRAWING	GENERAL APPRENTICESHIP ABILITY
Seven Spatial Tests (Mean Correlation)	·41	·27
Discrimination of Lines	·27	·28
Verbal Intelligence	·26	·35

Thus, the spatial tests showed a much higher correlation with engineering drawing than did the verbal test. On the other hand, the verbal test showed a higher correlation with general apprenticeship ability than did the spatial tests.

Knight (1949) has reported a follow-up investigation begun in Middlesex in 1943, to obtain data on the effectiveness of tests of the spatial type for selecting pupils for junior technical schools. Of the 1,200 candidates who took the original selection tests, some 306 were included in the final follow-up.

The selection procedure took place in three stages. Candidates were first rated by their head teacher for their supposed ability to profit from a course of further instruction. A battery of spatial tests was administered to exceptional candidates, with a view to picking out those best fitted for technical education. This battery consisted of the N.I.I.P. Form Relations, Memory for Designs and Space Perception Tests. Evidence of performance in the school course was collected at the end of the first and second years and this was compared with the selection test results and the head teachers' ratings. Correlations were calculated between these two sets of data at the end of the first year and of the second year respectively of the technical school course.

At the end of the first year, the correlations were:

Headmasters' rating and school performance	·2387
Selection test scores and school performance	·2426

At the end of the second year, a common test of attainment was set to all pupils remaining in the six technical schools. This time, the correlations were markedly different:

Headmasters' rating and follow-up test performance	·1670
Selection test scores and follow-up test performance	·4690

Thus, in the second instance, the superiority of the selection tests over the headmasters' ratings for selecting pupils for the technical course is marked. While the course remained general, there was little to choose between ratings and selection tests, but as the course became more specifically technical, the prognostic value of the technical tests became considerably enhanced, while that of the headmasters' ratings decreased. Since an ordinary intelligence test was not included in the testing programme, however, it is not possible to deduce whether the spatial tests would have had greater validity for selecting for technical courses than other types of test (e.g. verbal or non-verbal).

There is extensive evidence of the value of spatial tests for selecting industrial workers in many branches of industry.* As an example, we may quote the findings of Oxlade (1951) who obtained some data on the validity of spatial tests for selecting power sewing-machine operators.

The validity of the tests, on criteria of proficiency and quality of work, is shown by biserial correlation coefficients in Table 20.

Table 20

Validity of spatial and other tests for selecting power sewing-machine operators (Oxlade)

TEST	QUALITY OF WORK	RATING FOR PROFICIENCY	COMBINED CRITERION
Minnesota Paper Form-board	·55	·53	·77
Paper Folding Test (Australian N.I.I.P.)	·31	·31	·41
Otis Test (mainly Verbal, partly non-Verbal)	·43	·23	·41

The second and third columns show the correlations with quality of work and proficiency respectively, and the fourth column shows the correlations with the combined criterion. It is clear that the spatial Minnesota Paper Form-Board Test has a marked superiority over the other two tests, and the spatial Paper-Folding Test gives a better index of proficiency than does the Otis intelligence test.

Spatial tests were used extensively in the British Services during the Second World War and a large amount of information

* For data on the validity of fourteen N.I.I.P. tests for selecting engineering apprentices, see the validity study by Frisby, Vincent and Lancashire (1959).

on validity for the different branches of the three arms is now available. It needs to be pointed out, however, that some of the better tests were not used extensively because of the exigencies of war time conditions. Thus, the N.I.I.P. Form Relations Test was seldom employed because of its heavy paper consumption. Also, a creative response version of the paper-formboard (which is preferable to the selective response versions) was discarded in the Navy because of the subjectivity of scoring "in spite of the advantage that this can be 'got across' to dull recruits more readily than othei types of spatial test."

The fact that some of the better spatial tests were not extensively used in the British Services may partly account for the conclusion reached by Vernon and Parry (1949), "that while there is ample evidence of the vocational value of spatial tests among adolescents with little mechanical experience, very rarely were they found to assist in the selection of adult mechanics in the Services."

They mention that such tests did not show any marked correlation with radar operating or other jobs involving prominent visual components. In answer to this, it might be pointed out that a high correlation between radar operating and spatial tests is perhaps not to be expected, since the principal task of the radar operator is the comparatively routine one of rotating a handle in such a way as to keep a 'blob', seen on the screen of a cathode-ray tube, continuously behind the cross-wire.

It is unfortunate that the spatial test most widely used in the Navy, Army and A.T.S. was the Squares Test. Many investigations, such as Shuttleworth's, have shown that this test has relatively poor validity compared with other spatial tests. No doubt it had great appeal in the Services because of the ease and speed with which it may be marked. Yet, in spite of the fact that its *k*-loading is comparatively low (compared for example with the R.A.F. spatial test K_6 or with Memory for Designs (S.P. 97) which was often given in the Navy), Squares was not without its occasional successes.

Thus, Vernon and Parry write of the Squares Test: "Not only did it show better when compared with operational, as distinct from training, criteria among Royal Marine signallers and Coastal Forces ratings, but also higher rates in the regular (continuous service) Navy did unusually well and advancement correlated with educational ability chiefly among conscripts (hostilities only recruits). In the A.T.S., Squares was outstanding among draughtswomen and certain anti-aircraft personnel. There was fair agreement with practical efficiency tests in the infantry."

It is remarkable also that in a large group of men referred by personnel selection officers to army psychiatrists, Squares provided better differentiation between men given low psychiatric indices and those passed with high indices than did any of the other tests. Thus, "Recruits picked out as lacking in combatancy or questionable in emotional stability did particularly badly in the test (Squares)."

There would appear to be some correlation between spatial ability and emotional stability or 'toughness', and some confirmation of this connection is also provided by the same authors.

"In Coastal Forces, 185 motor launch and motor-gunboat ratings were assessed on several qualities by their officers (by the conference method). . . . With 'dependability', the coefficients for Abstraction, Mathematics and Squares were ·25, ·17 and ·30 respectively. Thus, in this instance, the spatial test did show up better than *v*:*ed*-tests."

Squares also showed higher operational than training validities for A.T.S. personnel engaged in anti-aircraft duties. Thus, the correlation with assessments of efficiency after serving two or more years is given as ·25, whereas the correlation during the training stage was ·11. Most of the other tests showed higher validities in the training stage, but dropped considerably in validity at the operational stage. (The other test which increased its validity was Spelling. Perhaps spelling involves a component of visuo-spatial ability!).

It is interesting to compare these findings with similar ones for another type of spatial test, an Assembly Test of the Stenquist type which was used extensively in the Services. While this test was found to be of little value for selecting instrument or radio mechanics or electricians it gave moderately high correlations in several infantry, gunnery and sapper units.

"Particularly spectacular were the Assault Course marks of 88 men in the 54th R.A.C., with which Assembly correlated ·572, Agility ·330 and Squares ·217, and no other test higher than 0·1. Conceivably, therefore, Assembly, like Bennett and Squares, is associated as much with a kind of general practical intelligence as with specifically mechanical aptitude." The remarkably high correlation between Assembly and Assault Course marks suggests that spatial ability may also be associated with a personality dimension of 'toughness' or—to use a military expression—'guts'.

In the educational field, some interesting results have been obtained on differences between various types of mental test for predicting success in different college faculties. Vernon (1939) for example, has reported that verbal tests correlate about equally with science and with arts subjects, while non-verbal tests agree distinctly better with the science subjects than with arts. With students at the London School of Economics, Himmelweit (1950) found that verbal tests were most useful for predicting academic performance, while non-verbal and spatial tests gave correlations which were barely significant. On the other hand, Petrie (1948) found that for medical students, the correlations with success of the non-verbal and spatial tests were of the same order as those of the verbal tests. Thus, non-verbal mental ability and spatial ability seem to be of greater importance in a medical course than in the type of curriculum studied at the London School of Economics.

Sanders (1948) has reported that in Australian universities, verbal tests are better than non-verbal for selecting both arts and science students, but that an academic examination is also necessary for science students. The mean I.Q. for failing students in arts and law was 110+, while in science and applied science it was 120+. The difference was found in both verbal and non-verbal sections of the intelligence test, but the superiority of the failing science students was greater in the latter.

Garside (1957) has published correlations between the examination marks of 108 university engineering students and various predictors such as G.C.E. Ordinary and Advanced Level, Higher National Certificate (A_1) results, and verbal and non-verbal test-scores. The results showed that G.C.E. Advanced Level or A_1 results gave the best prediction of the engineering marks. The cognitive tests gave lower correlations, in the neighbourhood of ·3, with first-year examinations and near zero values with second-year and final examinations.

Garside accounted for the vanishing second-year and final examination validities by supposing that owing to the elimination of weaker students the second year and final examinations are reached only by those students who are intellectually more capable. The verbal test showed slightly higher correlations than a mixed verbal and non-verbal test, while Peel's non-verbal test (VS 23) showed low correlations both with first year and final examination marks. The predictive values of all the cognitive tests were low compared with G.C.E. Advanced Level and A_1 results.

Hohne (1951) has reported that the Revised Minnesota Paper Formboard Test correlated negatively with student success in arts, and gave somewhat similar results in other faculties, including even engineering. When a student's formboard score was high in relation to his verbal test score, a 'fail pattern' was produced, and vice versa. Probably this result indicates that the criterion of success was based mainly on marks in essay-type examinations. Since it is known that spatial ability is a desirable, and in some cases essential, quality for certain technical and scientific occupations, Hohne's finding raises the question of the validity of essay-type examinations when used as the sole qualifying criteria for entry into these occupations.

Some interesting follow-up results for engineering apprentices have been reported by McMahon and his colleagues (1961) of the Applied Psychology Unit, University of Edinburgh. Each year since 1954, Ferranti student and craft apprentices have passed through a selection procedure at this Unit. The boys had been accepted by Ferranti before they were tested, so none was rejected as a result of the procedure. Tests applied were non-verbal intelligence (Raven's Matrices), Mill Hill Vocabulary, Arithmetic-Mathematics (Vernon), Mechanical Comprehension (Gupta), Form Relations (N.I.I.P.) English Essay, Instructions Test, and an Abstractions Test (Applied Psychology Unit).

Each boy was given a half-hour interview, reports were written, and predictions made in the form of an order-of-merit. There were both theoretical and practical criteria of success, including Technical Theory Qualifications, Scaled Supervisors' Ratings and Assessments of Practical Skill (see Table 21).

Table 21

Validity of tests given to engineering apprentices (McMahon)

	TECHNICAL THEORY QUALIFICATION (N = 82)	SCALED SUPERVISORS' RATING (N = 82)	FACTORY PRACTICAL RATING
Arith.-Maths. (Vernon)	·800	·657	·01
Abstractions (A.P.U.)	·669	·523	·09
Instructions Test	·654	·504	·05
Mechanical Comprn. (Gupta)	·630	·533	·12
Matrices (Raven)	·580	·488	·15*
Form-Relations (N.I.I.P.)	·576	·383	·19†
Essay	·635	·421	
Vocabulary (Mill Hill)	·551	·444	

* Significant at P= ·05 level † Significant at P= ·01 level

For 82 apprentices, followed up after five years, correlations with Technical Theory Qualifications and Supervisors' Ratings were very encouraging. The multiple correlations were so high that prediction of individual performance seemed possible. The best weighted combination of three tests gave a multiple correlation of ·855 with Technical Theory Qualifications, the three tests being Arithmetic-Mathematics (Vernon), Abstractions (A.P.U.) and Form-Relations (N.I.I.P.). The first two tests alone yielded a multiple-correlation of ·837 so that the inclusion of the N.I.I.P. spatial test resulted in an improved prediction.

The attempt to predict practical skill, however, gave much less encouraging results. More than 200 boys were tested between 1954 and 1957 and factory ratings of practical skill were obtained in 1960. Thus, the predictor variables were the boys' test-scores and the ratings by interviewers of their practical hobbies and interests. The correlations of the tests with the criterion were far from encouraging. It is interesting to note, however, that the highest correlation (·19) was that given by the spatial test, Form Relations (N.I.I.P), this being the only correlation significant at the P = ·01 level.

The hobby and interest rating was quite valueless. Its correlation with the factory practical rating was —·003 for the whole group. It also gave a negative correlation with the Technical Theory Qualification (—·03), as well as with the Scaled Supervisors' Rating (—·04). These near-zero results strongly suggest that little reliance should be placed on assessments of interest in hobbies for the long-term prediction of success in theory or practical skill in engineering.

The fact that the correlations of the tests with ratings of practical skill were so low may perhaps be accounted for by the well-known 'halo-effect', which tends to contaminate subjective ratings. Since the boys were well-known to the supervisors who assessed their practical skills, it is highly probable that the ratings would be influenced by their likes and dislikes.

According to Vernon and Parry, "American service psychologists have presented evidence from several naval jobs to show that mechanical and other specialised tests are more valid than verbal-educational tests when the criteria consist of objective measures of proficiency, but less valid when they consist of instructors' gradings." This may be because the gradings may be influenced by the instructors' impressions of the testees' brightness rather than being based exclusively on the objective evidence provided by the work actually done.

Since there is a tendency for high spatial ability to be associated with low verbal ability and vice versa (the aptitudes being bipolar when considered separately from *g*), if two boys have the same level of general ability, the one who is more gifted spatially may be less gifted verbally. Such a boy may have a poorer scholastic record and may be considered to be less bright in general. Also, as already mentioned, there are grounds for believing that spatial ability may be linked with certain temperamental traits (such as shyness and unsociability) which may influence the instructor's judgment unfavourably—a kind of negative 'halo' effect.

It is possible, therefore, that if the Edinburgh psychologists had based their ratings of practical skill on evaluations of specimens of work done without the assessors knowing the names of the boys concerned, the correlations might have been higher. Under such conditions the predictive value of spatial tests would probably be enhanced.

It would be a serious omission to make no reference to the vast amount of work which has been carried out in America on the validation of spatial and mechanical tests. The impact of factor-analysis on the American testing movement has resulted in recent years in the development and widespread use of multiple-aptitude batteries. Instead of yielding a single score, these test-batteries provide a profile of scores in a number of tests, each corresponding to a trait identified by factor-analysis. All of these test-batteries provide scores in one or more spatial factors as well as in other familiar factors such as the verbal, numerical, reasoning, perceptual speed, etc.

One of the multiple-aptitude batteries which has been particularly well validated is the D.A.T. (Differential Aptitude Tests), constructed by Bennett, Seashore and Wesman for the Psychological Corporation.

The Space Relations Test of this battery represents a combination of two approaches to the measurement of spatial ability. One of these is the ability to visualize an object constructed from a given pattern or net. The other is the ability to imagine how the object would appear, if rotated in various ways. The items in this spatial test are all of the same type, and combine the functions of the two approaches.

They all require the mental manipulation of objects in three-dimensional space. The stated purpose of the test is to evaluate the ability to manipulate things mentally and to create a structure in the mind from a plan. These abilities are said to be needed in such fields as draughtsmanship, dress-designing, architecture, art, die-making, and decorating, or wherever there is need to visualize objects in three dimensions.

Validity coefficients for this spatial test for large numbers of groups of pupils in different American schools are listed in the D.A.T. Manual. A representative selection of these coefficients, together with the corresponding figures for the Numerical and Abstract Reasoning Tests are shown in Table 22 (which has been extracted from *Essentials of Psychological Testing* by Cronbach, 1960).

Table 22

Validity of D.A.T. Space Relations and other tests for predicting success in high school courses (Bennett, Seashore and Wesman)

COURSE	GRADE	INTERVAL BETWEEN TEST AND MARKS	NUMBER OF PUPILS	CORRELATION OF MARKS WITH SPACE RELATIONS	NUMERICAL	ABSTRACT REASONING
Plane Geometry	10	1 year	48	·32	·47	·24
	10	,,	70	·20	·34	·19
	10	,,	77	·53	·57	·56
Solid Geometry	12	,,	47	·13	·33	·41
	12	1 semester	42	·18	·61	·25
Art	8	1 year	471	·20	·23	·16
	9	1 semester	44	·34	·41	·21
Mechanical Drawing	10	1 year	46	·02	·17	·43
	10	,,	44	·57	·49	·28
Shop Work	9	1 semester	142	·26	·27	·22
	8	1 year	471	·18	·28	·14
	10	3 months	42	·07	·06	·41
	8	1 semester	81	·33	·28	·50

Considered as a whole, these figures do not favour the space-relations test. In all cases quoted, except one, the validity coefficient for the space relations test is exceeded either by one or other or by both of the coefficients for the other two tests. Commenting on these results, Cronbach writes: "Though geometry undeniably requires reasoning about forms, tested spatial ability accounts for little of the variation in geometry marks. . . . Considered alone, spatial ability has modest validity. Considered alongside other predictors, we find that the predictive value of the test is due to its general factor content. . . . The remaining coefficients tell the same story. . . . These data, and data on other tests, point to the conclusion that spatial ability does not, per se, predict success on high school courses."

The findings of the present writer, obtained in this and in previous studies, are distinctly more favourable. An explanation of the difference may be sought partly in the fact that the D.A.T. Space Relations Test consists entirely of items of one type. Spatial Test I (N.F.E.R.), which is composed of six quite different sub-tests, must sample an individual's spatial abilities much more widely and hence might be expected to have greater predictive value. Secondly, the D.A.T. Test has been designed on the multiple choice principle for ease of marking and so the items are necessarily of the selective response type. Accurate perception and retention of shape or form is not so crucial for success in such items as in those of the creative response type. Finally the items probably measure the spatial orientation factor at least as much as the true visualization or *k*-factor.

An account has already been given of Hills' (1957) study of college mathematics grades, in which two spatial tests, Spatial Orientation and Spatial Visualization, were found to give fairly consistent correlations with criteria of success in several mathematics courses for students of physics and engineering. A comparison between the validities of Hills' spatial tests and those of the D.A.T. Space Relations Test suggests that spatial tests are more valuable for predicting success in mathematics courses in college than in high school.

Turning now to the American validity studies of spatial tests when used for vocational as distinct from educational selection, we find that the evidence is much more favourable. Ghiselli (1955) has summarized published evidence which shows that spatial tests have average predictive validities greater than ·30 for training or job proficiency in the following occupations: protective personnel, service personnel, mechanical repairmen, electrical workers, structural workers, processing workers, operators of complex machines and gross manual workers.* As an illustration, we may quote data given in the D.A.T. Manual for 111 students who took a watch repair course at the American Institute of Specialized Watch Repair. The correlation between scores on the D.A.T. Space Relations Test and the final course grades was the very satisfactory figure of ·69. Since the teachers did not see the test-scores which were obtained at the beginning of the course, the criterion data are not contaminated.

A vast amount of similar data on the predictive validity of spatial tests for numerous occupations has been accumulated by the United States Employment Service. This organization has developed a multiple aptitude test battery known as the General Aptitude Test Battery (G.A.T.B.), which is used throughout the United States for vocational guidance. The battery has been constructed as a result of many years of research on the prediction of vocational success and in the light of factorial studies such as those of Thurstone. The tests are given only through the state employment service, and the results are made available both to high school counsellors and to the employment service.

The G.A.T.B. comprises eight paper-and-pencil tests and four performance tests to measure nine distinct factors, viz.:

G—General reasoning ability (a composite of Vocabulary, Space Relations and Arithmetic Reasoning)
V—Verbal aptitude (Vocabulary)
N—Numerical aptitude (Computation, Arithmetic Reasoning)
S—Spatial aptitude (Three-dimensional Space)

* For a review of the literature of predicting success in trade and vocational school courses, see Patterson (1956).

P—Form perception (Tool Matching, Form Matching)
Q—Clerical perception (Name Comparison)
K—Motor co-ordination (Assemble, Disassemble)
F—Finger dexterity (Manipulation of small objects)
M—Manual dexterity
E—Eye-hand-foot co-ordination
C—Colour discrimination (Not measured by G.A.T.B.)

It is interesting to note that the United States Employment Service recognizes the existence, long disputed, of a General Intellectual Factor (Intelligence or G), and that it uses the Space Relations Test as one of three tests to measure it.

The U.S.E.S. has published an exhaustive list (1957) of the estimated traits required by workers in 4,000 jobs as defined in the *American Dictionary of Occupational Titles*. The trait requirements are listed under various headings, aptitudes, temperaments, interests, physical capacities, etc. For each aptitude these are usually given at one of five levels, indicating the proportion of the working population possessing the aptitude to a degree necessary for satisfactory job performance.

The scale is, in effect:

1. The highest 10 per cent of the working population.
2. The upper third, exclusive of the highest 10 per cent.
3. The middle third of the working population.
4. The lower third, exclusive of the lowest 10 per cent.
5. The lowest 10 per cent of the working population.

Of the 4,000 jobs, 84 are listed as requiring a minimum of spatial ability at level 1, i.e. within the top 10 per cent of the working population. Many of these 84 jobs are closely related, however, e.g. there are 26 different categories of engineer and 14 different categories of draughtsman.

The 84 jobs requiring top level spatial ability are listed in alphabetical order in Table 23.

Table 23

Occupations requiring top-level spatial ability, according to estimates of trait requirements prepared by U.S. Employment Service

1. *Air-plane Designer*
2. *Architect, Marine*
3. *Botanist*
4. *Cartoonist*
5. *Cartoonist, Motion Picture*
6. *Chemist, Metallurgical*
7. *Chemist, Physical*
8. *Detailer*
9. *Die Checker*
10. *Die Designer*
11. *Draughtsman, Aeronautical*
12. „ *Apprentice Marine*
13. „ *Architectural*
14. „ *Construction*
15. „ *Hull*
16. „ *Marine*
17. „ *Mechanical*
18. „ *Mine*
19. „ *Patent*
20. „ *Refrigeration*
21. „ *Ship Detail*
22. „ *Ship Engineering*
23. „ *Structural*
24. „ *Tool Design*
25. *Engineer, Agricultural*
26. „ *Air-conditioning*
27. „ *Automotive*
28. „ *Ceramic*
29. „ *Chemical Research*
30. „ *Combustion*
31. „ *Electrical Research*
32. „ *Gas Distribution*
33. „ *Hydraulic*
34. „ *Methods*
35. „ *Mining*
36. „ *Petroleum*
37. „ *Plant*
38. „ *Steam-power Plant*
39. „ *Production*
40. „ *Radio*
41. „ *Railroad*
42. „ *Refrigeration*
43. „ *Safety*
44. *Engineer, Salvage*
45. „ *Sanitary*
46. „ *Sheet-metal*
47. „ *Systems*
48. „ *Time-study*
49. „ *Traffic*
50. „ *Utilization*
51. „ *Welding*
52. *Geophysicist*
53. *Industrial Designer*
54. *Internal Combustion Engine Designer*
55. *Machinery and Tool Designer*
56. *Manager, Trade Mark and Copyright*
57. *Mathematician*
58. *Memorial Designer*
59. *Modeller*
60. *Neurologist*
61. *Obstetrician*
62. *Oculist*
63. *Oral Surgeon*
64. *Orthodontist*
65. *Orthopedic Surgeon*
66. *Osteopath*
67. *Painter*
68. *Pattern Checker*
69. *Pattern Lay-out Man*
70. *Pediatrician*
71. *Physicist*
72. *Production Planner*
73. *Psychiatrist*
74. *Psychologist, Industrial*
75. *Public Health Officer*
76. *Sculptor*
77. *Stage-scenery Designer*
78. *Surgeon*
79. *Tool Designer*
80. *Urologist*
81. *Veterinarian*
82. *Veterinary Bacteriologist*
83. „ *Pathologist*
84. „ *Surgeon*

It is of interest to note that the list includes a high proportion of scientific and technical occupations. As is to be expected, all classes of engineering and draughtsmanship are represented. Also, the following categories of scientists require high spatial ability, (i.e. within the top 10 per cent).

Botanist
Chemist, Metallurgical
Chemist, Physical
Geophysicist
Mathematician
Physicist
Psychologist, Industrial
Veterinary Bacteriologist
Veterinary Pathologist

Many medical and dental categories are also represented, viz:

Neurologist
Obstetrician
Oculist
Oral Surgeon
Orthodontist
Orthopedic Surgeon
Osteopath
Pediatrician
Psychiatrist
Public Health Officer
Surgeon
Urologist
Veterinarian
Veterinary Surgeon

Though the publication does not refer to empirical evidence, it is clear that the U.S. Employment Service regards high spatial ability as a prerequisite for success in the majority of technological and scientific occupations.

Chapter five

Follow-up and Factorial Studies of the Validity of Spatial Tests for Predicting Success on Secondary Courses

IN this chapter an account will be given of some investigations carried out by the writer to assess the validity of certain tests of spatial ability against criteria of success on courses in secondary grammar and technical schools.

The tests to be discussed are:

1. Spatial Test I (N.F.E.R.)
2. Moray House Space Test 1
3. Spatial Test 2 (N.F.E.R.)

Information regarding these spatial tests has been published elsewhere (Emmett, 1949; Smith, 1954), but it may be of some interest to give a brief account of the circumstances of their construction.

Spatial Test I (N.F.E.R.) was based on an early draft constructed by the writer in 1934. It was printed on behalf of N.F.E.R in 1950.

Spatial Test 2 (N.F.E.R.) was constructed in 1951 by A. F. Watts with the assistance of D. A. Pidgeon and M. K. B. Richards. Spatial Test 2 differs from Spatial Test 1, in that three of its five item types make use of drawings of three-dimensional objects though, so far as the writer is aware, no research has shown that the two tests differ significantly in factor content. Reviews of these tests by various authors have been published in the Fourth and Fifth Mental Measurements Year Books (ed. Buros 1953, 1959.).

M. H. Space Test 1 was developed in the Department of Education, University of Edinburgh, and was one of the series of tests formerly known as Moray House Tests. Work on it was initiated by Professor Godfrey Thomson in 1944, with the assistance of J. H. Gray and J. Y. Erskine. The project was continued by W. G. Emmett, in conjunction with J. T. Bain and L. F. Mills. The test was then printed and administered with a battery of other tests to a sample of 11-year-old pupils. A factor-analysis of the matrix of correlations of the resulting scores was begun by Professor Godfrey Thomson, continued by Z. Swanson and completed by W. G. Emmett, who used D. N. Lawley's Method of Maximum Likelihood. Emmett extracted four factors which were found to be significant, and he tentatively identified the first three of these as *g*, *v* and *k*.

Meantime, the writer had included M. H. Space Test 1 in the battery of tests which he administered to some 200 11-year-old boys in June and July, 1947. Like Emmett, he first applied Thurstone's Centroid Method to the correlations and then D. N. Lawley's Method of Maximum Liklihood. Using Lawley's test of significance he found only two significant factors. As already mentioned in Chapter Two, he interpreted the second factor as bipolar, the positive values corresponding to verbal loadings and the negative values of spatial loadings. It followed from this interpretation that the draft of Spatial Test 1 had a very substantial spatial loading, while both sections of M. H. Space Test 1 had relatively low spatial loadings. This interpretation rather than Emmett's appears to be confirmed by the results of a factor-analysis reported by Wiseman (1955). If this alternative interpretation is given to the second factor extracted from the Moray House correlation matrix in Emmett's analysis, using Lawley's Method, the same conclusion regarding M. H. Space Test 1 would seem to follow, i.e. both sections appear to have relatively low spatial loadings. If, however, following Emmett, the third factor is interpreted as the spatial factor, both sections of the test and particularly the three-dimensional section would appear to have very substantial spatial loadings.

Some information regarding the validity of M. H. Space Test I is contained in the manual. It states that assessments for seventy-one grammar school pupils in geometry, science and art at the end of the first year were found to have higher correlations with the scores in M. H. Space Test I than with the verbal intelligence, English and arithmetic scores in the admission examination. Also, in a secondary modern school, the correlations of M. H. Space Test I with assessments of forty-four boys after one year's work in science, technical drawing, woodwork and metalwork were found to be very satisfactory. These conclusions are presumably based on the results of calculations carried out by Z. Swanson and made available in duplicated form as shown in Tables 24 and 25.

A striking feature of these results is the much higher predictive validity of the two-dimensional compared with the three-dimensional section of the test. All seven regression coefficients of the former are positive, two being significant, whereas four of the

Table 24

Correlations of M. H. Space Test I *and other tests with marks in various school subjects (Swanson)*

SUBJECT	N	M.H. SPACE TEST I (2-DIM)	M.H. I SPACE TEST I (3-DIM)	M.H. VERBAL REASONING TEST	M.H. ENGLISH TEST	M.H. ARITHMETIC TEST	MULTIPLE CORRELATION
Geometry	71	·535	·352	·513	·146	·319	·653
Science	71	·508	·266	·437	·114	·352	·624
Art	71	·380	·390	·196	·034	—·001	·469
Science	44	·486	·308	·552	·296	·430	·600
Technical Drawing	44	·578	·380	·617	·457	·649	·711
Woodwork	44	·271	·226	·156	—·110	·022	·463
Metalwork	44	·232	—·094	·124	·077	·370	·485

(*The corresponding regression coefficients are shown in Table* 25.)

Table 25

Regression coefficients of M. H. Space Test 1 and other tests for predicting marks in various school subjects (Swanson)

SUBJECT	N	M.H. SPACE TEST I (2-DIM)	M.H. SPACE TEST I (3-DIM)	M.H. VERBAL REASONING TEST	M.H. ENGLISH TEST	M.H ARITHMETIC TEST
Geometry	71	·455*	—·135	·422*	—·099	·092
Science	71	·499*	—·241	·352*	—·100	·164
Art	71	·225	·279	·106	—·144	—·143
Science	44	·204	—·029	·561*	—·284	·102
Technical Drawing	44	·155	·093	·228	—·074	·422
Woodwork	44	·389	·026	·333	—·494*	—·152
Metalwork	44	·328	—·266	—·148	—·182	·451*

* *Regression coefficients marked with an asterisk are significant.*

seven regression coefficients of the latter are negative. These results lend support to the writer's interpretation of the loadings obtained in the factor-analyses which have just been mentioned. Since the three-dimensional section had a considerably higher loading on the third factor than the two-dimensional section, Emmett's identification of the third factor with *k* would lead to the expectation that the three-dimensional section would be the better predictor. This expectation has not been fulfilled in the Moray House validity study, so that there are grounds for doubting the correctness of the identification of the third factor with *k*. It is remarkable that all seven regression coefficients of the English test are negative, one of them being statistically significant (—·494). Thus, when scores in a spatial and a verbal test are available, a measure of attainment in English adds nothing to the value of these tests for predicting success in the subjects in question, and is in fact an inverse indication. The regression coefficient of the verbal test for metalwork is also negative.

In view of the conflicting interpretations which have been given to the loadings obtained in several factor-analyses involving the N.F.E.R. and Moray House spatial tests, it seemed desirable to the writer to attempt to compare their predictive validities when employed in approximately the same conditions. An opportunity to carry out such a follow-up study arose through the kindness of T. H. C. Walker, Headmaster of Tynemouth Technical School, who provided the necessary raw data for pupils admitted to the Technical School in Middlesbrough in the years 1949, 1950 and 1951.

Before considering the results of this follow-up study, some indication must be given of the statistical procedures involved. Detailed accounts of appropriate methods have been given by McClelland (1942), Emmett (1942), Burt (1943) and others.

McClelland's very thorough study involved the assessment and follow-up of more than 3,000 pupils in Dundee. Emmett's enquiry concerned the validity of the tests used in selecting some 765 children for secondary education in the West Riding of Yorkshire. Burt's article gives full details of the statistical methods used in the selection procedures carried out on behalf of the London County Council. All of these investigations involved the use of several test-scores or assessments, but in no case were spatial tests used.

Burt's work is of most interest in connection with the subject of spatial ability, since it was concerned with the selection of pupils for L.C.C. trade schools and technical institutions with a view to placing them subsequently with engineering firms. Prior to Burt's investigation, the usual procedure had been to set a written examination in English and arithmetic and to supplement this with more practical devices for assessing the pupils' ability in various kinds of 'mechanical' work. However, there had been continual disputes about the relative value of the different parts of these examinations. In order to shed some light on this issue, researches were carried out in which standardized tests were given every year to boys being considered for admission to certain trade schools. The results were compared with subsequent progress in the trade schools and with reports obtained later after each boy had been employed for some time with an engineering firm.

The following tests were usually employed:

1. Intelligence (verbal and non-verbal);
2. English;
3. Arithmetic;
4. Handwork (individual).

To determine the best weight of each of the tests for achieving the best possible assessment of subsequent efficiency, Burt used the method of weighting by partial regression coefficients. Formulae for calculating these coefficients and the corresponding value of the multiple correlations are given in the article (Burt, 1943).

Of course, the results obtained by this procedure relate only to a selected and therefore relatively homogeneous sample of the school population, namely those pupils selected for technical schools or trade schools. The correlations between the selection tests and the later performance of the pupils are lowered by this selection, and we can only estimate what these correlations would have been if the whole year-group had been followed up. It is necessary to adopt a well-known technique for 'correcting' the weights found in the narrower sample and so to deduce appropriate weights for the population as a whole.

Burt applied this method to data obtained for a sample of pupils who had been admitted to L.C.C. trade schools and for whom a criterion of success was available. Regression coefficients obtained for the sample are shown in the first row of figures and the estimated values for the general population in the second row.

Selected Sample (Actual Values)

	INTELLIGENCE	ENGLISH	ARITHMETIC	HANDWORK	MULTIPLE CORRELATION
Regression Coefficients	·139	—·046	·144	·379	·428

General Population (Estimated Values)

	INTELLIGENCE	ENGLISH	ARITHMETIC	HANDWORK	MULTIPLE CORRELATION
Regression Coefficients	·135	—·050	·165	·417	·536

The fact that the English test has a negative regression coefficient indicates that the pupil who is specifically good at English is likely to be less successful in the subjects taught in the trade schools.

A follow-up study of pupils selected for technical education in Middlesbrough

The object of this study was to assess the validity of tests of spatial ability and other selection tests against criteria of success in technical courses in a secondary technical school. Scores on the usual selection tests as well as on a test of spatial ability were correlated with marks obtained in internal and external examinations in a number of technical subjects taken (*a*) three years and (*b*) five years after the original selection examination.

Data were collected for pupils admitted to the technical school in Middlesbrough in the years 1949, 1950 and 1951.

The following samples of pupils were studied;

1. Sixteen groups of 13-year-old pupils who had been tested for re-allocation at 13 in 1949 and 1950, and who had taken M. H. Space Test I together with other selection tests.

2. Six groups of 13-year-old pupils who had been tested for re-allocation at 13 in 1951 and who had taken N.F.E.R. Spatial Test 1 as well as other tests.

3. Six groups of 11-year-old pupils who had been admitted to the technical school in 1951 after taking M. H. Space Test 1 and other tests.

In 1949, the English and arithmetic tests used were compiled by the head of the technical school and officers of the Local Education Authority. The tests used in 1950, however, were all

Moray House tests. All four tests were used in the selection procedure in each case. The selection was *not* based on the scores made in the three conventional tests only, the spatial tests being given after selection or after admission to the technical school.

In 1951, two batteries of tests were used, one for testing pupils recommended for re-allocation at the age of 13, and the other for administration to the whole of the 11 plus age-group. The second battery, together with teachers' estimates and school recommendation lists, had formed the basis of the selection procedure for all the selective schools in Middlesbrough. Pupils had been selected in the first place either for the Technical School or for the Hugh Bell Selective School on the basis of scores on the verbal, English and arithmetic tests, together with teachers estimates and school recommendation lists. In allocating these selected pupils between the Hugh Bell and the Technical School, use was made of the spatial test score and it was at this stage that a boy would be allocated to the Technical School almost entirely on the basis of a high score on the spatial test.

Differences between the spatial test-score and the verbal test-score, considered in conjunction with the attainment test-scores, were regarded as giving an indication of the suitability of a pupil for one or other of these two schools. It was considered that a good spatial test-score associated with a good arithmetic score was likely to indicate a greater measure of suitability for the Technical School while, on the other hand, a relatively good verbal test-score with a good English test-score was thought to indicate greater suitability for the Hugh Bell School.

The results of the follow-up study in Middlesbrough are shown in Tables 49 to 54 in Appendix 10. These tables give correlations between scores in individual tests and criteria of success in various technical examinations taken three or five years later. Tables showing the corresponding regression coefficients and multiple correlations are also given.

For nearly all technical subjects, the spatial tests yielded consistently higher correlations than the other tests. Correlations tended to be highest for engineering drawing, next highest for metalwork and lowest for woodwork. Building geometry yielded one high correlation (·635) and handicraft one almost as high (·628). There was a tendency for the internal examinations in any subject to yield higher correlations with the spatial test than the external examinations. The explanation probably lies in the fact that not all pupils who took the internal examinations were entered for the external examinations, as can be seen from a comparison of the numbers. Since it is the least promising pupils who are not allowed to take the external examinations, the range of marks in the latter tends to be smaller than the range in the corresponding internal examinations. Such a reduction in the range of the marks would account for the lower correlation.

Inspection of the tables of regression coefficients shows that the spatial tests have much higher predictive validities than any of the other tests. Thus, of the sixteen groups of pupils who took M. H. Space Test 1 at the age of 13, ten showed significant regression coefficients for M. H. Space Test 1. (These are indicated in the tables by means of asterisks.) Only one of these groups showed a negative regression coefficient and this was not significant.

The results for the verbal test were in marked contrast, since 11 of the 16 groups yielded negative regression coefficients, though only one of them was significant.* The English and arithmetic tests each yielded seven negative regression coefficients, though none of these was significant.

In the case of the groups of pupils tested at the age of 11 plus (Tables 51 and 52), M. H. Space Test 1 yielded only one negative regression coefficient, while the verbal, English and arithmetic tests yielded 4, 3 and 1 negative values respectively. The corres-

* Some of the significant positive regression coefficients may be spurious, e.g. that between English and building drawing (internal examinations, 1952). This English test was constructed by the head of the school and officers of the L.E.A. Being a 'home made' test, it may well have produced an abnormal distribution of scores, thus yielding inflated correlation and regression coefficients. The corresponding abnormally high multiple correlation (·977) is almost certainly spurious Some multiple correlations are certainly spurious since the calculated values were greater than unity, probably because of skew score distributions.

ponding figures for the groups who took N.F.E.R. Spatial Test 1 at the age of 13 are even more striking. The regression coefficients for the spatial test were all positive (three of them significant) while those for the verbal, English and arithmetic tests were negative in 3, 1 and 2 cases respectively.

The essential findings of the Middlesbrough study are given in Table 26. The regression coefficients for each sample were first 'corrected' to compensate for the effect of selection. Weighted averages of the corrected regression coefficients were then calculated for three independent groups of samples, as well as for all 28 samples. To facilitate comparisons between groups, the weights have been reduced to fractions of unity.

Table 26

Weighted averages of corrected regression coefficients for predicting success in technical courses (Middlesbrough study; Smith)

	SPATIAL TEST	VERBAL TEST	ENGLISH TEST	ARITHMETIC TEST
16 *samples* (*at* 13 *plus*)	·6814	—·1088	·0614	·1485
6 *samples* (*at* 11 *plus*)	·3746	—·2443	—·2924	·0884
6 *samples* (*at* 13 *plus*)	·4091	—·3562	·1377	·0969
28 *samples* (11 *plus and* 13 *plus*)	.6165	—·2222	—·0234	·1381

The bottom row gives average weights for all 28 samples. The results for the three independent sets of samples (rows 1, 2 and 3) show that the spatial test should be given the greatest weight, that the arithmetic test should be given a relatively small weight and that the verbal test should be given a negative weight. For one of the three sets, the results show that the English test should be given a negative weight and for the other two a positive weight. If all 28 samples are taken together, it appears that a suitable procedure would be to weight the spatial and arithmetic test in the ratio 4:1.

The prediction might be improved still further by including the verbal test as a suppressor variable and weighting it negatively. A variable which has a zero or negative correlation with a criterion, though correlating positively with the valid predictor variables, is known as a suppressor. It may be used to subtract unwanted variance from a predictor and this is a recognized technique, for which formulae have been given in a paper by Lubin (1957).

Such a procedure might be adopted if pupils are being considered for admission to a technical school only, though care would have to be taken to ensure that the pupils did not get to know that it would be advantageous to perform badly in the verbal test. If pupils are being selected simultaneously for grammar school courses and technical school courses, the verbal test could be given a positive weight in preparing the order of merit list for the grammar school and a negative weight in preparing the corresponding list for the technical school. Since the English test has negative or zero value for predicting success on technical courses, it should be used only for ensuring a minimum standard of attainment for entry to such courses.

When either of the two spatial tests was used in selection for the technical school at 13 plus, the mean multiple correlation was higher than when M. H. Space Test 1 was used at 11 plus. It would not be safe, however, to conclude from this evidence alone that selection for technical courses is more effective when carried out at the age of 13 plus than at 11 plus.

Whether it is desirable to select for secondary courses with a specialized bias at 11 plus or 13 plus (if indeed at all) is a question which involves educational and philosophical considerations outside the scope of this study. Husén (1962) has obtained some evidence which suggests that there is likely to be a greater loss of talent when selection takes place at 11 plus than at 13 plus and that there are advantages to be gained from retaining the common system at least until 13.

The evidence of the Middlesbrough follow-up study shows that, when pupils are being selected for a course which is purely or mainly technical, the best single predictor of success is a test of spatial ability and that the other tests commonly used in selection procedures add little to its predictive value.

A follow-up study of pupils selected for grammar-school and technical-school courses in Oldham

The object of this study was to assess the validity of a test of spatial ability (N.F.E.R. Spatial Test 1) and other selection tests against criteria of success in a variety of courses both in grammar schools and technical schools. Scores in six selection tests, including the spatial test and an essay, were available for pupils at the age of 11 plus and these were correlated with marks in G.C.E. examinations taken five years later. Data were collected for pupils admitted to secondary courses in 1954.

The selection procedure operated in Oldham was somewhat elaborate, because special efforts were made to counteract the differential effects of practice and coaching. Thus the verbal test was preceded by three full-scale practice verbal tests each of which was followed by one hour of 'coaching'. The testing sequence is shown in the following scheme.

Three M. H. Practice Verbal Tests (45 mins., 45 mins., 35 mins.).

1. M. H. Verbal Reasoning Test (35 mins.).
2. Spatial Test 1 (60 mins.).
3. Essay (40 mins.).
4. Mechanical Arithmetic (25 mins.).
5. Problem Arithmetic (60 mins.).
6. English Test (Comprehension, Vocabulary, etc., 50 mins.).

The Verbal Reasoning Test was taken by the whole of the age-group. Pupils who scored above average took the spatial and attainment tests. The tests in mechanical and problem arithmetic were home-made, being prepared by the Oldham Educational Guidance Panel. The essay was assessed independently by three members of the panel and scored on a seven-point scale. The level required for transfer to selective secondary education was roughly one-third of a standard deviation above the average. In the case of children near the border-line, account was taken of other evidence, viz. the cumulative school record card and the junior school head teacher's recommendation.

The results of the investigation are shown in Tables 55 and 56 in Appendix 10. An examination of the first of these tables shows that the majority of the correlations between the test-scores and G.C.E. results are positive, 30 of them being significant at the 5 per cent level of confidence.

The significant positive correlations for each test are given in order of magnitude in the following lists.

Spatial Test 1	
Mechanical Science (boys)	·492
Metalwork (boys)	·485
Art (girls and boys)	·404
Mathematics (girls)	·246
Mathematics (boys)	·223
Verbal Test	
English Language (boys)	·421
English Literature (boys)	·365
English Language (girls)	·356
Mathematics (girls)	·336
French (girls)	·325
English Test	
English Language (girls)	·617
English Literature (girls)	·468
English Language (boys)	·414
French (girls)	·381
Biology (girls)	·273
Mathematics (girls)	·269
Essay	
English Language (girls)	·473
English Language (boys)	·391
English Literature (boys)	·368
French (girls)	·326

Mechanical Arithmetic	
Chemistry (girls)	·441
Biology (girls)	·366
English Literature (girls)	·316
Mathematics (girls)	·309
Mathematics (boys)	·226
Problem Arithmetic	
Mathematics (girls)	·539
Biology (girls)	·352
English Language (boys)	·273
Mathematics (boys)	·222

The spatial test is clearly the most valuable for predicting success in the technical subjects (mechanical science and metalwork) and in art, but it has also substantial correlations with mathematics, both for boys and girls.

The verbal and English tests and the essay are all valuable for predicting success in linguistic subjects, such as English language, English literature and modern languages. All three gave significant positive correlations with French.

Mechanical and problem arithmetic are best for predicting success in mathematics, particularly with girls. The correlations of problem arithmetic with technical subjects are all substantial and positive, while the corresponding correlations of mechanical arithmetic are nearly zero.

There are relatively few negative coefficients and only one of these is significant (between the spatial test and chemistry). Negative correlations which reach or approach significance are shown in the following lists.

Spatial Test I	
English Literature (boys)	— ·299
Chemistry (boys)	— ·274 (sig.)
Biology (boys)	— ·247
English Language (girls)	— ·236
German (girls)	— ·231

Essay	
Metalwork (boys)	— ·301
Mechanical Science (boys)	— ·187
Biology (boys)	— ·187
Mathematics (boys)	— ·137

These negative correlations suggest that the spatial test has negative value for predicting success in linguistic subjects like English language, English literature and German. The negative indications for chemistry and biology may reflect the manner in which these subjects are examined, presumably by essay-type examinations. Spatial ability seems to be inversely related to success in subjects which depend on the acquisition of factual information.

The essay shows negative correlations with metalwork and mechanical science and negative or zero correlations with most of the sciences, including mathematics. These are in marked contrast to the strongly positive correlations with linguistic subjects, like French, German and English language and literature. Thus, there appears to be an inverse relation between the predictive values of the spatial test and the essay, the one correlating positively with subjects with which the other correlates negatively and vice versa.

The regression coefficients (Table 56) show many more irregularities than the correlation coefficients. Some are so inflated that the corresponding multiple correlations are obviously spuriously high, in some cases being greater than unity. As already suggested, an explanation of these anomalous values is probably to be sought in the deviations from normality of the raw-score distributions. The tests of English and arithmetic used in Oldham were 'home-made' and there is some evidence that the distributions of raw-scores on these tests were somewhat abnormal. Most of the anomalous regression coefficients are associated either with the two 'home-made' arithmetic tests or with the verbal test. A study of the values of the maximum and minimum scores in relation to the means shows that there is a marked bunching towards the top end of the distributions in the arithmetic tests and more especially in the test of mechanical arithmetic. The scores on the verbal test show a similar tendency, presumably because of the three sessions of practice and coaching (though an attempt had been made to counteract the bunching effect by reducing the time allowed for the test proper by ten minutes).

If we consider especially the regression coefficients which are statistically significant (discounting those which appear to be inflated for the reasons given), the following deductions would appear to be justified.

A spatial test should be given a positive weight in a test-battery intended to select pupils for courses involving metalwork, mechanical science, woodwork, art and mathematics. It should be given a negative weight, however, for courses which are predominately literary (e.g. English language and literature). A negative rather than a positive weight is also indicated for science courses such as chemistry, biology and physics (in which the examinations are usually tests of factual information).

A verbal test should be weighted positively for linguistic subjects and also for science subjects like physics and chemistry. It seems to have little value for predicting success in technical subjects.

An English test should be given a strongly positive weighting for courses in English literature and should be weighted positively for all the sciences, except mathematics. It tends to have a negative value for predicting success in technical subjects.

The essay should have a moderate positive weight for English language and literature, French and German. It should be weighted negatively for most of the sciences and probably also for technical subjects.

Mechanical arithmetic should be weighted positively for mathematics and most of the sciences and negatively for art and technical subjects. Problem arithmetic should be weighted positively not only for mathematics but also for art and technical subjects.

The general trend of the evidence suggests that spatial ability contributes to success in G.C.E. and other examinations in mathematics, art, mechanical science and in most technical subjects, such as engineering drawing and metalwork. Thus, by including a spatial test in the battery used for selecting pupils for technical courses, the number of such pupils likely to succeed could be substantially increased. It would also seem to follow that if a spatial test were included in the battery used for selecting pupils for grammar school courses, the number of pupils likely to succeed in mathematics could probably be increased.

A factorial study of tests and assessments used in the 11 plus allocation procedure in Carlisle

In this study the results are reported of a factor-analysis of the intercorrelations of eleven variables in respect of 489 Carlisle boys who were tested in the year 1956 when they were in the age-range 10:2–11:1 years.

It had been customary in Carlisle to administer as part of the secondary school allocation procedure, seven standardized tests, viz.:

Two verbal tests	(N.F.E.R.	and	M.H.)
Two English tests	,,	,,	,,
Two arithmetic tests	,,	,,	,,
One spatial test	,,	or	,,

Four of these (the N.F.E.R. series) were given in November and the remaining three, the Moray House series, in February. To minimise the differential effects of practice or coaching a practice verbal test was administered about one week before the first series of tests proper. The test-scores were entered on a record card, which also contained a record of independent assessments (made by the primary head teacher) of the pupils' standards in English, arithmetic, practical work and drawing. There was also a rating on a five-point scale of two personality qualities, emotional stability *W* and sociability *S*.

To help the head teachers to rate the personality qualities, the following guide had been provided:

1. *W* stands for Will and Character. The +2 pupil is emotionally stable, calm, dependable, steady, persistent, persevering. The −2 pupil is emotionally unstable, excitable, unreliable, changeable and lacking in persistence and perseverance.

2. *S* stands for Sociability. The +2 pupil is sociable, warm-hearted, easy-going, expressive, frank, co-operative, humorous, a good mixer and talkative. The −2 pupil is unsociable, cold, suspicious, reserved, secretive, aloof, serious, shy and quiet.

These guides were intended to assist the teachers to make reliable assessments of two well-established personality variables, viz. emotional stability and sociability or extraversion. The first variable was intended to correspond to Webb's character factor *W*, later identified by Eysenck (1953) and others with emotional stability. The qualities mentioned in the guide for assessing *W* are similar to those given by Cattell for the source trait *C*+ (Ego-strength), viz. emotionally stable, steadfast, calm, persevering, loyal, dependable. The second variable *S* is similar to Eysenck's dimension extraversion, which has been analysed by Cattell into three primary factors *H*+ (adventurous cyclothymia), *F*+ (surgency) and *A*+ (cyclothymia).

A factor-analysis was carried out of the intercorrelations of the eleven variables (seven ability and attainment test-scores and the ratings for emotional stability, sociability, practical work and drawing).

The matrix of correlations, given in Table 57 (Appendix 10), was analysed by Thurstone's Centroid Method, and the factor-loadings obtained after two iterations are shown in Table 27.

1. Since the first factor accounts for about 70 per cent of the variance, there is a large common element in all the test-scores and assessments. The eleven variables include a varied set of cognitive tests, so the first factor probably approximates to Spearman's *g*. The high loadings in this factor of the ratings for emotional stability and sociability may be due to the presence of a strong 'halo' effect in the personality ratings, showing that the teacher's estimate has been influenced by his knowledge of the pupil's scholastic ability. The higher *g*-loading of emotional stab-

Table 27

Carlisle study. Factor loadings of selection test-scores and teachers' assessments of personality traits and practical and drawing abilities (Smith)

TEST	I_0 g	II_0 a/p	III_0 v/k	h^2
English 25 (*M.H.*)	·8658	·3323	·2680	·9318
English 4 (*N.F.E.R.*)	·8678	·3028	·2892	·9284
Verbal 54 (*M.H.*)	·9353	·2039	—·0870	·9240
Verbal 4 (*N.F.E.R.*)	·9298	·1671	—·0798	·8988
Arithmetic 25 (*M.H.*)	·9042	·1435	—·1374	·8571
Arithmetic 4 (*N.F.E.R.*)	·9285	·1464	—·1833	·9171
Spatial 2 (*N.F.E.R.*)	·6728	·0375	—·2580	·5207
Sociability	·7384	—·2277	·1336	·6148
Emotional Stability	·8210	—·2468	·0621	·7388
Practical	·8139	—·3744	·0508	·8052
Drawing	·6863	—·4091	·0953	·6475
Percentage variance	70·25	6·68	2·93	79·86

Unrotated Factor Loadings from Correlation Matrix for 489 *boys* (*age* 10:2–11:1)
(*by Centroid Method, two iterations*)
a/p = academic/practical; v/k = verbal/spatial

ility than of sociability may be due to the fact that high g is conducive to character integration and emotional stability.

2. The second factor represents about 7 per cent of the variance. The loadings show a sharp differentiation between the scores on the tests and the assessments made by the teachers, particularly for practical work and drawing.

The loadings of the tests show a steady decline from high loadings for English to almost zero for the spatial test, while the loadings for the ratings show a corresponding decline from the negative value for sociability to the most extreme negative loading for drawing. Thus, English bears roughly the same relation to spatial ability among the test-variables as does sociability to drawing ability among the assessments.

We interpret this factor as one of attainment or interest in scholastic or bookish subjects as contrasted with skill or interest in practical subjects. It has some similarity to Alexander's well-known *X* factor and may reflect some temperamental characteristic, such as anxiety or drive.

The considerable negative loadings of the ratings for emotional stability and sociability may correspond to the finding reported by Furneaux (1962) that among university students neurotic introverts tend to do best at academic or bookish subjects.

3. The third factor represents about 3 per cent of the variance. It sub-classifies the second, differentiating the cognitive tests into two categories, the linguistic on the one hand and the spatial and numerical on the other. Loadings vary from the most positive value for the English test to the most negative value for the spatial test, the other loadings being distributed over this range.

This appears to be the familiar verbal/spatial factor. That the third, rather than the second, is the true verbal/spatial factor is shown by the fact that the difference between the English and the spatial loadings is much greater in the third factor than in the second. Also this factor differentiates more clearly between the verbal and the arithmetic tests.

There is less differentiation among the teachers' ratings, but it is noteworthy that the third factor loading of sociability is somewhat higher than that of emotional stability. While the difference between these loadings is scarcely significant, the pattern would be consistent with the interpretation that the sociable pupil tends to have greater verbal facility and so does better at English while the less sociable but more stable pupil tends to perform better at practical subjects.

It appears that the inclusion of the teachers' ratings in the analysis has made possible the separation of an academic/practical factor from the more familiar verbal/spatial one. If the ratings had not been included in the analysis, the two factors would probably have coalesced into one. These are probably the components which make up the factor repeatedly found among adult subjects and designated by Vernon *v:ed/k:m*. An alternative nomenclature, verbal: academic/spatial: practical, would perhaps be more appropriate, since it does not imply that the study of practical or technical subjects is *not* educational. It should be noted that the spatial test is differentiated from the other cognitive tests on both factors, representing some 10 per cent of the total variance. It appears to follow from the analysis, however, that teachers' ratings for practical work or drawing do not provide a measure of spatial ability, but only of practical as opposed to academic interests.

In this connection it should perhaps be mentioned that the evidence available so far tends to suggest that measures of practical interest have less value than spatial tests for predicting success on technical courses (e.g. Yates and Barr, 1960).

The finding that there are distinct spatial and practical interest factors may partly account for the conflicting interpretations which have been given to numerous tables of factor loadings in the past, and it may also explain why some investigators have claimed to find separate *F*- and *k*-factors, while others have found only one factor.

It is perhaps desirable to underline the significance of the finding, deduced from the foregoing analysis, that the spatial test revealed the presence of spatial ability while teachers' ratings for practical work and drawing were relatively ineffective for this purpose. It would seem to follow that pupils may possess an aptitude necessary for success in science, technology and the visual arts and yet their teachers may be quite unaware of its existence since they usually have no accurate means of diagnosis. There would appear to be a strong case for employing spatial tests for the early identification of talent, irrespective of the system of secondary school organization in use.

Conclusions

The evidence as a whole indicates that the best single predictor of success on technical courses is a test of spatial ability, and that the other tests used in the investigations add little to its predictive value.

A comparison of the results for different individual subjects suggests that these would be consistent with the interpretation that:

1. Pupils who perform well in verbal and English tests and in essays (relative to spatial tests) tend to do well in subjects for which the usual criterion of success is a written or essay-type examination; and

2. Pupils who perform well in spatial tests (relative to verbal and English tests) tend to do well in subjects for which the criterion of success depends on the execution of an actual job of work, whether in technical drawing, metalwork, woodwork, mechanical science, mathematics or art.

PART TWO

Chapter six

Spatial Ability and Conceptual or Abstract Thinking

Spatial tests designed to measure 'concrete' thinking

As has been mentioned in Chapter Two, technical abilities were originally believed to be mainly mechanical or practical and the earliest procedures for selecting pupils for technical courses were designed to assess abilities to manipulate elaborate mechanisms or concrete structures such as form-boards. Studies of these tests led to the isolation of the mechanical factor *m* by Cox and the practical factor *F* by Alexander. On the other hand, some of the early performance tests, such as Kohs' Blocks, were considered to provide measures of general intelligence. Spatial tests were originally paper-and-pencil versions of these performance tests, and it was not until the early thirties that it was shown that some of these paper-and-pencil spatial tests involved a spatial factor *k* over and above *g*. It has now become apparent that Cox's mechanical factor *m* and Alexander's practical factor *F* are largely the same as the spatial factor *k*. During the decade 1930–40, most psychologists believed that the three types of test measured different aspects of ability though it was suspected that they were related.

At that time, spatial tests were believed to measure an ability to think 'concretely', and this was certainly the view expressed by Spearman and Wynn Jones in their book, *Human Ability* (1950). Authorities such as Burt (1949) and Peel (1949) tended to refer to spatial tests as tests of practical ability, and most educational psychologists contrasted them with verbal intelligence tests, which were assumed to provide measures of higher abilities such as those involved in symbolical and abstract thinking. Thus spatial tests were supposed to provide evidence of a pupil's practical 'bias', while verbal tests gave a better indication of academic 'bias', and we have seen that there is some evidence to support this view. This attitude to spatial tests was also encouraged by some of the early studies which showed that they had validity for predicting success in woodwork, metalwork and other subjects involving work with the hands.

The diagnosis of brain injury

In recent years, increasing interest has been taken in the problem of diagnosing the presence of injuries to the brain or of organic deterioration of the brain. Since it is generally believed that such damage or deterioration is associated with impaired ability to form general concepts or to think abstractly, efforts have been made to construct tests of concept formation, such as the Kasanin-Hanfmann (1937), or of abstract thinking, such as the Goldstein-Scheerer tests of abstract and concrete thinking (1941). It has been claimed that these tests can be used both quantitatively and qualitatively for measuring or assessing the impairment of the function of the brain in brain-injured patients. It appears, however, that psychologists are tending to rely increasingly on various kinds of spatial test for measuring such impairment instead of using tests specifically designed to measure conceptual thinking. If this application of spatial tests is found to be justified, these tests will have an enhanced importance.

It has long been known that many abilities have a measure of cortical localization and that an impairment of these abilities may result from injuries in certain areas of the brain. The simple manipulative skills involved in the handling of common objects, such as scissors, may be disturbed as a result of lesions in the parietal lobe of the dominant hemisphere. Deficits in spatial and mechanical ability may result from lesions of the parietal lobe in the region of the angular gyrus. A centre for articulate speech is situated in the third frontal convolution of the left cerebral hemisphere for some 90 per cent of the population. One eminent neurologist (Ritchie Russell, 1948) has suggested that the brain mechanisms underlying thought and speech are practically identical and that the seat of these mechanisms is situated in the parieto-temporal region of the dominant hemisphere. Injury to the occipital lobes may result in an impairment in the functions of visual perception. Injuries involving only a small area of these lobes will cause blindness in a limited area of the field of vision. This is because there is a point-to-point correspondence between the surface of the retina and this area of the cortex. On the other hand, it is known that many functions of visual perception depend on regions outside the visual areas in the occipital lobes. Spatial perception may be disorganized by injuries in the posterior parts of the parietal lobes, as well as in the lateral parts of the occipital lobes. Spalding and Zangwill (1950) have described a patient who had well-developed visual patterns for numbers, letters and dates (usually called number-forms), and for whom these patterns were completely disrupted as a result of a wound in the parieto-occipital region. Local injury to the brain in the parieto-occipital region may also abolish visual imagery (Russell Brain, 1950) and may cause a complete cessation of dreaming (Humphrey and Zangwill, 1951).*

Ritchie Russell (1959) has quoted these observations as strong evidence that visual imagery, hallucinations and dreaming depend on normal or uncontrolled activity of the parieto-occipital region of the brain. There is evidence, however, that one of the effects of prefrontal leucotomy in psychotic patients is a reduction of dreaming (Partridge, 1959). Ritchie Russell (1959) has suggested that in these cases, the operation results in a loss of inhibitions which allows the formerly inhibited thoughts to range freely so that there is less tendency for them to appear in dreams. It is

* Chowdhury (1956) studied imagery but obtained very inconsistent results. Neither visualization nor kinaesthesis correlated with scores on spatial tests, though visualization showed a significant positive correlation with mechanical and scientific interests and information.

possible, however, that the main factor in the change is the reduction in the strength of visual imagery which has been reported to take place (Costello, 1956).

Costello also found that after leucotomy, the scores of his sample of patients on a test of spatial ability were more centralized (i.e. less spread out) and this effect may be linked with the change in the quality of visual imagery. He reported that subjects with weak controlled imagery did better in spatial tests, as well as in control of fluctuation with the Necker Cube, than subjects with vivid autonomous imagery. Thus, according to Costello, the ability to control visual imagery is more important for success in spatial tests than mere vividness, where this occurs in a type of imagery which tends to follow its own course, independently of other mental functions. Costello's results would lead to the expectation that high spatial ability would not necessarily be associated with a tendency to experience vivid and frequent dreams. That there is such an association, however, is suggested by the fact that some at least of the authors who have written extensively on dreams appear to have possessed high spatial ability. J. W. Dunne (1927) (author of *An Experiment with Time* and other works on the theory of serialism, based on experiments on dreams) testified to the fact that he was a very good dreamer. From internal evidence contained in his semi-autobiographical work *Intrusions*, published posthumously, it seems probable that he possessed high spatial ability (he was an engineer, a designer and inventor of aeroplanes, and he claimed to have an aptitude for chess and geometry). Alison Uttley (1953) is another writer who systematically recorded her dreams (published in *The Stuff of Dreams*) and who clearly had exceptional powers of visualizing. Like Beatrice Potter and Enid Blyton,* she made extensive use of her imagery in the large number of imaginative books she has written for the delight of young children. Since she took an honours degree in physics (an unusual course for a woman in the years before the war) she probably had high spatial ability.

* For an account of the development and psychological characteristics of these imaginative writers, see Lane, M. (1946) and McKellar, P. (1957).

Thus, there are grounds for suspecting that high spatial ability may be associated with a type of visualization which manifests itself in an exceptional capacity for dreaming (or at least for remembering and recording dreams). This capacity or tendency may be seriously impaired by brain injury.

The significant observation was made by Gelb and Goldstein in 1920 that some brain-injured patients were able to perceive the elementary parts and details of an object or structure but were unable to perceive simple configurations or gestalten. The brain injury seemed to have destroyed or impaired the ability to perceive a configuration as a whole. For example, they found that a patient suffering from a superficial wound in the occipital area was unable to perceive whether a line was bent or not, and yet his visual acuity was quite up to the average standard.

Much research has now been carried out on diagnosing brain damage, and evidence has accumulated that among tests which are most sensitive to the effects of such injury are certain kinds of spatial test such as Porteus Mazes, Kohs' Blocks, Cube Construction and various forms of Memory for Designs Tests like those devised by Bender and Graham and Kendall. The Bender Visual Gestalt Test (1938) has now been extensively validated. It has been reviewed in the Fourth Mental Measurements Yearbook (edited by Buros, 1953), and the two independent reviewers (Benton, A. L. and White, H. R.) stated that it possesses distinctive clinical merits for the evaluation of cerebral injury and disease.* The Memory for Designs Test (devised by Graham and Kendall) has also been extensively used and evidence is now available that it has value for differentiating patients suffering from organic mental disease from those with purely functional syndromes.

Spatial disability in cerebral palsy

It has frequently been noted that cerebral palsied children, who suffer from various kinds of brain damage, often exhibit a per-

* A more recent investigation, however, has yielded less favourable results. The conflicting evidence may perhaps be related to different marking procedures. Cf. Weinstein, S. and Johnson, L. (1964).

ceptual disability which is distinct from those handicaps directly affecting the control of the muscles. Dunsdon (1952) has referred to this disability as a lack of that 'spatial sense' which is needed to appreciate spatial patterns.

Mrs. E. M. Caldwell (1956), Headmistress of a school for spastic children, has published a study of cases of spatial disability in cerebral palsied children. This pamphlet lists the test scores of some thirty-three children who were attending the school in 1955. The data include both verbal and performance I.Q.s on the Wechsler Intelligence Scale for Children as well as non-verbal I.Q.s on Raven's Progressive Matrices. It is remarkable that only six of the thirty-three children had performance I.Q.s higher than their verbal I.Q.s and in two of these six cases, the non-verbal I.Q. on Raven's Matrices was lower than the verbal I.Q. The mean verbal I.Q. was 82·12 compared with a mean performance I.Q. of 68·09, the difference in favour of the verbal I.Q. being 14·03. In many cases, the discrepancy between the two I.Q.s was very marked, one child having a verbal I.Q. of 87 and a performance I.Q. of 40. Apart from the evidence of the test scores there was in the great majority of the children other evidence of gross spatial disability, such as difficulty in drawing shapes, in tracing or copying or in performing tasks such as simple jig-saw puzzles. Frequently the children found difficulty in dressing, in knowing for example which arm to put in the arm of a jumper. Many of them had a poor sense of direction and an inability to draw in the proper proportions. Often there were extreme difficulties in learning to write, with a tendency to reverse letter forms or the order of the letters in words. Some of the very young children showed a total inability to identify the simplest geometrical shapes, such as triangles, squares or circles (even when given a specimen to match). Yet these same children seemed to have no difficulty in identifying pictures of much more complex objects, such as umbrellas, pen-knives or stoves. The inability to recognize a simple geometrical form seemed to be a factor in their slowness in learning to read or write. The reading books in use at the school for spastics were illustrated with pictures of common objects which suggested the shapes of letters of the alphabet. This was helpful in teaching the children to recognize the letters.

Thus, a child who could not remember the form of the letter 'a' could identify it, because it was shaped like an apple cut down one side, and the letter had been learned in association with a picture of a cut apple. By relating the form of the letter by means of some detail to a familiar concrete object, the difficulty of learning could be overcome. The success of this teaching device suggests that the disability involved an incapacity to recognize and remember form in the abstract. It is significant that there was no difficulty in recognizing a concrete object (apple) whose shape suggested the abstract form (letter 'a').

Further evidence that the disability was basically associated with the perception of configuration or form, was provided by a study of the children's drawings,* many of which showed gross errors in proportion, in some cases amounting to complete disorganization. One child drew a house in which the doors, windows and chimneys were scattered over the sheet of paper and not located in the picture of the building at all. Other children drew a figure of a man whose legs were four or five times as long as the body. In other cases, the head was several times larger than the body. Eyes, nose and mouth would be drawn in absurd places on the face, and sometimes outside the face altogether. The general impression gained from studying these children was that there is an intimate association between cerebral palsy and severe spatial disability, and that almost any kind of brain damage is liable to result in a deficit in spatial ability.

Much evidence is now available from controlled investigations that there is in fact such an association. As it would be tedious to report all these studies in detail, it will perhaps be sufficient to quote from reviews of the literature, as reported in recent publications.† In most of the investigations, groups of brain-damaged

* Drawings of the human figure may be used for the diagnosis of mental defect (Borsada, 1959).

† For detailed references and abstracts, the reader is referred to Abercrombie (1963).

and non-brain-damaged mentally retarded children have been equated for mental age, intelligence quotient and chronological age and compared for performance on various types of spatial test.

One group of children consisted of what are known as 'exogenous' cases, i.e. where the case history indicated a prenatal, natal or post-natal disease or injury which appeared to have damaged the brain. The other group of 'endogenous' cases consisted of children whose case history provided no evidence of disease or injury resulting in damage to the brain, but for whom there was evidence of mental retardation in the family group.

In their review of a number of such controlled investigations, Cruickshanks *et al.* (1957) have concluded that the evidence points to an association between brain-injury and impaired performance in various kinds of perceptual tasks, in both the visual and tactual areas.

One of these tasks was the Bender Visual Gestalt Test. The evidence is quite clear that brain-injured adults and children perform in an inferior manner on this test. Also, two studies, one with adults and the other with children, have indicated impaired performance on the Ellis designs as well as on the Bender Visual Gestalt Test. Two further studies have shown that brain-injured adults have greater difficulty in locating hidden figures in tests of the Gottschaldt type. Again, impaired performance on form-board tests of the Seguin type has been shown in two studies, one with a group of cerebral-palsied children and the other with a mixed group of children and young adults. Several studies have shown impaired performance on the tests of Strauss and Werner, which emphasize figure-ground perception, but these studies are not conclusive owing to questionable diagnosis of brain injury.

In the field of tactual perception, there are some indications that impairment is not specific to the locus of damage, although there is evidence of greater impairment of design recognition when damage is to the parietal area and greater impairment in ability to discriminate objects when damage is the temporal area. Almost all studies have found considerable overlap in the distributions of the scores of brain-injured and controls. The most clear-cut differences are found with the simpler phenomena such as 'apparent motion' and design reproduction.

Cruickshank *et al.* found that the cerebral palsy groups of children performed consistently worse than non-handicapped children on the Syracuse Visual Figure-Background Test, the Marble Board Test, and the Tactual Motor and Maze Tests. Their findings were consistent with those of many previous studies in showing impaired performance among the brain-injured. The principal disagreement with previous studies was the low correlations between the test-results and in this respect their results differed from those of Teuber and Bender who found generalized impairment to be the rule.*

Gallagher (1960) has also provided a detailed summary of studies comparing the performance of exogenous and endogenous mentally retarded children in a variety of tests. We shall mention the main investigations reviewed by Gallagher where these are relevant to the topic of spatial disability.

Werner and Thuma (1942) studied the relation between brain injury and ability to perceive apparent motion. None of the brain-injured children studied saw apparent motion, while all but one of the non-brain-injured were able to perceive such motion.

McMurray (1954) projected moving Lissajou's figures on a screen and asked the subjects to point in the direction in which the figure was moving and to indicate quickly when a change in direction occurred. The exogenous group of children perceived a significantly fewer number of reversals than the endogenous group.

Werner and Strauss (1941) investigated the pathology of the perception of figure-background relationships. They found that the brain-injured children responded much more frequently to the background material than to the objects in the foreground. Werner (1945) studied performance on the Rorschach Ink Blot

* Teuber (1959) has reported that in brain-injured adults, figure-ground discrimination may be impaired, whatever the site of the lesion.

Test and found that the whole responses of the brain-injured group were generally poorly integrated, showing evidence of a fragmentary and chaotic approach to the blots. They lacked ability to integrate elements into a comprehensive configuration, gave more bizarre and idiosyncratic responses and tended to perseverate.

Halpin and Patterson (1954), and Halpin (1955) studied the performance of brain-injured children on the Goldstein-Scheerer Tests and on the Bender Visual Gestalt Test. They reported that these tests elicited a greater number of break-downs in Gestalt in the brain-injured children than in the non-brain-injured children. They considered that inability to integrate patterns was a more decisive characteristic of the brain-injured children than the tendency to rotation and reversal of figures.

Bensberg (1950, 1952) used the Marble Board Test developed by Strauss and Werner as well as the Bender Visual Gestalt Test. He found that the brain-injured children were inferior in the accurate reproduction of the designs, and produced a significantly greater number of reversals. Cassell (1949) used tests of motor speed, form perception and reproduction of designs and found that the brain-injured children were inferior in all three types of test.

We may also mention a number of experiments in which comparisons were made using tests of conceptual development. In one of these, carried out by Strauss and Werner (1942), groups were asked to place objects in meaningful conjunction with two pictures, one of a boy drowning and the other of a building on fire. The brain-injured group used many more human figures and twice as many objects as the endogenous group. Also, they seemed to base the selection of many objects upon unusual or apparently insignificant details.

Bijou and Werner (1945) studied language development by presenting a list of nouns under conditions similar to those used in the administration of the Binet vocabulary test. This experiment is of particular interest in that the brain-injured group obtained a *higher* score than the non-brain-injured group. They identified more words correctly and the authors concluded that they had a *higher* range of vocabulary. On the other hand, they tended to make less use of function in their definitions and were more inclined simply to describe the properties of the objects being defined. The general trend of the results of these investigations suggests that brain-injured children tend to have difficulty in concept formation.

Wedell (1959) has reported a study of visuo-spatial perception in different types of cerebral-palsied children. Four matched groups were compared with each other and with a control group of non-brain-injured children. The four groups of brain-injured children were:

1. One of spastics with bilateral motor defect.
2. One of spastics with left unilateral motor defect.
3. One of spastics with right unilateral motor defect.
4. One of athetoids.

The fourth group (athetoids) were characterized by recurrent, irregular, involuntary movements which are believed to result from extrapyramidal tract damage in the basal ganglia.

The I.Q.s of the children ranged from 60 to 120 and C.A.s from 6 to 10. Randomized and representative sampling was achieved by including in each group the first appropriate subject found from hospital or clinic records.

The groups were compared for performance on a test-battery designed to include a variety of tests from pattern recognition to free construction. The results suggested that while there was a large amount of overlap in the performance levels of all groups, perceptual impairment was associated with spasticity rather than with athetosis, and with bilateral and left-sided spasticity rather than with right-sided. Presumably, it follows that greater perceptual impairment resulted when damage occurred in the right hemisphere than in left. It is interesting to note that Wedell found no significant relationship between visual or motor handicap and mental test performance.

The effects of prefrontal leucotomy on spatial test performance

The findings of the very extensive researches which have been done on the effects of the form of brain injury known as prefrontal leucotomy (or lobotomy) are of great interest in connection with our theme.

Halstead (1951) has used a type of spatial test in order to assess the effect of damage to the frontal lobes on the ability to abstract. For many years, he had been working on the problem of constructing tests for measuring different brain functions. He has described in this article a test which he considers to be one of the few which are sensitive to the effects of the removal or impairment of the frontal lobes.

It consists of a form-board with ten cut-out wooden shapes which must be fitted into the appropriate recesses in the board. The subject is blindfolded and is never permitted to see the material. He is given an initial trial with the dominant hand and then a second trial with the other hand. After this a third trial is given in which both hands may be used.

It was found that by the end of the third trial, the brain-damaged as well as the normal subjects can clearly identify the shape of each block. Yet, they have no clear notion or schema of the board at this stage. Some learning has usually taken place with normal subjects, however, since they take less time for the second trial in spite of the shift of the task to the non-dominant hand. There is usually a further reduction in the time required in the third trial. If asked to draw an outline of the board as he imagines it to be, following the third trial, the normal individual shows that he has developed a good mental map or scheme of the stimulus. But, this is not true of individuals in whom the prefrontal lobes of the brain have been removed.

This was clearly shown in the drawing of a female subject who had had a bilateral prefrontal lobectomy, in comparison with another subject who was a normal control. These individuals had the same formal psychometric I.Q. Though the first subject had required 250 per cent more time in contact with the test materials than the second, her drawing indicated that by comparison, the resulting scheme was fragmentary and non-isomorphic. The contrast between the two drawings was very striking. It is interesting to note also that the differences did not arise from an inability of either subject to draw a square, cross or triangle, since they had already shown that they could do this in a previous test. Each of the three shapes was involved in the tactual form-board situation. Yet the patient with the prefrontal lobectomy seemed to be unable to reproduce these forms in the test situation.

Halstead's form-board test seems to be a combination of the Seguin-Goddard Form-Board and a test of Memory for Designs, both types being well-known spatial tests. Thus, one might expect the score in the test to provide a good measure of spatial ability. The remarkable difference between the two performances reported by Halstead, suggests that the removal of the frontal lobes results in a marked deficit in spatial ability, though the ordinary I.Q. may be unaffected.

Hebb (1942) has demonstrated that the I.Q. may or may not be affected and may in fact be maximum for the scale (approx. 160) when the greater part of both frontal lobes has been removed (about 30 per cent of the cerebrum). It does not follow from this evidence that the removal of these lobes involves no loss of ability, but only that the ordinary tests of intelligence are not sensitive to the loss. Halstead, himself, believes that the cortex of the frontal lobes is an important seat of the function of conceptual thinking, though this is a general property of the cerebral cortex. He thinks it probable that the general factor *g*, which Spearman finally interpreted as an abstraction factor is the same as his (Halstead's) A factor which he conceived to be an aspect of biological intelligence concerned with the capacity for abstracting general principles or for integrating experience.

It is remarkable that one of the earliest and simplest types of spatial test, the Maze Test devised by Porteus, has been found to provide a measure of the abilities characteristic of the frontal lobes. It has long been known that the Maze Test involves a personality stability factor in addition to intelligence and it has been used for assessing qualities such as planfulness, and freedom from impulsiveness or irresolution (cf. Cattell, R. B., 1948).

But Porteus (1947) has claimed that his Maze Test is very significantly sensitive to changes in intelligence resulting from pre-frontal leucotomy. He maintains that there is a close correspondence between clinical assessments and maze test performance of leucotomized patients. As the patient recovers from the operation, increased planfulness is reflected in improved scores obtained in successive administrations of the maze test.

This finding has been confirmed by numerous workers. Petrie (1949) observed twenty patients before and after leucotomy and reported that the changes resulting from the operation are in the direction of a decrease in intelligence, a decrease in neuroticism and a movement away from extreme introversion towards the extravert end of the scale. The change from an anxious, depressed introvert to a cheerful extravert may be quite startling.

Among the changes noted were:

1. A reduction in motor perseveration scores.
2. A decrease in the rate of fluctuation of an ambiguous figure (Wheatstone cube).
3. An increase in fluency (though not reaching the level of significance).

All these changes noted by Petrie suggest a movement from introversion to extraversion. (Though it might be maintained with equal justification that the movement is from schizothymia to cyclothymia. According to Eysenck, the dimension of Kretschmer's typology is not to be identified with that of Jung.)

Crown (1951) has published a summary of the results obtained by numerous investigators on the changes observed following pre-frontal leucotomy. There is general agreement with Petrie's finding that the Porteus Maze Test and certain types of verbal test show the greatest deficits. Of other performance tests, scores on Kohs' Blocks and Alexander's Passalong Test tend to show a slight, but non-significant rise after leucotomy. In one report, the

Goodenough Drawing-a-Man Test showed a statistically significant increase. Vidor (1951) has suggested that one of the main reasons for the improvement in the Kohs' Blocks score, which was significant in her investigation, is certainly the greater speed with which the patient works after the operation. This test is limited for time and scoring is graded according to the amount of time required.

Though quantitative changes have been found to be small for the majority of cognitive tests studied, most observers agree that there are very considerable qualitative changes in the patients' abilities. For examples, Freeman and Watts (1942) have reported that "lack of foresight seems to be one of the most characteristic manifestations of deficiency in frontal lobe characteristics". They state that Rorschach personality profile studies show qualitative changes in the direction of loss of initiative, planning ability, creativeness, self criticism and the like. Recovery of planfulness, so important in self direction, proceeds rather slowly even in improved cases, and usually ends at a mediocre rather than a high level.

In view of these statements that post-operative leucotomy patients are deficient in higher abilities, the peculiar sensitiveness of the Porteus Maze Test is very remarkable. Porteus claimed that whereas a control group showed an average gain in Maze Test scores of almost two years, on a second application of the Maze, the lobotomy cases had a two-year loss. Petrie has confirmed that a marked loss in ability to perform the Maze Test occurs after leucotomy, followed by an improvement. (The critical ratio for the decrease after three months was 3·14 and after nine months 1·67.)

Porteus (1945) also administered the test to groups of mental defectives and found high correlations with social competency. The correlation between his measure of social competency and the Stanford Binet I.Q. was ·62, whereas with the Maze Test, it was ·87. Thus, the Maze Test provided a more valid index of social competency, and it was found that the greater the level of mental defect, the better was the indication. Delinquents, however, tended to score relatively highly in relation to their social ratings.

The evidence that there is an association between Maze Test score and social competency and qualities of personality and the suggestion that it may provide an indication of higher abilities, such as foresight and planning ability, are of great interest in connection with the subject of this study. The Maze Test is undoubtedly a type of spatial test and the question arises whether the special qualities of this test are to be found in other spatial tests though perhaps not to the same extent.

There are good grounds for supposing that the Maze Test measures the *k*-factor, though not all investigators have classified it as a *k*-test in the past. The fact that boys perform better than girls on mazes suggests that it has something in common with typical spatial tests. Also, Alexander (1935) found with his group of adults, that the Porteus Maze Test had approximately the same *F*-loading as the three tests of his performance scale, suggesting that the *F*- (or *k*-) loading of the Maze Test is substantial. Burt has published the results of a factor-analysis which shows the *k*-loading of Mazes to be ·382. It is possible that other spatial tests possess similar properties to those of the Maze Test, but these may be less conspicuous because of a relatively higher *g*-loading or because the score is more critically dependent on the time-allowance (as in Kohs' Blocks).

There is little agreement among investigators as to whether or not *abstraction* is affected by prefrontal leucotomy. Eysenck (1952) states that qualitative observation of responses leaves little doubt that there is considerable deterioration in the ability to generalize. Kisker (1943) and Jones (1949) thought that there are no important changes, whereas Greenblatt *et al.* (1947) Yacorzynski *et al.* (1949) and Malmo (1948) considered that there is a loss on tests of abstract thinking.

Yacorzynski *et al.* (1948) found that there were marked differences after leucotomy in the scores on tests of the type of Vigotsky and Kohs' Blocks. The results suggested that after the operation, reasoning and concept formation are markedly affected when the subject has to deal with factors removed from his immediate environment, i.e. abstract concepts. Yet, he is capable of handling his immediate environment as well as pre-operatively.

Malmo (1948) attempted to measure changes after leucotomy and gyrectomy in certain special psychological functions, including that of abstract thinking. On tests of vocabulary, there were post-operative changes in the direction of greater concreteness of definition. Small groups of patients showed a loss of ability to think abstractly on the Halstead Sorting Test and on Kohs' Blocks. In a discussion about some of the tests commonly used to measure ability to think abstractly, such as the Vigotsky and Halstead's Grouping Behaviour Test, Crown (1950) makes the comment that further research is needed to decide whether the abstraction group factor supposed to be measured by these tests differs from group factors already widely recognized.

Goldstein (1941) was the first to emphasize that the task of breaking down a pattern into its constituent parts involves an 'abstract attitude'—the same function which he believed to underlie performance in any kind of sorting behaviour, whether in the Weigl Colour-Form Test, the Sorting Test or the Hanfmann-Kasinin Test. These tests which Goldstein considered to be tests of 'abstract attitude' are also believed by many psychologists to be tests of ability to form concepts, but none of the factorial studies which have been carried out with these tests have clearly demonstrated the presence of factors other than the well-established *g*- *v*- and *k*-factors. Semeonoff and Trist (1958) have published a number of such analyses but only in the case of one test, a Grouping Test based on the principle of object sorting without the concrete material, was a factor found which seemed capable of interpretation as a 'conceptual thinking' factor. This interpretation could scarcely be accepted, however, without much further confirmation.

On the other hand, the highly *k*-loaded Block Design Test (Kohs') has been considered by many psychologists, such as Rapaport (1950) to require the analytic and synthetic processes involved in conceptual thinking. This is just one of many observations which suggest that, among the already established group factors, the *k*-factor of the present study seems to have as strong a claim as any to be considered as a factor of importance in tasks involving conceptual or abstract thinking.

Thurstone's Closure Factors

Thurstone (1949) has made the suggestion that the two closure factors C_1 and C_2 which have been identified by him in several studies may be involved in tasks requiring higher cognitive functions. The suggestion is contained in the following passage:

"The first closure factor C_1 (speed of closure) seems to facilitate the making of a closure in an unorganized field; the second closure factor C_2 (flexibility of closure) seems to facilitate the retention of a configuration in a distracting field.

"If this . . . interpretation of the two factors has any generality beyond the perceptual domain, then one could imagine that factor C_1 determines the ease with which the subject can unify a complex situation whereas the second factor C_2 determines the ease with which he can keep in mind the essential features against distraction. . . . The first closure factor might be associated with inductive thinking, whereas the second closure factor might be more associated with deductive thinking."

Pemberton (1952) has made a study of these closure factors in an attempt to establish a relationship with higher cognitive processes, such as that suggested by Thurstone. He administered 25 cognitive tests to adult students and extracted eight factors from the resulting intercorrelations. Two of these were identified as speed of closure C_1 and flexibility of closure C_2. The second of these factors C_2 had highest loadings on a test of Concealed Figures (·53) and on a test of Copying (·41) as well as substantial loadings on Figure Classification (·39), False Premises (·39), Number Series (·27) and Designs (·26).

The first of these tests is a version of the well-known Gottschaldt Figures Test, requiring the identification of a relatively simple figure embedded in a more complex one, and the second is based on the MacQuarrie Test, requiring the subject to copy figures in the dotted spaces provided. Both of these are familiar spatial tests of the *k*-type. Pemberton rotated his factor loadings to oblique simple structure so that his primary factors are correlated, and his C_2 factor had a correlation of ·54 with another factor which he identified with the Space factor S_1. It seems very probable that these two correlated factors correspond to the Visualization (V_z) and Space (S) factors respectively, which have been reported by numerous American factorists, and which are usually considered by British psychologists to be sub-factors of *k*.

If C_2 is in fact the Visualization factor (corresponding more closely than S to the British *k*), Pemberton's interpretation of it as an abstraction factor is highly relevant to our discussion of the relation between spatial ability and abstract thinking. Pemberton writes: "What seems to be required in all these tests (involving C_2) is freedom from 'Gestaltbindung'. . . . In Concealed Figures, one must break the gestalt formed by the large figure in order to find the small figure. . . . The C_2-factor seems to represent the ability to abstract. According to Goldstein and Scheerer, a characteristic of abstract behaviour is to 'grasp the essential of a given whole; to break up a given whole into parts, to isolate and synthesize them'. This seems a very good description of what one must do in the Copying Test."

Most of the tests found by Pemberton to have loadings in C_2 are spatial tests, though one of them is a Number Series Test having a loading of ·27. This does not invalidate our interpretation of it as the *k*-factor, since other workers such as Werdelin (1958) have obtained moderate spatial loadings of this order in tests of Number Series. If we are correct in our identification of C_2 with *k*, Pemberton's suggestion is equivalent to the statement that *k*-factor represents the ability to abstract.

M. D. Vernon (1947) has reported an investigation of Thurstone's closure factors, in which the test materials were presented in a tachistoscope. From a study of the intercorrelations of her tests, she concluded that they fell into two main groups. The first type seemed to involve rapid discrimination of fine details of shape, while the second depended on the assimilation of shapes and the comprehension of their meaning. She suggested that these two types of material involved Thurstone's Speed of Closure (C_1) and Flexibility of Closure (C_2) factors respectively. The first of these also seems to correspond to the well-known factor of Perceptual Speed (P). The second type of test material gave moderate correlations with a spatial *k*-test and with Part 2 of Heim's Test A H 4, which involves both *g* and *k*. (Heim, 1947.)

This finding provides confirmation of our suggestion that Thurstone's factor C_2 called by him "Flexibility of Closure" is in fact the same as the *k*-factor.* More recently, Sultan (1962) has obtained evidence that, for 13–14 year old boys, Flexibility of Closure is identical with *k* and Speed of Closure is the same as the Perceptual Speed factor (P).

Lovell (1955) has carried out an investigation in which he attempted to identify a factor of conceptual thinking in a variety of so called concept formation tests. These tests were modified so that they could be administered to a group simultaneously and were included in a battery of varied cognitive tests, including some tests of motor perseveration or disposition rigidity.

A factor-analysis of the resulting table of correlations yielded several significant factors. Three of these were identified satisfactorily with the usual *g*-, *v*- and *k*-factors, but the same certainty could not be claimed for the identification given to two further factors. One of these was present mainly in the concept formation tests and the other had loadings in some of the rigidity tests and Lovell identified them as concept formation and rigidity factors respectively.

Loadings in the former were somewhat uniform and were not large even in the concept formation tests. The other factor had substantial loadings in only two of the ten rigidity tests (Creative effort ZEK and Creative effort 239).

* It should perhaps be pointed out, however, that in Thurstone's earlier study (1944) it was the first factor extracted (Factor A) which most closely corresponded to *k* and Thurstone tentatively named it "Strength of Perceptual Closure" while another factor was identified as "Flexibility of Closure".

The Memory for Designs Test, which comprised fourteen of the Bender Visual Gestalt and Ellis Designs, had a loading of ·62 on the spatial factor but a non-significant loading on Lovell's supposed categorization factor. Gottschaldt Figures and Kohs' Blocks had substantial loadings of ·60 and ·62 on the spatial factor, but only ·19 and ·19 respectively on the categorization factor. The Shipley Abstraction Test, which presumably measures the ability to abstract, had a non-significant loading on the categorization factor.

It is worth noting that the tests which have been found most useful in practice for diagnosing brain damage (usually associated with impaired ability to think abstractly) had high loadings on the spatial factor, but near zero loadings in Lovell's categorization factor, e.g. Memory for Designs (Bender and Ellis), Kohs' Blocks and Gottschaldt Figures. Thus, there seems to be some doubt as to the correctness of the identification of Lovell's fourth factor as ability to categorize, an ability which is believed to be absent in varying degrees in brain lesion cases and in organic psychotics.*

Effects of severe brain injury

There is now a large body of evidence that in severe cases of brain injury, conceptual thinking is more seriously affected than by simple leucotomy operations. There is also extensive evidence that such patients usually experience great difficulty in performing spatial tests. In view of the possibility that these two manifestations of severe brain injury may not be unconnected, it will be worth studying the relevant evidence in some detail.

* It is true that Lovell showed that his factor had a substantial correlation (·50) with an external criterion of stimulation (he calculated the point biserial correlation for educationally stimulated versus depressed groups). Also, Butt's work (1957) suggests that the factor is strongly linked with secondary school achievement.

The writer agrees with Lovell's suggestion that there is a definite element of flexibility linked with the factor. But in some ways it behaves as an inverse of *k*, which had a correlation of − 0·24 with stimulation. It is perhaps premature to regard it as a conceptualization factor until it has been shown to have diagnostic value with brain-injured or organic patients.

Hebb (1939) has reported a case of a patient who had a serious brain operation, following an accident at the age of 20. The operation was a right temporal lobectomy. In spite of the fact that he showed marked cognitive and social deficiencies, such as inability to comprehend a situation rapidly or to follow the interplay of conversation, his performance was above average on verbal, Stanford-Binet and other linguistic tests, including printed verbal analogies. However, he made very low scores on spatial tests such as Maze, Cube-Construction and Form Board. Hebb states that the defect, as determined psychometrically, was one of form-perception, visual and non-visual. This case provides an instance in which there is a clear association between certain cognitive and social deficiencies and a pronounced lack of spatial ability, though performance on ordinary verbal intelligence tests was relatively unaffected.

Jarvie (1960) has reported a study of intellectual changes in seventy-one ex-service men with brain wounds due to high-velocity missiles. Seven of these men showed marked deficits in a number of tests of the problem-solving type such as Raven's Progressive Matrices (1938), the Hartford Retreat Test and Dominoes, but other kinds of intellectual activity, in particular the ability to understand and organize verbal material, were largely unaffected. Spatial tests which showed substantial deficits were W.A.I.S. Picture Completion, and the Porteus Maze Test, the latter showing a very great loss. Yet, in the case of one patient, who showed a marked spatial deficit, verbal ability was well-preserved, a score of 34 out of 40 being gained on a Vocabulary Test. This patient was a prolific reader.

Costa and Vaughan (1960) reported a well-controlled study of the verbal and perceptual performance of patients with lateralized cerebral lesions. There were 18 patients with left temporal lesions, 18 with right temporal lesions and 18 normal controls, the three groups being carefully matched for age and education. The controls performed significantly better ($P<\cdot 05$) than the lesion cases in the following non-verbal and spatial tests:

1. Raven's Progressive Matrices (modified: items were made into form-boards to allow physical manipulation);
2. Knox Cubes;
3. W.A.I.S. Block Design (both with normal and extended time limits).

Thus there is definite evidence that patients with right or left temporal lesions show substantial deficits in their scores on non-verbal and spatial tests. On the Mill Hill Vocabulary Scale, however, the patients with right temporal lesions actually obtained a *higher* mean score than the controls, though the left lesion cases performed significantly less well than the other two groups. ($P<\cdot05$).

The spatial tests showed the greatest deficits, more especially the highly *k*-loaded W.A.I.S. Block Design. The weaknesses in this test were even more apparent when it was administered with three times the normal time-limit (the critical ratio F being 7·36). The right-lesion cases did significantly worse ($P<\cdot05$) than the left-lesion cases on Block Design, both with normal and extended time-limits. An analysis was made of the numbers of patients who improved their score on this test when extra time was allowed, with results as follows:

	IMPROVED	NOT IMPROVED
Control group	13	5
Left lesion group	11	7
Right lesion group	5	13

These differences were statistically significant ($P<\cdot05$).

Thus, spatial disability results from lesions in both temporal lobes, *but the effects are particularly serious when the lesion occurs in the right temporal lobe.* These findings accord with a statement by Zangwill (1953) that he had been much impressed by the frequency with which visual-spatial disturbances have been associated with lesions of the non-dominant cerebral hemisphere—the right in right-handed persons. These cases may show extreme defects in the ability to understand spatial relationships and to perform fine manipulations under visual control. Zangwill includes illustrations showing severe disorganization in drawings and in the assembly of the manikin figure by patients with lesions of the right cerebral hemisphere.

The inverse phenomenon seems to occur in the case of lesions associated with language disturbances. These are most severe when they occur in the left hemisphere, and this is true of left-handed as well as right-handed persons. Out of ten left-handed cases selected for study by Humphrey (1951), five had had asphasia following a left-sided and five aphasia following a right-sided head injury. In general, the five patients with left-sided injuries sustained the more severe and lasting language disabilities. It was interesting to note, however, that the latter were relatively more impaired on spelling whereas the cases with right-hemisphere lesions were relatively more impaired on calculation.

The writer has not been able to find any experimental data relating to the possibility of an association between relatively high spatial ability and left-handedness. Lombroso (1891) has listed a number of artists, presumably men of high spatial ability, who were left-handed—Michelangelo, Leonardo da Vinci, Raphael de Montelupo and Sebastian del Piombo. No doubt other names could be added to the list, e.g. Ronald Searle and Peter Scott. Burt (1950) has mentioned that many distinguished surgeons have been either left-handed or ambidexterous. There is the interesting and unexplained fact that left-handedness, like superior spatial ability, is commoner among males than females. Burt found that just under 6 per cent of boys and just under 4 per cent of girls are left-handed. Clark (1957) found somewhat higher percentages, 8 per cent and 5·9 per cent respectively, the difference being statistically significant. In the absence of direct evidence relating high spatial ability to left-handedness, however, it is perhaps unwise to pursue this speculation further.

The spatial factor and form perception

At this point, it is appropriate to refer to a hypothesis advanced by Cruickshanks *et al.* (1957) regarding the nature of the perceptual impairment which is characteristic of spastic as distinct from athetoid children. The tests which they used in their investigation were originally developed to measure the figure-ground aspect of perception, but their findings led them to question the extent to which it was the deleterious effect of background which is responsible for the poorer performance.

The alternative hypothesis which they offered was suggested by a comparison between the tactual motor results of their own study and those obtained in a study by Dolphin (1952). The designs used in Dolphin's study had been simpler, and yet the cerebral palsied children tested in his investigation showed much poorer performance than those employed in their own. In seeking for an explanation for this rather striking difference, it was noted that whereas they had used rubber head nails which were adjacent to one another to form the design, in Dolphin's study the nails were separated. This observation led them to enquire whether impairment of the ability to 'organize' individual stimuli into a whole is not of greater importance than the effect of background in impairing the performance of cerebral palsied children. On this hypothesis, the more isolated the individual stimuli, the greater would be the difficulty one might expect. A similar explanation would also apply to the results obtained on the Marble Board Test. The fact that the highest correlation was obtained between the Tactual Motor Test and the Marble Board Test for the spastic group of children lends itself to this type of explanation. The Syracuse Visual Figure-Background Test did not appear to involve this ability, since in this test the task is to discover a figure which is to some extent obscured by the background pattern.

The writer has long maintained the hypothesis that the type of spatial ability which involves the k-factor is an ability to perceive or recognize the structure or form of a figure *as a whole* as opposed to the ability to perceive details. This hypothesis, which was suggested by a consideration of the properties of spatial tests having high k-loadings, has been advanced in theses and published articles (1937, 1952, 1954). A relevant passage in the Ed.B. thesis submitted in 1937 reads as follows (page 20):

"The question then arises as to why the group factor does not show itself so strongly in Recognition A (Gottschaldt Figures) as in Recognition B (Cross-Pattern Test). It seems likely that the fact that the tetrads for Recognition A are lower (though one of them is more than four times the P.E.) may be due to the more effective 'camouflaging' of the figures in Recognition A than in Recognition B. In the former, an ability to form a clear impression of a figure *as a whole* will not serve so well as an ability to note significant details, which reveal its presence in a more complex figure. This may also explain its higher saturation with *g*. . . .

"These considerations suggest that the essential ability involved in working these tests having a common group factor is that required to form and retain a *clear impression of a shape or pattern as a whole*. . . . Apparently, the group factor with which we are concerned enters into abilities involving *critically* the perception of gestalten of shape, but not those involving simple gestalten of magnitude (e.g. discrimination of sizes of circles, squares, etc.) or the more complex gestalten of symmetry, roundness, etc. Using the word 'form' in the sense used by Granit, we may describe the factor as a 'form-perception factor'."

It was of some interest to the writer to find that Spearman expressed a somewhat similar point of view in the following passage from the book *Human Ability*, published in 1950.

"The senior writer happened to notice that such tests can readily be performed in two distinct manners. One may be called analytic in the sense that attention wanders from one element of the figures to another. The other mode of operation is comparatively synthetic in that the figures (or their constituents) are mentally grasped in much larger units (sometimes called 'wholes'). The former procedure, not the latter, tends to load noegenetic processes with *g*."

The passage suggests that Spearman might have given his support to the hypothesis that the *k*-loading of a test may reflect the extent to which it involves the perception and retention of organized configurations or gestalten. The use of the phrase in parentheses, "sometimes called 'wholes' ", however, may suggest a reluctance to accept such a view. This may be not unconnected with the fact that in 1937 when Spearman read the writer's thesis, not only was he reluctant to admit the existence of a spatial factor as detracting from the simplicity of his Two-Factor Theory, but he was also strongly critical of the theories of the gestalt psychologists. It was in 1937 that he published his two volume history *Psychology down the Ages* which contained a chapter strongly attacking the views of the gestalt school.

This chapter, entitled 'The Confusion that is Gestalt Psychology', ended with the following passage:

". . . They have been led far from genuine science. In place of this, they have only been able to substitute some dynamic theorems which, besides being hypothetical in extreme degree are so vague that . . . like the prophecies of an astrologer . . . anything can be read into them, nothing read out of them. Altogether, if Associationism may be regarded as Psychological Enemy No. 1, cannot Gestaltism put in a claim to be at any rate No. 2?"

In view of this virulent denunciation of Gestalt Psychology by Spearman, the gestalt explanation of *k* factor must obviously be considered with some caution. We might test the hypothesis by applying J. S. Mill's Method of Agreement and Difference, i.e. by searching for some characteristic which is present in spatial tests having high *k*-loadings and absent in other types of spatial test known to have low *k*-loadings.

In the former class, we might list Pattern Perception, Paper Formboard (or Fitting Shapes) and Memory for Designs which have repeatedly shown *k*-loadings of ·5 or over. (In Sultan's research, the second and third of these tests had $g + k$-loadings of ·67 and ·66 respectively).

In the latter class, we might include tests such as Street Gestalt Completion or Perceptual Speed which are diagrammatic in content but have relatively low *k*-loadings. In Sultan's analysis, the respective $g + k$ loadings were ·11 and ·35. In the writer's view these two tests depend more on an ability to perceive significant or meaningful details than on the ability to perceive and retain 'in mind' the structure or configuration of a diagram as a whole. Abstraction seems to be involved in the process of perceiving or reproducing the gestalt of an abstract design. The items of the Street Gestalt Completion Test consist of groups of shapes but these are incomplete silhouettes of common objects such as a ship or aeroplane. Identifying these silhouettes may involve less abstraction because recognition may be achieved by noting a characteristic detail such as a mast or propeller. A somewhat similar distinction was mentioned in our discussion of the learning difficulties of spastic children. It was noted that some of these handicapped children had difficulty in learning to recognize the letter 'ɑ', although they had no difficulty in recognizing an object such as an apple. The device of associating the shape of the letter with that of a cut apple had been found helpful in teaching the children to remember the abstract form of the letter.

Perceptual speed tests may require the subject to identify a standard form from a number of figures one (or more) of which is identical with the standard. The variants, however, differ only in respect of detail and not in the structure or gestalt. Hence, these tests have usually a relatively low *k*-loading.

Diagrammatic tests which depend for success on the noting of explicit relationships between the parts of a figure usually have low *k*-loadings though they may have high *g*-loadings, as mentioned by Spearman. An example of this type of test is Progressive Matrices by Raven and Penrose, which was used as a grading test in the services during the war and is generally regarded as a good *g*-test. When administered to males, its spatial loading was found to be negligibly low, though for some unexplained reason it was found to have a consistently higher spatial loading when given to groups of women. It is not a true *k*-test, because it does not involve the perception of organized *configurations* in a way which is *critical* for successful performance. It involves explicit trial and error and the checking and cross-checking of relationships between the different parts of the figures. There are few items which require the imaginal manipulation or retention of a figure as a whole or as an organized configuration. The writer (1954) has carried out a factor-analysis of a battery of tests which included Progressive Matrices (cf. Table 28). Instead of using the total

Table 28

General and spatial factor loadings of a varied battery of spatial tests. Factor loadings (rotated) obtained by the centroid method, for 164 *boys and girls in the age-range* 11:0 to 11:11 *(Smith)*

		TEST	ROTATED FACTORS I_2 g	II_1 k	III_1	h^2
	A	*M.H.T.* 39 *(pp.* 1, 3, 5, 7*)*	·7063	·0355	·6644	·9416
	B	*M.H.T.* 39 *(pp.* 2, 4, 6*)*	·6510	·0323	·6690	·8724
	C	*Matrices (A, C, E)*	·8592	·1684	·2023	·8073
	D	*Matrices (B, D)*	·8709	·0001	·0319	·7595
Spatial Test I (NFER)	E	*Fitting Shapes*	·5025	·5721	·2515	·6431
Spatial Test I (NFER)	F	*Form Recognition (after Gottschaldt)*	·4410	·3898	·3162	·4464
Spatial Test I (NFER)	G	*Pattern Recognition*	·6133	·4630	·3035	·6826
Spatial Test I (NFER)	H	*Shapes Recognition*	·3361	·4181	·1283	·3231
Spatial Test I (NFER)	J	*Comparisons and Inverse Drawing*	·5322	·5337	·3731	·7072
	K	*Memory for Shapes*	·4471	·4816	·0000	·4318
Spatial Test II (NFER)	L	*Match Boxes*	·5398	·3600	·3252	·5258
Spatial Test II (NFER)	M	*Block Building*	·3377	·6342	·0590	·5197
Spatial Test II (NFER)	N	*Paper Folding*	·4131	·4010	·1593	·3569
Spatial Test II (NFER)	O	*Model Recognition*	·3846	·6700	·2482	·6584
Spatial Test II (NFER)	P	*Reverse Drawing*	·4535	·6726	·4373	·8493
		Sum of Squares	4·7673	3·0283	1·7295	9·5251
		Percentage of Variance	31·78	20·19	11·53	

score, however, he derived two scores, one for Sets A, C and E and the other for Sets B and D. The first of these scores was found to have a small spatial loading of ·17 while the second had a zero loading. Keir (1949) and Vernon (1950) have also carried out a factor analysis of the items of this test and have found a bipolar factor contrasting sets B and D with sets C and E (and possibly A). Keir suggested that the contrast could readily be accounted for by the fact that in general, the items in the B and D sets were solved most readily by an 'analytical' or 'verbalized' procedure, while those in Sets C and E were more amenable to a 'synthetic' or 'intuitive' procedure. These contrasting procedures could be regarded as corresponding to Meumann's 'diffusive' versus 'concentrative' or 'fixative' types of attention. (The words 'analytical' and 'synthetic', which the present writer prefers to avoid, are here being used in the sense employed by Spearman and Wynn Jones in the passage quoted from *Human Ability* on a previous page. The same terms are used by Kretschmer in connection with his two main types of personality, but in a different and opposing sense, for it is the person with a 'fixative' mode of attention who is described as analytical by Kretschmer.)

The section of the Matrices test which has a small spatial loading (A, C, E) is that which is most readily worked by attention to the figure as a whole, that is by a concentrative or fixative mode of attention. The other section with the lower or zero spatial loading (B, D) consists of items which are solved most readily by a verbalized procedure, such as finding an explicit rule. The D set, for example, consists largely of 'permutations'.

The writer has suggested in the article referred to that this principle is more generally applicable. The tests which have somewhat lower *k*-loadings (such as Gottschaldt Figures and Paper Folding) can usually be solved by a procedure involving attention to details ('diffusive' attention) while those tests which have high *k*-loadings require the subject to grasp and manipulate mentally figures as wholes, e.g. Paper Form Board (Fitting Shapes), Pattern Perception, Block Building. In the latter tests, a 'fixative' or 'concentrative' mode of attention will be most helpful.

The distinction can perhaps be understood most readily by considering the Memory for Designs Test in which eight large designs are exposed one at a time for ten seconds and then removed and the subject is given one minute in which to reproduce each design. Those subjects who can form and retain an image of the design will be best served by a 'fixative' mode of attention. Having fixated the design, they will retain the figure 'in mind' as a complete gestalt and will have no difficulty in reproducing the figure in its correct proportions. On the other hand, subjects who form visual images with difficulty will be best served by a 'diffusive' mode of attention. They will tend to glance at different parts of the figure during the exposure and will attempt to remember as many details as possible. They will produce a design which may include most of the necessary details, but may well be incorrect as an organized structure or whole. The proportions of the figure may be quite incorrect.

The various forms of the Memory for Designs Test, such as the N.I.I.P. version, have usually been found to have high *k*-loadings, perhaps because the method of scoring gives considerable credit for correct reproduction of proportions. (The loading has been found to vary with different markers, and this variability may be a reflection of differences in spatial ability among the markers.)

Such a difference in mode of attention would account for the fact that brain-injured children who show spatial disabilities have difficulty in performing figure-background tests, such as the Syracuse Visual Figure-Background Test. As we have already mentioned, studies by Werner and Strauss (1941), Cruickshank *et al.* (1957) and others have shown impaired performance on this type of test. It would be reasonable to suppose that children whose spatial disabilities are reflected in a diffusive mode of attention would tend to be distracted by the details of the background instead of being able to fixate attention on the organized figure in the foreground.

Some confirmation of the writer's hypothesis has been obtained by Taylor (1960), in a factorial investigation specifically designed to test the hypothesis. Taylor included the Memory for Designs Test in a battery of eleven tests (verbal, non-verbal and spatial) administered to groups of 100 boys and 100 girls, having an average age of 14 years 4 months.

The Designs Test was marked in three ways:

1. According to the original N.I.I.P. marking scheme;
2. According to the correctness of detail;
3. According to the correctness of the representation of proportions.

To facilitate the marking according to the second and third schemes, the Goodenough Drawing-a-Man Test was added as an item additional to the eight of the Memory for Designs Test. This increased the possible range of scores, particularly for detail (cf. Table 29).

Table 29

General and spatial factor loadings of spatial, geography and other tests. Unrotated centroid factors, after one iteration, for 100 *boys and* 100 *girls, average age,* 14 *years* 4 *months (Taylor)*

TEST OR VARIABLE	I_0	II_0	III_0
	g	*k/v*	
M.H. Verbal Reasoning (Series 51/52*)*	+ ·383	— ·208	— ·362
Non-verbal 3 *(N.F.E.R., Calvert)*	+ ·648	— ·063	— ·271
Spatial 1 *(N.F.E.R., Smith)*	+ ·800	+ ·353	+ ·134
Spatial 1 *(Subtests* 1 *and* 6*)*	+ ·724	+ ·342	+ ·149
Clerical 1 *(N.F.E.R., Richards)*	+ ·368	— ·251	— ·341
Geography (School Marks)	+ ·487	— ·343	+ ·098
Geography (Locations, Map Form)	+ ·634	— ·533	+ ·289
Geography (Knowledge, Verbal Form)	+ ·542	— ·524	+ ·329
Geography (Distributions, Map Form)	+ ·543	— ·393	+ ·250
Memory for Designs (N.I.I.P.)	+ ·767	+ ·339	— ·264
Memory for Designs (marked for Accuracy of Detail)	+ ·434	+ ·300	— 270·
Memory for Designs (marked for Correctness of Proportions)	+ ·739	+ ·427	— ·223
Sex (Male/Female)	+ ·179	+ ·530	+ ·441
Per cent Variance	48·76	20·28	11·08

For both boys and girls, the second method of marking (i.e. for details) produced a much lower *g*-loading as well as a lower *k*-loading. The third method of marking (i.e. for proportions) produced the highest *k*-loading for the combined sample, although for both boys and girls it yielded a slightly lower *g*-loading than the first method of marking. (The latter result might conceivably be due to the inclusion of the Goodenough Test which would probably reduce the reliability slightly.)

Perhaps the most interesting finding of the study was the fact that the third method of marking (for proportions) produced a very large sex-difference in favour of boys, while the second method of marking (for accuracy of details) cause the sex-difference to 'swing' markedly in favour of girls.

The differences in mean score for boys and girls were as follows (Table 30):

Table 30

Difference of means for boys and girls in N.I.I.P. Memory for Designs Test (Taylor)

MARKING SCHEME	DIFFERENCES OF MEANS (BOYS' LESS GIRLS')	CRITICAL RATIO
1. *Original Scheme*	+ 3·12	3·477
3. *Accuracy of Details*	− 0·67	0·324
3. *Correctness of Proportions*	+ 11·90	8·005

The increase in the difference in means in favour of boys when the drawings were marked for the correctness of the proportions is very striking, the critical ratio being more than 8. The result strongly suggests that this method of marking increases the spatial content of the test, since it is well-known that tests with high spatial loadings show a marked sex-difference in favour of boys. The equally striking 'swing' in favour of girls when the designs were marked for accuracy of details points to the opposite conclusion and confirms the results of the factor-analysis, which showed that this method of marking reduced the spatial loading of the test. Thus, Taylor's results provide strong support for the writer's hypothesis that the spatial loading reflects the extent to which the test involves *critically* the ability to perceive and retain 'in mind' a configuration *as a whole.*

Wider significance of the spatial factor

There are indications, however, that the factor is not confined to the *visual* perception of shapes or patterns, but may be involved in perception in other modalities such as touch or hearing or in the perception of configurations in numerical or mathematical symbolism, such as matrices or determinants. At the Twelfth International Congress of Psychology held in Edinburgh in 1948. El Koussy himself suggested the possibility that the *k*-factor might have importance in other perceptual fields, such as the tactual or the auditory. He asked the question, "Does the musical composer need an auditory *k*-factor?" Certainly, there is now considerable evidence from many factorial studies that some tests which are completely without items involving shapes or geometrical outlines consistently appear to have loadings in the *k*-factor.

In his *Factorial Study of Perception*, Thurstone (1944) found several non-geometric tests, such as Brightness Contrast and a Mirror Test, which had considerable loadings in his factor *A* (which is the same as *k*). Werdelin (1958) found that two number series tests had moderate or low loadings on the spatial factor isolated in his study and identified with *k*.

The first of these tests required the subject to continue simple series of numbers like the following:

1, 2, 4, 8, 16, . . .
2, 8, 18, 32, 50, . . .

The second test required the subject to score out terms of the series which were incorrect as in:

1, 2, 3, 9, 5, 6, 7, 8, . . .
1, 2, 9, 16, 25, 49, 64, . . .

The loadings of these two tests on the spatial factor were found in four studies to be as follows:

Loadings on the spatial factor S *or* k

	ALPHA STUDY	SUB-STUDY A	SUB-STUDY B	BETA STUDY
Number Series I	·17	·23	·34	·38
Number Series II	·08	·09	·08	·27

Werdelin's findings do not stand unconfirmed. Pemberton found that a Number Series Test had a loading of ·27 on his C_2 factor (probably the same as k). Also, Guilford *et al.* found that an Arithmetic Reasoning Test had a loading of ·38 on his Visualization factor Vz (the same as k) and this finding has been reported in previous Air Force researches, the characteristic loading being about ·20. This test required the subject to find the answer to arithmetic-reasoning problems presented in such a manner that the method of solution had to be determined by the subject. Thus, a typical feature of this type of test-material was that the subject had to find the rule or law underlying the problem for himself. This is precisely what is required in the Number Series Tests. These are really particular types of the well-known Abstractions Test, devised by Shipley, which consist of miscellaneous series of letters, words or numbers, the underlying rule in each case having to be deduced by the subject. It is interesting to note that though the Shipley Abstractions Test contains no spatial or geometrical items, it was found by Lovell (1955) to have a spatial loading of ·17.

The following are typical Shipley Abstractions items:*

"Wherever you see an asterisk, one letter or number is missing. Write in the missing letters or numbers.

"L M N O P Q *
5 15 25 35 45 55 **
LUCK LICK LACK FOUL FOIL ****
AzM bXn DvO gTp ***"

The investigation by Sultan (1962) showed the Shipley Abstraction Test to have a loading of ·61 in the first factor extracted and identified as $g + k$. Lovell's Concept Formation Test based on Vinacke's figures, to be classified according to two or more mutually exclusive principles, had a loading of ·52 in this factor. Since these loadings are not far short of those of the spatial tests themselves, there are grounds for suspecting that the spatial

* The examples are quoted from Vernon, P. E. and Parry, J. B. (1949), *Personnel Selection in the British Forces*, London, University of London Press Ltd.

tests provide measures of 'abstracting' or 'conceptualizing' ability. If subsequent research should confirm that tests such as abstractions, number series and arithmetic reasoning do genuinely involve a substantial amount of *k*, it will be necessary to extend our conception of the spatial factor to embrace abilities to perceive and recognize patterns which cannot be considered to be spatial or geometrical in any sense. The factor might still be appropriately described as a 'form perception' factor, where the word 'form' is interpreted in the wider or more general sense in which it is used by gestalt psychologists. It may well turn out that 'form-perception' is a more appropriate descriptive term for these tests than 'spatial.' The writer used this name for *k*-tests in 1937. It is perhaps unfortunate that it has since been applied by American psychologists to tests of Perceptual Speed (P-factor) which measure the facility to perceive detail embedded in background material. Such tests can scarcely be regarded as true measures of an ability to perceive 'form'.

An anomaly which puzzled Spearman

The conception of spatial ability which emerges from recent researches, such as those of Werdelin and Sultan, is so all embracing that one is led to enquire whether the process of perceiving and assimilating these general patterns or configurations (whether spatial or non-spatial) is not in fact a process of 'abstraction'. An affirmative answer to this question would account for an anomaly which appears to have puzzled Spearman. As the outcome of his long effort to elucidate the nature of the general factor *g*, Spearman finally formulated the following generalization:

Tests which have high *g*-loadings must possess two essential properties:

1. They must involve noegenetic processes
2. They must be abstract.

As he showed in a posthumously published article (Spearman, 1946), in which he analysed the results of several large scale investigations involving the administration of a large number of varied tests, this combination of noegenesis and abstractness did account for the high and low *g*-loadings *almost* perfectly. There was, however, a single exception and this was a test of spatial perception, which, in spite of *not* being abstract, tended to have high *g*-loadings. Spearman was basing his generalization on the results of investigations carried out in the United States of America, the Spearman-Holzinger Unitary Trait Study (1936) and the later somewhat similar studies successively undertaken by Holzinger, Harman and Swineford.

In the Unitary Trait Study, which comprised 94 tests given to 1,100 pupils, two tests of spatial perception had *g*-loadings with the very high ranks of first and fourth, and in the Thornton School Study, involving 28 tests, a test of visual perception had the high rank of sixth. Since Spearman believed that these tests involved 'concrete' rather than 'abstract' thinking, their high *g*-loadings were inconsistent with his generalization that abstractness is an essential property of a good *g*-test.

Spearman's discussion of the problem, however, does not appear to provide a solution to the difficulty. A satisfactory explanation might be that though these tests appear to be concrete in content, they actually involve a process of abstraction. If we regard the process of perceiving and assimilating a gestalt as a process of abstraction (abstracting the form or structure) then the exception disappears. It is possible that any process of abstraction may involve in some degree the perception, retention in memory, recognition and perhaps reproduction of a pattern or structure.

If this is indeed the explanation of what Spearman called the "anomaly of spatial perception", the unexpected fact that some spatial tests, such as N.F.E.R. Spatial Test 1, have very high *g*-loadings in addition to very substantial *k*-loadings, takes on a new significance. If there are psychological grounds for regarding *g* and *k* as a single factor (and the analysis of Sultan's data suggests that this might be satisfactory statistically), then spatial tests have a strong claim to be regarded as true abstractions tests, if not super-*g*-tests. There would be good grounds for preferring them, because of their superior reliability, to concept-formation or sorting tests such as those of Goldstein and Scheerer, Weigl, Vigotsky, Berg and others. As Vernon (1953) has pointed out, no one has yet proved that these are anything more than rather unreliable tests of *g*.

Certainly, the long-standing view of psychologists such as McFarlane (1925), Alexander (1935) and Spearman (1950), that there is a dichotomy between concrete and abstract intelligence, has been misleading. The corollary that spatial tests measure an ability to think concretely while verbal tests measure an ability to think abstractly seems to be based on a fallacy.

Gestalt perception and conceptual thought

The hypothesis that there is an intimate association between form perception and the process of abstraction has received weighty support from the animal psychologist K. Z. Lorenz (1951), who has approached the problem from a different point of view. In a contribution to a Symposium on 'Aspects of Form', he has advanced an interesting theory to account for such an association. We quote the relevant passage from the article:

"In the simplest and without doubt phylogenetically most primitive form, Gestalt perception is nothing else than the function of another constancy computor, which enables us to perceive the shape of an object as one of its permanent properties. It is as well to remind English-speaking readers that the original, non-scientific meaning of the word 'Gestalt' is equivalent to that of 'shape' or 'form'. In ordinary German, one cannot speak of the Gestalt of a melody or a movement, but only of that belonging to an object of constant spatial shape. The original survival value of Gestalt perception indubitably lies in perceiving constant shape as the supremely important property of individual objects.

"If I turn the pipe which I am smoking, while writing these lines, to and fro, between my fingers, its image assumes an immense number of different contours, yet its shape, as I perceive it, remains perfectly constant.

"This faculty is so familiar to us that we fail to realize what a tremendous feat it is on the side of the computor to 'deduce' the permanent form from the innumerable combinations of sensory data which represent the ever-changing contours of the moving pipe as it is depicted on the retina. . . .

"The computor which enables us to perceive the shape of objects as constant, though immeasurably more complicated, is functionally akin to that of colour and of size constancy, in that it originally evolved in the service of the same function of recognizing individual objects. But, in the course of evolution, any organ may change its function . . . and a central nervous computor is nothing else than an organ. Organs have a queer knack of suddenly developing unsuspected applicabilities and can be turned to tasks entirely different from those in whose service they originally evolved. Two such changes of function have taken a decisive part in the evolution of Man. One was that of the prehensile hand and of the central representation of space correlated with its function.

"The other was that of Gestalt perception.

"All effects of constancy, including that of Gestalt, are based on the single function of extricating the essential constant factor by abstracting from the inessential variable sensory data. The differentiation of this function attains an amazing development in the service of shape constancy, and it needs only to be driven one little step further to make possible an absolutely new operation miraculously analogous to the formation of abstract, generic concepts. Not only small children, but also higher birds and mammals, are able to perceive a supra-individual, generic Gestalt in all the individual objects of the same kind.

"The same faculties which enable these organisms to recognize one individual dog in all shades of light, at all distances and from all angles, need only carry their abstraction from the inessential one step further to render possible the momentous feat of perceiving one common Gestalt in all dogs of all races, different though they may be.

"A monkey, a cat, a raven, or a young child, is certainly not able consciously to abstract the zoological diagnosis of *Canis familiaris Linnaeus*, indubitably it is the performance of the Gestalt computors which enables them to see 'the' dog 'in' all the different representatives of the species. Very probably this function of generic recognition achieved by Gestalt perception is not only the phylological precursor of conscious abstraction. We know by much observational and experimental evidence that the human capacity of Gestalt perception by far exceeds that of all animals. In my opinion, the great change of function just described is one of the indispensable conditions which had to be fulfilled in order to make possible conceptual thought and speech.

"I hold that Gestalt perception of this type is identical with that mysterious function which is generally called 'Intuition', and which indubitably is one of the most important cognitive faculties of man. When the scientist, confronted with a multitude of irregular and apparently irreconcilable facts, suddenly 'sees' the general regularity ruling them all, when the explanation of the hitherto inexplicable all 'at once' jumps out at him with the suddenness of a revelation, the experience of this happening is fundamentally similar to that other when the hidden Gestalt in a puzzle-picture surprisingly starts out from the confusing background of irrelevant detail. The German expression *in die Augen springen** is very descriptive of this process.

* To spring to the eyes.

Chapter seven

The Relationship between Spatial Ability and Temperament

Review of previous findings

THERE is now a very considerable body of evidence of a relationship between spatial ability and temperament.

Dellaert (1934) showed that when unstable and inferior subjects are given both verbal and performance tests, their inferiority is more marked in the scores on the performance tests. Jastak (1934) found differences in 'level' between vocabulary tests and tests requiring some degree of performance ability. His results showed that grossly maladjusted children tend to obtain higher scores in the vocabulary tests than in the performance tests, while normal subjects tend to have similar scores in both types of test. Uhler (1937) studied the test-scores of 820 schoolchildren and found that those children whose non-verbal ability was markedly superior to their verbal ability showed delinquent or aggressive behaviour; where the reverse relation held between the scores, there was evidence of neurotic or psychopathic characteristics.

Earl (1939) found that adult morons "who showed a marked preponderance of verbal ability tend to be unstable personalities with a neurotic preference for symbols rather than realities". Those whose verbal scores were markedly lower than scores on performance tests seemed to be suffering from a verbal neurosis, i.e. a neurotic attitude towards verbal processes, which in his view reflected early educational difficulties.

Wells (1948) made a detailed study of 18 young adults, eight of whom were chosen because of large differences between their verbal and quantitative test-scores.

The tests were:

1. The Scholastic Aptitude and Mathematical Attainment Tests of the College Entrance Examination Board.
2. The verbal and number portions of a test like the Modified Alpha Examination (Psych. Corp., 1943).
3. A vocabulary test (after O'Connor).
4. Rorschach protocols.
5. Kohs' Blocks Test (available for only some of the subjects).

Wells concluded from his study of the 18 cases that there was a significant association between the verbal facility trait complex and sociophilia, and moreover that this is almost certainly a general phenomenon. The opposite tendency for lack of sociability to accompany quantitative—spatial ability was not so well made out. Wells admits that the systematic evidence on the spatial side was meagre, but he claims that Freyd's early findings as to the lessened sociability of the spatially apt have not been contradicted.

It is clear, however, from the figures given by Wells that, if he had studied a sample of cases showing large differences between verbal and spatial scores instead of between verbal and numerical scores (or between scholastic aptitude and mathematical attainment), the contrast with regard to sociability would have been much more marked.

One of the cases Wells considered to be a 'verbalist' actually had higher scores on the spatial Block Assembly than on verbal Alpha, and so was not a true verbalist. It is significant that this was the only one of the so-called verbalist group who was described as asocial and shy. Of the four who did relatively well on the number Alpha and mathematical attainment tests, one was rated as outstandingly asocial and this subject had the highest score of the 18 in the spatial Block Assembly test. Thus, Wells' study can be quoted as offering strong support to the view that high verbal ability relative to spatial ability tends to be associated with sociability, while relatively high spatial ability tends to be accompanied by asocial traits. None of the cases in Wells' verbal facility group had an asocial rating, while the group of physical scientists was certainly less sociable. Wells regarded this tendency for verbal facility to be accompanied by social traits as having a general validity. He points out, however, that Cattell (1945) has noted an opposite tendency when the criterion is a multiple choice verbalism (" the verbalism of cerebrotonia"). He also maintains that his observations support the usefulness of the temperament classification formulated by Sheldon and Stevens.

Bradford (1948) has pointed out that relative weakness at performance tests is characteristic of many of the failures in the 11-plus examination, and is even to be noted among university students who eventually gain a poor pass degree at the first or second attempt. He believes that verbal bias may be an indication of emotional maladjustment. He has presented psychographs showing marked weakness in spatial ability in the case of three pupils who failed in the 11-plus examination, and also for two maladjusted university students. He points out that a selection battery devised to differentiate those who have a verbal bias from those who have a spatial bias, if equally weighted on the verbal and spatial sides, will tend to direct some maladjusted pupils to the grammar school.

Cattell (1948) has noted that "some tests, notably Mazes, Pass-along and Kohs' Blocks seem to be better done by boys than by girls, and evidently involve some temperamental factor of initiative and emotional stability, but other tests involving manipulative skill (e.g. the Seguin) show no such difference". The fact that the first three tests are *k*-tests, showing the well-known sex difference, points to the conclusion that the presence of the spatial factor and the association between the scores and temperamental qualities are related phenomena. We have already discussed the remarkable sensitivity of the Maze Test to changes resulting from the operation of prefrontal leucotomy, and we have referred to its high correlation with measures of social competency.

That the association with personality or temperamental qualities is not peculiar to Maze Tests or Performance Tests is shown by the fact that a somewhat similar association has been noted with paper-and-pencil tests of the familiar type. We have already quoted a statement by Vernon and Parry (1949) that "Army recruits picked out by psychiatrists as lacking in combatancy or questionable in emotional stability did particularly badly in the Squares test." Squares also gave a correlation of ·217 with assault course marks for 88 men in the R.A.C. when no other test apart from Assembly and Agility, gave correlations higher than ·1. The correlations of Assembly and Agility were ·572 and ·330 respectively.

Thurstone (1944) has claimed that administrators and leaders did particularly well in the spatial test consisting of Gottschaldt diagrams. More recently, Semeonoff and Trist (1958) have reported that subjects who do relatively well on the form-board type of performance test, known as the Carl Hollow Square, have characteristic interests and personality traits. Such persons must be spatially gifted for the Carl Hollow Square is a wooden version of the familiar fitting shapes test. These high-scoring subjects fall into three categories:

1. Persons highly skilled in mechanical occupations and pursuits.
2. Test sophisticated subjects who are *not* concerned to maintain prestige in relation to mechanical pursuits.
3. Efficient secretaries and other people whose work benefits from mild obsessional tendencies.

Semeonoff and Trist suggest that, with the possible and partial exception of the last group, the common factor appeared to be *absence* of neurotic tendency. The Carl Hollow Square is of special interest, since it had the highest spatial loading of all the performance tests studied by Semeonoff and Trist. Halstead and Slater (1946) found that a combination of high scores on Carl Hollow Square, together with previous experience, gave the best prediction in selection of neurotic patients for training in engineering occupations.

Eysenck, Granger and Brengelmann (1957) studied the performance of groups of normal, neurotic and psychotic adults on a large number of objective tests, including several spatial tests. In those which had been shown to have high loadings in Thurstone's closure factor *A* (which is the same as the spatial factor *k*), normals were found to perform better than neurotics or psychotics. In the case of Thurstone's Space Test (Primary Mental Abilities), this difference was significant at the 1 per cent level of confidence, and it was in the same direction in the case of the Street Gestalt Completion Test, though not quite significant at the 5 per cent level.

Surprisingly, however, in Gottschaldt Figures and Block Design, neurotics made the best performance and psychotics the worst. These latter tests had loadings on Thurstone's factor *E* (flexibility of closure) as well as on *A*, and the authors thought that this might account for the superior performance of the neurotics on these two tests. The dark vision test was found to have a substantial loading (·449) on the spatial factor, high spatial ability being associated with superior dark vision. This result accords with other findings on the personality correlates of spatial ability, since Granger (1955) has shown that introverts and dysthymics show better dark-vision adaptation than extraverts and hysterics.

That there is an association between spatial or mechanical ability and introversion has been noted by numerous writers, including early workers such as Freyd (1924) and Bingham (1926).

Freyd noted that "the socially-inclined group seems to be related to the extravert and the mechanically inclined to the introvert", and Bingham observed that there is a tendency towards introversion in persons whose occupations require ability to deal with concrete objects or mechanisms. He wrote, "The boy with little more than average mechanical ability, but with an exaggerated tendency to shrink from his social environment, spends more time in playing with mechanical contrivances. His interest in mechanisms grows apace with increase in his mechanical knowledge and skill. He eventually develops a marked vocational tendency which would have been less in evidence had he been less prone to introversion. His ultimate mechanical ability is to that extent a function of his social personality trends. . . . Both interest and ability are functions of personality. Each affects and modifies the other. Vocational ability grows with exercise and training. Interest in any type of activity usually increases with growth of pertinent knowledge and skill. A bias towards introversion, then, is favourable to the enhancement of both interest and ability in dealing with machines." (p. 360.)

Burt has expressed a somewhat similar view, pointing out that there is a peculiarity characteristic of a large proportion of those who shine in mechanical tests and mechanical occupations. Such persons are extraverted for things, but introverted for persons, and unable to deal adequately with persons, they gain power over things. If, in addition, they are not glib with words, there is a further compensating mechanism.

Thus, Burt's theory amounts to much the same as Bingham's, but neither seems to be adequate to account fully for the association, which may be observed in quite young children. When we consider extreme instances, it becomes apparent, that the tendency must be primarily constitutional. Burns (1950) has described cases of children who manifested marked mechanical interests together with various shades of schizoid personality traits at quite an early age: "There is the type of case now known as 'infantile autism', starting in infancy where speech is almost absent and there is a very marked lack of relationship to persons, while there is an obsessional interest in objects, particularly of a mechanical nature. Some of these children, while not completely autistic (to use a term which is not perhaps adequate) grow up into the very eccentric type of individual, who never fits into society, but manages to live with fair success in a more or less private world."

Hebron (1957) has investigated the personality profiles of pupils showing either relatively high verbal ability or relatively high spatial ability, in the course of an extensive survey involving the testing of some 1,500 school pupils in secondary modern schools. Among the tests administered were Verbal and Non-verbal Intelligence Tests, the Ballard Reading Test, a Mechanical Arithmetic Test, the Kingston Number Concept Test and N.F.E.R. Spatial Test 1 (Smith). Objective tests to measure the temperamental traits of surgency and desurgency were also included and ratings of three personality qualities were obtained (independence, self-confidence and perseverance).

From the entire sample of 1,500 pupils, 76 were chosen who showed very high scores on the spatial test relative to their scores on the verbal test. These pupils showed superior scores on the Mechanical Arithmetic and Number Concept tests, though correspondingly inferior scores on the Ballard reading test. This finding suggests that these spatially gifted pupils had a greater capacity for understanding mathematical concepts. The objective temperament tests showed them to be slightly more desurgent and less surgent and they were rated more highly for the qualities independence, self-confidence and perseverance.

From the original sample, another group of 56 pupils were chosen who were at the opposite extreme, i.e. their verbal abilities were very superior compared with their spatial abilities. They showed almost precisely the opposite characteristics in all the tests. They had inferior scores on the Mechanical Arithmetic and Number Concept tests but correspondingly superior scores on the Ballard reading test. They were slightly less desurgent (on two of the temperament tests) and slightly more surgent (on one of the tests) and they were rated *less* highly for the personality qualities self-confidence and perseverance. These findings by Hebron are consistent with results reported by other investigators.

An experiment on the personality correlates of spatial ability

Results broadly in agreement with those reported in the previous section have been obtained by the writer in two experiments with secondary school pupils.

In the first of these, the relationship between spatial ability and personality variables was investigated by means of a self-rating questionnaire. The I.P.A.T. Junior Personality Quiz (Cattell, Beloff, Flint and Gruen) was administered to 56 boys in two modern schools and a technical school. Non-verbal Test 3 (Calvert) and Spatial Test 1 (Smith), both N.F.E.R. tests, were also administered. Scores on two Moray House Verbal Reasoning Tests were available, and a Mathematical and Technical Test (Prak) had been given to 15 of the boys in a class in the technical school. The age-range of the boys was from 10½ to 13.

In order to limit the amount of labour involved in the analysis, only four of the twelve personality variables in the questionnaire were actually correlated with the ability scores. The variables selected were Cattell's factor 3 (neuroticism), 6 (cyclothymia*), 7 (adventurous cyclothymia) and 11 (surgency). All scores were expressed in standardized form and were adjusted for age. The correlations obtained for 56 boys are shown in Table 31. Corresponding correlations for the 15 boys who had taken the Prak Mathematical and Technical Test are shown at the side, though these were not included in the analysis. To reduce the number of negative correlations in the matrix as far as possible, the signs o two of the variables were reflected. Thus, variable 7 appears as desurgency instead of surgency and variable 6 appears as emotional stability or ego-strength instead of neuroticism. By this simple device, all the correlations in the matrix became positive, with the exception of two and these are negligibly small.

The main table of correlation coefficients is made up of four distinct blocks, viz.:

A. The block showing correlations between the verbal, non-verbal and spatial tests.
D. The block showing correlations between the four personality variables.
B and C. The blocks containing cross-correlations between the ability tests and the personality variables.

* Cattell states that the internal consistency of this factor-score is quite low in the child population. In the J.P.Q. this factor is intended to be only experimental.

S.A.—15

Table 31

Correlations of scores in three tests of ability and four personality factors (I.P.A.T. Junior Personality Quiz, 56 boys 10½–13 years) (Smith)

	ABILITIES			PERSONALITY FACTORS				
	VERBAL TEST (M.H.)	NON-VERBAL TEST 3 (N.F.E.R.)	SPATIAL TEST I (N.F.E.R.)	CYCLO-THYMIA (A)	ADVENTUR-OUS CYCLO-THYMIA (H)	EGO-STRENGTH (O — AND C +)	DE-SURGENCY (F —)	MATHEMAT-ICAL AND TECHNICAL TEST (PRAK) (15 BOYS)
Verbal Test (M.H.)		+ ·745	+ ·548	— ·021	+ ·049	— ·001	+ ·158	+ ·684
Non-verbal Test 3 (N.F.E.R.)	+ ·745		+ ·569	+ ·108	+ ·067	+ ·002	+ ·177	+ ·599
Spatial Test 1 (N.F.E.R.)	+ ·548	+ ·569		+ ·168	+ ·015	+ ·013	+ ·337	+ ·661
Cyclothymia (A)	— ·021	+ ·108	+ ·168		+ ·463	+ 487	+ ·368	— ·245
Adventurous Cyclothymia (H)	+ ·049	+ ·067	+ ·015	+ ·463		+ ·378	+ ·233	— ·130
Ego-strength (O — AND C +)	— ·001	+ ·002	+ ·013	+ ·487	+ ·378		+ ·302	— ·406
Desurgency (F —)	+ ·158	+ ·177	+ ·337	+ ·368	+ ·233	+ ·302		+ ·316

The correlations in blocks A and D are all positive and significant. Those in blocks B and C are mostly small and all *except one* are non-significant.

The exception is the substantial positive correlation between Spatial Test 1 and Desurgency. For the 15 boys who took the Prak Test, there is a similar substantial positive correlation between the Prak Test and Desurgency, which shows that the high value is not accidental.

The matrix of correlations was first analysed by Thurstone's centroid method and the resulting factor loadings obtained after two iterations are shown in Table 32. Three factors were extracted accounting for about 30 per cent, 22 per cent and 4 per cent of the variance respectively.

Table 32

Unrotated factor loadings from matrix of correlations in Table 31 *(scores of* 56 *boys,* $10\frac{1}{2}$–13 *years, using Thurstone's centroid method with two iterations)*

		I_0	II_0	III_0	h^2
	Verbal Test (M.H.)	·586	·590	·225	·741
	Non-verbal Test 3 (N.F.E.R.)	·638	·565	·137	·746
	Spatial Test I (N.F.E.R.)	·619	·403	− ·343	·664
I.P.A.T. JUNIOR PERSONALITY QUIZ	*Cyclothymia (A)*	·566	− ·527	− ·048	·600
	Adventurous Cyclothymia (H)	·427	− ·419	+ ·218	·405
	Ego-strength (O − and C +)	·432	− ·493	+ ·129	·447
	Desurgency (F −)	·518	− ·188	− ·241	·362
	Percentage Variance	29·87	22·31	4·44	58·62

To facilitate interpretation, axes I_0 and II_0 were rotated through an angle of 41° 32′, thus making the loading of Non-verbal Test 3 zero in the second factor. By this means, first factor loadings of the three tests of cognitive ability were maximized, while the loadings of the personality ratings became negligibly small, with the exception of that for desurgency.

The rotated loadings are shown in the following table:

Table 33

Rotated factor loadings from matrix of correlations in Table 31 (scores of 56 boys, $10\frac{1}{2}$–13 years, axes I and II rotated through 41° 32′)

	I_1	II_1	III_0	h^2
Verbal Test (M.H.)	·829	— ·053	·225	·741
Non-verbal Test 3 *(N.F.E.R.)*	·853	·000	·137	·746
Spatial Test I (N.F.E.R.)	·731	·109	— ·343	·664
Cyclothymia (A)	·074	·770	— ·048	·601
Adventurous Cyclothymia (H)	·043	·597	·218	·405
Ego-strength (O — and C +)	— ·004	·656	·129	·447
Desurgency (F —)	·263	·484	— ·241	·362
Percentage Variance	28·94	23·26	4·44	56·64

1. The first factor bears some resemblance to Spearman's *g*, since it loads the three cognitive tests heavily and more especially Non-verbal Test 3, which requires eductive thinking with exclusively non-verbal material. Desurgency has a not inconsiderable loading in this factor (·263), possibly because high general ability disposes towards serious rather than social pursuits.

2. The second factor differentiates mainly between the four personality variables and the three cognitive tests, though the spatial test has a small positive loading. It would be unwise to push the interpretation of this factor too far, since it is probably an artefact arising from the two different kinds of test-material, self-rating questionnaires and cognitive tests.

3. The third factor is clearly the well-known verbal/spatial factor. Referring to the table of *unrotated* loadings, it will be noted that the third factor sub-classifies the second. Among the cognitive tests, it differentiates between the verbal and non-verbal tests on the one hand and the spatial test on the other. Among the personality variables, it differentiates in a similar way between the cyclothymias on the one hand (especially *H*) and desurgency on the other. Thus, verbal ability bears the same relation to spatial ability among the tests as adventurous cyclothymia bears to desurgency among the self-ratings. Perhaps the most interesting result of this analysis is the spatial loading of desurgency (almost as high as that of Spatial Test 1).

Adventurous Cyclothymia ($H+$) has a loading of the same sign as the verbal and non-verbal tests on this factor, but opposite in sign to that of the spatial test.

Thus, according to the results of our analysis of the I.P.A.T. questionnaire scores and ability test scores, spatial ability is associated both with desurgency and with withdrawn schizothymia. According to Cattell (1957), factor F surgency-desurgency, even more than cyclothymia-schizothymia, is associated with the breadth factor in body-build, surgents being short and stocky. Thus, we might expect spatially gifted individuals to have a tendency to be tall and lean. If we use the terminology suggested by Rees and Eysenck (1945), our results would lead to the expectation that high spatial ability tends to be associated with leptomorphic physique and introverted temperament; in Kretschmer's system (1925) with leptosome or athletic physique and schizothyme temperament; in Sheldon's system (1940) with ectomorph physique and cerebrotonic temperament.

It is of some interest to compare these findings with the conclusions reached by Cattell and Drevdahl (1955) regarding the personality qualities of academically successful men and more particularly of research workers. Drevdahl (1954) investigated the personality-interest factors which distinguish creative, productive, graduate students in arts and science, from uncreative persons of equal ability. He found the creative significantly more schizothyme, self-sufficient, withdrawn, sophisticated, desurgent and radical. This general pattern was largely confirmed by Cattell and Drevdahl (1955), who contrasted the mean personality profile of 114 eminent researchers (physicists, psychologists and biologists) with that of 69 leading academic administrators, 81 outstanding teachers, and the general population. It is remarkable that the most striking personality differences which Cattell and Drevdahl found between researchers and administrators or teachers (viz. schizothymia, withdrawnness, desurgency and self-sufficiency) are very similar to those which we (and other workers) have found to be associated with high spatial ability. This finding may perhaps be interpreted in the light of our discussion of the relationship between spatial ability and problem solving (cf. p. 195 ff.). The person with relatively high spatial ability has a marked tendency to seek for and recognize regularities and patterns in his experience. He tends to experience tensions when he becomes aware of a lack of completeness in any of these patterns and he continues to search until he achieves the most satisfactory completion or 'closure'. It might be expected that such a person would be attracted to scientific research because in this occupation a tendency to recognize problems and to seek for their solution would be recognized to be valuable and might be appropriately rewarded.*

Spatial ability and interests

There is some evidence that spatial ability is associated not only with characteristic personality qualities, but also with practical, mechanical or scientific interests.

Peel (1948) and Lambert (1949) constructed an interest test of the information type, which contrasts 'practical' with 'academic interests'. In this test, the questions are grouped in sixes, three intended to relate to practical and three to academic interests. The testee is asked to answer three questions from each group, the assumption being that the items selected will be in the dominant field of interest. To eliminate the effect of general ability, an index is computed called the *P*-Index given by the formula:

$$\frac{P-A}{P+A} \times 100$$

where P and A are the numbers of correct answers in each category.

Spatial ability has been found to be moderately associated with 'practical' interests and verbal ability with 'academic' interests. Peel has reported the following correlations with *P*-Index:

* Cf. Abercrombie (1960), for a relevant discussion of the nature of scientific thinking.

	p-INDEX
Alexander's Performance Scale (spatial)	·2490
M.H. Intelligence Test (verbal)	— ·2609

Wiseman (1955) has reported corresponding figures for the Peel-Lambert test as follows:

	p-INDEX
N.F.E.R. Spatial Test I	·126
M.H. Intelligence Test (verbal)	— ·138

In a follow-up study, Lambert has shown that the Peel-Lambert Interest Test gave improved discrimination, when administered to the top 30 per cent of 11 plus boys.

The Devon Interest Test (Fitzpatrick and Wiseman, 1954) is an interest questionnaire (not an information test like the Peel-Lambert Test). It is intended to provide an index of the relative strength of academic and practical interests. There are 96 items, arranged in blocks of six, each containing two practical, two academic, one social and one distractor. The testee is asked to indicate which items are liked, which are disliked and which are never done and then to go back and indicate first and second choice. The theory underlying the test is that a pupil who indicates an *A* or *P* preference in face of strong distractions really does show strong interests in one or other of these areas. The test was administered to a sample of 175 boys aged 11 plus, together with tests of intelligence, attainment and spatial ability and the Peel-Lambert Interest Test (Wiseman, 1955). Three factors were extracted from the matrix of correlations and after rotation these were identified as the general intellectual factor, an interest factor and the spatial factor. The second of these (the interest factor) was present mainly in the Devon Test, to a less extent in the Peel-Lambert Test and scarcely at all in the verbal, non-verbal and spatial tests. It is interesting to note that the analysis shows the N.F.E.R. Spatial Test 1 has a much higher spatial loading (·456) than the M.H. Space Test 1 (·109), a result in agreement with previous findings.

Correlations between the two parts of the Devon Interest Score and scores in the other tests were as in Table 34:

Table 34

Correlations between spatial and other tests and the practical and academic scores of the Devon Interest Test (Wiseman)

	DEVON P	DEVON A
M.H. Intelligence Test (Verbal)	— ·001	·013
M.H. Arithmetic Test	— ·019	— ·055
M.H. English Test	— ·036	·139
N.F.E.R. Non-verbal Test I (Jenkins)	·015	— ·020
M.H. Space Test I	·129	— ·017
N.F.E.R. Spatial Test I	·144	— ·129
Peel Practical Score	— ·087	— ·149
Peel Academic Score	·089	·177
Peel Difference	·126	— ·216

All the correlations are rather low, including those with the Peel test, which suggests that the two Interest tests are measuring different factors. The percentage variance of the rotated loadings for the three factors shows that the interest factor is more influential than the spatial factor in this battery. The variances were:

General ability	43 per cent
Interest	13 per cent
Space	8 per cent

The only substantial loadings in the interest factor were those of the two sections of the Devon Interest Test and these account for most of the 13 per cent variance. An examination of the content of the test shows that the *P* score seems to be based almost entirely on items indicating a preference for working with tools or with machines.

A factor-analysis of scores for 254 boys aged 13 plus showed that the *P* score had a somewhat similar factor pattern to a report-form score based independently on teachers' estimates. Wiseman has suggested a method of technical-grammar allocation using both a spatial test and the Devon Interest Test and he claims that this results in positive classification of about 60 per cent of pupils. The Devon practical and academic scores appear to be more effective for differentiating between technical and grammar pupils than the Peel and Lambert difference score. Thus, if the correctness of the classification can be confirmed in follow-up investigations, the Devon Interest Test would be a useful instrument for differential selection. It is very desirable that a follow-up investigation should be carried out, for the value of an interest test for selection purposes depends on the stability of interests and not much positive evidence is yet available on this question. It is possible that an interest in machines or in working with the hands may be a passing phase. Reference has already been made to the findings of McMahon (1961) and his colleagues in Edinburgh, which showed that assessments of interest in hobbies had no value for predicting success among engineering apprentices.

Thurstone (1951) found that among students, mechanical ability and interest correlated with the personality traits Vigorous, Active and Reflective and negatively with the trait Sociable. Also mechanical ability and interest correlated positively with scientific and artistic interests and negatively with literary, musical, computational and clerical interests.

North (1950) has carried out a factor-analysis of the Guilford introversion-extraversion scores (S.T.D.C.R.) and found two primary factors which were defined on the basis of item-analysis as:

1. Cycloid emotionality and depression (cyclothymia).
2. Impulsiveness and freedom from restraint (rhathymia).

The first factor was related significantly in the positive direction to literary interests (·23) and in the negative direction to interest scores in mechanics (— ·30), computation (— ·31) and science (— ·20). There was a correlation of ·08 with clerical interests and of — ·12 with sex. Thus, according to North's identification of the factors, we should expect mechanical, computational and scientific interests to be accompanied by schizothymic personality traits. Eysenck (1960), however, has reinterpreted North's data identifying the first factor as Neuroticism and the second as Extraversion-Introversion. Since it is the first of the two factors which is probably more closely related to spatial ability, Eysenck's interpretation would lead to the expectation that high spatial ability is associated with emotional stability (the inverse of neuroticism).

The writer (Smith, 1954) has shown that spatial ability is associated with masculine attitudes and interests by giving six tests, including two spatial tests to a sample of boys and comparing the results with the scores on Form B of the Terman and Miles Attitude-Interest Analysis Questionnaire. The latter provides a score on a scale of masculinity/femininity.

The correlations for 26 boys aged 13 plus are shown in Table 35.

Table 35

Correlations between spatial and other tests and the Terman and Miles Attitude-Interest Analysis Questionnaire (Smith)

TEST	CORRELATIONS WITH MASCULINITY/FEMININITY SCORE
1. *Spatial Test* 1 (*N.F.E.R.*)	·416
2. *Group Test* 81 (*Spatial, N.I.I.P.*)	·314
3. *Group Test* 36 (*Verbal, N.I.I.P.*)	·218
4. *Abstractions* (*Vernon*)	·208
5. *Mill Hill Vocabulary Test*	·198
6. *Reasoning Arithmetic* (*Ballard*)	·164

The correlations of Spatial Test 1 and the spatial Group Test 81 with the masculinity/femininity score are therefore higher than the corresponding correlations of various verbal tests and an arithmetic test. These figures are consistent with results obtained in other investigations. For example, a group of 329 delinquent boys showed a correlation between the Stenquist Mechanical Ability Test and M/F score of $·306 \pm ·038$, while the mean correlation of various verbal tests with M/F score was found to be ·19 (Terman and Miles, 1936).

Thus we should expect to find high spatial ability associated with masculine attitudes and interests, a result which is consistent with the well-known sex-difference in spatial test-scores in favour of males.

French (1959) published tables of correlations for large groups of college students between scores in 16 aptitude tests, measures of interest in 14 different subjects and 12 personality traits.

Two spatial tests (*Vz* and *S*) correlated more highly with interest in mathematics than with interest in any of the other 13 subjects. Though the correlations were low, because of the large numbers in the groups they were statistically significant. *Vz* and *S* gave correlations of ·19 and ·21 respectively with interest in mathematics for a group of 437 men and corresponding correlations of ·25 and ·21 for a group of 587 women. The same two spatial tests had low negative correlations with sociability (— ·08, — ·10) and with gregariousness (—·25, — ·14) for the group of men. For the group of women, the correlations with sociability were (— ·09, — ·07) and with gregariousness (·01, ·04). The difference in the sign of the correlations with gregariousness for men and women suggests that there is perhaps a sex difference in the association between spatial ability and personality.

The figures shown in Table 36 have been extracted from French's tables.

Table 36

Correlations between two spatial tests and measures of various personality traits (French)

	437 MEN		587 WOMEN	
	Vz	*S*	*Vz*	*S*
Surgency	— ·10	— ·06	— ·02	·02
Sociability	— ·08	— ·10	— ·09	— ·07
Self-sufficiency	·19	·10	·06	·08
Self-confidence	·02	·01	·07	·10
Gregariousness	— ·25	— ·14	·01	·04
Nervousness	— ·11	— ·11	— ·08	— ·10
Emotionality	— ·08	— ·11	— ·08	— ·04

Though the correlations given in the table tend to be low, they show a substantial measure of consistency and are in line with the findings reported by other workers.

Roe (1953) has reported the conclusions reached in studies of groups of outstanding living American scientists, including 20 biologists, 22 physicists, 14 psychologists and 8 anthropologists. Scores were obtained on high-level verbal, numerical and spatial tests, together with information from projection tests and detailed interviews. It was found that individual differences in score were very wide in each group. The physicists as a whole scored significantly higher on the spatial test than the biologists, the difference in the score on a verbal test being non-significant. It is of interest that the physicists obtained higher scores on the spatial test than did any of the other groups of scientists studied.* It appeared that, once a certain minimum score was exceeded, degree of verbal intelligence was unrelated to professional success within these groups. This finding suggests that scientific talent cannot be equated with high I.Q. in the traditional sense. Roe also noted that the physicists as a group tended to be unsociable, and showed an independence of personal relations generally.

Summary of findings on spatial ability and temperament

Taking together all the evidence on the relationship between spatial ability and temperament, we feel justified in drawing the following conclusions:

1. Low scores on spatial tests and some performance tests relative to verbal tests tend to be associated with emotional instability. (Dellaert, Jastak, Uhler, Earl, Bradford, Vernon and Parry.)

2. High scores on spatial tests relative to verbal tests tend to be associated with personality qualities such as self-confidence, perse-

* If high spatial ability is important for success in university physics, it would help to account for the high negative correlation (— ·66) obtained by Williams (1950) between 1st year university physics and subsidiary H.S.C. English (n = 24).

verance, vigour, activity, reflectiveness, self-sufficiency, freedom from nervousness and from emotionality (Hebron, Thurstone, French).

3. High scores on certain performance tests such as Mazes, Passalong, Kohs' Blocks, Carl Hollow Square are associated with personality qualities such as emotional stability, initiative and freedom from neuroticism (Cattell, Semeonoff and Trist).

4. Normals tend to perform better than neurotics or psychotics on the commoner types of spatial test. (Eysenck, Granger and Brengelmann.)

5. Relatively high spatial or mechanical ability tends to be accompanied by introverted, schizothymic, desurgent or asocial traits. Relatively high verbal ability tends to be associated with extraverted or social traits. (Freyd, Bingham, Burt, Wells, Thurstone, Hebron, French, Smith.)

6. Relatively high spatial or mechanical ability tends to be associated with masculine attitudes and interests; relatively high verbal ability with feminine attitudes and interests. (Terman and Miles, Stephenson,* Smith.)

7. The Maze Test provides a better measure of social competency than the Stanford-Binet, and is claimed to provide an indication of planning ability and foresight. (Porteus.)

8. Relatively high scores on performance or maze tests or even on non-verbal tests may be associated with delinquent or aggressive behaviour. (Porteus, Uhler.)

The foregoing evidence on the association between spatial ability and temperament is consistent with the earlier discussion on the relationship between scores on spatial tests and brain injury. It has been noted repeatedly (for example, by Petrie) that the behaviour of brain injured patients (or of patients who have undergone a leucotomy operation) tends to be more strongly extraverted than before the injury or operation. The change shown by these patients from the former introverted personality has been described as often quite startling.

* Cf. Stephenson, W. (1949), *Testing School Children*, London, Longmans, Green, p. 97.

Since we have found that high spatial ability tends to be associated with introverted (or desurgent or schizothymic) traits, we might expect that any injury which tends to impair a person's spatial ability might also tend to produce a change of personality in the direction of extraversion. We have an illustration of this association in the typical leucotomy patient, who usually shows both kinds of change as a result of the operation.

The outcome of the researches on the temperamental correlates of spatial ability may perhaps be conveniently summarized in the form of certain generalizations which were stated by the writer in 1952, namely that there is a correspondence between the following contrasting pairs:

Spatial ability as contrasted with verbal ability, and

1. A 'fixative' or 'concentrative' mode of attention as contrasted with a 'diffusive' mode of attention.
2. A tendency to attend to a configuration as a whole rather than to attend to details.
3. Masculine as contrasted with feminine attitudes and interests.
4. Schizothymia as contrasted with cyclothymia.

To this list, should perhaps be added a fifth pair:

5. Emotional stability as contrasted with emotional instability.

We shall discuss each of these contrasting pairs in turn. The relationship to spatial ability of hypothetical functions variously described as inertia, perseveration, rigidity, inhibition is very complex and will be discussed in Chapters Eight and Nine.

Fixative and diffusive attention

An essential distinction underlying all these contrasting pairs is that between two different modes of perception referred to above as the distinction between a 'fixative' and 'diffusive' mode of attention. This has already been referred to in our chapter on spatial ability and abstract thinking in connection with the discussion of *k*-loaded tests, which involve the perception of the structure or form of a figure as a whole as opposed to the perception of details. The distinction seems to have been suggested originally by Meumann (1907), who maintained that the abilities to concentrate and to diffuse attention produce respectively: "two quite distinct types of intelligence. According as the capacity of a man tends towards the one or other side of attention, he is disposed towards learned observation and scientific thinking or towards the practical vocations of life.

"The concentrative kind ought to be possessed by the man of science; the diffusive kind by such men as teachers, officers, conductors of orchestras and hotel proprietors."

Burt has referred to this distinction in connection with the different methods of attacking test problems, which give rise to the well-marked and recurrent bipolar factor. "The comprehension of a relational complex, it would seem, can be arrived at in two different ways, explicit or implicit. The inferences from the positive and negative test-saturations are confirmed by the subject's introspections. Many of the examinees, particularly those of a 'fixating' type generally begin by dissecting or analysing the complex whole, which is presented by the test-problem; they thus apprehend the connecting relations explicitly, and then seek to apply those relations in a systematic fashion to elicit a suitable solution.

"Others, particularly those of a 'fluctuating' type, seem to depend more upon a complex synthetic activity comparable to the activity often popularly described as intuition—the activity whereby we implicitly comprehend the essential character of a whole, without analysing it into its component parts or distinctly formulating their relations."*

"The former type includes most of those who possess a marked

* The writer has expressed the contrast between the two types somewhat differently in a later passage (pages 240–2).

scientific bias; the latter most of those who possess a marked gift for aesthetic appreciation."

The writer has attempted to account for this distinction in terms of differences in the persistence of neural processes. Let us consider how such differences might affect performance on a spatial test such as Memory for Designs, which is a well-known test with a high *k*-loading.

In the N.I.I.P. form of this test, there are eight cards each with a simple design. They are exposed one at a time for ten seconds and then removed and the subject is allowed one minute to reproduce each design. Clearly, if the subject's visual impression tends to persist for a relatively long period after the stimulus has been removed, he should have less difficulty in reproducing the design on paper. Since the visual impression will tend to persist, there will be less need to fixate different parts of the figure during the exposure.

If, however, the subject's constitutional make-up is such that visual impressions persist for a relatively short time after the removal of the design, there will be a greater need to 'diffuse' attention over the various parts of the figure, noting details on the way. Thus, in memorizing complex visual material for immediate reproduction, the person whose visual processes tend to persist or recur (e.g. in the form of an image) will be best served by acquiring a 'fixative' habit of attention, while the person whose processes persist only for a short time will find a 'diffusive' habit more advantageous. Such a distinction might be accounted for in terms of a difference in the strength of inhibitory effects.

We might also expect to find that these differences are reflected in different speeds of reading. Such differences have frequently been noted, as Burt (1949) has pointed out in the following passage:

"But, when we consider more precisely *how* different persons cognize an organized whole, i.e. the particular way in which they attend, a suggestive difference is discernible. Faced with some unfamiliar object or pattern—say a sentence, to be read aloud, like 'Fair waved the golden corn'—one child will focus his glance fixedly on one little group of letters after another, uttering the whole in detached instalments—

"Fair , wav -ed , the , gold——en , corn.'

"Another, whose eye roves rapidly up and down the line, will produce some impressionistic version superficially corresponding to the general visible scheme, if not to the detailed parts—'A fairy waved her golden wand.' The difference between these two modes of attack has been noted again and again. Sully, Binet, Meumann, John Adams and numerous schoolmistresses who have tried to teach small children to read or to observe have commented on this curious contrast. Meumann, whose description is perhaps the most complete, speaks of 'attention-types' and calls them the 'concentrating' or 'fixating' type and the 'diffusive' or 'fluctuating' type respectively."

Since the 'fixating' type of pupil tends to read slowly, taking one syllable at a time, we might expect him to be somewhat, lacking in verbal facility. The 'diffusive' type, on the other hand, should be more rapid in extracting meaning, and formulating it in words and so would be expected to have greater verbal facility. Hence, it would not be surprising to find that the latter type had some superiority in tests of verbal intelligence, particularly in those in which a time-limit is imposed. But even in some non-verbal tests, such as Progressive Matrices, a certain 'diffusiveness' or flexibility of attention is likely to confer some advantage, since in working the items it is necessary to shift the attention frequently from one part of the figure to another.

In working spatial tests, however, as we have seen, the fundamental process is not that of perceiving details in rapid succession, but the perceiving and assimilation of a figure as a complete Gestalt, retaining it in mind and recognizing or reproducing it in a new position. A pupil who can fixate the figure as a whole, assimilate it in a single glance and reproduce it without having to note details, would have some advantage. A facility for forming visual images would be of great assistance and a person possessing such a facility would require to make only a single fixation. He would not find it necessary to diffuse attention over the figure in an attempt to remember details.

Thus, the bipolar verbal/spatial factor to which we have referred so often may be regarded as a bipolar attention factor, positive loadings representing 'diffusive' or 'fluctuating' attention and negative loadings 'fixative' or 'concentrative' attention, the former mode corresponding to the verbal loadings and the latter to the spatial loadings.

Flugel, Moore and Burt have investigated the relation between this bipolar factor of attention and other cognitive and temperamental traits, and Burt (1949) has described their findings thus:

"These differences emerged most clearly in a long series of experiments on the teaching of reading, and thus have an indoubted importance for the educationalist and the vocational adviser. The relation of this bipolar factor to other cognitive and temperamental traits proved to be close and complex.

"In particular, there appeared to be appreciable correlations between the following:

"1. A tendency to a 'fixating' as contrasted with a 'fluctuating' type of attention.

"2. A tendency to an 'objective' (*observateur*) type of apprehension as contrasted with a 'subjective' (*interprétateur*) type as revealed in perceptual tests.

"3. A 'perseverating' type or tendency as revealed in tests of memory or the like.

"4. A tendency towards emotional stability when assessed by interview or behaviour.

"5. A tendency towards introversion as contrasted with extraversion (according to one or two investigators)."

It can scarcely be accidental that the concomitants of 'fixative' attention, as described by Meumann and Burt, namely, scientific interest, emotional stability and introversion, are all qualities which have been found to be associated with high spatial ability relative to verbal ability.

Attention to 'wholes' and attention to details

Reference has already been made to our theory that a person with relatively high spatial ability tends to grasp a figure mentally in relatively large units. He looks at it as a whole, instead of allowing his attention to wander from one element to another. He pays attention to the form or structure rather than to the details.

Evidence for this view is afforded by the results of the experiment by M. D. Vernon,* in which a variety of types of material were presented tachistoscopically. She correlated the scores obtained using six types of material with scores in the N.I.I.P. Form Relations Test and with the two parts of Heim's Test AH4, the second part of which involves the *k* factor. The correlations fell into two groups. The first group included types of material requiring rapid discrimination of fine details of shape, while the second depended on the assimilation of shapes as wholes, or on the comprehension of their meaning. It was the second group, not the first, which gave moderate correlations with the spatial tests. Thus, Vernon's findings lend support to the view that spatial ability depends more on the perception of figures as wholes rather than on the perception of details.

This is a characteristic which, according to Kretschmer, distinguishes schizothymes from cyclothymes, i.e. schizothymes have a tendency to attend to wholes, while cyclothymes have a relatively greater tendency to attend to details. It would follow that on the Rorschach Test, schizothymes and cyclothymes would show marked differences when a comparison is made between the number of whole *W* versus the number of detailed *D*, *d* answers. According to Eysenck (1952) this expectation is borne out in actual fact, the difference being significant at the level $P < \cdot 01$. It is interesting also that Rorschach believed that whole *W* responses pointed to a tendency to interest in the abstract, while major detail *D* responses indicated a tendency to use practical common sense, and minor detail *d* responses indicated petty interests. Cf. Mons (1947).

* Already referred to on page 196.

Masculinity and femininity

Evidence has been adduced to show that relatively high spatial or mechanical ability tends to be associated with masculine attitudes and interests while relatively high verbal ability tends to be associated with feminine attitudes and interests.

According to Stephenson (1949), "Men who score much higher in *v* than in *g* and *k* (and therefore gain scores which are typical of women on the average) tend to be effeminate in some way—whether they simper, twitter, are coy, or are merely gently over-refined and orchid-like."

Thus there are good grounds for supposing that there is a correspondence between the spatial/verbal bipolar ability factor and the masculinity/femininity dimension of personality, which has been so thoroughly studied by Terman and Miles (1936). In their extensive analysis of occupational groups, Terman and Miles have listed these in order from the most to the least masculine. Of the nine groups, the most masculine consisted of professional engineers and architects, while the least masculine consisted of editors, journalists, clergymen, ministers and artists. It can scarcely be accidental that the two professions which are top in the list are the two which are most likely to require the exercise of spatial ability (viz. engineering and architecture). Draughtsmen were also high in the list. The most probable explanation of the high mean scores of these groups would seem to lie in the fact that spatially gifted individuals tend to become engineers, architects and draughtsmen because they find that they are successful, or believe that they are likely to be successful, in these pursuits. Since high spatial ability tends to be associated with masculine personality traits, so members of a profession which tends to recruit spatially gifted individuals will tend to show high mean scores on the M/F questionnaire. It is perhaps significant that most of the professions listed in the lowest group of Terman and Miles' list are likely to recruit persons of exceptional verbal ability, e.g. editors, journalists, clergymen and ministers. Editors and journalists require to be fluent in writing and clergymen and ministers to be fluent in speech.

Schizothymia and cyclothymia

It might be expected that high verbal ability would be associated with characteristic personality qualities, just as high spatial ability has been found to be correlated with qualities such as schizothymia, desurgency and emotional stability. There is considerable evidence that verbal fluency is associated with cyclothymic or surgent traits. Eysenck (1953) has reviewed studies by Hargreaves (1927), Cattell (1934), Notcutt (1943), Gewirtz (1948) and others and has concluded that there can be little doubt as to the existence of a correlation between fluency and extraversion or surgency. Holzinger (1934, 1935), Thurstone (1938) and Fruchter (1948) and others have shown that fluency tests have loadings on *g* (intelligence) *V* (verbal ability) and probably *W* (word fluency).* It is not definitely established which of these components corresponds to the temperamental factor.

If the main verbal factor *V* is correlated with cyclothymia, extraversion or surgency it would appear that spatial and verbal abilities correspond to antithetical personality qualities.

Such a theory had appeared reasonable to the writer, but he had refrained from developing it because it seemed to be contradicted by a finding reported by Himmelweit in 1945 and confirmed by Foulds in 1956. They claimed that they had obtained values of the ratio $\frac{\text{non-verbal I.Q.}}{\text{verbal I.Q.}}$ for groups of hysterics and dysthymics which were in the direction opposite from that to be expected from the theory.

Himmelweit found that the ratio $\frac{\text{non-verbal I.Q.}}{\text{vocabulary}}$ was low for dysthymics and high for hysterics, and Eysenck interpreted this as evidence that introverts had a lower ratio than extraverts. He

* There are at least four verbal fluency factors (Christensen and Guilford, 1963). For a survey of the literature on verbal abilities, see Morgan (1956).

explained it by supposing that introverts condition more easily than extraverts, social pressure causing them to learn more words through reading and hence to acquire a higher vocabulary.

More recently, however, Black, Walton and Stevens (1961) have stated that Himmelweit used the timed version of the Progressive Matrices Test (with a 20-minute time-limit) as her measure of non-verbal I.Q., though this is contrary to a statement in Eysenck's account of the research (1947). Black, Walton and Stevens argued that the differences Himmelweit found reflected variations in responsiveness to stress, rather than differences in the rate of acquisition of vocabulary arising from differences in introversion-extraversion.

To test this hypothesis, they conducted an experiment with 236 subjects. From these they formed three groups each of 23 subjects—dysthymics, hysterics and normals. These were closely matched for age and for percentile score on unstressed (i.e. untimed) Progressive Matrices. No significant differences in vocabulary level were found between any of these groups.

A second experiment was then carried out to test the alternative hypothesis that differences in stress-reactivity accounted for Himmelweit's results. It was expected that when working under timed conditions, dysthymics would perform rather more badly on an unfamiliar task (Progressive Matrices) than on a familiar task (Mill Hill Vocabulary) compared with hysterics and psychopaths. The results were in accordance with expectation. The dysthymics did badly in the stressed matrices compared with their vocabulary level, whereas hysterics and psychopaths obtained matrices scores which were superior to their vocabulary levels. The differences were highly significant. Thus there are no grounds for supposing that dysthymics are superior in vocabulary to hysterics when matched for non-verbal intelligence under unstressed conditions.

E. C. Venables (1963) also failed to confirm Himmelweit's reported difference in $\frac{\text{non-verbal I.Q.}}{\text{verbal I.Q.}}$ ratio between high E scorers and low E scorers on the M.P.I. extraversion/introversion scale. She found that students with high N and low E scores on the M.P.I. questionnaire (the 'neurotic introverts') had the highest achievement ratio although their scores on verbal tests tended to be *lower.* Eysenck's thesis that differences in conditionability account for the observed differences between introverts and extraverts was not confirmed. Her results appeared to support Champion's contention that it is motivational differences which are operative.

Thus the findings of Himmelweit and Foulds can no longer be regarded as evidence contrary to the hypothesis that high spatial ability is associated with schizothymia and high verbal ability with cyclothymia.* Differences between spatial and verbal ability

* That there could in fact be no contradiction between Himmelweit's results and the writer's hypothesis is suggested by the interpretation we have given to Factor II in the analysis of data for Carlisle boys, reported in Chapter five.

The loadings of the tests and assessments in factors II and III were as follows correct to two decimal places and with signs reversed):

	PRACTICAL FACTOR II *p/a*	SPATIAL FACTOR III *k/v*
English 25	—·33	—·27
English 4	—·30	—·29
Verbal 54	—·20	+·09
Verbal 4	—·17	+·08
Arith. 25	—·14	+·14
Arith. 4	—·15	+·18
Spatial 2	—·04	+·26
Sociability	+·23	—·13
Emotional Stability	+·25	—·06
Practical	+·37	—·05
Drawing	+·41	—·10

The boys who were high in the second factor, which we identified as practical/academic rather than spatial/verbal, were given high ratings by their teachers for drawing and practical work and were considered to be emotionally stable and sociable. They did badly in all the tests except the spatial and were particularly bad at English. Such pupils might be described as 'stable extraverts'. Pupils low in this factor would be 'neurotic introverts', like the students reported by Furneaux (1962) and Venables (1963) to be the highest academic achievers. There may be may well be associated with antithetical personality qualities. The question may be asked whether these contrasting ability profiles are characteristic of certain personality types such as those described by typologists, such as Jung, Kretschmer or Sheldon. The writer has found it interesting to attempt to relate his findings to some of the hypotheses advanced by Kretschmer.

This typological system embraces several main hypotheses, but the one which is of interest in connection with the present enquiry is that there is a continuum of temperament (schizothymia-cyclothymia) which is correlated with body-build, schizothymes tending to be leptosomatic (lean) and cyclothymes to be pyknic (plump). Linford Rees (1960) has reviewed comprehensively the extensive and controversial literature which has been stimulated by Kretschmer's work and the present writer will not attempt to discuss the controversy in detail. Of the investigators whose results tend to confirm the hypothesis that there is an association between leptosomatic/pyknic body-build and schizothymia/cyclothymia we may quote Van der Horst (1916), Kibler (1925), Enke (1928), (1953), Lindberg (1938), Misiak and Pickford (1944), Smith and Boyarsky (1943) and Brattgard (1950). Of the workers whose studies have given negative results, we may mention Klineberg, Asch and Block (1934), Kraines (1938) and Pillsbury (1939).

The general trend of evidence on both normal and abnormal individuals suggests that there is some association between phy-

some relationship between the inverse of this practical/academic factor and the 'verbalism of cerebrotonia' referred to by Cattell (1945) and Wells (1948). We have often observed that there is a type of person whose verbal ability is high relative to his spatial ability and who tends to be impractical and introverted and perhaps emotionally unstable. Such persons may have leptosomatic physique and may seem to be lacking in toughness. They may be the same as the dysthymics (neurotic introverts) studied by Eysenck. They must be distinguished clearly from the true schizothymics, who also tend to be unsociable but who obtain much higher scores on spatial tests than on verbal tests. The latter tend to have greater emotional stability than the dysthymics, though they are also prone to anxiety.

It is the true spatial/verbal factor (factor III in the analysis of the data for Carlisle boys) which is associated most closely with the antithetical personality traits 'withdrawn schizothymia/adventurous cyclothymia'.

5. Francis Bacon, philosopher of science (1561–1628)
Radio Times Hulton Picture Library

6. Charles Keene, artist (1823–1891)
by courtesy of the Trustees of the Tate Gallery, London

7. Franz Schubert, composer (1797–1828)
Radio Times Hulton Picture Library

8. George Frederick Handel, composer (1685–1759)
National Portrait Gallery, on loan from the Rt. Hon. the Earl Howe

sique and personality along the lines proposed by Kretschmer and Sheldon, although it is not so strong as was originally supposed. Linford Rees (1960) states in his survey that the recent researches on body-build suggest that one of the fundamental variations appears to be linearity-laterality, corresponding to the leptomorphic-eurymorphic continuum described by Rees and Eysenck (1945). Muscle and fat seem to be additional factors determining variations in physique. Work on Sheldon's system by Sills (1950), Ekman (1951) and Howells (1951) indicates strongly that the ectomorphy and endomorphy of Sheldon's typology are not independent factors, but opposite manifestations of one underlying factor and basically one continuum. Brattgard's results are particularly cogent since ratings of personality attitudes were obtained some time before the assessments of body-build and were not carried out initially with the intention of determining psychophysical correlates. Using the Strömgren index on 1,000 cases from a psychiatric clinic, he found that syntonic (i.e. cyclothymic) personality traits were associated with pyknic body-build and psychasthenic personality traits with leptosomatic body-build.

In a review of the evidence in 1960, Eysenck concludes that there exists a correlation of the order of ·3 to ·5 between eurymorph/leptomorph body-build and introversion/extraversion. In addition, he thinks that there may be a specific relationship between schizophrenic disorder and leptomorph body-build, and/or between manic-depressive illness and eurymorph body-build. Eysenck prefers to apply the Jungian terms extraversion/introversion to the dimension of personality associated with the physique continuum. He regards this dimension as distinct from that which is central to Kretschmer's system, viz. cyclothymia/schizothymia, though many psychologists have considered that these terms refer to the same dimension. Vernon (1953) has published a diagram of the main personality dimensions which shows the dimension cyclothymia/schizothymia as distinct from extraversion/intraversion but obviously highly correlated. The diagram shows the schizothyme as differing from the introvert in having greater emotional stability or character integration. Cattell (1957) regards extraversion/introversion as a surface trait which is essentially produced by a composite of source traits Cyclothymia *A*, Surgency *F* and Adventurous Cyclothymia or Parmia *H*. Most descriptions of cyclothymia/schizothymia, according to Cattell, refer to a combination of factors *A* and *H*. All three factors, but especially *H*, are associated with the pyknic/leptosomatic continuum of body-build.*

Kretschmer has emphasized the concept of dissociation (Spaltung) as of fundamental importance in distinguishing the mentality of the schizothyme from that of the cyclothyme. By dissociation he means "the ability to form separate and partial groupings within a single act of consciousness; from this results the ability to dissect complex material into its constituent parts.... In Kretschmer's view, schizothymes tend to have a mind which is 'dissociative', 'abstractive' or 'analytic', whereas cyclothymes have a tendency to be 'integrative', 'global' or 'synthetic'." (Eysenck, 1950.)

Kretschmer has proposed a series of experimental tests for measuring this trait of dissociative ability and differentiating by this means between schizothymes and cyclothymes. Eysenck (1959) has reviewed the evidence relating to these tests and has concluded that the majority of them do in fact succeed in differentiating cyclothymes from schizothymes and pyknics from lepto-

* A difficulty in the way of accepting an identification of the dimensions cyclothymia/schizothymia and extraversion/introversion is the ambiguity of the classification of the person of athletic or muscular physique.

Kretschmer regards the athletic as essentially schizothymic in temperament, being closer to the leptosomatics than to the pyknics. In Sheldon's system, persons of mesomorphic physique are described as somatotonic in temperament, being particularly fond of action and physical adventure—the extraversion of somatotonia. On the M.P.I. scale of temperament, persons who prefer action to planning for action are given a positive rating for extraversion. Thus, Venables (1953) found that engineering apprentices tend to be high on Extraversion on the M.P.I. questionnaire compared with University students and the general population.

The writer, on the other hand, tends to think of the typical engineer as being schizothymic in temperament, more interested in machines than in persons. There is no contradiction here provided it is not assumed that the dimensions cyclothymia/schizothymia and extraversion/introversion are identical.

somatics. He points out, however, that it does not follow that we can postulate the existence of a single trait embracing different tests just because they all differentiate between schizothymes and cyclothymes. In order to do this it is necessary to show that the tests correlate positively with one another and preferably to carry out a factor-analysis.

Payne (1954) investigated this problem by administering seventeen 'dissociation' tests to 100 normal subjects. Though he claims that the group of tests included all the major tests that Kretschmer had described, none of the scores correlated significantly. The matrix of correlations showed only chance fluctuations from a mean value of zero. Payne concluded that the ability to dissociate one's attention is very specific and is entirely a function of the tasks involved. This outcome was quite unexpected for apparently Payne had undertaken the investigation fully expecting to extract a general factor of 'dissociation' running through most, if not all, of the tests.

Before accepting Payne's view that this result is fatal to Kretschmer's theory of 'dissociation' it would be necessary to ensure that the negative result could not be accounted for in other ways. The tests would have to be examined in detail to ensure that they were appropriate in all respects.* In the writer's view, there is already evidence that there is a factor of 'dissociation' operating as a bipolar factor of attention, differentiating different types of test-material and having the personality correlates to be expected from Kretschmer's theory. We have already quoted relevant passages from an article by Burt (1949).

The German word *Spaltung* has been translated as 'cleavage capacity' and this seems an appropriate expression for describing an ability 'to form separate and partial groupings within a single act of consciousness', or 'to dissect complex material into the constituent parts'. The term appears to be particularly appropriate for describing the kind of ability required to perform certain kinds of spatial test, e.g. the paper form-board or fitting

* Payne seems to have based several of his tests on the principle that dissociation implies an ability to attend to two activities simultaneously.

shapes test, in which a large shape has to be divided up to correspond to a number of smaller shapes; or the cross-pattern test, in which a pattern of crosses has to be identified and isolated within a larger pattern. The block-building test requires the subject mentally to 'cleave' a large block into smaller blocks and so to identify the number of smaller blocks required to build up the larger block.

It would be of some interest to repeat Payne's experiment, using a battery which included a number of suitable spatial tests. A spatial factor would certainly emerge in the factor-analysis, and if the writer's theory is not wide of the mark, some at least of Kretschmer's dissociation tests would have loadings in this factor. We should certainly expect a Rorschach difference score (contrasting the number of whole responses with the number of detail responses) to have a considerable spatial loading.* This is to be expected because Taylor (1959) has found that when the Memory for Designs Test is scored in two ways 1. for correctness of proportions and 2. for correctness of details, the spatial loadings and corresponding sex-differences in mean score are markedly different.

The writer made the suggestion in 1952 that *k*-tests provide a measure of 'cleavage capacity' and that high spatial ability is associated with the personality traits to which Kretschmer applied the term schizothymia. Shortly afterwards, a very similar view was published independently by Pemberton (1952), in connection with a study of the relation between Thurstone's closure factors and temperament. Pemberton administered twenty-five cognitive tests to a group of 154 students, and extracted eight factors from the intercorrelations. The temperamental qualities associated with the two tests which had the highest correlations with each of the eight factors were then studied. We shall concern ourselves mainly with only two of Pemberton's eight factors, namely his C_2 and S_1 factors which he calls 'flexibility of closure' and 'the first space factor' respectively. It has already been mentioned that the C_2 factor was found to be present in the following

* Payne took the percentage of detail responses as a measure of dissociation.

tests—Concealed Figures (Modified Gottschaldt), Copying (Modified MacQuarrie), Figure Classification, Number Series, and Designs. The first two tests which had the highest C_2 loadings are well-known *k*-tests and there are reasons for believing that *k* may also enter into the others. Sultan (1962) found that with grammar-school pupils of 13-14 years of age, the 'flexibility of closure' factor is identical with the *k*-factor and 'speed of closure' with the perceptual speed factor. Thus, there are strong reasons for regarding Pemberton's findings on the relation of factor C_2 to temperament as being applicable to the *k*-factor. He found that people with high scores on tasks involving flexibility of closure C_2 regard themselves as socially retiring, independent of the good opinion of others, analytical and interested in theoretical and scientific problems; and they express a dislike of rigid systematization and routine. Pemberton's discussion of the temperamental correlates of C_2 is of great interest, and we quote the relevant passage in full.

"Goldstein and Scheerer list eight modes of behaviour which they regard as characterizing the abstract or conceptual attitude. The tests with loadings on C_2 seem to require several of these, namely, the ability to abstract common properties, to hold in mind simultaneously various aspects, to break up a given whole into parts, to plan ahead ideationally and to shift from one aspect of a situation to another. They mention that the ability to detach the ego from the outer world, and the ability to account for acts to oneself are also characteristic of the abstract attitude. The lack of sociability and independence of social conventions expressed by the subjects scoring high on Concealed Figures (which is a longer form of the Gottschaldt Figure Test) and Copying suggest that these subjects do detach their egos from the outer world.

"Smith (1951) in a recent study also found that high scores on Gottschaldt Figures were associated with social detachment. These findings seem to tie in with the results of Witkin's experiment (1949) in which he found that people who were able to ignore the visual clues afforded by the tilted room—i.e., detach their egos from the external environment—and rely on their body sensations to determine their vertical orientation were the people who scored highly on his modification of the Gottschaldt test.

"The dislike for routine and lack of tidiness characterizing our high C_2 group may also be indicative of these subjects' independence of superficial, rigid rules. This seems to stem from their flexibility, and not from impulsivity as their scores do not show any positive association with items dealing with impulsivity, and they say that they think of the conseqeunces before acting. This is consistent with Goldstein's 'ability to plan ahead ideationally'. High scores on reflectiveness and imaginativeness also indicate the ability for thinking things over, and the tendency towards inner rather than outer orientation. However, the detachment of the high C_2 group from the outer world does not seem to be so complete as to be unrealistic, for they state that they are interested in achievement and recognition.

"The marked theoretical and scientific interests displayed by the high C_2 group point to the pleasure these people derive from analysing, abstracting and generalizing, showing that 'ability and interest in analytical reasoning tend to go hand in hand'. This corroborates Gehlmann's (1951) significant correlation between Gottschaldt Figures and interest in physical science, and Jay's (1950) finding of a positive relationship between the same test and the theoretical score of the Allport-Vernon.

"The characteristics of the high C_2 group, particularly their poor routinizing and sociophobia, are reminiscent of Sheldon's cerebrotonic and Kretschmer's schizothymic type. Kretschmer believes a distinguishing characteristic of the schizothymic to be 'the ability to form separate and partial groupings within a single act of consciousness; from this results the ability to dissect complex material into its constituent parts' (quoted in Eysenck, 1950).

"This is an apt description of the ability that seems to be required for the performance of flexibility of closure tasks."

There was a marked contrast between the temperamental qualities associated with the two closure factors, flexibility of closure C_2 and speed of closure C_1. The majority of the items associated with C_1 pointed to an outward rather than an inward orientation as characteristic of this group. It was differentiated from all the other high-scoring groups by an emphasis on tidiness, systematization and practicality. Pemberton also included in his battery two tests (Figures and Cards) intended to measure a separate Space Factor S_1 probably the spatial orientation factor, identified in numerous American studies. Since it had a correlation of ·54 with C_2, it corresponds to a sub-factor of the British *k*. The personality correlates which Pemberton found for his factor S_1 suggest strongly masculine qualities. The group who did well on this factor were of the "strong, silent he-man type" rating themselves as uncommunicative, undemonstrative, unsympathetic but also decisive and self-confident. This factor showed a marked sex difference, men doing better than women, as nearly always occurs with spatial tests.

In an investigation reported by the writer in 1952, it was found that pupils who did relatively well in N.F.E.R. Spatial Test I appeared to have characteristic personality qualities as shown both by self-ratings and teachers' ratings, suggesting greater emotional stability and forcefulness. An analysis of the pupils' self-ratings also suggested that spatial ability might be associated with schizothymia, since spatially gifted pupils seemed to have a slightly greater preference for *not* being watched. The circumstance that both Pemberton and the present writer should independently reach the conclusion that high scores on similar types of spatial test should be associated with schizothymia or cerebrotonia can scarcely be explained away as mere coincidence. Hebron has shown that pupils who did relatively well in Spatial Test I were rated slightly more highly for independence, self-confidence and perseverance and also for desurgency, and these are qualities which might be expected to be associated with schizothymia.

Thus, several independent studies suggest that spatial abilities, such as *k*, *Vz*, C_2 or S_1, are associated with characteristic personality qualities which may be considered typical of the schizothyme. S_1 seems to be particularly associated with the masculine 'he-man' qualities characteristic of the athletic type of schizotyme, while Vz or C_2 may relate more to those of the seclusive asthenic. Both types of personality would be expected by Kretschmer to exhibit superior dissociative ability. In his view, the distinction between dissociation and integration is of fundamental importance and underlies a whole series of polarities in psychological makeup, for example:

1. A tendency to prefer abstract to concrete thinking;
2. A tendency to prefer analysis to synthesis in reasoning;
3. A tendency to adopt an idealistic rather than a realistic attitude to life;
4. A tendency to react to form rather than to colour;
5. A tendency to perseveration rather than to non-perseveration in thought or action;
6. A tendency to build up emotionally toned complexes rather than the absence of such a tendency.

Kretschmer believed that individuals of schizothymic temperament tend to have greater abstracting ability than cyclothymes. They have a greater fondness for systematic and profound thinking and a greater capacity for concentrating attention. The cyclothyme is less inclined to analytical thinking, but shows greater mobility of attention, greater alertness, verbal dexterity, more many-sided activities and a habit of observant, collecting empiricism.*

Of the vast amount of research which has been stimulated by Kretschmer's writings, some has tended to confirm and some to deny the deductions made from his system. The first of the six deductions listed above was investigated by Boldrini and Mengarelli (1933), who found that, of 1,000 university professors, the asthenics tended to have abstract thought and the pyknics tended to have concrete thought, which supports Kretschmer.

The third deduction was investigated by Eysenck and Gilmour (1944), who found no significant differences in respect of idealistic and realistic attitudes to life. The fourth deduction has been in-

* The 'convergers' and 'divergers' described by Hudson (1961) and by Getzels and Jackson (1962) seem to correspond essentially to the personality types described by Kretschmer.

vestigated by a long succession of workers from Scholl (1927) onwards, with somewhat conflicting results. In general, however, these studies tend to support Kretschmer's view that schizothymes are more frequently characterized by form attitude, while cyclothymes are more frequently characterized by colour attitude (e.g. Oeser, 1932); a similar correlation also seems to have been established with asthenic and pyknic body-build (Lindberg, 1938).

Keehn (1953, 1954) has investigated the hypothesis that the colour reactions on the Rorschach test are part of a general tendency to colour reactivity. He applied a battery of colour-form tests to a group of 200 subjects and extracted two factors from the resulting correlations. The Rorschach colour score had no saturation on the first factor, a colour-non-colour factor. It had, however, a saturation of ·6 on the second factor which was tentatively identified as one of whole-part reaction. Thus, the Rorschach colour responses seemed to depend not upon colour per se but upon reaction to the stimulus as a whole rather than to any part of it. It would seem to follow that it is the form-reaction and not the colour reaction which is important in the Rorschach colour-form score. Presumably, a spatially gifted subject would tend to perceive the form or configuration, while a subject lacking spatial ability would fail to perceive the form and would attend to the colour instead. The Rorschach principle that a pure colour response expresses a tendency to passion, temper or uncontrollable emotion would follow from the fact that relative weakness in spatial ability tends to be associated with emotional instability.

The theory that the concept of dissociative ability has a high degree of generality as a personality trait is in line with our belief that spatial ability itself must be regarded as having a wider significance than a mere aptitude for visualizing or manipulating spatial materials. Reference has already been made to Pemberton's view that the flexibility of closure factor C_2 (which seems to be the same as k) cuts across the content of the test-material and represents an ability to abstract from any kind of material. Pemberton also thought that C_2 was a factor of analytical thinking. Since tendencies to abstraction and analysis are considered by

Kretschmer to result from 'dissociative ability' it would seem possible and even probable that if this hypothetical ability exists at all as a unitary trait, it is identical with *k*. If so, we can investigate the truth of the other hypotheses in Kretschmer's system by enquiring whether high spatial ability is associated with the other personality traits listed by him, e.g. idealism, perseveration, emotionally toned complexes, etc.

Thus, it is possible that the distinction we have described between the two modes of perception of spatial configurations, 'fixative' and 'diffusive' respectively, is a particular case of a general principle which has a wide applicability. Just as mental energy may be concentrated or diffused when directed to the consideration of a spatial configuration, so it may be applied in either way to problems of a more general kind. Such a distinction is implied in popular speech when it is said that a person 'can't see the wood for the trees'. The same person may, however, be extremely efficient at dealing with the 'trees' in his immediate environment. The comfortable cyclothyme tends to be engrossed in his surroundings and to live in the immediate present, but is less given to abstract and profound thinking about ultimate issues. Such persons may be efficient organizers and administrators.

The other type of person, the schizothyme, tends to fix his attention on the 'wood' and for that reason may pay less attention to the 'trees' (observing the configuration rather than the details). He is the type of person who pursues an idea to the neglect of all other considerations, like the inventor who makes it possible for others to accumulate fortunes while himself dying in poverty (e.g. Trevithick, Friese-Greene, Goodyear) or the artist who displays unswerving devotion to art to the exclusion of all other interests (e.g. Gaudier-Brzeska, Gauguin, Van Gogh).

Kretschmer believed that exaggeration of the tendency to dissociation is characteristic of the schizoid or schizophrenic. When the tendency becomes marked, the person becomes incapable of the ordinary affairs of everyday life and tends to preoccupy himself with abstract problems of little immediate importance. In extreme cases, the condition becomes morbid and the patient becomes divorced from reality, tending to live in a bizarre and grotesque world of phantasy.

The absence of the tendency to dissociation results, in Kretschmer's view, in a synthetic way of looking at mental content, which characterizes the mentality of the cyclothyme. Such persons are often humourists, happy spirited and realistic, 'with their feet on the ground'. The integrative or synthetic tendency may also become exaggerated, when manic-depressive illness may ensue.

It must be stated, however, that the theory that schizophrenic and manic-depressive illness are extreme manifestations of the schizothyme—cyclothyme polarity in temperament is still very much disputed by psychologists. Eysenck (1952) carried out an investigation specifically to test the hypothesis and failed to find confirmation. It is possible that typological theories such as those of Kretschmer and Sheldon are too simple to fit all the facts, particularly those relating to morbid mental conditions.

Until recently it has been widely believed that schizophrenics as a group tend to be abnormally concrete in their thinking, a view maintained by Hanfmann and Kasinin (1942) and Goldstein (1939). More recent investigations, however, have suggested that the main difference between schizophrenics and normals, as shown for example in sorting tests such as the Goldstein-Scheerer, is that the former tend to produce unusual generalizations when compared with normals. A more acceptable theory of schizophrenic thought is that due to Cameron (1947) who suggested that the concepts of schizophrenics are over-generalized. Payne and Hewlett (1960) have investigated this theory and reviewed the many other experiments which have been carried out to test it. They concluded that it has received strong support from all these investigations. Thus, it would appear that the disability which afflicts the schizophrenic, far from being an inability to generalize, is a tendency to over-generalize, to form very large vague categories, such as 'having to do with God'.

In view of this conclusion, which is at variance with widely accepted beliefs, it is of interest to study the evidence relating to the performance of schizophrenics on tests of spatial ability relative to other cognitive tests. If our theory that spatial ability is associated with ability to think abstractly is well-founded, we should expect schizophrenics to perform relatively well on this type of test.

Observations made by Rapaport (1950) and by Harper (1950) using the Weschsler Adult Intelligence Scale suggest that this deduction is in fact correct. Schizophrenics tend to perform relatively well on spatial tests (such as Block Design) compared with verbal tests, while depressives show an opposite tendency. Beech (1956) tested groups of normals, neurotics, depressives, schizophrenics and brain-damaged patients with a 'drawing design test'. He found that schizophrenics produced significantly more accurate drawings (i.e. with better proportions) than the other groups, though they tended to work more slowly. Payne and Hewlett (1960) repeated the experiment with carefully matched groups and obtained results tending in the same direction. Mean scores for correctness of proportions were in the order —schizophrenics, dysthymics, normals, hysterics, depressives— schizophrenics being highest and depressives being lowest, though in this case the differences did not reach the level of significance. Since the differences were in the same direction as those found by Beech, these results suggest that the order—schizophrenics, dysthymics, normals, hysterics, depressives—reflects the relative degree of spatial ability found in these groups. which were matched for pre-illness intellectual level in the first place. These finding are in good agreement with the writer's hypothesis that there is a correspondence between the pairs:

1. Spatial ability as contrasted with verbal ability, and
2. Schizothymia as contrasted with cyclothymia.

They also tend to bear out the theory that spatial ability is associated with a greater ability (or perhaps a greater tendency) to generalize. As we have seen, schizophrenics as a group tend to have relatively high spatial ability in contrast to brain-injured patients who tend to be relatively poor on spatial tests. One of the weaknesses of the former is a tendency to over-generalization or "over-inclusion", whereas the most serious weakness of the latter is an inability to generalize at all or to form inclusive concepts. Brain-damaged patients might be said to suffer from 'under-inclusion' in contrast to schizophrenics who tend to be 'over-inclusive' in their thinking. This view, originally proposed by Cameron, has received strong confirmation in the findings of Beech (1956), Shapiro (1957) and Payne and Hewlett (1960).

Shape Constancy and Field Dependence

We conclude this chapter with some references to the work on 'shape-constancy' and 'field dependence', topics which are both highly relevant to the subject of spatial ability in its relation to personality.

Thouless (1932) found that schizothymes tended to have lower shape constancy (or a lower index of phenomenal regression) than cyclothymes, though the difference was not significant. Ardis and Fraser (1957) found a similar difference between introverts and extraverts, when the instructions were analytic in bias, and this difference was highly significant. Since Thurstone (1944) found that his Shape Constancy Test had the highest loading in his A factor (*k*) (high spatial ability being manifested as a lower tendency to shape constancy) the findings of Thouless and of Ardis and Fraser indicate that high spatial ability is associated with schizothymia or introversion, a result which is in line with the writer's conclusions.

The extensive work of Witkin and his colleagues (1954, 1962) on 'field dependence' is of very great interest in connection with the theme of the present chapter. 'Field dependent' persons were found to be less successful than 'field independent' persons in detecting 'hidden figures' in tests of the Gottschaldt type. They showed less capacity for active analysis and for differentiation and for imposing a structure on the field in tasks involving perception and thinking, such as Rorschach ink-blots. They tended to find difficulty with the block-design, picture completion and object-assembly parts of standard intelligence tests. Yet they performed just as well as more 'field-independent' people on other portions of intelligence tests and they could do even better on portions concerned with vocabulary, information and comprehension. It is clear from these results that the distinction between 'field-dependent' and 'field-independent' persons is closely similar to the distinctions which have been found between persons showing relatively high verbal and spatial abilities respectively.

Witkin and his colleagues have found that the different kinds of behaviour manifested by these two types of person fell into an intrinsically coherent pattern. This pattern suggested a consistency in psychological functioning which pervaded the individual's perceptual, intellectual, emotional, motivational and social operations. Thus an investigation into individual differences in an apparently narrow perceptual activity developed into a study of broad differences among people in what seemed to add up to a 'style of life'. Of the many such differences which were found only a few will be mentioned here, but these should give an indication of their variety and range. When seated in a tilted chair, within a markedly tilted experimental room with room and chair aligned, 'field dependent' people were less likely to experience themselves as upright. They tended to be guided by the axes of the surrounding visual field rather than by sensations from within the body. When attempting to solve Duncker's well-known insight problems they did not so readily see alternative uses for items serving a familiar function. It was found that they tended to change their stated views more readily in the direction of the attitudes of an authority. They seemed to be particularly attentive to the faces of those around them and, as a result, tended to be better than relatively 'field independent' persons at recognizing people they had seen only briefly before. Oh the whole, they tended to favour occupations which involved contact with people and which were popular within their group.

In their overall adjustments they were no more prone to disturbances or pathology than 'field-independent' perceivers, though it was found that the disturbances they showed were likely to take a very different form. They tended to show symptoms suggestive of deepseated, unresolved problems of dependence, such as alcoholism, obesity, ulcers and asthma. When such persons developed severe pathology, they more frequently showed hallucinations as part of the symptom picture.

'Field independent' people, on the other hand, were more capable of functioning with a fair degree of autonomy from others. Some of them, however, were strikingly isolated individuals, over-controlled, cold and distant and unaware of their social stimulus value. In severe pathological states, such persons were likely to develop delusions, in some cases bordering on schizophrenia and to have expansive and euphoric ideas of grandeur or to engage in unrealistic attempts at maintenance of identity.

Psychiatric patients diagnosed as hysterics were found to be significantly more 'field-dependent' than obsessive-compulsive patients. Significant sex differences were also demonstrated, women being more 'field dependent' than men. In personality tests such as the Rorschach tests and the T.A.T., 'field dependent' persons showed passivity, readiness to submit to authority, little self-esteem and a tendency to anxiety. 'Field independent' persons, on the other hand, were much more active, independent, self-reliant and self-confident.

Most of these personality differences have already been shown to be associated with the verbal-spatial profile of abilities. It is, therefore, clear that the contrasting modes of field approach, referred to by Witkin himself as global and analytical respectively, are essentially the same as Kretschmer's integrative and dissociative or Meumann's diffusive and fixative modes of attention.

Witkin and his collaborators have now assembled a vast amount of evidence which demonstrates that a person's mode of perception and thinking, reflected in his performance in certain kinds of spatial test and in some specialized laboratory situations, also manifests itself in his whole personality organization, including the quality of his awareness of the social world around him. All this evidence may be quoted as direct support for a contention which the writer has long maintained and which forms the theme of the present chapter (Smith, 1937, 1952, 1954).

Chapter eight

Spatial Ability and Motor Perseveration

THERE is a remarkable parallel between the history of research on perseveration and that on spatial ability. Both fields of enquiry were opened up in an attempt to find an answer to what seemed a relatively simple problem. Both fields attracted numerous investigators (sometimes the same investigator, as in the case of Stephenson). Both topics passed through numerous vicissitudes, owing to the contradictory results obtained by different workers, some of whom found no evidence for the existence of a factor at all. There has been a tendency to devise a wide variety of tests to measure the supposed function, and some of these were later found to bear no relation to the original concept.

In the case of spatial ability, there has been a tendency towards fragmentation, so that instead of one single all-embracing factor as claimed by some workers, others have claimed as many as six or even eight. A similar development has taken place in the study of perseveration. With the increasing variety of tests, workers have found an increasing number of factors and one recent investigator has claimed as many as six (Chown, 1961). As in the history of studies on spatial ability, there has been a proliferation of names (perseveration, secondary function, mental inertia, disposition rigidity, creative effort rigidity, ideational rigidity, etc.).

The term 'perseveration' was originally introduced by Neisser in 1894 and was used by Müller (1900) to denote a quality which conferred consistency of thought and action, but which would be detrimental in occupations involving rapid changing from one activity to another. Gross (1902) and Heymans and Wiersma (1906) distinguished between "deep-narrow" and "broad-shallow" types, the former being supposed to have a greater degree of perseveration. Eysenck (1960) has reviewed in some detail the subsequent work done on the concept of perseveration, showing how the supposed general factor has given place to a number of relatively independent factors such as sensory perseveration, motor alternation perseveration and disposition rigidity. A remarkable feature of the many studies in this field is the consistency with which certain *motor* perseveration tests have been found to be indicative of certain personality or character qualities. Lankes (1916) reported such a relationship in 1916, but the correlation was found to be negative (—·26) opposite in sign to the result expected.

Cattell (1946) administered seven perseveration tests, mostly motor, to 100 women students and obtained an average inter-correlation of ·20. He identified a factor as the "general disposition rigidity" factor, which had its highest loading in reverse writing of letters and numbers, but which was also present in a perceptual speed test involving the reading of a printed passage in which the words and letters were printed in reverse order. In a second study, Cattell reported the correlations of the perseveration scores of the 100 women students with scores for ten of his personality factors. The perseveration or disposition rigidity score correlated negatively with dominance (—·44) and with character integration (—·34). Very similar results were obtained with a sample of 200 men. Cattell concluded that it is reasonable to regard the *p* score as a measure of emotional instability or neuroticism, the regression of *p* on the neuroticism factor being curvilinear, as was found by Pinard in 1932. The relationship with personality qualities seemed to be strongest in tests involving reverse writing of letters and numbers, which were found by Cattell to have *p*-loadings of ·76 and ·79 respectively.

Walker, Staines and Kenna had pointed out in 1943 that Pinard's original classification of children into groups of high, moderate and low perseverators was a classification based on their *initial* difference in performing two motor activities and not based on their relative difficulty in alternation at all. This meant that it was inadmissible to attempt to explain the relationship between these *p* scores and personality traits in terms of the original notion of 'mental inertia'. They suggested that the personality traits must be associated with differences in the ability to make 'creative effort' (e.g. in writing letters mirrorwise). They also remarked that the cause of this association is something that remains to be finally demonstrated. Since these 'creative effort' motor perseveration tests were not measuring the function they were originally devised to measure, there was no longer any reason to expect that they should correlate with personality qualities. The fact that they have been found repeatedly so to correlate obviously required explanation.

A possible solution might lie in the suggestion made by Pratt Yule in 1952 that these motor perseveration tests are really inverse measures of spatial ability. The hitherto inexplicable inverse relationship between *p* scores and emotional stability would then be the same phenomenon as the well established direct association between high spatial scores and emotional stability.

Stephenson (1949) illustrated the nature of spatial ability with the phrase "High *k* is shown by the child who can draw the letter R as it would appear reflected in a pool of water, without having to think explicitly about it." Since most batteries of motor perseveration tests include tasks in which the *Y* activity involves mirror-image writing or backward stroke writing, an unknown amount of *k*-factor may be involved. Some tests such as the well-known *S* test may require not merely mirror-writing, but also an ability to organize perceptual data into fresh gestalten, an ability which probably involves some *k*-factor. Some types of spatial test require an ability to rotate a figure mentally into another position, and this seems to be the kind of ability required for the H⌶ test, which is a 'creative effort' disposition rigidity test, used by Notcutt, Cattell and others. It is also possible that the test in which the subject has to write a name like 'John Smith' with reverse strokes would, in the words of El Koussy, require an "ability to obtain or a facility to utilize visual spatial imagery".

This supposition is borne out by the results of a factor-analysis reported by Lovell (1955). A creative effort perseveration test

Table 37

Matrix of correlations of a varied battery of tests with Pinard Perseveration score for 21 pupils, 13 years of age (Smith)

	INFORMATION TEST	ART MARKS	DRAWING MARKS (TEST)	V. AND N.V. TEST (OTIS)	SPATIAL TEST I	GEOMETRY MARKS (PRACTICAL)	ALGEBRA MARKS	PERSEVERATION (PINARD)	ARITHMETIC MARKS
Information Test (Verbal)	—	·699	·394	·333	·095	·269	·053	·387	·094
Art Marks	·699	—	·627	·563	·572	·594	·312	·055	·207
Drawing Marks (Test)	·394	·627	—	·351	·377	·312	·005	−·115	·045
Verbal and Non-verbal Test (Otis)	·333	·563	·351	—	·738	·649	·277	−·331	·473
Spatial Test 1 (N.F.E.R.)	·095	·572	·377	·738	—	·670	·329	−·251	·503
Geometry Marks (Practical)	·269	·594	·312	·649	·670	—	·642	−·203	·529
Algebra Marks	·053	·312	·005	·277	·329	·642	—	·061	·556
Perseveration Score (Pinard)	·387	·055	−·115	−·331	−·251	−·203	·061	—	·131
Arithmetic Marks	·094	·207	·045	·473	·503	·529	·556	·131	—

involving writing Z E K forwards and then in reverse Z Ǝ ꓘ was found to have a k-loading of ·20, though loadings for other so-called disposition rigidity tests were not significant. In the Pinard Test, certain letters or symbols have to be written upside down or mirror-wise (S, △), and the method of scoring reflects the initial difference in the performance of the familiar and unfamiliar activities (i.e. between S and Ƨ and SƧ). Since the ability to reproduce a configuration mirrorwise is known to involve k, we might expect subjects with high spatial ability to make low scores on the Pinard motor perseveration test.

This hypothesis was tested by carrying out a factor-analysis of test-scores of a class of 21 pupils, who had taken a draft of Spatial Test 1, the Otis Intelligence Test and Pinard's Test of Motor Perseveration. Since the sample is small, too much weight should not be attached to the results. It is considered, however, that the loadings do reflect the kind of relation expected to hold between spatial ability and motor perseveration.

The loadings obtained after two iterations, using Thurstone's Centroid Method are shown in Table 38.

Table 38

Factor loadings obtained in an analysis of the correlations shown in Table 37 (by Centroid Method)

	I_0	II_0
Information Test (Verbal)	·435	·719
Art Marks	·804	·440
Drawing Marks (Test)	·491	·357
Verbal and Non-verbal Test (Otis)	·815	— ·108
Spatial Test 1 (N.F.E.R.)	·788	— ·211
Geometry Marks (practical)	·865	— ·212
Algebra Marks	·482	— ·306
Non-perseveration (Pinard)	·081	— ·308
Arithmetic Marks	·524	— ·370

The matrix of correlations for this experiment is given in Table 37. By reversing the sign of the motor-perseveration scores so that they became measures of non-perseveration, the loading of the first factor in this test became positive. Two factors were extracted, the first factor corresponding approximately to Spearman's *g*. The Otis and spatial tests and marks in art and practical geometry are seen to have high *g*-loadings, while the score for non perseveration shows a near zero *g*-loading (as was found by Pinard.

The bipolar factor has the highest loading on the test of information (verbal) and moderate negative loadings on Spatial Test 1, Geometry, Algebra, Arithmetic and Non-perseveration. Thus, the second factor contrasts a highly verbal test with the spatial and mathematical tests. It is reasonable to interpret this factor as the well-known verbal/spatial bipolar factor. The three mathematical tests would appear to have *k*-loadings not very different from that of the spatial test, and this result would be consistent with those obtained by other investigators, such as Wrigley and Sultan. On the other hand, the second factor loadings of the art and drawing marks seem to be rather heavily biased towards the verbal pole, perhaps because the marking criterion did not take account of spatial ability. If this interpretation of the second factor is correct, the high negative loading of the Pinard Non-Perseveration Score suggests that there is an inverse relationship between *k* and this measure of motor perseveration. Thus, the Pinard motor perseveration test seems to involve *k* (inversely) and to have a negligibly small loading in *g*.

This result is consistent with the findings of Cattell and Tiner (1949), in a factor-analysis of some data for 100 male college students. Their first centroid factor contrasts spatial ability as measured by Flags (—·47), Gottschaldt Figures (—·45) and Cattell's Culture Free Test (—·40) with Motor Perseveration (+·17) and Fluency (+·19). Thus, they also appear to have found an inverse relationship between high spatial ability and motor-perseveration.

The finding that the Pinard Test score is inversely related to spatial ability is of considerable interest since Pinard noted that there was a very striking relationship between scores on his motor-perseveration test and qualities of character. This relationship was found to hold both with school pupils and with adult mental patients. Pinard reported that:

"About 75 per cent of the most self-controlled and persevering subjects showed only a moderate degree of perseveration (motor), whereas about 75 per cent of the most difficult and unreliable subjects proved to be extreme perseverators or extreme non-perseverators."

Both the extreme perseverators and the extreme non-perseverators tended to lack persistence and self-control and to be obstinate, unreliable, 'touchy' and 'difficult'. The two extreme groups, however, showed characteristic differences. Whereas the extreme perseverator tended to be nervous, sensitive, effeminate and sentimental, the non-perseverator tended to be inconsiderate, tactless and critical.

These temperamental qualities are very similar to those which have been found to characterize persons of low and high spatial ability respectively. Persons who are relatively low in spatial ability tend to be feminine, sensitive and neurotic (emotionally unstable), whereas persons relatively high in spatial ability often show qualities of toughness, aggressiveness, tactlessness and even delinquency. (cf. Dellaert, 1931; Uhler, 1937; Earl, 1939). These findings accord with the results obtained by Cattell (1946) in the two investigations already mentioned. The scores in his "creative-effort" perseveration tests showed substantial negative correlations with dominance and character-integration, qualities which have been found to accompany high spatial ability.

Cattell (1957) has also reported that low motor perseveration is associated with high accuracy in perceptual gestalt completion as well as with good performance in analysing Gottschaldt figures, both of which activities, and especially the latter, involve *k*-factor. These three tests provide a measure of Cattell's primary source trait U.I.(T) 19—Critical Practicality. Cattell states that persons high in Critical Practicality are better with machines and ideas than with people, are perfectionists and do not relax easily. This factor also correlates significantly with masculinity, which again is known to be associated with relatively high spatial ability. Cattell has also found that low motor perseveration is associated with "interest in science, mathematics, abstract impersonal studies and out-of-doors interests", all typically masculine interests which might be expected to go along with high spatial ability.

The negative correlation between motor perseveration scores and measures of emotional stability or character integration has been reported repeatedly. Cattell lists low motor perseveration as first among the objective tests of his factor UI (T) 23-Neural reserves, which he identifies with the inverse of neuroticism. He quotes six independent studies confirming the substantial relation between motor rigidity (classical perseveration) and neuroticism, thus providing strong confirmation for the findings of early workers such as Lankes, Pinard and Howard.*

* There is quite a different form of perseveration which is characteristic of brain-damaged children and which does not occur in normal or mentally defective children. It has frequently been noted that brain-damaged children tend to repeat activities they have once begun. For example, they may be unable to stop counting at a given number, or they may write a word correctly and then write it over and over again. They may continue to place beads on a board over and above the number requested by their teacher.

Werner (1946) has reported several experiments in which eighteen pairs of endogenous and exogenous children (matched for M.A. and I.Q.) were tested for perseveration tendencies. In one such experiment, a series of cards with various dot patterns was presented by tachistoscope and the child was asked to draw the pattern after each exposure. The experiment was arranged in two phases. In the first phase, the patterns were similar in shape and relatively simple and in the second phase they were quite different and more difficult. In the case of the designs which were similar there were no differences in perseveration between the two groups. But in the second phase, with the more difficult designs, while the endogenous children made no perseverations at all, the brain-injured children made 20 per cent perseverations in all trials, tending to repeat the simpler patterns shown in the first phase.

McMurray (1954) compared a group of fifteen exogenous and fifteen endogenous children in a modification of the Wisconsin Card Sorting Test. In this test, the pack consists of twenty-seven cards with figures varying in three ways, in colour, shape and number. The test requires the child to deduce which of these variables the examiner is using to sort the cards. When the child has identified the variable being used for sorting, the examiner changes the key variable and a measure of perseveration is obtained from the number of cards sorted before the child becomes aware of the shift. The results showed that the brain-injured child-

That exceptional facility in writing backwards with reversed strokes may be a manifestation of high spatial ability is illustrated by the following individual case. A student known to the writer claimed to possess this facility and demonstrated that he could write upside down as easily as in the normal way, and backwards with reversed strokes as well as forwards. He said that he had never practised these activities and that he had possessed this special ability for as long as he could remember. It may be regarded as fairly certain that he would obtain a low score on the type of motor perseveration test in which the *Y*-activity involves inverse writing, or writing with reversed strokes, and the score is given by $\frac{X}{Y}$ or X-Y. Cattell found that this type of test had by far the highest loading in the classical motor perseveration *p*-factor.*

Thus, there can be little doubt that this student would be given a low assessment for motor perseveration as measured by Cattell's battery. To investigate the possible relationship between *p*-score and other qualities, the student was invited to work a number of cognitive tests as well as Cattell's 16 P.F. Personality Questionnaire.

His raw scores in the cognitive tests, together with possible scores, are shown in Table 39.

The student's performance on the two tests of general ability

ren perseverated significantly on the sorting tasks. These experiments provide evidence that brain-injured children tend to have difficulty either in integrating perceptual stimuli or in shifting effectively from one such stimulus to another. The results may be regarded as showing that the brain-injured group were either relatively weak in gestalt-perception or in the ability to discard one such perception in order to take on another. The latter ability has been termed 'flexibility of closure' by Thurstone and has been shown to involve a factor C_2 which appears to be identical with *k*. Thus, the symptoms of perseveration described in these experiments seem to result from a deficit in spatial ability.

* Rim (1954) carried out an analysis of scores in a number of perseveration tests and extracted four factors. One of these factors had very high loadings in three tests of Cattell's battery, all consisting of tasks involving writing backwards, viz.:

	LOADING
(*a*) The word 'ready'	— ·609
(*b*) One's own name	— ·900
(*c*) The number 237	— ·519

Table 39

Scores on spatial and other tests obtained by a subject who showed exceptional capacity for mirror-writing

TEST	ACTUAL RAW SCORE	POSSIBLE SCORE
Form-relations, N.I.I.P. (Spatial)	55	65
Memory for Designs, N.I.I.P. (Spatial)	49	52
Progressive Matrices, Raven (Non-verbal)	52	60
Group Test 100 B, N.I.I.P. (Verbal and non-verbal)	62	95

(Progressive Matrices and Group Test 100 B) was somewhat less than average for the student population. Thus, his score on Progressive Matrices was lower than 56, the mean for the student population as reported by Leybourne White. His scores on the spatial tests, however, were relatively high, in the case of the Memory for Designs Test being very close to the maximum, and well above the mean for the student population. Thus, the tests confirmed that he had exceptional spatial ability, as the writer suspected from the prowess he had shown in inverse writing. His scores on the I.P.A.T. 16 Personality Factor Questionnaire corresponded closely to the findings already reported on the personality correlates of spatial ability. His scores on four of the factors were:

Table 40

Scores on four personality factors obtained by the subject who showed exceptional capacity for mirror-writing

FACTOR	SCORE
Cyclothymia (Factor A)	7
Surgency (Factor F)	10
Adventurous cyclothymia (Factor H)	11
Emotional Stability or Ego-strength (Factor C)	20

His highest score in any of the sixteen factors was that for Emotional Stability (20) and his three lowest scores were for factors *A* Cyclothymia (7), *F* Surgency (10) and *H* Adventurous Cyclothymia (11). Thus, the questionnaire clearly indicated that this student was highly stable emotionally as well as being schizothymic and desurgent.

It would appear that a natural facility for mirror-writing is a distinctive trait of the spatially gifted. This would seem to be a reasonable explanation of the finding, reported by Cattell, that low motor perseveration correlates with interest in mathematical, engineering and other spatial subjects.

It may also account for a finding reported by Morrisby (1955) that the Motor Perseveration Test of the Differential Test Battery correlates negatively (—·30) with G.C.E. (O level) Physics and positively (+·20) with G.C.E. (O level) French. Morrisby, however, did not intend this test to be a measure of ability. He calls it Speed Test 2, one of four speed tests, the profile on which is intended to reflect the individual's "intellectual personality". It is clear from Morrisby's notes on the profiles that Speed Test 2 has quite a different significance from the other three speed tests. Persons low on Speed Test 2 but high on the others are said to be "able to accept new ideas, with a pragmatic, co-operative but independent outlook. They are fairly free with criticisms and suggestions, not particularly tactful but reasonable and considerate". Persons relatively *very* low in Speed Test 2 but high in the other speed tests are "so receptive of new ideas that they seem constantly to be smitten with overwhelming but ephemeral enthusiasms". This description rather suggests high "flexibility of closure, a suggestion which would accord with the writer's hypothesis regarding the motor-perseveration test.

It is perhaps worth mentioning that Leonardo da Vinci, who was so gifted in many fields requiring high spatial ability, wrote his voluminous manuscript notes in mirror-writing. Da Vinci is perhaps an outstanding example of a genius who was constantly receptive to new ideas, of which many were never carried to fruition.

The mathematician, Lewis Carroll, also appears to have had a facility for mirror-writing for he sometimes corresponded with his young friends in a code which he called 'looking-glass writing'.

Chapter nine

Spatial Ability, Critical Fusion Frequency, Alpha Rhythm and the Reticular Formation

THE relationships which have been found to occur between scores on motor perseveration tests and personality traits such as emotional stability, show that these tests do not measure the tendency to perseveration as it was originally conceived. When first introduced, the term was supposed to refer to a lag in mental processes, a kind of mental inertia (to use the term favoured by Spearman). This hypothetical lag was referred to as secondary function by Gross and Wiersma and was thought to be the physiological basis of introversion.

The fact that a test such as Memory for Designs has usually been found to have a very high spatial loading suggests that a constitutional tendency for visual processes or images to persist may be helpful or even necessary for successful performance on spatial tests. Such a tendency might be regarded as a form of sensory perseveration* and one might hope to be able to measure it by means of a flicker technique, such as that employing a rotating disc with differently coloured sectors. The disc might be expected to blur at a lower rotation rate for subjects with high sensory perseveration.

Biesheuvel (1938) obtained some evidence in favour of this hypothesis. Using a device similar in principle to the stroboscope, he concluded that the speed of fusion yields a measure of perseveration. He obtained ratings on a questionnaire dealing with

* Shevach (1937) found that tests of sensory perseveration correlated negatively with 'emotional instability', unlike tests of motor perseveration which have a positive correlation with emotional instability.

personality traits thought to be connected with perseveration. By this means, he selected two groups of perseverative and non-perseverative children and claimed that the results showed that the groups differed significantly with respect to the threshold of flicker fusion. Biesheuvel's claims have been criticized on statistical grounds by Wynn Jones (1939), who asserted that the evidence is not sufficiently strong to justify attaching value to the test for measuring perseveration in the *individual.*

Subsequent research, however, has confirmed that there is a relationship between rate of flicker fusion and personality traits, though it is perhaps not yet quite clear what dimension of personality is being measured. Krugman (1947) and Goldstone (1955), working with a test of visual flicker fusion, both found that the neurotic groups tended to have lower thresholds of discrimination of flicker frequency than the more normal groups. As Eysenck (1960) has pointed out, however, since both Krugman and Goldstone used dysthymics (neurotic introverts) as representatives of their high neuroticism groups, it is uncertain whether the low C.F.F. thresholds were due to the neuroticism or to the introversion of the subjects.

Goldstone reported his findings as follows:

"One observes a lower flicker threshold for those groups designated high anxiety than for those groups designated low anxiety. These group differences appear reliable at the ·005 level of confidence and indicate a reduced sensitivity to flicker in the high-anxiety groups." These results agree with Krugman's, who obtained correlations of — ·62 and — ·45 between anxiety and flicker fusion frequency. Friedl (1954) found a correlation of — ·34 between critical fusion frequency and anxiety in 63 normal subjects. Buhler (1953) tested flicker fusion rates in a group of persons before and after undergoing minor surgery. It was assumed that before undergoing surgery the patients would be more anxious. The results were in accord with expectation, i.e. flicker fusion rates were lower before surgery than after.

Eysenck (1952) quotes figures showing that flicker fusion frequency differentiated significantly at the 5 per cent level between normals, anxiety patients and hysterics, the anxiety cases having the lowest fusion frequency and the normals having highest.

Thus, several independent investigations have led to the same conclusion that there is a marked association between high anxiety and reduced sensitivity to flicker. The writer prefers to interpret this well-established finding by relating high anxiety to desurgency or schizothymia rather than to neuroticism (the term used by Eysenck for emotional instability).*

It is reasonable to regard high anxiety as a manifestation of both desurgency and schizothymia, for Cattell (1957) states that desurgents tend to be worrying, anxious, obsessional and unable to relax compared with surgents, who tend to be placid and content. Similarly, he states that schizothymes tend to be secretive and anxious, while cyclothymes tend to be frank and placid.

Thus, it appears that both the traits with which high spatial ability is associated (viz. desurgency and schizothymia) imply a tendency to anxiety. Hence, there are grounds for expecting high spatial ability to be associated with anxiety. Since low flicker fusion frequency has been shown repeatedly to be associated with anxiety, we might expect to find an inverse relation between high spatial ability and flicker fusion frequency.

Such a relationship would be expected to hold, if we make the assumption that high spatial ability must involve a tendency for

* The writer prefers to avoid the term 'neuroticism', which is used by different authors in different senses and has given rise to much confusion.

Eysenck (1963) means by neuroticism "an inherited disposition, closely linked with the lability of the autonomic system, which governs a person's emotional reactivity". He regards anxiety "as a conditioned fear reaction which is particularly characteristic of dysthymic neurotics, i.e. of persons who are high on the factors of neuroticism and introversion". (He states that Cattell uses the terms 'neuroticism' and 'anxiety' in exactly the opposite senses.)

In the writer's view schizothymes tend to be both anxious and emotionally stable while cyclothymes may be less anxious but more emotionally unstable. Schizothymes may be either sensitive or tough, the asthenics tending to be more anxious and the athletics (the strong, silent he-men) more tough. Cyclothymes vary among themselves from the vivacious to the serious and their emotional instability shows in a liability to changes of mood from happiness to sadness without apparent cause. They are less prone, however, to anxiety and often give the impression of being placid and care-free.

visual imagery to persist and so may be a manifestation of sensory perseveration. High spatial ability would then correlate inversely with critical flicker fusion frequency, since high sensory perseveration would cause blurring at a lower frequency.

The suggestion that high spatial ability might be a manifestation of sensory perseveration (i.e. persistence of sensory processes) was advanced by the writer in 1951 (Smith, 1952), the suggested relationship being expressed as a correspondence between the two dimensions:

1. Cyclothymia as compared with schizothymia.
2. Low compared with high sensory perseveration.

This hypothesis implies that the duration of the effect of a stimulus will be greater for the schizothyme than for the cyclothyme. Various explanatory principles might be invoked to account for such a phenomenon, such as "accumulation and dissipation of reactive inhibition" suggested by Eysenck (1955), or "cortical conductivity" employed by Klein and Kretch (1952).

The suggestion would imply, in terms of Eysenck's principles, that high spatial ability is associated with weak inhibitory effects, a condition which characterizes the schizothyme. Since injury to the brain usually impairs a person's spatial ability we should expect it to have the effect of increasing inhibitory effects and tending to make the person more extraverted or cyclothymic.*

The finding by Beech (1958) that a group of schizophrenic patients made more accurate drawings than any other groups of subjects, including normals, may be interpreted as being consistent with the writer's hypothesis. Also in line with it are the results of some experiments on the duration of the Archimedes' Spiral Effect, reported by Claridge (1960):

* The evidence for the theory that the effects of brain damage are analogous to satiation appears to be equivocal. Jaffe (1954) attempted to duplicate the Klein and Krech study, but was unable to obtain statistically significant differences between the brain-injured group and controls.

Table 41

Duration of spiral after-effect (Claridge)

	MEAN	S.D.
Normals	10·16	4·560
Dysthymics	15·78	5·486
Hysterics	9·74	5·337
Schizophrenics	14·78	6·996

It will be noted that the schizophrenic group had a considerably longer duration of the after-effect than the normal group, the difference being significant ($p < 0·05$). The high standard deviation of the schizophrenic group probably indicates that there is a variety of clinical types subsumed under this heading. It also suggests that this group may include some patients who have a longer duration of the after-effect than any in the other groups.

Whatever the explanation of the after-effect, an inhibition theory would lead to the expectation that the length of the after-effect would be negatively correlated with extraversion. Work with this test on the brain-injured, especially that of Price and Deabler (1955), Gallese (1956) and to some extent that of Holland and Beech (1958) offers support for the hypothesis since these subjects had diminished after-effects, a result to be expected on the supposition that brain damage increases extraversion.

Some indirect support for the hypothesis linking spatial ability inversely with critical flicker fusion frequency comes from studies relating both of these variables to alpha index (i.e. proportion of alpha rhythm in the E.E.G.).

The relationship between spatial ability and alpha index has been determined in a study of Mundy-Castle (1958), in which he gives the results of a factor analysis of the scores of 34 adults in the sub-tests of the Wechsler Bellevue Intelligence Test together with measures of alpha index and alpha frequency. Alpha index was measured by assessing the percentage of occipital alpha rhythm greater than 5 microvolts present in a strip recorded in 100 seconds. The resulting table of correlations showed that alpha index correlated positively with the verbal sub-tests and negatively with the performance (or spatial) sub-tests.

The figures were as follows:

Table 42

Correlation between Alpha Index and Verbal, Non-verbal and Full-scale I.Q.s (Mundy-Castle)

	CORRELATION WITH ALPHA INDEX
Verbal I.Q.	·333
Non-verbal I.Q. (largely spatial)	— ·166
Full-scale I.Q.	·098

Mundy-Castle extracted five factors from the matrix of correlations by the centroid method and applied orthogonal rotations using a modification of the method proposed by Reyburn and Taylor. The first two rotated factors were identified as visual and verbal respectively, presumably corresponding closely to the familiar *k* and *v*. The following loadings in these two factors are of interest.

Table 43

Relation between Alpha Index, Mean Alpha Frequency and spatial and verbal factor-loadings (Mundy-Castle)

VARIABLE	I VISUAL (*k*)	II VERBAL (*v*)
Verbal I.Q.	— ·063	·760
Practical (spatial) I.Q.	1·010	·242
Full-scale I.Q.	·675	·585
Mean alpha frequency	·418	— ·029
Alpha index	— ·332	·665

These results show that verbal ability tends to be associated with high alpha index and low alpha frequency, while spatial ability tends to be associated with low alpha index and high alpha frequency. Mundy-Castle concludes that differences in habitual mental imagery, which are reflected in the characteristics of the alpha rhythm, may also contribute to differences in verbal as opposed to practical intelligence.

There appears to be a close relationship between alpha rhythm and critical flicker fusion frequency, for high correlations have been reported between the latter and alpha index (i.e. proportion of alpha rhythm present). Chyatte (1954) has reported a correlation as high as ·855. Since high spatial ability correlates negatively with alpha index there are good grounds for expecting that it will also correlate negatively with critical flicker fusion frequency.

Kelty (1960) has claimed to have shown that an inverse relationship exists between alpha index and a personality trait called "behavioural alertness". He administered the Minnesota Multiphasic Personality Inventory to a group of subjects and obtained a significant correlation of — ·23 between alpha index and Welsh *A*-scores on the M.M.P.I. The Welsh *A*-factor represents a dimension of 'behavioural alertness', characterized by traits ranging all the way from calmness and apathy to the extreme of tension and anxiety. The association between high *A*-scores and low alpha indices on the one hand and between low *A*-scores and high alpha indices on the other was present during all experimental conditions, e.g. resting, attention and visual stimulation. Since there is evidence from studies by Mundy-Castle and others that high spatial ability is associated with low alpha index and vice versa, Kelty's study provides some ground for supposing that spatially-gifted persons are likely to be 'behaviourally alert' and that very high spatial ability may be associated with extreme tension and anxiety.

That some connection exists between spatial ability and the alpha rhythm of the E.E.G. is suggested by the findings of researches relating the alpha rhythm to imagery, which were initiated by Golla, Hutton and Grey Walter (1943). These researches showed that individuals may be classified into three main groups, according to the degree of alpha activity in the E.E.G.

The three groups were:

1. Those showing little or no alpha activity, the maximum

amplitude being 10 microvolts and showing no appreciable change during mental activity, whether with eyes open or closed (M-type).

2. Those showing an alpha amplitude within the normal range (10–50 microvolts) with eyes closed; blocking entirely, or much attenuated with eyes opened; and diminished if mental activity takes place with the eyes closed (R-type).

3. Those showing an alpha amplitude above 10 microvolts, persisting during mental activity relatively unchanged or in 'bursts' and unaffected by the eyes being opened or closed (P-type).

These groups were designated M, R and P respectively, (M for minus, R for responsive and P for persistent). Several surveys have shown that the proportions vary a good deal according to occupation but, in general, about two-thirds of an ordinary group of people selected at random are found to be of the R-type and the remaining third are about evenly M and P. The proportion of M-types is usually somewhat higher in science students than in arts students.

Short and Grey Walter (1954) suggested that individuals composing these groups belong to different imagery types. M-type patterns were characteristic of predominantly visual thinkers and P-type patterns of verbal thinkers. R-type patterns were thought to occur in individuals who could make use of both verbal and visual imagery in their thinking. Persons in the R-group were more favoured since they could combine data from the different sense organs more readily than could those in either the M- or P-groups. On the other hand, in stereognostic tests (identifying patterns on concrete blocks when blind-folded), persons in the R-group did less well than those in the other groups. The explanation offered for this finding was that the consistent use of one type of imagery whether visual, verbal or kinaesthetic was more likely to lead to success than the use of more than one type. The view was also put forward that geniuses often belonged to extreme M- or P-types because such persons tended to concentrate and persevere along one line of thinking.

In 1955, the writer suggested that the distinction between M- and P-types (i.e. between persons possessing mainly visual and mainly verbal imagery), might correspond to the familiar distinction between persons who perform well on spatial and verbal tests respectively. However, subsequent investigations have yielded somewhat conflicting results.

Drever (1955) found no significant difference in scores on spatial tests given to groups of M-, R- and P-types. Also, doubt was cast on the suggestion that the suppression of alpha rhythm provides an objective indicator of the process of visualizing.

Barratt (1956) carried out an investigation to test whether the hypothesis is tenable under the condition of problem-solving. He did in fact find that suppression of the alpha-rhythm occurs to a significantly greater degree whilst solving a visual problem than when solving a verbal one. However, suppression of alpha rhythm occurred under both conditions, and he concluded that his results on the whole did not support the view that suppression of alpha rhythm provides an objective indicator of the process of visualizing. Imagery appeared to be only one of many factors which may produce suppression effects.

Walter and Yeager (1956) investigated the effect of the complexity of the visual image in relation to alpha suppression. In one of their experiments while the E.E.G. was being recorded, the subject was asked to open his eyes and to look at a card with printed diagrams. After closing his eyes, he was asked to recall first a circular diagram, then a rectangular one. At the end of the recording, he was asked to make a drawing of both diagrams from memory. No significant relation was found between the accuracy and the percentage of alpha reduction during active vision or recall. It was found, however, that subjects who reproduced the drawings most accurately had during the resting state with eyes closed, a low potential (mean 20·2 microvolts) relatively non-rhythmical type of electrical activity from the occipital areas. Subjects who reproduced the drawings inaccurately had a higher potential (mean 32 microvolts) rhythmical activity during the resting state.

Since the score for the accurate reproduction of the designs is likely to provide a measure of the subject's spatial ability, Walter and Yeager's study offers support to the view that there is an inverse relationship between spatial ability and mean alpha amplitude in the resting state. These findings are obviously well in agreement with the results of Mundy-Castle's study, which have already been mentioned.

Stewart and Macfarlane Smith (1959) have reported an investigation carried out to test the suggestion made in 1955 by the writer that there might be a relationship between performance in tests of spatial or verbal ability and

1. type of alpha rhythm; and
2. percentage of alpha suppression when solving a problem requiring visual imagery.

Four paper-and-pencil tests (two spatial, one verbal and one non-verbal) were administered to 96 adults, 51 men and 45 women, the mean ages being 29 and 22 respectively. Mean I.Q's calculated from scores on Moray House Adult Intelligence Test 1 (verbal) were respectively 122 and 117.

The other cognitive tests administered were:

Memory for Designs (N.I.I.P.).
Spatial Test 1 (N.F.E.R., Smith).
Non-verbal Test 3 (N.F.E.R., Calvert).

Individual E.E.G. recordings were taken during which the subjects were asked four questions orally, designed to involve one type of thinking predominantly, either verbal or visual. Questions 1 and 3 were thought to be mainly 'verbal' and 2 and 4 mainly 'visual'. An analysis of the verbal reports made by the subjects after answering the questions appeared to confirm that the questions evoked the kind of imagery intended.

It was found that there was a significantly larger decrease in the amplitude of the alpha rhythm whilst the subject was solving a 'visual' problem than whilst solving a 'verbal' one, thus confirming the result reported by Barratt. It was also noted when the two 'visual' problems were being attempted, that a greater amount of suppression occurred with the question reported to evoke the more vivid image.

The highest scores in the two spatial tests were obtained by subjects who showed the greatest reduction in alpha amplitude when the eyes were open or when solving a visual problem. It was only in the case of one of the spatial tests, however, Memory for Designs, that the difference in reduction between high-scoring groups and low-scoring groups was significant. The trend was in the same direction for Spatial Test 1, though the difference was not statistically significant.

The E.E.G. records for the whole sample of subjects were examined and classified into three groups according to the M-, R-, and P-types described by Golla, Hutton and Grey Walter (1943). When the mean scores in the written cognitive tests for the three alpha groups were compared, none of the differences was found to be statistically significant. However, for each test the nearest approach to significance occurred in the difference in means between P- and R-groups (e.g. for Memory for Designs the critical ratio of the difference in means was 1·44). These differences were in agreement with the hypothesis that Ps tend to be 'verbal' rather than 'visual' in their thinking, for they did less well than the Rs in the two spatial tests and better than the Rs in the verbal and non-verbal tests. Thus, the trend of the evidence both from the oral and from the written tests, provides some support for El Koussy's statement that "*k*-factor depends on the ability to obtain and the facility to utilize visual, spatial imagery".

In an attempt to confirm the finding reported by Walter and Yeager that an accurate reproduction of a diagram was associated with a low potential alpha rhythm, a comparison was made between scores in the Memory for Designs Test and the mean value of the resting potential when the eyes were closed. The spatial scores were arranged in four groups, in descending order of performance, and mean values of the resting alpha potential were calculated for each group. While the highest mean resting potential occurred in Group 3 (the group with the second-lowest mean spatial score), none of the differences were significant.

Thus, the investigation failed to confirm the findings reported by Walter and Yeager. A possible explanation of the differing results may perhaps be found in the different methods of scoring the diagrams used in the two investigations. Walter and Yeager had their drawings sorted into three categories by four judges classifying by general impression, whereas Stewart and Macfarlane Smith had their drawings marked by one person according to a prepared scheme, maximum credit being awarded for the correct representation of proportions.

Whatever the explanation of the differing results, the evidence reported by Mundy-Castle appears to confirm the view that there is a connection between high *k*-factor and low alpha index. This was essentially one of the hypotheses which Stewart and Macfarlane Smith set out to test before the publication of the papers by Walter and Yeager and by Mundy-Castle.

Since these associations seem to be fairly definite, we should expect that the personality qualities associated with high spatial ability would be found in individuals whose E.E.G. records show high alpha frequency and low alpha index or perhaps low alpha amplitude. Gastaut (1954) has attempted to classify the personality qualities which, according to various investigators, are associated with three E.E.G. syndromes: (*a*) hyperexcitability, (*b*) cortical instability, and (*c*) hypoexcitability.

This classification is of interest in that the three syndromes, which seem to correspond to Grey Walter's M-, R- and P-types, show when taken in that order a diminishing alpha frequency and an increasing alpha index and amplitude. Thus we might expect to find the first syndrome occurring in persons of high spatial ability, the second in persons relatively less gifted spatially, and the third in persons better endowed verbally than spatially. It should perhaps be stressed that Gastaut recognizes that his attempt at psychological classification is very imperfect and should be regarded as a working hypothesis at present on trial. The information contained in Table 44 is taken partly from a similar table given by Gastaut and partly from the text of his paper.

Eysenck (1960), following Mundy-Castle (1956, 1957), has suggested that the quickness and hyperactivity accompanying high alpha frequency are symptoms of extraversion, while the slowness and hyporeactivity associated with low alpha frequency correspond to introversion. The writer, however, would interpret the results differently and in an opposite sense. The hyperactivity, hypersensitivity, nervousness and anxiety seem to be the same as Kelty's 'behavioural alertness' and may be identified with the overintensity and apprehensiveness of cerebrotonia. Thus, they are more closely related to introversion or schizothymia than to extraversion. Similarly, the hyporeactivity associated with low alpha frequency may correspond to Kelty's 'calmness and apathy' and may be identified with the slow reactivity, relaxation and complacency of viscerotonia. These are qualities exhibited by one type of extravert, the viscerotonic or cyclothymic extravert.

There is fair agreement between the characteristic qualities of Groups (*a*) and (*c*) and those which have been found to be associated with high and low spatial ability respectively. For example, the spatially gifted person tends to be active, independent and anxious and sometimes has qualities of leadership. The person who lacks spatial ability tends to be passive, dependent, submissive, obedient, conformist and to lack aggressive tendencies. This opposition seems to correspond to that between masculinity and femininity.

The three syndromes described by Gastaut also show some affinity with the threefold classifications of temperament proposed by typologists such as Kretschmer and Sheldon.

Thus, Group (*a*) seem to have the qualities of the extreme type of leptosomatic schizothyme (the cerebrotonic of Sheldon), viz. hypersensitive, hyperactive, nervous. The qualities 'active, independent, with tendency to leadership' correspond to the more energetic, medium type of schizothyme (the systematic organizer).

Group (*b*) seem to have the qualities of the athletosomatic schizothyme (termed colledothyme by Strauss). They tend to be either phlegmatic or explosive, hence calm but susceptible to violent reactions. They have a greater tendency to delinquency and crimes of violence than the other types (cf. Glueck and Glueck,

Table 44

Relation between characteristics of Alpha Rhythm and qualities of personality (adapted from a table given by Gastaut)

CHARACTERISTICS OF E.E.G. RECORDS	FREQ. OF ALPHA RHYTHM	CHARACTERISTICS OF PERSONALITY	AUTHORS QUOTED
(a) HYPEREXCITABILITY SYNDROME	11–13 CYCLES/SEC.		
Rare and rapid alpha rhythms of small amplitude, grouped in short bursts on desynchronized activity.		*Active, independent personality; tendency towards leadership.*	*Saul, Davis and Davis* (1949)
		Hypersensitive, hyperactive, nervous.	*Gastaut* et al. (1951).
Intermittent photic driving.		*Tendency towards anxiety state.*	*Ulett* et al. (1953).
(b) LABILITY OR VERSATILITY SYNDROME	9–11 CYCLES/SEC.		
Alpha rhythm rare, associated with slower or more rapid waves or both.		*Impatient, aggressive, hostile.*	*Saul, Davis and Davis* (1949).
Subject to almost instantaneous modulation of amplitude.		*Calm and not anxious, but susceptible to rapid and violent reactions, grumbler, affective lability.*	*Gastaut* et al. (1951).
Intermittent photic driving.		*Violent, intolerant, aggressive, egotist, impatient, suspicious.*	*Walter* (1953).
(c) HYPOEXCITABILITY SYNDROME	8–9 CYCLES/SEC.		
Slow, strong regular rhythms of continuous large amplitude, no desynchronized intervals.		*Passive, dependent, submissive, tending to shy away from effort, danger and responsibility.*	*Saul, Davis and Davis* (1949).
No intermittent photic driving.		*Obedient, no aggressive tendencies, conformist.*	*Palmer and Rock* (1953).
		Slow, even temper, calm.	*Gastaut* et al. (1951).

1950). Group (*b*) seem to have most of the bad qualities of this type of schizothyme, e.g. hostile, intolerant, suspicious.

Group (*c*) have the qualities of one type of pyknic cyclothyme—the depressive, inhibited rather than the lively, the melancholic rather than the manic. The qualities of obedience, conformity and even temper are essentially those of the sluggish, soft, complacent cyclothyme.

The reticular formation in the brain stem

Increasing interest is now being taken in the mechanism of 'attention' as a result of researches by Magoun (1950) and others on the reticular formation in the brain stem. This is an anatomically diffuse system of neurones which has connections passing from the mid-brain to the cortex and from the cortex back to the mid-brain. It forms a type of 'feedback' system in which messages can be received, sent to the cortex and then returned to the mid-brain along with relevant information from the memory and associative areas. Thus, one of the functions of the reticular formation seems to be that of an integrative mechanism. It also seems to be a non-specific alerting mechanism which reduces cortical thresholds and so increases attention and efficiency. It may provide a central control which selects and determines which parts of the cortex will be active from among all those which might be excited by incoming stimuli. This central control seems to underlie the process to which we refer when we use the word 'attention'. It has a closely interrelated reticular network and radiating projections which terminate in the layers of the cortex. Thus it is capable of facilitating or inhibiting conduction processes.

Since the alpha rhythm is intimately related to processes of attention it is possible that one of the functions of the reticular formation is the regulation of the alpha rhythm.

If we accept the evidence of Mundy-Castle's study that differences in habitual mental imagery are reflected in the characteristics of the alpha rhythm, we might expect to find that differences between spatial and verbal abilities are related in some way to the functioning of the reticular formation of the brain stem.

We may attempt to understand how this system may be involved in spatial perception by considering an analogy. We may liken the operation of the reticular system to the selectivity control of a radio set. We are familiar with the requirement that radio receivers should be capable of adjustment so that they operate efficiently both for near-by and distant stations. On the one hand they are required to give high-quality reproduction of the signal from a nearby station which is much stronger than any other station, and on the other hand they may be required to pick up a programme from a distant station whose signal is weak compared with those on neighbouring frequencies. For high-fidelity reproduction of the stronger signal, a wide range of frequencies should be received, whereas to select the weak distant station free from interference it is essential that the band of frequencies received should be very much narrower.

The radio set can be adjusted to satisfy either requirement by means of the selectivity control, which can alter the width of the frequency response curve.

We may think of the reticular brain stem formation as a filter mechanism which may function as a selectivity control. High selectivity makes possible the concentration of attention on certain aspects of the field of vision to the exclusion of others, producing the narrow-range mode of attention which has been described as 'fixative' or 'concentrative'. Low selectivity corresponds to the widely ranging mode of attention which has been described as 'diffusive'. This enables the individual to assimilate more information from a wider field, but impairs abstraction by reducing the concentration of energy required for the identification of a structure or pattern in a multitude of details. Relatively high spatial ability seems to be associated with the fixative mode of attention which produces high selectivity.

This selective property of the mind seems to be a function of the reticular formation of the brain stem. It is probably because of the widely ramifying connections of this system that damage to almost any part of the brain impairs its functions and so reduces the selective power of the attention mechanism. This may account for the fact that most forms of brain injury seem to be associated with spatial disabilities, with increased distractibility, and with an impaired ability to differentiate between figure and background in typical figure-ground tests.

The brain-damaged patient may be compared to a radio set with an inefficient selectivity control, which fails to separate out signals from distant stations because they are swamped by strong signals from local stations. The schizophrenic patient is like a radio set permanently adjusted for high selectivity. While able to discriminate effectively between weak signals from distant stations, the quality of the reception even from strong local stations is seriously impoverished and distorted.

Thus the possession of a highly selective reticular system may be both an asset and a liability. On the credit side, there is an enhanced capacity for perceiving structure by inhibiting attention to details. On the debit side, there is some loss in the richness of experience because of a diminished capacity for switching attention easily from one detail to another. An exaggerated tendency to impose structure on one's experience by ignoring elements which do not fit into the structure might well result in paranoia (or systematized delusions).

Integration of experience into wholes is achieved only by inhibiting the perception of inessential or irrelevant details. This is a well-known principle of the Gestalt school, known as the law of *prägnanz*, according to which the mind has a tendency to organize the stimulus situation into as 'good' an experience as circumstances will permit. A drawing of a circle with a gap tends to be seen as a complete circle because the mind tends to perceive the best structure possible and does so by inhibiting perception of the gap.

The exceptional ability of the spatially-gifted person for perceiving structure or form may depend on a capacity for selective inhibition of experience and this may be a general characteristic of his whole personality.

Chapter ten

General Conclusions and Epilogue

1. Current selection procedures for admission to grammar schools and to most technical schools give greater weight to verbal abilities than to spatial abilities. As a consequence, in these schools the proportion of pupils with high spatial ability is very much less than the proportion with high verbal ability.

2. It is probable that selection procedures, both official and unofficial, operating at other stages of the educational ladder, differentiate in favour of pupils of superior verbal ability and against pupils of superior spatial ability.

3. It follows that a considerable proportion of pupils, gifted with exceptional spatial ability, are being debarred from advanced educational courses where these abilities could be utilized and cultivated.

4. A survey of research on spatial abilities shows that many types of spatial test have validity for selecting candidates for numerous technical and scientific courses and occupations.

5. Follow-up studies show that spatial ability may contribute to success in G.C.E. and other examinations in mathematics, art, mechanical science, and in many technical subjects, such as engineering drawing, metalwork, woodwork, handicraft, building drawing, and building geometry.

6. By including a spatial test in the battery of tests used for selecting pupils for such courses, the number of pupils likely to succeed could be substantially increased.

7. The findings of the writer's investigations, considered in the light of other research, suggest that a spatial test could be included with some advantage in the battery of tests used for selecting pupils for grammar schools. This would probably increase the

number of such pupils likely to become mathematical or scientific specialists or scientific research workers. It might, however, have the effect of reducing the number of pupils likely to be successful in linguistic subjects, such as English or modern languages.

8. Tests of verbal reasoning and English tend to yield negative regression coefficients in the equations for predicting success in some technical subjects. Thus, in selecting pupils for courses in these subjects, there is a case for weighting these test-scores negatively. Preferably, tests of attainment in English should be used only for ensuring a minimum standard of attainment in this subject.

9. The writer's follow-up enquiry shows that the best single predictor of success on technical courses is a test of spatial ability, and that the other tests used in the enquiry add little to its predictive value.

10. If all the samples of technical school pupils followed-up are considered together (i.e., taking no account of differences in subject) it appears that the most suitable procedure for selecting pupils for a technical school course is to dispense with a test of verbal reasoning and to weight the spatial and arithmetic tests in the ratio 4:1.

11. The inclusion of the verbal reasoning test as a suppressor variable (i.e., weighting it negatively) in selecting for a technical course, such as woodwork, may increase the predictive value of the spatial test by as much as 6 per cent. Such a procedure would be unsatisfactory if pupils were being considered for admission to a technical school only, because it might become known to the candidates that it would be advantageous to perform badly in the verbal reasoning test.

12. If, however, pupils are being considered simultaneously for admission to grammar school courses and technical school courses, the verbal reasoning test could be given a positive weight in preparing the order of merit list for the grammar school course and a negative weight in preparing the corresponding list for the technical school course.

13. The follow-up studies show that the English essay has positive validity for linguistic subjects such as English language, English literature and modern languages, but it may have negative validity for mechanical science and metalwork and negative or near-zero validity for mathematics, physics, chemistry and biology.

The regression coefficients show that for predicting success in science subjects, the weighting of the English essay should be negative. It follows that in selecting pupils for grammar schools, procedures which give positive weighting to the essay are likely to have the effect of denying admission to pupils with potential ability for science subjects.

14. The follow-up studies also show that the spatial test may have negative validity for many grammar-school subjects, such as English language, English literature, modern languages, physics, chemistry and biology. The regression coefficients show that for predicting success in these subjects, the spatial test should in general be weighted negatively. The opposite is true, however, for subjects such as mathematics, art, woodwork, metalwork and mechanical science.

These findings show that spatially gifted pupils are relatively less gifted for the majority of the traditional grammar school subjects. In the past, many grammar-school teachers may have inferred that such pupils are relatively less 'intelligent' or 'academically gifted'. That such inferences were made is borne out by the fact that many eminent scientists and engineers were reported to be backward or dull at school.

15. Until fairly recently, tests of verbal ability or verbal reasoning were called intelligence tests and were believed to provide measures of 'abstract intelligence', whereas tests of spatial ability were regarded as measures of a specialized mechanical aptitude or of 'concrete intelligence'. Reasons have been given for believing that spatial tests may be better measures of ability to think abstractly or to form general concepts than verbal tests.

16. Numerous studies of brain-damaged subjects, including cerebral palsy cases, have been reviewed. The conclusion is drawn

that a great majority of such subjects are characterized by a marked deficit in spatial ability compared with other abilities.

17. Experiments have been carried out by the writer which show that spatial ability is associated with the personality qualities of withdrawn schizothymia (H—), desurgency (F—), masculinity and low motor perseveration (P—). Since all four of these personality traits are believed to be associated with the length/breadth factor of body-build, there are reasons for supposing that high spatial ability is associated with leptosomatic or athletic physique.

18. To account for the association between low motor perseveration score and high spatial ability, an hypothesis is advanced which supposes that many so-called motor perseveration tests, involve in the Y-activity an element of reverse or inverse writing and so measure spatial ability inversely. As evidence in support of the hypothesis, reference is made to the hitherto unexplained facts that high motor perseveration scores have been consistently found to provide a measure of emotional instability and that low motor perseveration scores correlate with interest in mathematical, engineering and other spatial subjects.

19. The follow-up studies have shown that a spatial test has significant validity for predicting success in G.C.E. mathematics, both for boys and girls. A review of the literature suggests that spatial ability becomes increasingly important in more advanced mathematical studies, in which greater emphasis is placed on analytical and abstract thinking and on problem-solving.

20. The foregoing evidence (para. 19) suggests that spatial tests may have value for selecting good research workers in certain fields, such as in mathematics and the physical sciences. Confirmation of this conclusion is found in the fact that the personality qualities found to accompany high spatial ability are very similar to those reported by Cattell and Drevdahl to distinguish good researchers from good academic administrators and teachers.

21. Evidence from three independent studies suggests that there is an association between spatial ability and certain proper-

ties of the alpha rhythm of the E.E.G. (high frequency, low alpha index or low mean resting alpha amplitude).

22. If the association claimed to exist between high spatial ability and low alpha index can be regarded as established, it appears to follow from Kelty's study that spatial ability is accompanied by 'behavioural alertness', low spatial ability being characterized by 'calmness and apathy' and very high spatial ability by 'extreme tension and anxiety'.

Table 45 presents in summary form a statement of the conclusions reached in this study regarding the relationship between verbal and spatial abilities and other characteristics.

Table 45

Summary of conclusions reached in this study regarding the relationships between verbal and spatial abilities and other characteristics

DIFFUSIVE ATTENTION	FIXATIVE ATTENTION	REFERENCES
When observing a configuration, tends to note and remember more details.	*When observing a configuration, tends to pay more attention to form as a whole.*	*Meumann, E.* (1907) *op. cit. Burt, C.* (1949): Brit. J. Educ. Psychol., 19, 3, 197–198.
v-FACTOR { *Verbal Reasoning, Verbal Fluency, Vocabulary, Clerical Ability*	*k*-FACTOR { *Spatial, Drawing, Mechanical, Practical Abilities.*	*Vernon, P. E.* (1950): The Structure of Human Abilities.
Cyclothymic Personality Traits. *Liability to Manic Depressive Illness.*	*Schizothymic Personality Traits.* *Liability to Schizophrenic Illness.*	*Kretschmer, E.* (1925): Physique and Character. *Westphal, K. (1931) Quoted by Eysenck, H. J.* (1952), *op. cit.*, p. 204.
Pyknic Physique.	*Leptosomatic or Athletic Phŷsique.*	*Linford Rees* (1960), *op. cit.*
Emotional Instability.	*Emotional Stability.*	*Earl, C. J. C.* (1939), *op. cit.*
Adventurous Cyclothymia (H+) Surgency (F+)	*Withdrawn Schizothymia (H—) Desurgency (F—)*	*Pemberton, C.* (1952), *op. cit.; Hebron, M. E.* (1957), *op. cit.; Smith,* I. *Macfarlane, cf. Ch.* 7.

DIFFUSIVE ATTENTION	FIXATIVE ATTENTION	REFERENCES
Tendency to Hysteria.	*Tendency to Obsessional Anxiety. Paranoia.*	*Eysenck, H. J.* (1947): Dimensions of Personality.
Placidity.	*Behavioural Alertness.*	*Kelty* (1960), *op. cit.*
Femininity.	*Masculinity.*	*Stephenson, W.* (1949): Testing School Children, *p.* 97. *Smith, I. Macfarlane* (1954), *op. cit.* *Terman, L. and Miles, C.* (1936), *op. cit.*
Low Frequency Alpha Rhythm.	*High Frequency Alpha Rhythm.*	*Walter, R. D. and Yeager, C. L.* (1956), *op. cit.* *Mundy-Castle, A. C.* (1955), *op. cit.*
High Amplitude Alpha Rhythm.	*Low Amplitude Alpha Rhythm.*	*Stewart, C. A. and Macfarlane Smith, I.* (1959), *op. cit.*
High Motor Perseveration Score.	*Low Motor Perseveration Score.*	*Smith, I. Macfarlane, cf. Chapter* 8.
Literary, Historical, Social or Humane Interests.	*Practical, Mechanical, Mathematical or Scientific Interests.*	*Thurstone, L. L.* (1951), *op. cit.* *North, R. D.* (1949), *op. cit.*
	Drawing Interests.	*Peel, E. A.* (1948), *op. cit.*
Field Dependence.	*Field Independence.*	*Witkin, H. A.* et. al. (1954). *Witkin, H. A.* et al. (1962).

Epilogue

There is a striking parallel between the chequered history of research on spatial abilities and the even more controversial history of the exploration of the unconscious. The discovery of the spatial factor, like that of the unconscious, can scarcely be said to have been welcomed by psychologists in general. There was the same tendency first to deny its existence, as occurred in the case of the unconscious, and then to ignore it or to minimize its importance. There was a tendency to place more reliance on the reports of investigators who obtained negative results than on the reports of those who claimed that their findings were positive. When the facts regarding the existence of the factor could no longer be dismissed, it was suggested that the abilities were too amorphous or ill-defined to permit of accurate measurement, or that they had not 'matured' sufficiently to be measurable in pupils of school age.

When tests of demonstrated high reliability and validity were made available, there was a marked reluctance to make practical use of them. It was argued that differences between scores on verbal tests and spatial tests were too small to permit of reliable differentiation in a sufficient number of cases. In this dilemma, verbal tests were invariably preferred to spatial tests, even when selecting pupils for technical or scientific courses. It was pointed out that verbal tests had greater validity for most subjects and in any case it was essential that scientists and technologists should be able to express themselves clearly and intelligibly in words.

It is now apparent that far from being unimportant educationally, spatial abilities are necessary for the successful study of most practical and technical subjects and of the more advanced branches of mathematics, physics and engineering. High spatial ability is essential in most scientific and technological occupations. For these studies and occupations verbal tests do not measure the appropriate abilities at all, and the essay examination may actually have negative validity.

The parallel between verbal and spatial abilities on the one hand and the conscious and unconscious domains of the mind now becomes more striking. The mind has been compared to an iceberg, one-ninth of it being above water and eight-ninths of it below. The conscious mind may be likened to the part above water and the much larger and more dynamic unconscious to the larger part of the iceberg under water.

It is becoming clear to psychologists that in a somewhat similar way, the abilities of the mind are essentially bipolar. For long the position seems to have been held that only the top part of the bipolar iceberg, the verbal part, really mattered and the other, submerged part, the spatial, could be safely ignored. But now it appears that spatial abilities are in some way more fundamental, more basic and dynamic than verbal abilities. High spatial rather than high verbal ability is a prerequisite for success in advanced mathematical and technical courses and is probably essential in many fields of scientific research.

Studies made at the other end of the ability scale, of brain damaged and cerebral palsied children have shown that the gross educational and social disabilities of these children are associated with spatial more than with verbal deficits. The education of these children is a more intractable problem than that of children with purely verbal handicaps. Lack of verbal ability is certainly a handicap in certain occupations, such as that of journalist or preacher, but it is no obstacle to success in many highly technical occupations. There is an increasing tendency for communication to take place by means of formulae, plans, diagrams, blue-prints, models, films and many other devices.

At the present time, there is a developing educational crisis, because of the unsatisfied demand for personnel trained and qualified in all fields in which spatial ability is of fundamental importance. The technical revolution has put a premium on spatial ability at all levels, whether required for tile-laying or for topology. It is strange that in this situation there appears to be some reluctance on the part of educationists to accept the positive evidence for the value of spatial tests for educational guidance and selection; there is certainly tardiness in applying the findings in practice. It is as if this evidence, like that pertaining to the unconscious, relates to a kind of knowledge which is unwelcome to the majority of educationists.

An explanation of this anomaly may perhaps be found by regarding it as a particular instance of a more general phenomenon. Few would deny that the educational system has displayed a remarkable inertia in face of the urgent need for trained technical and scientific manpower brought about by technological change. It is well-known that until comparatively recently the universities in Britain have shown little interest in industry or in scientific research (Ashby, 1959). The industrial revolution took place almost entirely without the help of the universities. An explanation of the inertia of the educational system must be sought in the values which it inculcates; and it is likely that the resistance to spatial tests is at least partly due to a cultural tradition which values verbal abilities more highly than technical abilities. Such a tradition is being perpetuated by the grammar schools which have tended to adopt the values of the great English public schools. Since the latter institutions, like the universities, have tended to meet the needs of an aristocratic and privileged class it is scarcely surprising that they placed a low valuation on technical abilities. Until comparatively recently in their history, the education they provided was appropriate for future administrators, jurists, politicians and clergymen. Like the education favoured by the Romans in the period of the decline of the Empire, there was an overvaluation of fluency of speech and skill in the literary arts (Boyd, 1921).*

The qualities which make for greatness in scientists and engineers are of a different kind; ability to think abstractly and analytically together with skill in visualizing spatial relations in two or three dimensions, and skill in manipulating objects with the hands. All these qualities, which are vitally important in almost all branches of science and engineering, are measured by appropriate tests of spatial ability. These qualities have been largely ignored in the public school system and in only a few instances, as at Oundle, was there any attempt to cultivate them. Since these schools found their inspiration mainly in the classical literature of antiquity, there was little incentive to study spatial or mechanical aptitudes, which were thought to be associated with the occupations of artisans.

It is a remarkable fact, however, that long before the era of industrialism, some of the ancient Greek philosophers had an intuitive appreciation of the importance of spatial abilities. The

* The attitude of a Roman man of letters to technical occupations may perhaps be gleaned from Martial's advice—"Make the fool of the family an architect".

Greeks were undoubtedly highly endowed with these abilities. Described as 'a race of geometers' their achievements in sculpture and architecture have been unequalled for sensitivity to proportion and to design. Plato himself, though an aristocrat of the Greek leisured class and little interested in technology, seems to have realized the importance of spatial ability, for the lintel above the entrance to the Academy bore the inscription:

"Let no one ignorant of geometry enter my door."

This was no idle motto, for it is recorded that the requirement for admission was insisted upon in practice. It seems to have been a screening device, which was essentially a test of spatial ability. Whether or not the device was found to be valid in the experience of the school, Plato's high valuation of geometry was fully justified later when the influence of his school culminated in the brilliant scientific achievements of the Alexandrians as exemplified in the work of Euclid, Archimedes, Apollonius, Hero, Philo, Eratosthenes, Hipparchus and many others.

But it is only in our own day, with the application of factor-analysis to the study of mental abilities, that it has become possible to understand why Plato's screening device should have validity for the successful pursuit of philosophy.

Appendix 1

Scientists and men of letters

THE writer has carried out an experiment to determine whether eminent scientists and men of letters could be classified in one category or the other, with greater than chance success, from an examination of their portraits. A selection of post-card portraits of eminent scientists and men of letters was obtained from the National Portrait Gallery in London. After excluding pictures of men who might be thought to belong to either category (e.g. Benjamin Franklin), 37 cards remained. These were presented by means of an episcope to a class of 81 students in an Education Department. In certain cases, details on the portrait which might have provided a clue to the classification were concealed.

The order of presentation of the portraits was as follows, the classification as scientist or man of letters being indicated by the letter S or L in brackets.

1.	Butler, S.	(L)	17.	Stephenson, G.	(S)
2.	Richardson, S.	(L)	18.	Priestley, J.	(S)
3.	Bunyan, J.	(L)	19.	Steele, R.	(L)
4.	Newton, I.	(S)	20.	Spencer, H.	(S)
5.	Watt, J.	(S)	21.	Faraday, M.	(S)
6.	Marvell, A.	(L)	22.	Harvey, W.	(S)
7.	Arkwright, A.	(S)	23.	Mill, J. S.	(L)
8.	Smeaton, J.	(S)	24.	Trollope, A.	(L)
9.	Boyle, R.	(S)	25.	Herschell, W.	(S)
10.	Hobbes, T.	(L)	26.	Darwin, C.	(S)
11.	Davy, H.	(S)	27.	Boulton, M.	(S)
12.	Gibbon, E.	(L)	28.	Scott, W.	(L)
13.	Southey, R.	(L)	29.	Wren, C.	(S)
14.	Pepys, S.	(L)	30.	Johnson, S.	(L)
15.	Rennie, J.	(S)	31.	Huxley, T. H.	(S)
16.	Thackeray, W. M.	(L)	32.	Boswell, J.	(L)

33. Kelvin, (S)
34. Dryden, J. (L)
35. Lister, (S)
36. James, H. (L)
37. Chesterton, G. K. (L)

Thus, there were 18 portraits of men of letters and 19 of scientists. The students were asked to record on a prepared sheet the letter L or S against the number of the card, according as they considered the portrait to represent a man of letters or a scientist. If they recognized the portrait, they had to write the name of the person on the sheet. If they did not recognize the portrait, they had to give their reasons for classifying as L or S.

The score was the number of portraits classified correctly as L or S minus the number identified by name. Thus the score provided a measure of the ability to classify correctly as L or S a portrait of an unknown person. Of course, this method of scoring penalized the students for being able to identify the portraits by name. Only a very small proportion of the portraits were identified in this way, however. The frequency distribution of the number of portraits recognized by name is shown in Table 46, the categories of students being shown separately, viz. Arts, Science and Fine Art.

Table 46

Frequency distribution of numbers of portraits of men of letters and scientists identified by name by three groups of students

NO. OF PORTRAITS RECOGNIZED BY NAME	FREQUENCY			TOTAL FREQUENCY
	ARTS	SCIENCE	FINE ART	
0	12	17	4	33
1	7	9	7	23
2	7	2	4	13
3	2	0	1	3
4	2	1	0	3
5	0	0	0	0
6	4	0	0	4
7	2	0	0	2
Totals	36	29	16	81

Thirty-three students, i.e. 41 per cent, recognized none of the portraits by name. The highest number of correct identifications by name was seven, and this was obtained by two history students. Arts students in general were better at recognizing the portraits than the others. The science students did relatively badly, the median number of portraits recognized by them being zero. Four honours graduates in mathematics recognized none of the portraits, though they included well-known pictures of scientists such as Newton, Faraday, Boyle, Priestley and Kelvin. Five honours graduates in biology or botany recognized none of the portraits though Darwin, Huxley and Harvey were represented. The average number of portraits recognized by name for all students was only 1·333.

The average number of unrecognized portraits correctly classified as L or S was 19·74, compared with a mean chance expectation of 17·83 $\left(\text{i.e. } \frac{37 - 1{\cdot}333}{2}\right)$. Thus, the ability of the students to classify portraits of unknown persons as L or S was significantly greater than chance expectation, the difference being 1·91.

The probability of this difference occurring by chance is less than ·01 ($t = 4{\cdot}86 > 2{\cdot}75$ for $N - 1 = 80$).

In attempting to interpret this result, it is important to bear in mind the fact that none of the students had attended lectures on typology while in the Education Department, though one student actually used the word 'pyknic' in referring to one of the portraits.

It might be argued that the significant difference between the obtained mean score and the score expected by chance might be due to the influence of unconscious association. The students may have seen portraits of men of science in textbooks or displayed in a science laboratory and may have formed associations which helped them to classify the portraits of the scientists without being able to identify them by name. That this explanation may be partly true is suggested by some of the reasons given for choices, e.g. "vaguely familiar", "looks like an illustration in a 19th century scientific book". In some cases, however, these vague associations gave rise to wrong identifications or classifications. The vague association theory does not account for the remarkable measure of agreement between the descriptive terms used by the students in explaining why they assigned portraits to either class.

Some students actually formulated clear-cut principles for classifying the portraits. For example, the student who obtained the highest score (28) wrote:

"Rightly or wrongly, I began to associate tight lips with scientists and sensitive lips with men of letters." It is remarkable that from card No. 22 onwards every classification made by this student was correct. Another student who obtained the superior score 23 wrote: "All technical types had a sharp critical look, which was absent in the literary types." A woman student with a score of 20 wrote: "The mouth is a good indication. Those with tight lips and firm jaw are technical. Those with a long, oval face are literary. Those with angular or square heads are usually technical. Those with a 'far-away' look in the eyes are literary." A fine-art student with a score of 24 wrote: "The more carefully and splendidly dressed are literary." A woman student who obtained the low score of 14 stated that she was guided principally by the factor of sympathy as revealed in the face. "Lack of sympathy, or acuteness as revealed in the eyes, indicated the scientist." Thus, students who based their choice on objective indications, such as physique or style of dress, appeared to make more correct classifications than those who tried to interpret the feelings portrayed in the faces.

When a composite picture is constructed from the adjectives and other descriptive terms employed by students to indicate their reasons for classifying as L or S, a well-defined stereotype emerges. Seven students used the word "sensitive" to describe men of letters, and six used one or other of the terms "penetrating, piercing or keen" to describe the eyes of typical scientists (cf. Table 47).

Each of the above descriptive terms was used by at least one student. If the same (or a very similar) expression was used by more than one student, the number of students who used it is shown in brackets.

Thus there was a general tendency shown in about half of the completed questionnaires to picture the typical scientist as "thin-faced, tight-lipped with keen, penetrating eyes", to have a hard, firm, determined, severe expression and to be cold, unsympathetic and withdrawn in temperament. The corresponding picture of the typical literary man was full-lipped, fat, possibly feminine, with a soft, expressive mouth and a warm-hearted, kindly, temperament, either witty and jolly or meditative and soulful.

There is a remarkable similarity between these contrasting composite pictures and the descriptions of the standard schizothymic and cyclothymic types as portrayed by Kretschmer. Schizothymes are

Table 47

Composite picture constructed from descriptive terms given by students to indicate their reasons for classifying portraits as scientific or literary

SCIENTIST	MAN OF LETTERS
Sharp, Critical, Severe, Stern Look (7)	*Sensitive* (7)
Penetrating, Piercing, Keen Eyes (6)	*Dreamy Expression* (5)
Thin Lips or Face (3)	*Sensuous Lips or Face* (5)
Determined Lips or Face (2)	*Feminine Face* (3)
Small or Tight Mouth (2)	*Full Lips and Expressive Eyes* (2)
Set Look, Determined Eye-brows	*Delicate Face* (2)
Firmness of Features	*Flabby Face* (2)
Cruel, Suspicious Eyes	*Sympathetic Eyes* (2)
Piercing, Keen Gaze (2)	*Kindly Appearance*
Withdrawn, Remote (2)	*Warm-hearted; Sensitive Hands*
Expression of Concentration (2)	*Meditative, Soulful*
Unrelenting, Calculating (2)	*Flamboyant* (2)
Shrewd Expression (2)	*Well-fed* (2)
Recessive, Enquiring Eyes	*Large Eyes, Broad Nose*
Hard, Firm, Penetrating Expression	*Softness of Mouth*
Strong Chin, Set Mouth, Broad Brows	*Expressive Mouth*
Knit Brows, Drawn Face	*Full, Expressive Face*
Dispassionate, Matter of Fact Expression	*Soft, Romantic, Whimsical*
Puritanical, Bitter	*Over-indulgent, Dissipated*
Cold, Abstract Look	*Witty, Jolly, Mobile*
Unsympathetic, Austere	*Genteel, Elegant, Languid*
Narrow, Unimaginative View	*Cynical, Sophisticated*
Practical, Commercial	*Connoisseur*
Severity of Dress	*Dandified Clothes, Flowing Robes, Pompous*
Lack of Ornamentation	*Foppish, Frills, Striped Waistcoat*

pictured as lean, with narrow faces and sharply cut features and the following temperamental qualities—unsociable, serious, humourless, severe, aloof, suspicious, cool, harsh, reticent, misanthropic, calm, cold, calculating, self-centred, shut-in, fanatical.

Cyclothymes, on the other hand, are usually portrayed as round-bodied, "tubby", broad-headed, full faced, mobile, "comfortable", with the following qualities—sociable, good mixer, lively, sprightly, quietly humorous, emotional, understanding, tender-hearted, kindly, soft, alternating between cheerful and sad.

No doubt the students' conceptions of typical scientists and literary men are based in part on stereotypes which may have been acquired from literature in which scientists and literary men are cast in these steretoypes. But one may ask, "How did the stereotypes originate in the first place?"

That there are genuine differences between the physical characteristics of persons with different intellectual abilities and interests has been shown by Parnell (1953). He found that among university students, different types of physique (somatotypes) tend to be associated with preferences for particular faculties. Thus, there was a tendency for the linear (or lean) type of physique to predominate among students taking courses in mathematics or physics, for the muscular type to predominate in mechanical engineering and mining and for the fat or pyknic type to predominate among those taking chemistry or law. These findings are reasonably consistent with what is known about the personality correlates of spatial and verbal ability. The fact that a large proportion of those taking subjects like English and history were ectomorphic may perhaps be accounted for by supposing that the asocial tendency of the ectomorph predisposes him to habits of extensive reading.

The relationship between personality and physique observed by Sheldon among adults has also been found to exist in children of seven. Davidson, McInnes and Parnell (1957) administered a number of tests to a sample of one hundred seven-year-old children who had also been classified as to type of physique by a modification of Sheldon's methods. It was found that endomorphs of either sex obtained the highest scores on the (largely verbal) Standford-Binet Intelligence Test, a result which might be due to the superior verbal ability of the endomorph. On the other hand, ectomorphs were by far the best readers as judged by the Schonell Graded Reading Test. They still appeared to do best when the influence of intelligence on reading level was eliminated. The investigators suggested that this was because the ectomorphs were putting more drive into acquiring reading skill than the endomorphs or mesomorphs. They drew the general conclusion that the 11-plus examination must favour ectomorphs rather than endomorphs or mesomorphs because it calls for essentially verbal rather than practical ability. A possible alternative partial explanation is that ectomorphs did better not so much because they possess superior verbal ability, but because they have greater drive (due perhaps to greater anxiety).

Unfortunately it does not follow that spatially gifted pupils have a better chance of being admitted to selective courses of secondary education by means of the conventional 11-plus examination. The successful candidates are likely to be those who do well in the standard tests of verbal, English and arithmetic abilities.

As we have shown in the factor-analysis of the Carlisle data (Chapter Five), pupils who were very *high* in factor II (the academic/practical factor) did very well in the verbal, English and arithmetic tests. These were given very low ratings by their teachers for practical work and drawing, and were considered to be both unsociable and emotionally unstable. Presumably these pupils correspond to Furneaux's 'neurotic introverts' (Eysenck's dysthymics) who may succeed in the 11 plus examination either because of greater verbal ability or because of greater drive.

The pupils who were *low* in factor III, however, (the verbal/spatial factor) did very well in the spatial tests, were superior in the arithmetic tests, did less well in the verbal tests and very badly in the English tests. These pupils, relatively lacking in verbal ability and more especially in verbal *fluency*, received low ratings for sociability and moderate ratings for emotional stability. It should be noted that they received much less favourable ratings for practical work and drawing than the pupils who were *low* in factor II.

There can be little doubt, therefore, that the conventional selection battery of verbal, English and arithmetic tests is strongly biassed both against pupils with high spatial ability and those with high practical interests. The former may correspond to the unsociable schizothyme whose spatial ability is high relative to verbal ability and who performs well in arithmetic and badly in English. The latter corresponds to a type who is both sociable and emotionally stable. He may be the stable extravert with muscular physique, found by Venables to give low N and high E scores on the M.P.I. questionnaire and who tends to predominate among engineering apprentices. He also has higher spatial than verbal ability but his all-round academic achievement tends to be low.

Appendix 2

Personality traits of artists, architects, engineers, mathematicians and physicists

IF the hypothesis that there is an association between high spatial ability and certain personality qualities is well-founded, we should expect to find such qualities in individuals who have demonstrated by their achievements that they possessed high spatial ability. Our researches suggest that typical qualities would be emotional stability, schizothymia, desurgency, masculinity, initiative, self-sufficiency and reflectiveness. It would not be unreasonable to expect to find references to such qualities in biographies of eminent artists, architects, caricaturists, mathematicians, physicists and engineers. It is unlikely that such men would have achieved distinction in their chosen profession, if they had not been gifted with outstanding spatial ability. A further indication of high spatial ability would be any evidence that they exhibited precocious drawing ability or a pronounced aptitude for, or interest in, geometry. Since spatial ability is often accompanied by mechanical interests, a further pointer would be evidence of skill or interest, at an early age, in the construction of mechanical toys or models.

Many famous mathematicians, such as Newton, Pascal and Monge, are reported to have shown such interests in childhood. The observation made by Kretschmer that most eminent mathematicians and physicists have been men of schizothyme temperament tends to confirm the view that successful study of mathematics and physics requires a high degree of spatial ability. Kretschmer also has noted that most of the famous mathematicians of history have manifested marked schizoid physical characteristics, e.g. Copernicus, Napier, Kepler, Leibniz and Newton. Some of the most eminent mathematicians of the present century have been men of schizothyme temperament, e.g. Einstein, Eddington, Hardy and Russell. According to Möbius (1907), the majority of mathematicians or mathematical physicists have been nervous, displaying many peculiar and eccentric traits. The mental disturbances of Pascal, the elder and younger Bolyai, Cardan, Newton, Mayer,* Ampère and Faraday were sufficiently unusual as now to be regarded as indicative of schizoid or schizophrenic tendencies (cf. Lombroso,† 1891; Kretschmer, 1931).

We might expect to find similar traits among artists, particularly among those who showed exceptional skill in the portrayal of form (e.g. Gainsborough, Dürer). We should not expect to find these tendencies to the same extent in artists whose reputation depended more on the treatment of colour effects than on the portrayal of form (e.g. Matisse, Dufy). Kretschmer has observed that the art of typical schizothymes shows a marked preference for classical beauty of form (e.g. Feuerbach) and a tendency to portray extreme tragic pathos (e.g. Michelangelo, Grünewald). Modern movements in art such as impressionism, cubism, surrealism and abstract art, are held by him to be symptomatic of the schizoid personality.

It is a remarkable fact that many artists and architects have shown themselves possessed of unusually strong motivation and drive. A frequent characteristic of artists, which is typically schizoid, is unswerving devotion to art to the exclusion of all other interests. Among architects, Wren and Pugin displayed extraordinary industry and energy in addition to great natural ability. Some artists have shown great strength of will, indomitable energy, and a conviction of their powers which was not always justified by the facts. This was true of Benjamin Haydon (1786–1846) who had a life-long struggle with debt and opposition and who died by his own hand.

That aptitudes for art, mathematics and engineering may be related manifestations of the same factor is suggested by the fact that it is not unusual to find outstanding artistic gifts in persons coming from families of engineers or mathematicians. Several of the brothers of Thomas Gainsborough were noted for their interest and skill in engineering, and Gainsborough himself had marked mechanical ability. Nasmyth, the inventor of the steam-hammer, was the grandson of a brilliant architect and the son of a talented artist noted for his portrait of Robert Burns. Whistler came of a family of engineers and there was

* The scientist J. R. Mayer was detained for thirteen months in a sanitorium, which he had entered voluntarily. His stay was prolonged because he was thought to need treatment for megalomania since he imagined himself to have made a discovery which he had not really made. In fact Mayer was the discoverer of, and first to announce, the important general principle of the conservation of energy (Lenard, 1933).

† Lombroso has given a very detailed account

mathematical ability in the family which produced Sir Joshua Reynolds and Charles Wellington Furse. Sometimes mathematical and artistic aptitudes are shown in the same person, as in the cases of Dürer, Da Vinci, Brunelleschi, Piero Della Francesca, and Wren. Fulton and Morse were painters as well as inventors.

It has often been observed that engineers as a class show characteristic qualities of physique and personality. Frequently they are tall and thin or tall and muscular and show remarkable vigour, enterprise and planning ability.* Sometimes they have exceptional gifts for leadership and organization and may become captains of industry (e.g. Ford, Morris, Krupp, Parsons, Hinton). As already mentioned, Galton believed that the foremost engineers "are possessed of singular powers of physical endurance and of boldness, combined with clear views of what can and cannot be effected". These characteristics are consistent with the finding that engineers tend to score high on tests of masculinity, and that high spatial ability tends to be associated with qualities such as initiative, vigour and forcefulness.

The following instances may be cited of eminence in engineering occurring in association with leptosomatic or athletic physique and schizothymic personality traits—Watt, Stephenson, G., Murdock, Trevithick, Ford, Morris (Lord Nuffield), Parsons and Hinton. To this list may be added the names of inventors such as Marconi, Fulton, Friese-Greene, Tesla, Baird and possibly Edison. The characteristic tendency of inventors to make it possible for others to accumulate fortunes while themselves dying in poverty may be partly due to a schizoid tendency to pursue an idea to the neglect of all other interests

* Venables (1963) found that the distribution of phenotype dominance among her engineering apprentices differed from that for University students, the deviations being very highly significant. Relatively to the University students, the apprentices showed a marked preponderance of mesomorph (muscular) somatotypes and a marked deficiency of endomorphs (fat). Parnell (1953) found a high proportion of muscular somatotypes among engineering and mining students.

Among the many examples which might to be quoted of eminence in engineering being associated with tall and well-developed physique we might mention Trevithick, Murdock and Hinton. Trevithick was said to be over 6 ft. 2 ins. in height and was noted as a wrestler and weight-lifter. Murdock was "a big, quiet, meditative and powerfully built Scot, who loved deeds rather than words". In our own day, Sir Christopher Hinton, engineer and pioneer in the development of atomic energy, is a giant in more senses than one. He is 6 ft. 6 ins. in height with facial characteristics which are long in proportion. Piccard, engineer and intrepid explorer of the stratosphere, was 6 ft. 3 in. in height.

(e.g. Papin, Symington, Crompton, Trevithick, Friese-Greene, Goodyear).*

Galton gives as instances of inherited talent for engineering the families of Watt, Stephenson, Brunel and the curious family of engineers and architects called Mylne, which went back for nine, if not twelve, generations—all able and many eminent in their professions.

Havelock Ellis (1904) found that there was a very notable predominance of craftsmen in the parentage of painters, to such an extent indeed that while craftsmen only constituted 9·2 per cent among the fathers of his group of eminent persons generally, they constituted nearly 35 per cent among the fathers of the painters and sculptors. It is difficult to avoid the conclusion, therefore, that there is a real connection between the father's aptitude for craftsmanship and the son's aptitude for art. To suppose that environment adequately accounts for this relationship is an inadmissible theory.

Ellis has also obtained some interesting data on the pigmentation (hair-colour and eye-colour) of different intellectual groups among men of genius. Classifying these groups according to an index of pigmentation, he found that men of science and painters, sculptors and architects tended to be fair, whereas men and women of letters and divines tended to be dark. These results were consistent with those obtained in another enquiry as to the index of pigmentation of all the persons whose portraits are to be seen in the National Portrait Gallery. In this case eye-colour was the primary basis of classification.

The mean indices for four groups were as follows:

Table 48

Mean index of pigmentation (eye-colour) of four groups of persons whose portraits appear in the National Portrait Gallery (Havelock Ellis)

GROUP	NUMBER OF INDIVIDUALS	INDEX OF PIGMENTATION
Men of Science	53	121
Artists	74	111
Men and Women of Letters	87	85
Divines	57	58

* Papin, Symington and Trevithick died destitute, Crompton left assets of £25, Friese-Greene and Goodyear were in financial difficulties for most of their lives, the latter being in debt to the extent of $200,000 at the time of his death.

In this table, a high index of pigmentation indicates that the eyes tended to be unpigmented (i.e. blue).

While it is probably true that the majority of scientists and technologists tend to be of schizothymic temperament, it would be incorrect to suppose that this would be a characteristic of scientists in general. It is not difficult to cite examples of men of cyclothymic temperament who have achieved scientific eminence. There are reasons for believing, however, that the scientific achievements of persons of the two main temperamental types have their characteristic excellences and defects.

Kretschmer held that the works of men of cyclothymic temperament show evidence of extreme versatility, of a tendency to cover a wide province of knowledge, of a preference for empiricism and observation, of a distrust of systematization and philosophical speculation and of an inclination to the easy popularization of knowledge. The diffusive habit of attention, taking in the details of the surroundings in a sweeping glance, results in an observant empiricism which would be particularly valuable in biology, chemistry and medicine. Kretschmer cites many examples of men of cyclothymic temperament who distinguished themselves in these sciences, in which spatial ability is likely to be relatively less important.

The scientific productions of schizothymes show quite different characteristics. According to Kretschmer, these are fondness for systematization, for formalism and for philosophical and metaphysical speculation. We should expect that the systematic and abstractive habit of thought of the schizothyme would be well suited to studies of the mathematical type. Kretschmer has suggested, moreover, that the schizothymic habit of 'fixating' attention, of mobilizing and maintaining mental energy at a single point, is more likely to bring about sudden advances. If this is the reason why most great revolutions in science—from Copernicus to Einstein—have been initiated by men of schizothymic temperament, there would seem to be a strong case for deploying schizothymes along the front line of scientific research.

If the contrast between verbal and spatial abilities is related to differences in type of imagery and to other constitutional characteristics, the distinction must be of a rather fundamental kind. It may be that herein is the root of the difference between the humanist and the scientist, between the literary person skilled in the use of words and the technologist who thinks in terms of blue-prints and diagrams. The view that such differences are basically constitutional need not be regarded as inconsistent with a belief that the "two cultures" (Snow,* 1959), of which so much has been said and written, are largely a reflection of differences in training and in educational background. Such acquired differences would in themselves be quite sufficient to account for a failure of communication between scientists and non-scientists.

It has been argued, however, that this lack of understanding is much more complete than that which exists between scientists themselves when trained in quite unrelated disciplines, such as bacteriology and nuclear physics. It is possible that the subtle differences in personality, temperament and interests which have been found to be associated with verbal and spatial abilities, and which are not primarily the result of training, may make for misunderstanding and intolerance. Grey Walter (1953) has described the difficulties of an imaginary couple. Peggy and Michael, who have different types of imagery, Peggy being an extreme persistent P-type and Michael an alphaless M-type. Because of their different ways of thinking, they react very differently to any new situation. Grey Walter suggests that when two people display unreasonable and irreconcilable differences of approach to a question, a difference in their ways of thinking may be the cause. Discussion between an alphaless M and a persistent P is usually fruitless and often acrimonious. Communication between them might be easier through an intermediary of the R-type, who can use both ways of thinking when necessary.

Such differences are almost certainly constitutional rather than cultural, since the same tendencies are found to run in families. It is known, for example, that the verbal fluency factor is associated with extraverted or cycloid traits which tend to be associated with a characteristic type of physique. It is not difficult to find examples of men of letters of plump physique who showed marked verbal facility, both in speech and in writing, e.g. Dr. Samuel Johnson, Sydney Smith and G. K. Chesterton.†

Johnson acquired a position in the literary circles of his day that has

* Snow's insight may have resulted from the circumstance that he is by training a physical scientist but by inclination (and perhaps by constitution) a man of letters.

† It is perhaps necessary in this connection to distinguish between fluency in speech and fluency in writing. Rogers (1952) applied a number of fluency tests to a group of 14-year-olds and obtained personality ratings. He found that the oral fluency tests showed some relation to surgent personality traits but the written fluency tests did not. It is not difficult to find examples of men of schizothymic temperament who lacked verbal fluency and yet who wrote clearly and even

rewarded the efforts of no other man. He became the acknowledged dictator of 'The Club', founded by himself and Sir Joshua Reynolds and numbering among its membership most of the literary figures of the period. His witty, dogmatic style of conversation has been made familiar by Boswell. Sydney Smith had also the reputation of being the wittiest man of his day. His conversation was brilliant and he became a popular figure in society.* G. K. Chesterton was regarded as a fountain of brilliant paradox. For thirty years he wrote the Notebook page of the *Illustrated London News*—an astonishing feat for any journalist. Prose and verse flowed unceasingly from his pen.

All three of these men were markedly pyknic in physique, and Chesterton's case suggests that wit and verbal fluency are proportional to corpulence! Chesterton was wont to remark that when he offered his seat in a tram, he usually found that he had offered it to three ladies! An extreme example of verbal inventiveness is found in the writing of Rabelais, whose language has been described as "a verbal feast of metaphors, neologisms, latinisms, synonyms and proverbs jumbled together in indigestible confusion".† Pyknic physique also seems to be associated with exceptional powers of mimicry, as in the case of Ustinov, possibly because of a link with superior auditory imagery.‡

Verbal fluency, however, is a trait which seems to be noticeably lacking in many mathematicians. Numerous references could be

brilliantly (e.g. Eddington). But for the best examples of fluency in writing we must turn to pyknic cyclothymes, such as Balzac who wrote 85 novels and much else in 20 years or, on a lower level, Edgar Wallace, who wrote some 150 novels in the same space of time.

* The mutual antipathy which existed between Sydney Smith and Sir Humphrey Davy may serve as a reminder that the phenomenon of the 'two cultures' is not peculiar to our own generation. Sydney Smith described Davy as a "very foolish coxcomb out of his crucibles" while Davy dubbed Smith as "an affable jester concealed under the gown of the sacred minister of religion".

† *Everyman's Encyclopaedia* (1949), 3rd edition, London, Dent.

‡ It should be particularly noted that the writer is not advancing the theory that all men of letters are pyknic or cyclothymic. The tragic genius of Thomas Hardy was typically schizothymic. But Hardy must have been well endowed with spatial ability, since he won several prizes at the Royal Institution of British Architects. R. L. Stevenson was another schizothymic novelist, who may well have been spatially gifted, for the vividness of his writing seems to have owed much to his dream imagery (his 'fairies'). Stevenson came of a Scottish family of engineers, his father, grandfather and uncle being noted for lighthouse construction and other engineering projects.

quoted to illustrate this contention. In Isaac Barrow's Mathematical Lectures (London, 1734) it is suggested that to say that a person is an accomplished mathematician implies that he will be a most wretched orator. Sylvester made a somewhat similar assertion in his Baltimore Address (Mathematical Papers, Vol. 3).

"I know, indeed, and can conceive of no pursuit so antagonistic to the cultivation of the oratical faculty.... as the study of Mathematics. An eloquent mathematician must, from the nature of things, ever remain as rare a phenomenon as a talking fish, and it is certain that the more anyone gives himself up to the study of oratorical effect the less will he find himself in a fit state to mathematicize.... When called upon to speak in public (the mathematician) feels as a man might do who has passed all his life in peering through a microscope, and is suddenly called upon to take charge of an astronomical observatory. He has to get out of himself, as it were, and change the habitual focus of his vision."

Verbal fluency, rather than a knowledge of vocabulary, seems to be the quality which is most often lacking, for some eminent mathematicians have shown a remarkable ability for acquiring a knowledge of languages (e.g. W. R. Hamilton, H. G. Grassman, W. K. Clifford).

Galton observed a lack of verbal fluency in himself and he certainly possessed mathematical ability, though he found the work for an honours degree in Mathematics at Cambridge at once too exacting and too dull. (He suffered severely from nervous strain and finally contented himself with a Poll degree.) Referring to his lack of verbal fluency he wrote:

"I waste a vast deal of time in seeking for appropriate words and phrases and am conscious, when required to speak on a sudden, of being often very obscure through mere verbal maladroitness, and not through want of clearness of perception. That is one of the small annoyances of my life."

The mathematician Hadamard (1945) quoted Galton's statement in full because, he says, in Galton's case he recognized his own. He states that he also experiences the rather regrettable consequence mentioned by Galton. Just as for Galton, translation from thought to language always required on his part a rather difficult effort. As tangible proof he makes the significant admission that it is difficult for him to deliver a lecture on anything but mathematical subjects without having written down practically every part of it, the only means of avoiding constant and painful hesitation in the expression of thought which is very clear in his mind. Hadamard is emphatic that words are totally absent from his mind when he really thinks and he completely aligns his case with Galton's.

The answers he received to the questionnaire he sent to mathematicians showed that their mental pictures were most frequently visual, though they might also be kinetic (kinaesthetic?) The eminent mathematician, George D. Birkhoff, for example, stated that he was accustomed to visualize algebraic symbols and to work with them mentally. Einstein used imagery which was mainly visual but might be muscular (kinaesthetic?), but words or language played no part at all. Wiener could think either with or without words. J. Douglas generally thought without words or algebraic signs.

G. Polya found that a word, the right word, could help to fix a mathematical idea in mind and that a proper notation could give him similar help. For B. O. Koopman, "images had a symbolic, rather than a diagrammatic, relation to the mathematical ideas."

According to Hadamard, the mathematicians Riemann, Klein, Bertrand and Hilbert had pronounced spatial intuition. In Hilbert's *Principles of Geometry*, diagrams appear on practically every page. Weierstrass, on the other hand, tended to avoid the use of figures. Poincaré has contrasted Weierstrass with Riemann describing the former as typically logical and the latter as typically intuitive. Hermite was remarkable in that he had a kind of positive hatred of geometry and yet had a highly intuitive mind.

Among the characteristics which from time to time have been attributed to mathematicians are a fondness for chess and music, a preference for Anglo-Catholic tenets in religion and a tendency to be disappointed with marriage (cf. Flemming, 1955). We might attempt to account for these hypothetical associations on the theory that mathematical ability is related both to spatial ability and to schizothymia. High spatial ability would account for an aptitude for chess. Zerbe (1929) claimed that chess demands high dissociative ability (*spaltung*) and found that it is played more frequently by leptosomatics than by athletics or pyknics. (Among students 74 per cent of leptosomatics, 53 per cent of athletics and 33 per cent of pyknics were found to play chess). There may be some connection between exceptional talent for chess and mental illness, for at least four brilliant chess players had severe breakdowns (Paul Morphy, Rubinstein, Steinitz and Torre).

Conceivably high spatial ability might be conducive to a fondness for classical music since it might assist in the appreciation of musical patterns of tone and rhythm. The mystical element sometimes found in the schizothyme temperament might be responsible for a preference for ritual and symbolism while the tendency to be withdrawn and unsociable might well be a source of unhappiness in marriage.

There seems to be a tendency towards pyknic physique among musicians, who might be expected to have exceptional auditory imagery. There is clear evidence of a tendency both for the ability and the physique to be inherited, as is exemplified in the Bach family. Beethoven, who was of short, stocky build, must have possessed remarkably strong auditory imagery, for some of his finest works were composed after he became totally deaf.

There is a striking contrast between the most characteristic temperamental qualities of men of letters and musicians on the one hand and the corresponding qualities of engineers, physicists and mathematicians on the other. Vigorous, masculine personalities such as Stephenson, Watt, Henry Ford and Marconi tended to lack sociability, humour and humane feeling. The contrast between a comfortable, humane, literary figure like G. K. Chesterton and an uncompromising, left-wing scientist such as J. D. Bernal or P. M. S. Blackett has prompted one wag to suggest that v/k seems to stand for Vatican/Kremlin!

The two main personality types also seem to be at opposite poles with regard to artistic appreciation and even to taste in dress (cf. Eysenck, 1941). The fat, rounded extravert tends to prefer brightly coloured, modern pictures, while the tall thin introvert tends to prefer a more old-fashioned picture in which shapes and forms are represented with due regard to proportion and balance. It is the latter, of course, who has relatively high spatial ability. Here we have a contrast between two types of artist, those who excel in colour and those who excel in form. It is the familiar contrast "between the Dionysian and the Apollonian, between the Venetian and Florentine, between the Romanticist and Classicist, between Titian and Raphael, between Rubens and Poussin, between Matisse and Picasso." The artists who were also mathematicians, such as Leonardo da Vinci, Albrecht Dürer and Sir Christopher Wren, belonged to the latter class.

It is sometimes argued that many men of letters of cyclothymic temperament have shown exceptional talent for sketching and must therefore have had a high endowment of spatial ability as well as of verbal ability. G. K. Chesterton and Max Beerbohm are given as instances. It is doubtful, however, if these are really exceptions to the rule that high spatial ability tends to be associated with marked schizothymic traits. Though Chesterton spent some years at the Slade Art School, apparently he never learned to draw or to paint and he was the despair of his teachers. As for Beerbohm, it has been said that while his drawings were carefully executed and were always highly amusing, "he could not draw at all in the ordinary sense."

One can be a successful comic artist without having the spatial ability essential to the caricaturist who must produce a recognizable likeness. The caricaturist must be able to distort characteristic details while still preserving an essential likeness. Such a tendency seems to occur automatically in certain pyschotic states. Accounts of experiences under the influence of drugs such as mescalin suggest that these might be helpful to the caricaturist. Mayer-Gross has given the following account of the kind of distortions which may occur:

"There were also visual hallucinations unconnected with my conscious thinking, especially friendly animals, little demons and dwarfs, fairy-tale ornaments and mythology from the aquarium, such as one sometimes sees on the walls of inns. The faces of people around me were slightly distorted as if drawn by a cartoonist, often with the emphasis on some small humorous, but nevertheless, rather characteristic feature" (Mayer-Gross, 1951).

Since the mental disturbances of psychotics such as schizophrenics seem to correspond rather closely to those which occur under the influence of mescalin, one might expect to find that persons with tendencies to schizophrenia might have an aptitude for caricature. Gillray and Lear may provide examples of such an association.

Huxley (1954) has suggested that the taker of mescalin experiences much more than an altered mode of perception. He receives "what Catholic theologians call a gratuitous grace". In Huxley's view the most valuable effect of the drug is the production through direct perception of an intuitive awareness and understanding which transcends the knowledge acquired through the medium of words.

Goethe, who was a supreme master of language as well as a talented painter, seemed to be aware of this possibility when he wrote, "We talk far too much. We should talk less and draw more. I personally should like to renounce speech altogether and, like organic Nature, communicate everything I have to say in sketches."

Most visualizers seem to be transformed by mescalin into visionaries, and in this state they seem to have something in common with schizothymic painters like Blake and El Greco, who were able to communicate a knowledge and awareness through their paintings more significant than anything they expressed in words. Huxley noted in his mescalin experiment, as have many others, that both form and colour took on a heightened significance. This observation accords with the fact that, while most schizothymic artists excelled in form rather than in colour, some of those at the extreme end of the temperament continuum seemed to excel *both* in form and in colour (e.g. Van Gogh).

Appendix 3

Some schizothymic artists and architects

THE following list includes the names of some artists and architects who appear to have exhibited high spatial ability together with well-marked schizothymic or schizoid traits (as far as could be judged from biographical accounts or from portraits).

ARTISTS		ARCHITECTS
Barry	Keene	Gropius
Bawden	Klee	Jones, Inigo
Beardsley	Landseer	Le Corbusier
Bernini	Lear	Mackintosh
Blake	Lowry	Nervi
Braque	Michelangelo	Pugin
Cézanne	Millais	Rohe, Mies van der
Chagall	Minton	Saarinen
Da Vinci	Modigliani	Wren
Dégas	Morland	Wright, F. Lloyd
Delacroix	Murillo	
Dürer	Palmer	
Ernst	Pasmore	
Feuerbach	Picasso	
Flaxman	Piper	
Fuseli	Pollock	
Gainsborough	Renoir	
Gaudier-Brzeska	Reynolds	
Gauguin	Romney	
Géricault	Rossetti	
Gillray	Sutherland	
Giotto	Toulouse-Lautrec	
Goya	Turner	
Greco	Van Dyck	
Grünewald	Van Gogh	
Haydon	Watteau	
Kandinsky	Whistler	

Notes on some schizothymic artists

BARRY, J. (1741–1806) An Irish painter, who showed a decided aptitude for drawing at an early age and who became an R.A. at the age of 32. His portraits are very fine.

His undoubted genius and loftiness of mind were accompanied by a fiery and turbulent nature. He lost his appointment as Professor of painting at the R.A. because of his bitter attacks on his fellow members.

He was a bigoted Roman Catholic, cared little for the society of his fellow men and lived alone in a wretched house, where he died in great poverty and squalor.

BEARDSLEY, A. V. (1872–98). English artist, who early showed remarkable drawing ability and achieved fame by the age of 21. All his work bears the stamp of the schizoid, its bizarre, dream-like qualities and meticulous detail being very striking. His drawings were delicate and exact and were characterized by fastidious elegance.

His fondness for portraying hermaphrodite figures is a typical schizoid symptom. Lean in physique, his deportment was awkward and sloppy. He died at the early age of 26 of tuberculosis—a typically schizothymic disease.

BERNINI, G. L. (1598–1680). Italian sculptor, painter and architect. He had enormous architectural commissions in and around St. Peter's and the Vatican in Rome. On no city has one man left a stronger imprint of his vision and personality. Bernini was a man of difficult and stormy character, but of deep piety who regularly practised the Jesuit spiritual exercises.

BLAKE, W. (1757–1827). English artist and poet, who early showed a pronounced aptitude for art and was sent to a drawing school at the age of 10. His visionary experiences were undoubtably schizophrenic in character.

Though of pyknic physique and only five feet in height, he constructed a mystical vision in both poetry and art which was typically schizoid.

BRAQUE, G. (1882–1963). French painter, sculptor and etcher. He was a leader of the Cubists. His work shows a perfection of balance and harmony between the colour and design.

DA VINCI, L. (1452–1519). was great as painter, sculptor, engineer, architect, scientist and inventor. From his earliest years he showed the greatest promise in many vocations requiring a high degree of spatial ability.

The fact that he never married and that there is no record of his having had a love affair, suggests the presence of a strong schizothymic component in his make-up.

DÜRER, A. (1471–1528), was famous as a painter, engineer and mathematician. His self-portrait painted at the age of 26 shows that he had a lean, asthenic physique. He is said to have been consumptive.

ERNST, M. (1881–), introduced the Dadaist movement in Cologne in 1919 and became a Surrealist in 1924. He has written that after having a hypnagogic vision which led him to 'explore' the symbolism, he succeeded "in being present as a spectator. . . . I had only to reproduce obediently what made itself visible within me" (Ghiselin, 1955).

FEUERBACH, A. (1829–80). Recognized as the leading painter of the German classic school. According to Kretschmer his work has the characteristics of the typical schizothyme, showing a marked preference for classical beauty of form.

FLAXMAN, J. (1755–1826), was sickly and slightly deformed as a boy. Always drawing, he became a precocious exhibitor and prize-winner. His genius was exclusively for form. A believer in Swedenborgian mysticism, he held stubborn and eccentric religious views.

FUSELI, H. (1742–1825), An artist whose paintings testify to his vivid imagination. It is reported that he ate pork for dinner in order to produce material for his nightmarish pictures. His art shows distortions and stylizations of form. There are many anecdotes of his eccentricities and sarcasms.

GAINSBOROUGH, T. (1727–88), called the father of modern English painting. It has been said that his natural gifts were as prodigious as those of Mozart. By the age of 10 he had "sketched every fine tree and picturesque cottage".

Gainsborough approximated to the popular conception of a painter as a Bohemian. Touchy and sensitive, he was always ready to pick a quarrel. He did as he pleased in company, and liked from time to time to get drunk among actors and musicians. He had marked schizoid tendencies (Russell, 1944), and his two daughters became insane.

GAUDIER-BRZESKA, H. (1891–1915), a sculptor, killed in the First World War. He is a very good example of a schizoid artist. Apparently normal in his youth, he seemed to deteriorate later and lived in the utmost poverty and filth. He produced a few works of art, stone carvings and drawings of animals, which show exquisite taste and remarkable workmanship, e.g. his 'Chanteuse Triste' in the Tate Gallery.

GILLRAY, J. (1757–1815), originally a letter engraver, he had by the age of 30 established himself as one of the most successful of English caricaturists. Although he attained outstanding eminence in this profession, he remained a moody man, solitary even in company. He developed intemperate habits and became insane while still a comparatively young man. He unsuccessfully attempted suicide by jumping from an upstairs window.

GOYA, F. J. (1746–1828). Spanish painter who had a passion for painting at an early age. According to Reitmann (1939), his pre-morbid personality, his bellicosity, his paranoid attitude and his autism were clearly schizoid. The relatively benign course of his illnesses is nothing extraordinary, considering his pyknic constitution.

During his morbid periods, his work showed abnormal features such as cut-off parts of bodies, sadistic elements and mixtures of male and female characteristics. These details are so frequent in the art of schizophrenics that they can be used as an aid to diagnosis.

EL GRECO (THEOTOCOPOULOS, D. T.) (1541–1614). Painter born in Crete and called El Greco.

A letter by a friend, Clovio, has been quoted as saying, "Yesterday I visited Greco, thinking to take a walk with him through the city. It was a most lovely day, with the spring sunshine at its best and would have given pleasure to anybody. The whole city was festive. When I went into his studio I was astonished; the shades were pulled so completely over the windows that you could hardly distinguish the objects in the room.

"Greco was seated in a chair—neither working nor asleep. He would not go out with me as he said the daylight blinded the light within him" (quoted by P. & L. Murray, 1959).

This anecdote suggests that El Greco had a schizothymic temperament, since it implies that he was subject to experiences of mystical illumination as well as having a distaste for ordinary sunlight. Sheldon has mentioned that a dislike of strong sunlight is a characteristic of the cerebrotonic temperament. El Greco's self-portrait shows that he had long, thin, finely-cut features.

"Greco's use of colour, often eerie and strident, with sharp contrasts of blue, yellow, shrill green, and a livid mulberry pink, the elongated limbs and nervous tension of figures, the feeling that the draperies swathing them have a life of their own—all these suggest the intensity of the painter's mystical experience and the catharsis he found in his art" (P. and L. Murray, 1959).

It is said that Court intrigues caused El Greco to retire and die in obscurity.

GRÜNEWALD, M. (*c.* 1475–1528). A German painter, engineer and architect. According to Kretschmer his work shows the schizothymic tendency to portray extreme tragic pathos. An example is his famous picture of the 'Crucified Christ'.

HAYDON, B. R. (1786–1846). English painter of indomitable, high-flaming energy and industry and full of a conviction of his own powers, which apparently was not justified. His life-long struggle with debt so preyed upon his mind that he became unable to paint, and died by his own hand.

KLEE, P. (1879–1940). Swiss surrealist painter.

"The artist," he wrote, "does nothing other than gather and pass on what comes to him from the depths." Klee has been described as an introvert, with a wall between himself and the world.

LANDSEER, SIR E. (1802–73), showed remarkable talent for drawing at an early age. He sketched cows and horses at the age of 6, exhibited at 14, and became an A.R.A. at 24. He was noted for the excellence of his forms.

In 1840 he had a severe breakdown, from which he seemed to make a complete recovery, but twenty years later he became the victim of hallucinations and delusions that bordered on dementia (probably schizophrenia).

LEAR, E. (1812–88). English writer and artist, who exhibited at the Royal Academy from 1850 to 1873. It was his books of nonsense verse, rather than his paintings and drawings, which gained him fame.

He was abnormally shy and self-conscious and seems to have found symbolical expression for his mental conflicts in nonsense verse. There is some resemblance between Lear and the schizothymic mathematician, Lewis Carroll.

MICHELANGELO (1474–1564). Italian painter and sculptor.

Michelangelo was schizothymic to the point of caricature. Petty-minded, bad tempered and suspicious, he suffered from attacks of persecution mania. Even when there was no necessity for thrift, he seems to have had an entire distaste for luxury, and for ordinary comforts. He ate very little and was usually content with a piece of bread taken while he worked. He slept little, usually wearing his clothes and boots. This total indifference to the pleasures of life was reflected in his work, which was stern even to bareness. "Gorgeous colour and rich apparel did not appeal to him, he had no feeling for the beauties of landscape; the world of beauty for him was entirely sculpturesque, the human form and that alone dominated his mind" (Dick, 1911).

Michelangelo's devotion to the portrayal of masculine beauty suggests that there was a homosexual psychical component in his make-up—a tendency which is found much more frequently in schizothymes than in cyclothymes.

MODIGLIANI, A. (1884–1920). Painter and sculptor, he was the greatest Italian artist of the twentieth century. He was one of the real leaders of modernism in art. His paintings are remarkable for their superb draughtsmanship, for their originality and for the curiously elongated heads of their subjects. Modigliani suffered from tuberculosis and died at an early age. Strikingly handsome and amorous, he once said "I am going to drink myself to death," and it is said that he did.

MORLAND, G. (1763–1804). English painter who showed remarkable talent for drawing at the age of five or six. Though he received no regular instruction, he painted with remarkable rapidity and his pictures reveal great beauty of conception and harmony of execution. In his animal studies, he approached very near to the perfection of Landseer.

It is said that from the age of 16, he abandoned himself to a dissolute and irresponsible mode of life, being a drunkard, loafer and spendthrift. Debt seems to have been his greatest incentive to work. When viewed in the light of his way of life, his artistic achievement is all the more remarkable. He was arrested for debt and died in prison.

PALMER, S. (1805–81). English painter and etcher who showed remarkable talent at an early age. At the age of 14, he exhibited three pictures at the Royal Academy. His self-portrait is one of the finest self-portraits ever painted. Though simple in composition, it is invested with a great, though restrained, intensity of emotion, portraying a very serious and determined personality.

Palmer was greatly influenced by the mystical outlook of William Blake. In his landscapes, he depicted a mystical loveliness transcending and transforming the physical reality. His son wrote—"After the Shoreham and Italian periods, the whole of my father's life became a dreadful tragedy."

PICASSO, P. R. (1881–   ). Spanish painter. The son of a drawing-master, he showed exceptional talent at an early age. The influence of Negro sculptures fitted in with his quest for the expression of form and helped, by the bizarre nature of their forms, to release him from the tyranny of the representational tradition in art. The dislocated forms and frightening imagery shown in his composition 'Guernica' (1936) and in other works carried out during the Second World War, may be regarded as symptomatic of the schizothymic temperament.

It has been said that no man has changed more radically the nature of Art. Like Giotto, Michelangelo and Bernini, Picasso stands at the beginning of a new epoch.

PIPER, J. (1903–   ). British painter and writer. His water-colours and aquatints of architectural subjects made him famous. He appears from photographs to have markedly leptosomatic physique.

POLLOCK, J. (1912–56). American artist. He has been described as taciturn, ascetic, and outwardly anguished, his behaviour reflecting anxiety.

REYNOLDS, SIR J. (1723–92). English portrait painter, who showed great artistic talent when very young. He was appointed president of the Royal Academy in 1768 and knighted in the following year. His draughtsmanship was superb, though he also possessed a wonderful sense of colour.

Reynolds was a self-contained, self-centred man whose interests were almost entirely intellectual. Cold and selfish, he seemed to be passionately attached to no one, but he never quarrelled. He has been described as "prudent in the matter of pins, a saver of bits of thread, a man hard and parsimonious. Public opinion pictured him close, cold, cautious and sordid."

He never married, and his whole life showed a strong tendency to emotional detachment.

ROMNEY, G. (1734–1802), the son of a cabinet-maker, early showed a mechanical turn of mind and learned to make violins. He also showed a marked aptitude for drawing and was apprenticed to a portrait painter. His best work has simplicity, poetical treatment, dexterous draughtsmanship and gives an impression of movement and of elusive grace. He acquired a popularity as a portrait painter which made him a rival to Reynolds.

Romney suffered from nervous restlessness and emotional instability. Periods of colossal ambition alternated with long sessions of comfortless brooding. "Fear has always been my enemy," he once said, "My nerves are too weak for supporting anything in public." (Russell, 1944).

ROSSETTI, D. G. (1828–82), showed outstanding talent both as a poet and painter by the age of 21.

His pictures show the dream-like qualities of symbolism characteristic of the work of schizoids. He created a new type of beauty, surrounded by a strange atmosphere, half mediaeval, half mystic and not a little morbid. He became addicted to the use of chloral which is said to have affected both his bodily and mental health. For a period he suffered from hallucinations and delusions of persecution and in 1872 he attempted suicide. His mysticism gives him an affinity with William Blake,

TURNER, J. M. W. (1775–1851). English landscape painter, early showed a talent for drawing and was apprenticed to an engraver. At the age of 23 he exhibited several pictures at the Royal Academy.

In temperament he was close, taciturn, sour and inscrutable. It is said that he inherited something of the temperament of his mother, who was subject to fits of insanity. Brusque and uncouth in manner, of little culture outside his art, he was most at home in the lower grades of society. He had a number of intimate friends, however, who had been able to penetrate the crust of eccentricity and churlishness below which he concealed a most sensitive nature. With the passing of the years, he grew more and more solitary in his habits. His private life became subterranean and secretive and he only emerged into public view at meetings and functions of the Royal Academy. His industry, however, never flagged and he accumulated a considerable fortune. Though regarded as miserly and misanthropic in his lifetime, he left his entire fortune of £140,000 to be devoted to philanthropic purposes.

VAN DYCK, SIR A. (1599–1641). Flemish painter, who received the patronage of Charles I. He established a formula for the grand style in portraiture which was to be accepted for generations.

He was said to be melancholic, and died at the age of 41 of 'disappointment'.

VAN GOGH, V. (1853–90) is a good example of a schizoid artist. Though there was an artistic tradition in his family, he showed no particular bent for painting as a boy. Possessing a physique of the athletic type, he developed a schizophrenic illness while still comparatively young, spent his latter days in an asylum and finally shot himself. His letters show that he was extraordinarily sensitive. He was specially noted for portraits, landscapes and still-lifes. His portraits of doctors and self-portraits painted while at the asylum were as great as any of his paintings. There is evidence in his biography that he had tendencies both to synaesthesia and high sensory perseveration.

"Vincent would sit himself down at the piano, strike a chord, listen intently, then shout 'Prussian blue!'; and before the bewildered man could recover there would be another chord or perhaps a single note repeated deafeningly, ending with a triumphant cry of 'Bright cadmium!' or 'Dark ochre!' or whatever colour Vincent associated with that particular sound." . . .

"His main theory at this moment, and the one in which he seemed to take most pleasure, was that the eye 'carried a portion of the last sensation it had enjoyed into the next, so that something of both must be included in every picture made' " (L. and E. Hanson, 1955).

WATTEAU, J. A. (1684–1721). French painter, famous for his 'Fêtes galantes'. Made a member of the French Academy in 1717, and painter to the king in the following year. His draughtsmanship was superb and he had a complete mastery of atmosphere and composition. From his youth he suffered from ill-health and had the irritable and capricious temper which so often accompanies tuberculosis. It is said that in his last years he was haunted by strange fancies and tormented by a dread of dying penniless. Nisbet (1891) states that he was melancholic and that his early death has been attributed to 'deception in love'.

WHISTLER, J. A. M. (1834–1903). Painter, lithographer and etcher, came of a family of engineers and his father is said to have shown exceptional mathematical ability.

Whistler's painting, especially his portraiture, was balanced, fragile and exquisite. Lean in physique, his peculiar, cantankerous disposition was well-known. Quarrelsome and pugnacious to an extreme degree, he had a deserved reputation as a mordant wit.

The contrast between the schizothymic and cyclothymic temperament is well illustrated in the well-known incident when, in response to one of Whistler's sallies, Oscar Wilde made the generous remark, "I wish I had said that," to receive the stinging retort, "You will, Oscar, you will".

LE CORBUSIER (JEANNERET, C. E.) (1887–). Swiss architect and painter, his extraordinary talent and insatiable capacity for absorbing visual impressions became evident at a very early age. For a time he was a painter of the modern school, but he set up as an architect, professing to discard all style in a purely engineering spirit. Believing that architecture is man's most noble form of self-expression, he is a dreamer and a visionary. Extremely sensitive to the proportions of figures, he insists that the Golden Mean is as valid today as when used in the design of Notre Dame. At the entrance to the well-known block of flats of his design in Marseilles, there stands his 'modulor' figure of a man with upraised arm; nearby there is a concrete block on which the 'modulor' proportions used in the building are precisely incised. "It is in such moments as these," he has said, "that architecture soars, leaving the brutal and material and attaining to spirituality." When he explained the 'modulor principle' to the late Albert Einstein, the great scientist told him that this provided "a range of dimensions which makes the bad difficult and the good easy".

Though Le Corbusier's ideas for long provoked intense controversy, he has now achieved world-wide fame and general acceptance. It has been said that Le Corbusier looks more like an English clergyman than an architect. "His face has the flat, almost monumental cast of an Easter Island head. The razor-edged features of the dead-white face and his black-rimmed spectacles have brought him the nickname of 'Corbu'—a variation of the word *corbeau* or raven.

"Although Corbu has many admirers, he has very few close friends. . . . On casual acquaintance he appears cold, suspicious, pugnacious, sarcastic (but quite humourless about himself), and arrogant. . . . But to the few people who know him well, Corbu is an entirely different sort of person; a man of tremendous charm, wit and great warmth; of scholarship, vision and superb taste." (P. Blake, 1960).

PUGIN, A. (1812–52), was an English architect who showed outstanding talent for design at a very early age. His first important work was the designing of the furniture of Windsor Castle, when he was only 15. A brilliant draughtsman, he was the architect of a number of churches and showed remarkable facility in designing church plate, vestments, wallpaper, textiles, furniture, etc. He provided detailed drawings for the Houses of Parliament. He is regarded as the pioneer of the revival of Gothic architecture in the nineteenth century. He died after a period of mental disorder at the early age of 40.

WREN, SIR C. (1632–1723) was the greatest British architect of modern times. At the age of 25 he was appointed Professor of Astronomy at Gresham College, London, and later Savilian Professor of Astronomy at Oxford. In the Principia, Newton speaks very highly of Wren's work as a geometrician. If his proposed plan for the laying out of London had been adopted, the city would have surpassed in spaciousness and dignity any other capital. One of the original members of the Royal Society, his energy was prodigious. His portrait suggests that he had somewhat sharp features and was probably leptosomatic in physique.

Appendix 4

Schizothymic engineers, inventors, mathematicians and physicists

THE following engineers, inventors, mathematicians and physicists probably had high spatial ability and exhibited well-marked schizothymic or schizoid traits. The engineers displayed strongly masculine traits and in some cases great organizing ability. Some of the mathematicians and physicists showed mental disturbances which may indicate schizophrenic tendencies, e.g. Newton, Ampère, Cardan, Pascal, the elder and younger Bolyai, Faraday, Cantor.

ENGINEERS

Baker	Hinton	Piccard
Crompton, R. E. B.	Jessop	Rennie
Da Vinci	Krupp	Stephenson, G.
Diesel	Locke, Joseph	Stephenson, R.
Ford	Morris	Trevithick
Fowler	Murdock	Watt, J.
Fulton (also a painter)	Parsons	Whitworth

MATHEMATICIANS

Abel	Descartes	Napier
Barrow	Galois	Newton
Birkhoff	Gauss	Pascal
Bolyai	Hardy	Pearson
Cantor	Kepler	Ramanujan
Cardan	Klein	Riemann
Clifford	Leibniz	Russell, B.
Copernicus	Lobachewsky	Steiner
D'Alembert	Monge	Stevinus

INVENTORS

Armstrong	Edison	Morse (also a painter)
Babbage	Friese-Greene	Tesla
Baird	Goodyear	Wright, O.
Cockerel	Marconi	Wright, W.

PHYSICISTS

Ampère	Einstein	Lenard
Blackett	Faraday	Maxwell, Clerk
Bernal	Fraunhofer	Mayer
Boyle	Fresnel	Planck
Broglie, De	Frisch	Rumford
Cavendish	Gibbs	Schrödinger
Chadwick	Heaviside	Snell
Curie, M.	Heisenberg	Thomson (Lord Kelvin)
Curie, P.	Hertz, H.	Von Guericke
Eddington	Laue, von	Wheatstone

Notes on some schizothymic engineers, inventors, mathematicians and physicists

BAIRD, J. L. (1888–1946). Scottish inventor who showed remarkable engineering skill at an early age. Like many other inventors (e.g. Davy, Marconi, Ford) as a boy he was fond of tinkering with pieces of machinery in an attic. At the age of 12, he rigged up a home-made telephone which connected his attic bedroom with the rooms of some of his playmates. His academic career was quite undistinguished.

Invention seems to have fascinated him, though most of his early inventions were not a commercial success, e.g. a pneumatic undersock, Osmo boot polish and a glass razor. By the age of 35 he seemed to have become a dealer in odd articles which no one else was prepared to touch. The prototypes of his early electrical inventions looked like Heath Robinson machines made up of biscuit tins tied together with string. He persevered for years single-handed in his television project when most people thought the idea was completely visionary. In 1925, he transmitted for the first time a television picture of the human face and, in 1941, first showed television in relief and in full natural colour.

He also invented the noctovisor, which enabled scenes to be perceived in total darkness.

Of a nervous and retiring disposition, Baird disliked showing himself off in public, but sometimes found it necessary to do this in order to finance his work. Until the last years of his life, he was short of money and frequently found it necessary to borrow from friends and relatives. He left assets of only £7,000.

TREVITHICK, R. (1771–1833). English inventor and engineer. As a boy he was fond of solitude and preferred the drawing of lines and figures to the preparation of legitimate lessons. His teacher reported that he was disobedient, slow, obstinate, very inattentive and frequently truant, but he did have an aptitude for mental arithmetic. As a young man he was a notable weight-lifter and it was said that as a wrestler he had no equal. In physique he was tall and athletic, his height being 6 ft. 2 in. or more.

From the age of 25 he experimented with model locomotives and at 30 completed the first steam carriage that ever drew passengers. He took out many patents, but had numerous unpatented projects, including a stern driving propellor. He died in Dartford, penniless.

WATT, JAMES (1736–1819). Scottish inventor and engineer. He showed remarkable practical skill at a very early age. "Jamie has a fortune at his finger-ends", was a common saying among his father's workmen (Carnegie, 1906).

He proved a backward scholar for a time at the grammar school and in one report was described as "dull and inapt". No one seems to have divined the latent powers smouldering within. Latin and Greek classics had no interest for him, but the spark that fired his imagination came at last—mathematics.

His temperament may be assessed from the following description quoted from Hesketh Pearson.

"In a company where James Watt was unknown he would have passed unnoticed. He would meditate for hours, hardly shifting his position. His face would seldom light up with pleasure; at the most a wrinkle would deepen from his nose to the corner of his mouth, which denoted that he was less unhappy than usual. His steady gaze was a little disconcerting to anyone who thought that he was the object of Watt's calm contemplation, and who failed to realize that the quiet

Scot was looking through him, and was only partially aware of his existence" (Pearson, 1943). (For his portrait, see plate 1.)

Watt was no man of affairs, and money matters were his special aversion. As he once wrote to his partner, Boulton, he "would rather face a loaded cannon than settle a disputed account or make a bargain." He was always of a meditative turn, was somewhat prone to melancholy and at times was plagued with nervous headaches and insomnia.

There are good grounds for believing that mathematical ability tends to be inherited. Probably, the most striking historical example is that of the Bernoulli family, which in three generations produced eight mathematicians, several of them outstanding.

According to Bell (1937):

"The most significant thing about the majority of the mathematical members of this family in the second and third generations is that they did not deliberately choose mathematics as a profession, but drifted into it in spite of themselves as a dipsomaniac returns to alcohol." Many of them started off by training in law, philosophy, theology or medicine, only to turn to mathematics later in life. This fact strongly suggests that their achievements in mathematics resulted from the possession of a marked special aptitude. Galton (1892) states that the Bernoullis were mostly quarrelsome and unamiable. The greatest of them, Jacques Bernoulli, was slow but sure and had a "bilious, melancholic temperament".

Another outstanding mathematical family was the Scottish family of the Gregories. Galton (1892) cites the Gregories as a striking example of hereditary scientific gifts. From the Rev. John Gregorie, who married in 1621, descended fourteen professors, many of whom showed outstanding mathematical or scientific abilities. From the middle of the seventeenth century to the middle of the nineteenth century with a gap of only a few years, members of the Gregorie family were professing either mathematics or medicine in one or other of the Scottish Universities. As a family, they were noted for being lucid, clear-sighted, advanced in their views and naturally leaders of men (Stewart, 1896).

ABEL, N. H. (1802–29). Norwegian mathematician who showed great promise and originality, but died prematurely of the schizothymic disease—tuberculosis. His great abilities were not fully appreciated by his contemporaries.

CANTOR, G. (1845–1918). German mathematician, who created a new field of mathematical investigation.

Through his work, the modern theory of infinite sets began to evolve, and this theory has profoundly influenced the development of analysis in the present century. In his fortieth year, he experienced the first of a series of breakdowns which occurred with varying intensity throughout his long life. His explosive temper added to his difficulties. Some of his best work was done in the intervals between one attack and the next. On recovering from a breakdown he noticed that his mind became extraordinarily clear.

According to E. T. Bell, Cantor was embittered by lack of recognition, for he believed that he had taken the first and last steps towards a rational theory of the infinite. His colleague, Kronecker, appears to have been largely responsible for Cantor's failure to obtain the position he craved in Berlin. It has been suggested by Hadamard (1945) that there was more in this situation than personal rivalry, that it was a case of "psychological incomprehension"—a failure by Kronecker to understand Cantor's mode of thinking. This suggestion is of great interest in connection with our theme, for a remarkable feature of most of Kronecker's work was its distinctly arithmetical tinge. "God made the integers," he said, "all the rest is the work of man." Apparently, he was never seriously attracted to geometry. It is tempting to suggest that at the root of Kronecker's failure to appreciate Cantor's work was the fact that the latter was spatially gifted while he was not.

CLIFFORD, W. K. (1845–79). English mathematician who died of tuberculosis at the early age of 34.

In a rigidly conventional age, he was marked by eccentricities of habit, dress and opinion. His religious views were those of an ardent High-Churchman, though later in life he turned violently against organized religion, especially "priestcraft". He seems to have possessed remarkable powers of visualizing. According to his friend, Pollock, "As he spoke, he appeared not to be working out a question, but simply telling what he saw. Without any diagram or symbolic aid he described the geometrical conditions on which the solution depended, and they seemed to stand out visibly in space. There were no longer consequences to be deduced, but real and evident facts which only required to be seen.... So whole and complete was the vision that for the time the only strange thing was that anybody should fail to see it in the same way." (Clifford, 1946.)

DESCARTES, R. (1596–1650). French mathematician and philosopher. He first recognized the real meaning of the negative roots of equations and founded analytical geometry. It is said that at the age of 23, he experienced three vivid dreams which changed the whole course of his life. He claimed that there had been revealed to him the magic key which would unlock the treasure house of nature. It is generally assumed that the "magic key" refers to his discovery of analytical geometry.

Descartes was cold and selfish in disposition, and lacking in sociability. He was deeply tinged with hypochondria and for years was chilled with an oppressive fear of death. He wrote: "I desire only tranquillity and repose." Lombroso records that he was almost incapable of expressing himself in public.

GALOIS, E. (1811–32). A French mathematician of remarkable originality. It has frequently been pointed out that there are some extraordinary similarities between his career and that of Abel.

The fact that he failed twice in the examinations for entrance to the Polytechnique may perhaps be explained by supposing that he possessed high spatial ability, but low verbal ability. His examiners reported that while his work in mathematics and physics was very good, he was sometimes obscure in expressing his ideas. In literature he knew absolutely nothing and seemed to have but little intelligence.*

A portrait of him shows that he was of asthenic physique. Apparently he annoyed his teachers because he was "original and queer" and "argumentative". He was killed in a duel at the early age of 20.

MONGE, G. (1746–1818). French mathematician who "was a born geometer and engineer, with an unsurpassed gift for visualizing complicated space-relations" (Bell, 1937). At the age of 14 he showed his remarkable mechanical talents by constructing a fire-engine without a guide or model. At 16 he made a map of Beaune entirely on his own initiative and constructing his own instruments for the purpose. The

* This first-magnitude blunder in selection is by no means an isolated case. Ramanujan, India's greatest mathematician, failed to matriculate at the University of Madras because of his weakness in English (Turnbull, 1929).

creator of the science of 'Descriptive Geometry', Monge undoubtedly possessed spatial ability of a very high order.

His personality, however, appears to have been unprepossessing. So halting in speech as to be almost a stammerer, he made up for his lack of fluency by means of an animated pantomime of gestures. Intense enthusiasm and naïve good nature were the most distinctive traits of his personality. He was ridiculed by Madame Roland, who judged him to have '*un esprit borné*' (shallow intelligence).

At the age of 50, Monge became an intimate friend of the Emperor Napoleon. In view of this friendship, it is quite possible that the Emperor had the mathematician in mind when he made the remark, quoted by Hume in his *Précis of Modern Tactics*, page 15, viz.:

"There are some who, from some physical or moral peculiarity of character, form a picture (*tableau*) of everything. No matter what knowledge, intellect, courage, or good qualities they may have, these men are unfit to command." Galton (1883) quotes this remark saying that he could not find the original authority, nor could he fully understand the meaning.

NEWTON, SIR I. (1642–1727). English mathematician. As a boy, Newton showed outstanding ability of a practical kind, though it has been said that he did badly at school, since for a time he was in the lowest form but one. He exhibited great ingenuity in constructing mechanical devices, such as water-wheels, flour-mills, clocks and sundials, and he had an intense love of drawing. Thus, he appears to have displayed at an early age the practical and mechanical interests which usually accompany high spatial ability. An outstanding aptitude for geometry is clearly apparent in the *Principia*, throughout which all the demonstrations are geometrical.

Throughout his life, Newton was notoriously absentminded and careless in appearance and dress. Languid and meditative in manner, often incoherent in speech, he rarely participated in general conversation. According to Lombroso, he was almost incapable of expressing himself in public, in this respect resembling Descartes. When engrossed in his work, "meals were ignored or forgotten, and on rising from a snatch of sleep, he would sit on the edge of the bed, half-clothed, for hours, threading the mazes of his mathematics." (Bell, 1937.) At the age of 49, he had a severe mental breakdown, during which he suffered from chronic insomnia, persecution mania and inability to eat. He was short but well-set in physique, with a square lower jaw and rather sharp features. His hair became white but remained thick till his death. Portraits show that his physique was asthenic or leptosomatic and it is clear that he possessed markedly schizoid traits. (See frontis.)

PASCAL, B. (1623–62). French mathematician. Pascal showed precocious geometrical ability as a boy. It is said that at the age of 12, he discovered for himself many properties of geometrical figures, and in particular the proposition that the sum of the angles of a triangle is equal to two right angles. At sixteen, he wrote an essay on conic sections and at eighteen he constructed the first arithmetical machine.

In 1654, Pascal abandoned his mathematical pursuits to take up residence at Port Royal, the main centre of the Jansenists in France. He had decided to turn his back on the world and to bury his talent "in contemplation of the greatness and misery of man". Always delicate, he had injured his health by his incessant study, and from the age of seventeen he suffered severely from insomnia and acute dyspepsia. On the day of his conversion in 1654, he had an escape from violent death in an accident, and he interpreted this as a warning from Heaven to mend his ways. For the rest of his life, he was haunted by hallucinations of a precipice before his feet. Pascal's resolve to abjure the world and his morbid desire for seclusion are typically schizoid traits.

RIEMANN, G. F. B. (1826–66). German mathematician.

Riemann was one of the most original mathematicians of the nineteenth century and his writings have been remarkably fertile in suggesting new lines of investigation. He wrote a celebrated memoir on the foundations of geometry. His work made possible the revolution in thought produced by Relativity.

He was undoubtedly schizothymic in temperament. From his earliest years, he was timid and diffident, with a horror of speaking in public or of attracting attention to himself. "In later life, his chronic shyness proved a very serious handicap and occasioned him much agonised misery till he overcame it by diligent preparation for every public utterance he was likely to make. The engaging bashfulness of his early manhood was in strange contrast to the ruthless boldness of his matured scientific thought." (Bell, 1937.) He died of tuberculosis at the age of thirty-nine.

CAVENDISH, H. (1731–1810). English experimental physicist and chemist.

It would be difficult to find any scientist of the eighteenth century, whose work was of more far-reaching importance than that of Cavendish. He was a gifted experimentalist, a highly competent mathematician, and he possessed to an outstanding degree the remarkable gift of knowing almost intuitively what kinds of problems were worth investigating.

According to his biographer Berry (1960), he took no part in public affairs, except to serve on some special committees and his life was almost wholly devoid of incident. An eccentric millionaire, he lived the life of a recluse. It has been said that "he did not love, he did not hate, he did not hope, he did not fear." Tall and thin in physique, he had a slight hesitation in speech which has been attributed to his shy disposition. He could be so embarrassed by compliments as to be reduced to total silence. He had a marked dislike of strangers and of women. On happening to meet a housemaid on the stairs, carrying a broom and a pail, he was so affected that he immediately gave instructions for a back stair to be built. To avoid personal contact, it was his practice to order his meals by leaving a note on the table.

He was similar to Newton in being reluctant to publish his discoveries. Long after his death, it was found that much of his unpublished work was of the highest value, and it seems that the real reason for his failure to publish was his excessive shyness (schizothymia).

EDDINGTON, SIR ARTHUR S. (1882–1944), an English mathematical physicist and astronomer, who made many original discoveries and who published numerous important books. He had a remarkable capacity for advancing startlingly original ideas. His later work was highly controversial and it is perhaps too early to assess its value.

Tall and spare in appearance, he had sharp features, an over-hanging brow and deep-set eyes. He spoke rarely and seemed to be almost incapable of speaking coherently without preparation. According to Crowther (1952), he could deliver the most brilliant prepared lectures, but often became completely and embarrassingly tongue-tied when questioned on them in subsequent discussion.

He was a bachelor, who lived entirely in the realm of thought. His mild and gentle presence gave no indication of the brilliance of his writings or of the boldness of his original ideas.

EINSTEIN, A. (1879–1955). German mathematical physicist.

According to the biography by Frank, Einstein was no child prodigy.

"Indeed it was a very long time before he learned to speak, and his parents began to be afraid that he was abnormal. Finally the child did begin to speak, but he was always taciturn, and never inclined to enter into the games that nursemaids play with children in order to keep both the children and themselves in good humour.

"Even when Albert was nine years old and in the highest grade of the elementary school, he still lacked fluency of speech and everything he said was expressed only after thorough consideration and reflection. . . . He was regarded as an amiable dreamer. And yet no evidence of special talent could be discovered". (Frank, 1948.)

It has been stated "that from the point of view of his teachers, Einstein was an unsatisfactory pupil, apparently incapable of progress in languages, history, geography and other primary subjects." He could not have been a brilliant student either at high school or at the university, for the exceptional nature of his gifts was not appreciated by any of his teachers. When he revisited his old school, he was mortified to find that the teacher who had inspired him most could not even remember him. On leaving the university he had difficulty in finding a post and for a time had to support himself by private tutoring. After a weary search for work, he obtained a stable appointment as examiner at the Patent Office at Berne. Upon the publication of his first monograph in 1905, the patent office clerk was promoted to be a lecturer at the university.

There is considerable evidence that Einstein's mental imagery was predominantly visuo-spatial rather than verbal. It is perhaps significant that his interest in mathematics was aroused by reading a book on geometry given to him by a Jewish medical student. In his reply to the questionnaire circulated by Hadamard (1945), Einstein stated that the words or the language, as they are written or spoken, did not seem to play any role in his mechanism of thought. The psychical entities which seem to serve as elements in thought were, in his case, of visual and some of muscular type. Conventional words or other signs had to be sought for laboriously only in a secondary stage, when the associative play was sufficiently established and could be reproduced at will. Reiser has stated that when Einstein was faced with a problem he had a "definite vision of its possible solution".

In temperament, he was introspective, shy and retiring. "Nothing could be more unwelcome to his sensitive and retiring character than the glare of the platform and the heat of public controversy." His own statements about himself show that there was a strong schizoid component in his personality. Thus, he wrote in *The World as I see It:*

"My passionate sense of social justice and social responsibility has always contrasted oddly with my pronounced freedom from the need for direct contact with other human beings and human communities. I 'gang my own gait', and have never belonged to my country, my home, my friends or even my immediate family with my whole heart: in the face of all these ties, I have never lost an obstinate sense of detachment, of the need for solitude—a feeling which increases with the years."

FARADAY, M. (1791–1867) was probably the greatest of all experimental investigators of the physical world.

The son of a blacksmith, who was very poor, Faraday received very little education. At 13 he went to his first job as errand boy in a bookseller's shop near his home, and for a year cleaned the windows, swept the floor of the shop, and delivered newspapers. He was a member of the sect called Sandemanians which, though small in numbers, had included some men of distinction, such as the engraver Cornelius Varley, one of three artist brothers, and the water-colour painter, George Barnard (Crowther, 1940). Crowther has suggested that the families of this exclusive sect were in-bred through intermarriage, and it is possible that there may have been a hereditary strain of high spatial ability.

Faraday had all the characteristics of the schizothyme. Individualistic almost to the point of caricature, he renounced social life more and more as he grew older. Apparently unable to collaborate, he never had a research assistant and he created no school. He refused the Presidency of the Royal Society. As in the case of Newton, his mental health broke down at the age of 49, and his scientific work was entirely suspended for about twenty months. He complained about feeling uncomfortable in the presence of strangers and found letter-writing a severe strain. He explained that he could not see people or even visit the houses of friends, because of "ill health connected with my head". However, he made a complete recovery and his mind became as acute as before.

Faraday's extraordinary achievement demonstrates that it is possible for a man with little formal education to make fundamental discoveries in science, provided that he has the requisite natural aptitude. In Faraday's case, there is little doubt that there was a high endowment of visuo-spatial ability, for he always conceived his problems in spatial terms (e.g. 'lines of force'), rather than in terms of mathematical symbolism. Indeed, he knew little formal mathematics. It is interesting to speculate as to what might have happened to Faraday if he had been sent to a grammar or public school where the staple diet was the study of the classics. Would he have been rated a dunce like Trevithick or Edison or would he have taken higher education in his stride like Lord Kelvin, who also had marked spatial ability? It may be doubted whether Kelvin would have done as well academically as he did (he was second wrangler) if his father, who was Professor of Mathematics at Glasgow, had not supervised his education from the earliest years. Kelvin's long and arduous preparation for a career in science is in marked contrast to that of Faraday, who obtained a post as 'bottle-washer' at the Royal Institution almost by accident. (It happened one day that a customer at the book-shop gave him a ticket for a course of lectures given at the Royal Institution by Sir Humphrey Davy.)

GIBBS, J. WILLARD (1839–1903). A mathematical physicist, whose very high reputation as America's greatest scientist bears a striking contrast to his lack of popular fame. The majority of students at Yale, where he was professor, did not know of his existence, much less of his greatness. It is said that during all the years of his membership of the Yale faculty, Gibbs made only one speech. After a prolonged discussion of the relative merits of mathematics and languages as cultural studies, he rose and uttered one short sentence—"Mathematics is a language".

Former pupils report that he was unaffectedly modest, gentle, self-contained and dignified and had no eccentricities. He took little part in social and political affairs. He never married and for most of his life he lived quietly in his eldest sister's home. He had some quality of deep isolation, an inhibited temperament which seemed to prevent him from discussing his ideas easily with others. He rarely told anyone what he was doing, until his work was ready for publication.

MAXWELL, J. CLERK (1831–79). Scottish physicist.

Universally recognized as the greatest theoretical physicist of the nineteenth century, Maxwell was regarded as a visualist by his contemporaries, though he inspired the more abstract nonvisual theories of the twentieth century. He had a powerful visual imagination and, like Kelvin, had a habit of making a visual representation, diagram or model of every problem.

There are numerous indications in his biography that he had schizothymic tendencies. According to Crowther (1935) "the most serious deficiency in his youth was lack of adaptation to social intercourse". In the summer of 1853 when studying for his examinations, he became seriously ill with "brain fever", as neurosis was described in the terminology of the day. The circumstances of his inaugural lecture as Cavendish professor of experimental physics suggest a typically schizothymic fear of a critical audience. Apparently, he deceived the University authorities regarding the date of the inaugural lecture, so that "it was delivered in an obscurely advertised place to a score of students". Maxwell "was not quite confident that his delivery would be completely successful" (Crowther, 1935). Two universities in his native land had the opportunity of appointing him as Professor, but both preferred men who were believed to be better teachers. Nicknamed 'Dafty' at school, he was considered to have a very unusual or uncommon personality, but not even the ablest of his fellow-students appreciated the greatness of his intellectual power.

Appendix 5

Some schizothymic philosophers

THE following eminent philosophers were men of leptosomatic physique and in some cases showed marked schizothymic or schizoid traits. (See portrait of Bacon, plate 5.)

Alexander, S.
Aristotle (also a scientist)
Bacon
Bergson
Böhme
Descartes (also a mathematician)
Hegel
Herbart
Jacobi, F.
Kant
Kierkegaard
Leibniz (also a mathematician)
Locke
Lotze
Mendelssohn, Moses
Mill, J. S.
Nietzsche
Rousseau
Russell, B. (also a mathematician)
Schleiermacher
Spinoza
Swedenborg (also a scientist)
Voltaire
Wittgenstein (also a mathematician and engineer)

Appendix 6

Some schizothymic chess champions

IT can scarcely be doubted that a high degree of spatial ability is essential for outstanding achievement in chess. This may be the explanation of the tendency, which has frequently been noted, for ability at chess and ability at mathematics to go together.* Quite a number of eminent chess masters were professional mathematicians or teachers and students of mathematics (Alexander, Anderssen, Euwe, Keres, Emanuel Lasker). Several were engineers (Botvinnik, Edward Lasker, Maroczy, Steiner) and one became an eminent physicist (Vidmar). Chess resembles mathematics in that it is necessary to start young to have any hope of achieving distinction. Hardy once said that mathematicians must be "caught young" and this rule seems to be true of virtuosi at chess.†

We might expect to find that the personality qualities associated with high spatial ability would be particularly in evidence among the great chess masters. It is certainly very noticeable that the greatest players have been men of strong and well-marked personality. It has been stated that egotism is such a frequent characteristic among them that it must be intrinsic to their personality make-up (Fine, 1952). Among those

* A notable instance of ability at chess and ability at mathematics going together is seen in the Penrose family. Professor Lionel Penrose, an eminent statistician and geneticist, is a noted chess player and the combination of abilities has also been shown by his sons. One son won the British chess championship and another son was very near master rank in chess when he decided to devote most of his energies to mathematics, subsequently becoming a Professor of Mathematics at Cambridge.

† Chess also resembles mathematics in having its child prodigies, some of whom later achieved world-wide fame (e.g. Capablanca, Reshevsky). That Reshevsky's precocious ability at chess was a manifestation of high spatial ability is suggested by a report of his performance in certain psychological tests which he took at the age of eight, before he had had any schooling. He distinguished himself in two tests involving the visualization of form and in a test of visual memory for digits. In the spatial tests (fitting shapes and dissecting shapes) his performance was outstanding and would have been remarkable in an adult (Reshevsky, 1948).

who were remarkable for toughness and aggressiveness were Staunton and Emanuel Lasker. Some were unpopular because they were domineering and arrogant (Tarrasch, Steinitz and Alekhine). Some of the most brilliant became morbidly withdrawn (Morphy, Torre, Rubinstein) and at least three suffered from severe delusions of persecution (Rubinstein, Nimizovitch, Morphy).

Among chess champions, the following showed well-marked schizothymic traits.

Alekhine
Anderssen (mathematics teacher)
Botvinnik (engineer)
Euwe (mathematics teacher)
Keres (student of mathematics)
Lasker, Emanuel (mathematician and philosopher)
Morphy
Nimzovitch
Reshevsky (accountant)
Rubinstein
Smyslov
Spielmann
Steinitz
Tarrasch (medical doctor)
Torre

Note on Paul Morphy (1837–84)

Paul Morphy is regarded by many of the most competent judges as the greatest chess player of all time. At the age of 22, after a triumphant succession of brilliant victories, he declared his career as a chess player finally and definitely at an end.

Subsequently he took up law as a profession but was unsuccessful in practice. Gradually, he relapsed into a state of seclusion and introversion, which culminated in unmistakable paranoia. In a well-known essay on the problem of Paul Morphy, Ernest Jones (1931) has advanced an elaborate psycho-analytical explanation of the tragedy. To the present writer, however, it seems probable that there is a more direct connection between Morphy's remarkable talent for chess and his equally remarkable personality. He seems to have possessed to a very striking degree both the assets and liabilities associated with outstanding spatial ability. During his brief public career as a chess player, he exhibited extraordinary self-confidence and endurance. In spite of a highly sensitive disposition he had a pleasing and charming manner. With the passing of the years he became progressively less sociable, gradually developing into an eccentric and irritable recluse, though he still exhibited his remarkable prowess at chess.

Appendix 7

Some cyclothymic biologists, chemists and medical scientists

THE following eminent biologists, physiologists, chemists and medical scientists were men of pyknic physique, as far as could be judged from photographs or portraits.

BIOLOGISTS AND PHYSIOLOGISTS	CHEMISTS	MEDICAL SCIENTISTS
Buffon	Arrhenius	Behring
Carrell, A.	Berzelius	Billroth
Darwin, Charles	Bunsen	Boerhaave
Gegenbauer	Fischer, E.	Brown-Séquard
Gmelin, J. G. (of a family of botanists and chemists)	Gay-Lussac	Darwin, Erasmus
Humboldt, Alex. von	Ostwald, Wilhelm	Gall
Lankester, Ray	Pasteur	Haller, von
Leeuwenhoek	Perkin	Harvey
Linnaeus		Hunter, J.
Mendel		Koch, R.
Moleschott		Lister
Pavlov		Ross, Sir R.
		Schleiden

Appendix 8

Some cyclothymic men of letters

In the following list are named a number of men of letters who had marked pyknic physique and who, in most cases, appear to have been cyclothymic in temperament. In some cases, there were symptoms of manic-depressive illness. (Portraits of Johnson, Belloc and Chesterton are shown in plates 3 and 4.)

Balzac
Belloc
Boswell
Bunyan
Burns, Robert
Chesterton, G. K.
Doyle, Conan
Dryden
Dumas (père)
Gibbon
Goethe
Howells
Hugo
Ibsen
James, Henry
Johnson, S.
Keller, G.
Kipling
Maeterlinck
Marvell
Maupassant
Pepys
Priestley, J. B.
Rabelais
Richardson
Scott, Sir Walter
Sheridan
Smith, Sydney
Steele
Sully-Prudhomme
Swift
Thackeray
Thomas, Dylan
Trollope
Ustinov, P.
Wallace, Edgar
Waugh, Evelyn
Wells, H. G.
Wilde, Oscar

Appendix 9

Some cyclothymic musicians

MANY musicians in the following list had marked pyknic physique and cyclothymic temperament (cf. portraits of Schubert and Handel in plates 7 and 8).

Bach, K. P. E.
Bach, J. C.
Bach, J. S.
Balakirev
Bax
Beethoven
Bloch
Brahms
Bruckner
Busoni
Dvořák
Glinka
Gluck
Handel
Haydn
Hindemith
Honegger
Lehar
Milhaud
Mozart
Mussorgsky
Purcell
Rossini
Rubinstein, Anton
Schönberg
Schubert
Schumann
Scriabin
Sibelius
Sousa
Strauss, J.
Strauss, R.
Sullivan
Tchaikovsky
Vaughan Williams
Wolf, Hugo

Appendix 10

Table 49

Statistical data obtained in follow-up and factorial studies carried out by the author

MIDDLESBROUGH STUDY

MORAY HOUSE SPACE TEST I (CORRELATIONS)

Validity of a battery of selection tests (including M.H. Space Test 1) taken at age 13 in 1949 or 1950. Correlations are shown between scores in individual tests and criteria of success in technical examinations taken three years later at age of 16.

SUBJECT	N	M.H. SPACE TEST I	M.H. VERBAL REASONING TEST	M.H. ENGLISH TEST	M.H. ARITHMETIC TEST
Metalwork (*Practical only, Internal Exam.*, 1952)	69	+ ·542*	+ ·190	+ ·135	− ·135
Metalwork (*Theory and Practical, Internal Exam.*, 1952)	64	+ ·379*	+ ·209	+ ·278*	+ ·036
Metalwork (*Practical only, Internal Exam.*, 1953)	65	+ ·241	− ·048	− ·087	+ ·096
Metalwork (*Theory and Practical, Internal Exam.*, 1953)	65	+ ·307*	− ·040	− ·061	+ ·189
Woodwork (*Theory and Practical, Internal Exam.*, 1953)	86	+ ·226*	− ·020	+ ·092	+ ·201
Woodwork (*Practical only, Internal Exam.*, 1953)	88	+ ·293*	− ·029	− ·133	− ·020
Woodwork (*Theory and Practical, Internal Exam.*, 1953)	86	+ ·325*	− ·109	− ·212*	− ·003
Handicraft (*J.M.Bd.G.C.E.*, 1952)	17	+ ·628*	+ ·234	+ ·434	+ ·198
Handicraft (*J.M.Bd.G.C.E.*, 1953)	24	+ ·227	− ·349	− ·088	− ·192
Geometrical Drawing (*Internal Exam.*, 1952)	66	+ ·428*	+ ·310*	+ ·190	+ ·070
Geometrical Drawing (*Internal Exam.*, 1953)	50	+ ·072	+ ·157	− ·075	− ·112
Geometrical Drawing (*J.M.Bd. G.C.E.*, 1953)	12	− ·193	+ ·224	+ ·428	− ·192
Building Drawing (*Internal Exam.*, 1952)	16	− ·110	− ·207	+ ·562*	+ ·051
Building Drawing (*Internal Exam.*, 1953)	23	+ ·419*	+ ·174	− ·140	+ ·184
Building Geometry (*Internal Exam.*, 1952)	16	− ·070	− ·009	+ ·109	− ·146
Building Geometry (*Internal Exam.*, 1953)	23	+ ·635*	+ ·255	− ·136	+ ·027

* Significant at 5 per cent level of confidence.

Table 50

MIDDLESBROUGH STUDY

MORAY HOUSE SPACE TEST I (REGRESSION COEFFICIENTS)

Best weightings of test-scores in the selection battery for predicting success in technical examinations taken three years later. Pupils were originally tested in 1949 or 1950 at age 13.

SUBJECT	N	REGRESSION COEFFICIENTS: M.H. SPACE TEST I	M.H. VERBAL REASONING TEST	M.H. ENGLISH TEST	M.H. ARITHMETIC TEST	MULTIPLE CORRELATION WITH CRITERION
Metalwork (*Practical only, Internal Exam.*, 1952)	69	+ ·747*	— ·009	+ ·093	— ·263	+ ·672
Metalwork (*Theory and Practical, Internal Exam.*, 1952)	64	+ ·455*	+ ·120	+ ·447	+ ·089	+ ·570
Metalwork (*Practical only, Internal Exam.*, 1953)	65	+ ·336	— ·146	— ·111	+ ·015	+ ·315
Metalwork (*Theory and Practical, Internal Exam.*, 1953)	65	+ ·503*	— ·214	— ·049	+ ·177	+ ·447
Woodwork (*Theory and Practical, Internal Exam.*, 1952)	86	+ ·496*	— ·441	+ ·298	+ ·592*	+ ·517
Woodwork (*Practical only, Internal Exam.*, 1953)	88	+ ·650*	— ·190	— ·374	— ·229	+ ·500
Woodwork (*Theory and Practical, Internal Exam.*, 1953)	86	+ ·656*	— ·367	— ·426	— ·223	+ ·587
Handicraft (*J.M.Bd.G.C.E.*, 1952)	17	+ ·695*	— ·268	+ ·360	+ ·238	+ ·760
Handicraft (*J.M.Bd.G.C.E.*, 1953)	24	+ ·293	— ·838*	+ ·390	— ·340	+ ·624
Geometrical Drawing (*Internal Exam.*, 1952)	66	+ ·665*	+·457	+ ·246	+ ·179	+ ·697
Geometrical Drawing (*Internal Exam.*, 1953)	50	+ ·066	+ ·569	— ·410	— ·103	+ ·369
Geometrical Drawing (*J.M.Bd. G.C.E.*, 1953)	12	— ·435	— ·140	+ 1·306	+ ·522	+ ·715
Building Drawing (*Internal Exam.*, 1952)	16	+ ·102	— ·815	+ 1·423*	— ·065	+ ·977
Building Drawing (*Internal Exam.*, 1953)	23	+ ·760*	+ ·638	— ·502	+ ·942	+ ·821
Building Geometry (*Internal Exam.*, 1952)	16	+ ·002	— ·117	+ ·301	— ·428	+ ·310
Building Geometry (*Internal Exam.*, 1953)	23	+ 1·356*	+ ·947	— ·733	+ ·776	—

* Significant at 5 per cent level of confidence.

Table 51

MIDDLESBROUGH STUDY

MORAY HOUSE SPACE TEST I (CORRELATIONS)

Validity of a battery of selection tests (including M.H. Space Test 1) *taken in* 1951 *when the pupils were* 11 *years of age. Correlations are shown between scores in individual tests and criteria of success in technical examinations taken five years later.*

SUBJECT	N	M.H. SPACE TEST I	M.H. VERBAL REASONING TEST 46	M.H. ENGLISH TEST 22B	M.H. ARITHMETIC TEST 22
Engineering Drawing (Internal Exam., 1956)	47	+ ·408*	− ·071	− ·263	+ ·030
Engineering Drawing (G.C.E. Assoc. Exam. Board, 1956)	27	+ ·298	− ·154	+ ·047	+ ·063
Metalwork (Theory and Practical, Internal Exam., 1956)	39	+ ·283	− ·033	− ·259	− ·087
Metalwork (G.C.E. Assoc. Exam. Board, 1956)	21	+ ·187	+ ·064	− ·126	+ ·071
Woodwork (Theory and Practical, Internal Exam., 1956)	36	+ ·312	− ·148	− ·106	+ ·019
Woodwork (G.C.E. Assoc. Exam. Board, 1956)	23	− ·072	− ·168	+ ·042	+ ·101

* Significant at 5 per cent level of confidence.

Table 52

MIDDLESBROUGH STUDY

MORAY HOUSE SPACE TEST I (REGRESSION COEFFICIENTS)

Best weightings of test-scores in the selection battery taken at age 11 for predicting success in technical examinations taken five years later. The pupils were originally tested in 1951.

SUBJECT	N	REGRESSION COEFFICIENTS: M.H. SPACE TEST I	M.H. VERBAL REASONING TEST 46	M.H. ENGLISH TEST 22B	M.H. ARITHMETIC TEST 22	MULTIPLE CORRELATION WITH CRITERION
Engineering Drawing (Internal Exam., 1956)	47	+ ·747*	— ·083	— ·634	+ ·301	+ ·697
Engineering Drawing (G.C.E. Assoc. Exam. Board, 1956)	27	+ ·680	— ·658	+ ·501	+ ·186	+ ·582
Metalwork (Theory and Practical, Internal Exam., 1956)	39	+ ·426	+ ·163	— ·666	— ·048	+ ·540
Metalwork (G.C.E. Assoc. Exam. Board, 1956)	21	+ ·325	+ ·003	— ·364	+ ·083	+ ·336
Woodwork (Theory and Practical, Internal Exam., 1956)	36	+ ·307	— ·307	+ ·076	+ ·006	+ ·365
Woodwork (G.C.E. Assoc. Exam. Board, 1956)	23	— ·004	— ·328	+ ·022	+ ·071	+ ·252

* Significant at 5 per cent level of confidence.

Table 53

MIDDLESBROUGH STUDY

N.F.E.R. SPATIAL TEST I (CORRELATIONS)

Validity of a battery of selection tests (including N.F.E.R. Spatial Test 1) taken in 1951 when the pupils were 13 years of age. Correlations are shown between scores in individual tests and criteria of success in technical examinations taken three years later.

SUBJECT	N	SPATIAL TEST I (N.F.E.R.)	M.H. VERBAL REASONING TEST (ADV. 9)	M.H. ENGLISH TEST 18	M.H. ARITH-METIC TEST 18
Engineering Drawing (Internal Exam., 1954)	52	+ ·622*	+ ·027	— ·003	— ·106
Metalwork (Theory and Practical, Internal Exam., 1954)	52	+ ·346*	— ·048	+ ·150	— ·299*
Metalwork (G.C.E. J.M. Board, 1954)	19	+ ·335	— ·313	+ ·146	— ·004
Woodwork (Theory and Practical, Internal Exam., 1954)	52	+ ·474*	— ·178	— ·014	— ·151
Woodwork (G.C.E. J.M. Board, 1954)	24	+ ·234	— ·099	+ ·343	— ·223
Geometrical Drawing (G.C.E. J.M. Board, 1954)	19	+ ·037	+ ·559*	— ·105	+ ·693*

* Significant at 5 per cent level of confidence.

Table 54

MIDDLESBROUGH STUDY

N.F.E.R. SPATIAL TEST I (REGRESSION COEFFICIENTS)

Best weightings of test-scores in the selection battery for predicting subsequent success in technical examinations. Pupils were originally tested in 1951 at the age of 13.

SUBJECT	N	REGRESSION COEFFICIENTS: SPATIAL TEST I (N.F.E.R.)	M.H. VERBAL REASONING TEST (ADV. 9)	M.H. ENGLISH TEST 18	M.H. ARITHMETIC TEST 18	MULTIPLE CORRELATION WITH CRITERION
Engineering Drawing (Internal Exam., 1954)	52	+ ·833*	— ·036	+ ·024	+ ·192	+ ·705
Metalwork (Theory and Practical, Internal Exam., 1954)	52	+ ·279*	+ ·060	+ ·143	— ·283	+ ·447
Metalwork (G.C.E. J.M. Board, 1954)	19	+ ·502	— 1·250	+ ·214	+ ·362	+ ·768
Woodwork (Theory and Practical, Internal Exam., 1954)	52	+ ·603*	— ·538	— ·048	+ ·122	+ ·603
Woodwork (G.C.E. J.M. Board, 1954)	24	+ ·140	+ ·104	+ ·414	— ·102	+ ·433
Geometrical Drawing (G.C.E. J.M. Board, 1954)	19	+ ·242	+ ·565*	+ ·180	+ ·641*	+ ·866

* Significant at 5 per cent level of confidence.

Table 55

OLDHAM STUDY

N.F.E.R. SPATIAL TEST I (CORRELATIONS)

Validity of a battery of selection tests (including N.F.E.R. Spatial Test 1) *taken in* 1954 *when the pupils were* 11 *years of age. Correlations are shown between scores in individual tests and criteria of success in G.C.E. Examinations taken five years later.*

SUBJECT	N	SPATIAL TEST I	VERBAL TEST	ENGLISH TEST	ESSAY	MECH. ARITH.	PROB. ARITH.
Metalwork	21 *Boys*	·485*	·192	—·131	—·301	·110	·384
Mechanical Science	21 *Boys*	·492*	·304	·143	—·187	·043	·335
Art	26 *Girls* 8 *Boys*	·404*	·193	·281	·128	·007	·261
Woodwork	32 *Boys*	·241	·167	·123	·156	—·023	·148
Mathematics	92 *Boys*	·223*	·120	—·042	—·137	·226*	·222*
Mathematics	84 *Girls*	·246*	·336*	·269*	·193	·309*	·539*
Physics	61 *Boys*	—·074	·227	·221	·070	·141	·028
Physics	16 *Girls*	—·084	·079	·394	—·029	·255	—·026
Chemistry	55 *Boys*	—·274*	·241	·199	—·010	·005	—·109
Chemistry	28 *Girls*	·032	·140	·279	·161	·441*	·290
Biology	51 *Boys*	—·247	—·137	·135	—·187	—·011	—·022
Biology	66 *Girls*	·223	·229	·273*	—·042	·366*	·352*
French	41 *Girls*	·112	·325*	·381*	·326*	·081	·143
German	26 *Girls*	—·231	·176	·355	·373	·263	—·225
English Language	55 *Boys*	·144	·421*	·414*	·391*	·050	·273*
English Language	41 *Girls*	—·236	·356*	·617*	·473*	·253	·126
English Literature	31 *Boys*	—·299	·365*	·248	·368*	·022	·227
English Literature	51 *Girls*	—·011	·245	·468*	·228	·316*	·248

* Significant at 5 per cent level of confidence.

Table 56

OLDHAM STUDY

N.F.E.R. SPATIAL TEST I (REGRESSION COEFFICIENTS)

Best weightings of test-scores in the selection battery (including Spatial Test 1) for predicting success in G.C.E. Examinations taken five years later. Pupils were originally tested in 1954 and took the Northern Universities Joint Matriculation Board Examinations in 1959.

SUBJECT	N	REGRESSION COEFFICIENTS: SPATIAL TEST I	VERBAL TEST	ENGLISH TEST	ESSAY	MECH. ARITH.	PROB. ARITH.	MULTIPLE CORRELATION
Metalwork	*21 Boys*	·546	·053	— ·504	— ·280	— 1·146	1·258	·885
Mechanical Science	*21 Boys*	·390	— ·031	— ·048	— ·080	— ·392	·703	·640
Art	*26 Girls* / *8 Boys*	·340*	— ·156	·326	·024	— ·901	·332	·531
Woodwork	*32 Boys*	·283	·112	— ·011	·236	— ·629	1·024	·537
Mathematics	*92 Boys*	·205	·195	— ·083	— ·156	1·208	·506	·692
Mathematics	*84 Girls*	·064	·390	— ·084	·173	·811	1·567*	—
Physics	*61 Boys*	— ·223	·806	·255	— ·049	·798	— ·429	·594
Physics	*16 Girls*	— ·268	— ·041	·806	— ·537	2·652	— 1·711	—
Chemistry	*55 Boys*	— ·582*	1·172*	·283	— ·232	— ·189	— ·298	·730
Chemistry	*28 Girls*	— ·042	·054	·236	— ·018	2·266	·045	—
Biology	*51 Boys*	— ·318	— ·264	·364	— ·366*	— ·246	·564	·472
Biology	*66 Girls*	·035	— ·104	·430	— ·208	1·788*	·474	·965
French	*41 Girls*	·093	·561	·288	·293	·107	—· 080	·543
German	*26 Girls*	·019	·183	·324	·166	1·592	— 1·127	·937
English Language	*55 Boys*	— ·062	·448	·223	·185	— ·438	·625	·702
English Language	*41 Girls*	— ·199	·452	·600*	·120	— ·066	— ·470	·748
English Literature	*31 Boys*	— ·509*	·761	·140	·130	·382	·805	·839
English Literature	*51 Girls*	— ·197	·187	·674*	— ·079	1·453	·045	·903

* Significant at 5 per cent level of confidence.

Table 57

Carlisle Study. Matrix of correlations of selection test-scores and teachers' assessments of personality traits and practical and drawing abilities (for 489 boys in age-range 10:2 to 11:1).

	ENG. 4 (N.F.E.R.)	ENG. 25 (M.H.)	VERBAL 4 (N.F.E.R.)	VERBAL 54 (M.H.)	ARITH. 4 (N.F.E.R.)	ARITH. 25 (M.H.)	SPATIAL 2 (N.F.E.R.)	PRACT-ICAL	DRAWING	EMO-TIONAL STA-BILITY	SOCIA-BILITY
English 4 (N.F.E.R.)	—	·934	·857	·863	·793	·770	·527	·627	·520	·656	·586
English 25 (M.H.)	·934	—	·861	·868	·797	·779	·534	·605	·496	·647	·582
Verbal 4 (N.F.E.R.)	·857	·861	—	·919	·864	·835	·694	·674	·555	·726	·634
Verbal 54 (M.H.)	·863	·868	·919	—	·881	·861	·688	·680	·550	·711	·627
Arith. 4 (N.F.E.R.)	·793	·797	·864	·881	—	·957	·668	·708	·560	·731	·658
Arith. 25 (M.H.)	·770	·779	·835	·861	·957	—	·617	·701	·546	·718	·657
Spatial 2 (N.F.E.R.)	·527	·534	·694	·688	·668	·617	—	·544	·466	·531	·409
Practical	·627	·605	·674	·680	·708	·701	·544	—	·769	·724	·644
Drawing	·520	·496	·555	·550	·560	·546	·466	·769	—	·598	·576
Emotional Stability	·656	·647	·726	·711	·731	·718	·531	·724	·598	—	·747
Sociability	·586	·582	·634	·627	·658	·657	·409	·644	·576	·747	—

Appendix 11

List of paper-and-pencil tests of spatial ability

TEST	AUTHOR(S)	APPROXIMATE DATE OF PUBLICATION
Maze Test	S. D. Porteus	1915
Copying and Drawing from Memory	A. Binet	1917
Picture Completion	R. Pintner and M. M. Anderson	1917
Army Group Intelligence (Beta) (including spatial sub-tests such as paper form-board)	U.S. Division of Psychology	1918
Mental Manipulation of Space Relations	H. N. Irwin	1918
Matching Solids and Surfaces	A. L. Rogers	1918
Spatial Relations, A and B	L. L. Thurstone	1918
Hands Test	L. L. Thurstone	1918
Engineering Aptitude Test	L. L. Thurstone	1918
Drawing a Man	C. Burt	1921
Figure Orientation (Chelsea Tests)	P. B. Ballard	1922
Imagery Test	C. H. Griffiths	1924
Mechanical Ability (Tracing, tapping, dotting, copying, blocks, pursuit)	T. W. MacQuarrie	1925
Form Relations (N.I.I.P.)	A. Macrae	1926
Memory for Designs (N.I.I.P.)	F. M. Earle	1926
Drawing a Man	F. L. Goodenough	1926
Embedded Figures	K. Gottschaldt	1926
Form Discrimination	C. B. Davenport	1927
Visual Designs	F. W. Ellis (modified by M. E. Goudge and H. W. Crane)	1927

TEST	AUTHOR(S)	APPROXIMATE DATE OF PUBLICATION
Visual Designs	W. Healy	1927
Spatial Relations Examination, Problem 4 (Paper folding)	L. L. Thurstone and W. B. Jones	1927
Minnesota Mechanical Ability Tests (including paper form-board)	D. G. Paterson, R. M. Elliott, L. D. Anderson, H. A. Toops and E. Heidbreder	1928
Spatial Representation	O. Julian	1928
Visualization	E. Claparède	1929
Gestalt Completion	R. F. Street	1931
Visual Perception (figure classification)	C. Spearman	1932
Spatial Relations (cube-counting, matching)	C. C. Brigham	1932
Revised Minnesota Paper Form-Board	R. Likert and W. A. Quasha	1934
Overlapping Shapes	W. Stephenson	1935
Overlapping Shapes (with directions)	A. A. El Koussy	1935
Area Discrimination	A. A. El Koussy	1935
Form Equations, A. B and C	A. A. El Koussy	1935
Correlate Eduction, A and B	A. A. El Koussy (after Spearman)	1935
Band Completion	A. A. El Koussy (after Spearman)	1935
Spatial Analogies	A. A. El Koussy (after Stephenson)	1935
Pattern Perception (cross patterns)	W. Stephenson	1935
Visual Motor Gestalt	L. Bender	1938
Primary Mental Abilities (Spatial sub-test)	L. L. Thurstone and T. G. Thurstone	1938
Shapes Test (N.I.I.P.)	P. Slater	1940
Recognition of Designs (N.I.I.P.)	P. Slater	1940
Group Test 80A (N.I.I.P. Mental manipulation of shapes)	P. Slater	1943

TEST	AUTHOR(S)	APPROXIMATE DATE OF PUBLICATION
Survey of Space Relations Ability	H. W. Case and F. Ruch	1944
Squares Test	after Rybakoff	1944
Chesterfield Test (Spatial section, including squares and square completion)	C. Spearman	1944
Survey of Object Visualization	D. R. Miller	1945
Visual Retention for Clinical Use	A. L. Benton	1946
Memory for Designs	F. K. Graham and B. S. Kendall	1946
Differential Aptitude Tests (Space relations sub-test)	G. K. Bennett, H. G. Seashore and A. G. Wesman	1947
Spatial Visualization (visualization of rotated clock)	J. P. Guilford and W. S. Zimmerman	1947
Spatial Orientation (orientation of boat)	J. P. Guilford and W. S. Zimmerman	1947
General Aptitude Test Battery (Spatial aptitude sub-test)	U.S. Employment Service	1947
Moray House Space Test 1 (square and cube counting, overlapping shapes, reflected forms, block completion)	G. H. Thomson, J. H. Gray, J. Y. Erskine, J. T. Bain L. F. Mills and W. G. Emmett	1947
Duplex Series of Ability Tests: Nos 3 & 4, Part II (Mathematical and Mechanical Aptitudes)	F. M. Earle	1947
Technical Selection Test T.S.8 (pattern checking)	E. A. Peel	1948
Technical Selection Test V.S.10 (pattern checking)	E. A. Peel	1948
Object Aperture Test (space visualization)	P. H. Du Bois and G. Gleser	1948
Mathematical and Technical Test (includes memory for designs subtest)	J. L. Prak	1948

TEST	AUTHOR(S)	APPROXIMATE DATE OF PUBLICATION
Group Test 81 (N.I.I.P.) (cross pattern and dissecting shapes)	P. Slater	1949
Spatial Test 1 (N.F.E.R.) (dissecting shapes, embedded figures, cross-pattern, shape recognition, form analogies, inverse drawing)	I. Macfarlane Smith	1950
Spatial Test 2 (N.F.E.R.) (match boxes, shapes and models, square completion, paper folding, block building)	A. F. Watts, D. A. Pidgeon and M. K. B. Richards	1951
Paper Form Board (Vz–1)	L. L. Thurstone	1952
Punched Holes (Vz–2)	L. L. Thurstone	1952
Surface Development (Vz–3)	L. L. Thurstone	1952
McGill Closure Test (gestalt completion)	C. M. Mooney	1954
Differential Test Battery (shapes sub-test)	J. R. Morrisby	1955
Flags Test (revised)	L. L. Thurstone and T. E. Jeffrey	1956
Aptitude Classification Tests (S.R.A.) (assembly and identification of components, sub-tests)	J. C. Flanagan	1957
Spatial Test 3 (N.F.E.R.) (sections, plans, projections and nets of solid objects)	I. Macfarlane Smith and J. S. Lawes	1959
Object Completion Space Form (completion, shapes and models)	J. W. Curtis	1960
Development Test of Visual Perception (eye-motor co-ordination, figure-ground, form constancy, position in space, space relations)	M. Frostig	1961

For details of publisher and price and for critical reviews of many of the tests listed above, reference should be made to the appropriate *Mental Measurements Yearbook*, edited by O. K. Buros and usually published by the Gryphon Press, Highland Park, New Jersey, U.S.A. Yearbooks have been published for 1938, 1941, 1949, 1953, 1959 and 1964.

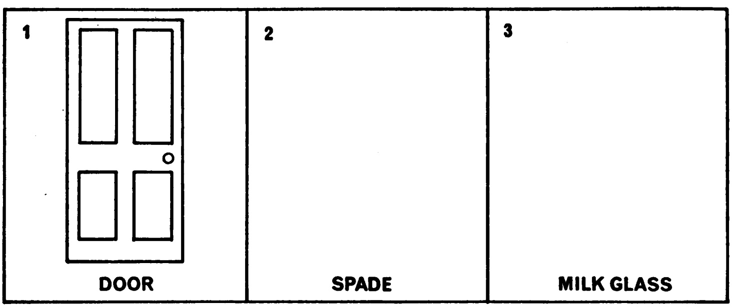
Appendix 12

(Some of the following items are reproduced from N.F.E.R. Tests by kind permission of the Director, Dr. Wall.)

Samples of items from spatial tests

DRAWING

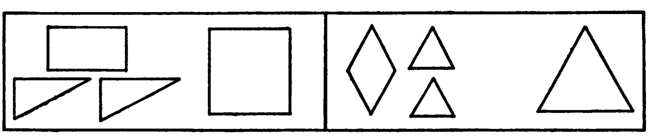
In each space, make a drawing of the object named there. Make the drawings large, as shown in the drawing of the door in the first space. Do not spend a lot of time on detail, but be sure that you draw the outline of the shape correctly.



SHAPE DISSECTION (PAPER FORM-BOARD)

Each of the spaces below encloses a number of small figures and also one large figure. The large figure on the right can be cut up to form the small figures on the left.

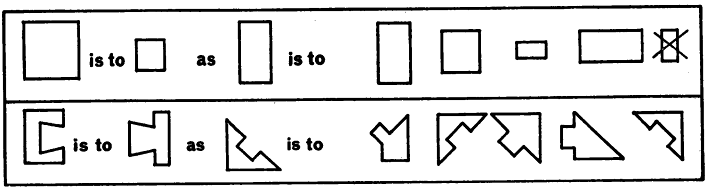
Draw lines on the large figure to show how it should be cut to form the smaller figures.



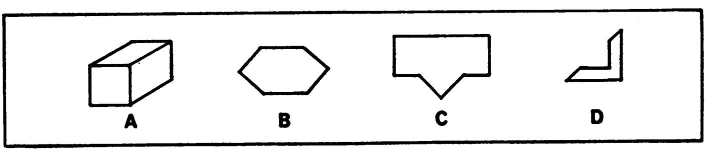
SPATIAL ANALOGIES

Look at the figures in the top row. 'Large square' is to 'small square' as 'large oblong' is to 'small oblong'. The small oblong has been crossed out because it bears the same relation to the large oblong as the small square does to the large square.

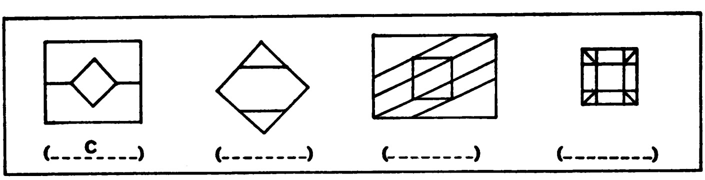
Cross out the correct figure in the second row in the same way.



EMBEDDED FIGURES



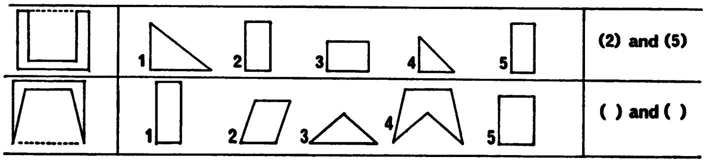
The four figures A, B, C and D are printed above. Now in each of the drawings underneath, one of these figures is hidden. Try to find which of the figures A, B, C or D is hidden in each drawing and write its letter in the brackets underneath. The first one has been done for you.



SQUARE COMPLETION

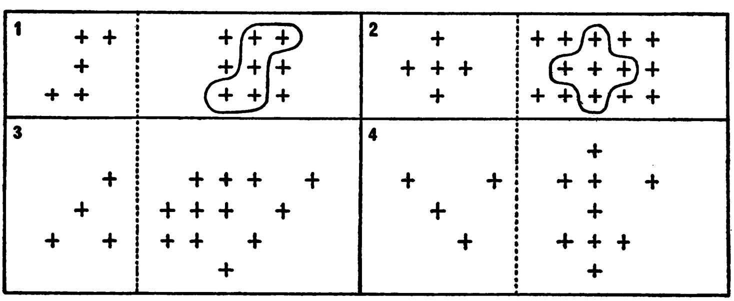
On each line there is a square with a piece cut out and five pieces with numbers beside them. Two of the five pieces can be fitted together so that they fill up exactly the space cut out of the square. Find them and put their numbers at the end of the line.

The first one has been done for you. Look at it carefully. Then do the second one yourself.



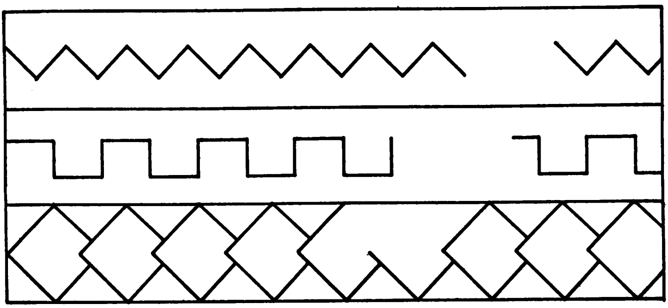
PATTERN PERCEPTION

In each of the spaces below there are two patterns of crosses. The smaller pattern on the left is hidden in the larger pattern on the right. Pick out those crosses in the right-hand pattern which form the left-hand pattern and draw a line round them. Thus, the pattern inside your line should be the same as the pattern on the left-hand side. The first two have been done for you.



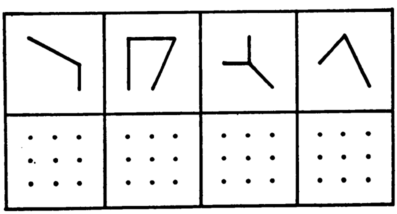
PATTERN COMPLETION

Complete the patterns in the spaces below.



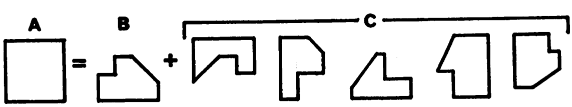
INVERSE DRAWING

In the lower space of each figure draw the upper figure as if seen reflected in a pool of water.



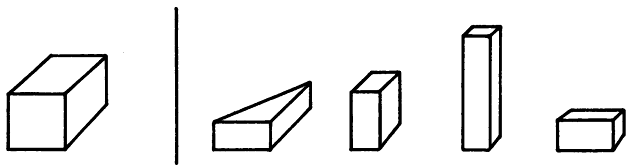
FORM EQUATIONS A

Underline the figure under C which when added to B will make the square A.



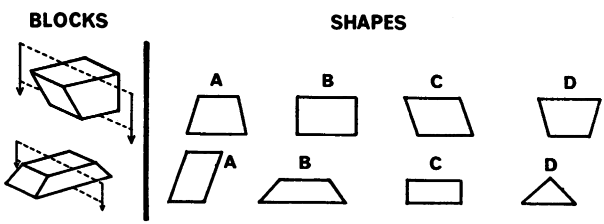
BLOCK BUILDING

How many of the smaller blocks in the row below are needed to build the larger one on the left? Write the number on each block.



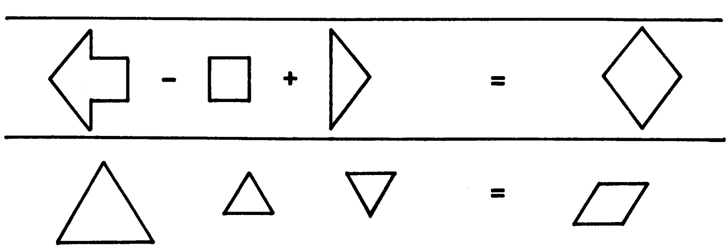
SECTIONS OF SOLIDS

Each question shows a block of wood. Imagine a cut made where shown by the dotted lines. Place a cross (X) on one of the four drawings on the right which shows the shape of the cut face.



FORM EQUATIONS B

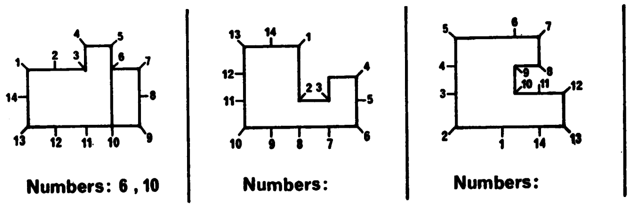
Look at the three figures on the left-hand side of the top row. By subtracting the second from the first, and then adding the third, you could make up the figure on the right-hand side. So a — has been put before the second and a + before the third. Do this with the others in the second row.



SQUARES

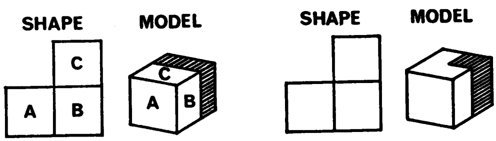
All the shapes below can be cut into two parts which will fit together again to form a square. For example, in the first shape, if a cut is made through points 6 and 10 the part cut off will fit in the top left-hand corner and the two pieces make a square.

In each case draw the line through which the cut must be made and write the numbers through which the line passes in the space provided. The first one has been done for you.



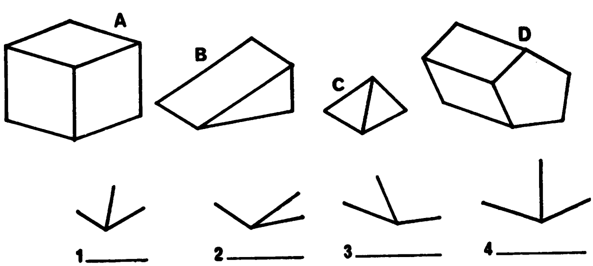
SURFACE DEVELOPMENT

On the shape draw lines to show where you would cut to remove the parts which would be the shaded portions if the paper were folded to form the model.



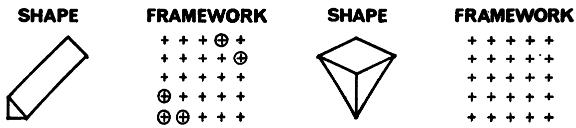
ANGLE RECOGNITION

In the top row are drawings of four blocks. Each question shows a drawing of three lines. These three lines have been copied from a corner of one of the blocks. Put the letter of this block under the three-line diagram.



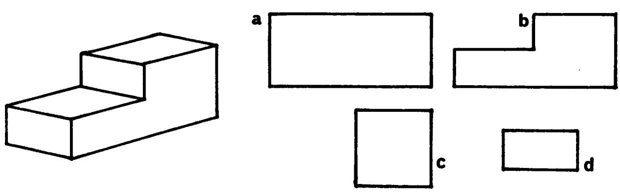
COPYING

Each question shows the shape of a solid block and a framework of crosses. On the second framework put circles round the crosses you would join up to make exactly the shape shown. The first has been done for you.



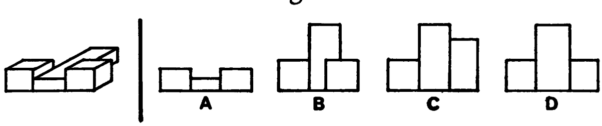
SURFACE RECOGNITION

The diagram below shows a model with the shapes of its faces labelled a, b, c and d. On each shape put a number showing how many times that face has been used to build the model.



PROJECTIONS OF SOLIDS

The left-hand drawing shows several blocks placed together. Put a cross (X) on one of the four drawings on the right of the thick black line which shows the view looking down on the blocks.



Bibliography

Chapter one

ALEXANDER, JOYCE. *Scientific Manpower*. London, Hilgar and Watts, 1959.

COCKCROFT, SIR JOHN. Address to the Royal Society of Arts. May, 1961.

DEMPSTER, J. J. B. 'An Investigation into the use of Verbal and Spatial Tests in the selection of Boys for Grammar and Secondary Technical Schools.' Ph.D. Thesis, Univ. of London, 1951.

EDWARDS, REESE. *The Secondary Technical School*. London, Univ. of London Press Ltd., 1960.

GOOCH, A. G. 'Some Aspects of Selection for Technical Courses in Secondary Schools.' *Vocational Aspect*, 1962, **14**, 29, pp. 154–9.

MCINTOSH, D. M. *Educational Guidance and the Pool of Ability*. London, Univ. of London Press Ltd., 1959.

MCINTOSH, D. M. 'The Pool of Ability. Further Reflections.' *Times Educational Supplement*, 18th May 1962.

NISBET, J. and BUCHAN, J. 'The Long-term Follow-up of Assessments at Age Eleven.' *Brit. J. Educ. Psychol.*, 1959, **29**, 1, pp. 1–8.

PAYNE, G. L. *Britain's Scientific and Technological Manpower*. Stanford, Stanford Univ. Press, 1960.

SMITH, I. MACFARLANE. 'Some Aspects of Selection for Technical Courses in Secondary Schools. A reply to Mr. Gooch.' *Vocational Aspect*, 1963, **15**, 30, pp. 18–21.

THWAITES, BRYAN. Inaugural lecture in the Dept. of Theoretical Mechanics, Univ. of Southampton. Extract from report in *Times Educational Supplement*, 28th May 1961.

VAIZEY, J. Quoted in the *Observer*, 13th August 1961.

VERNON, P. E. *The Structure of Human Abilities*. London, Methuen, 1950.

YATES, A. and BARR, F. 'Selection for Secondary Technical Courses—a Report of a Pilot Investigation'. *Educational Research*, 1960, **2**, pp. 143–8.

YATES, A. and PIDGEON, D. A. *Admission to Grammar Schools*. London, published for N.F.E.R. by Newnes, 1957.

Science and the Future of Britain. London, Labour Party Pamphlet, 1961.

Signpost for the Sixties. A statement of home policy submitted to the 60th Annual Conference. London, Labour Party Pamphlet, 1961.

Scientific and Engineering Manpower in Great Britain. A Report issued by the Ministry of Labour and National Service and the Advisory Council on Scientific Policy, 1956. London, H.M.S.O., 1956.

Education and Professional Employment in the U.S.S.R. (Compiled by Nicholas de Witt.) Report published by the National Science Foundation in the United States, 1962.

The Use of Spatial Tests in Selection for Secondary Technical Schools at Eleven Plus. Report to Southampton Education Committee, 1950.

Spens Report. Report of the Consultative Committee on Secondary Education with Special Reference to Grammar Schools and Technical High Schools. London, H.M.S.O., 1938.

The Long-Term Demand for Scientific Manpower. Report of the Advisory Council on Scientific Policy. London, H.M.S.O., 1961.

Chapter two

ADCOCK, C. 'A Re-analysis of Slater's Spatial Judgment Research.' *Occup. Psychol.*, 1948, **22**, 4, pp. 213–16.

ALEXANDER, W. P. 'Intelligence, Concrete and Abstract.' *Brit. J. Psychol.*, Monogr. Suppl. No. **29**, 1935.

ALLEN, E. P. and SMITH, P. *First, Second and Third Reports of Research.* City of Birmingham Education Committee, 1931, 1934, 1939.

ANDERSON, G. V., FRUCHTER, B., MANUEL, H. T. and WORCHAL, P. *Technical Report—Survey of Published Data and Current Status of Research on Spatial Factors.* Univ. of Texas, 1952.

BARRATT, E. S. 'An Analysis of Verbal Reports of Spatial Problem-solving.' Unpublished Ph.D. Thesis, Univ. of Texas, 1952.

BROWN, W. and STEPHENSON, W. 'A Test of the Theory of Two-factors.' *Brit. J. Psychol.*, 1933, **23**, pp. 352–70.

BURT, C. *The Factors of the Mind.* London, Univ. of London Press Ltd., 1940, p. 103.

BURT, C. 'The Structure of the Mind. A Review of the Results of Factorial Analysis.' *Brit. J. Educ. Psychol.*, 1949, **19**, 2, pp. 100–11.

CATTELL, R. B. *A Guide to Mental Testing.* London, Univ. of London Press Ltd., 1936.

CLARKE, G. 'The Range and Nature of Factors in Perceptual Tests.' Ph.D. Thesis, Univ. of London, 1936.

COX, J. W. *Mechanical Aptitude.* London, Methuen, 1928.

DEMPSTER, J. J. B. 'Symposium on the Selection of Pupils for different types of Secondary Schools. V: The selector's point of view.' *Brit. J. Educ. Psychol.*, 1948, **18**, 3, pp. 121–33.

DREW, L. J. 'An Experimental Enquiry into the Methods of Selection for

Technical Education based on Multiple Factor-Analysis.' M.Ed. Thesis, Univ. of Leeds, 1944.

DREW, L. J. 'An Investigation into the Measurement of Technical Ability.' *Occup. Psychol.*, 1947, **21**, 1, pp. 34–48.

EARLE, F. M. and MACRAE, A. 'Tests of Mechanical Ability.' *Nat. Inst. Industr. Psychol. Rep.* No. 3, 1929, p. 42.

EARLE, F. M. and MILNER, M. et al. 'Use of Performance Tests of Intelligence in Vocational Guidance.' *Industr. Health Res. Board Rep.* No. 53, 1929.

EMMETT, W. G. 'Evidence for a Space Factor at 11 plus and earlier.' *Brit. J. Psychol.* (Stat. Sect.), 1949, **2**, 1, pp. 3–16.

FORTES, M. 'A New Application of the Theory of Noegenesis to the Problems of Mental Testing.' Ph.D. Thesis, Univ. of London, 1930.

FRENCH, J. W. 'The description of Aptitude and Achievement Tests in terms of Rotated Factors.' *Psychometric Monograph* No. 5, 1951.

FRUCHTER, B. 'Measurement of Spatial Abilities.' *Educ. Psychol. Measmt.*, 1954, **14**, 2, pp. 387–95.

GALTON, F. *Hereditary Genius.* London, Macmillan, 2nd ed. 1892, p. 323.

GHAREIB, R. M. EL. 'Factorial Analysis of Practical Ability and its Relation to other Intellectual Abilities and Personality Traits.' Ph.D. Thesis, Univ. of Edinburgh, 1949.

GOTTSCHALDT, K. 'Über den Einfluss der Ehrfahrung auf die Wahrnehmung von Figuren.' *Psychol. Forsch.*, 1926, **8**, p. 261.

GUILFORD, J. P. 'Some Lessons from Aviation Psychology.' *Amer. Psychologist*, 1948, **3**, pp. 3–11.

GUILFORD, J. P. 'Factor Analysis in a Test Development Program.' *Psychol. Rev.*, 1948, **55**, pp. 79–94.

GUILFORD, J. P. and LACEY, J. I. 'Printed Classification Tests.' *A.A.F. Aviat. Psychol. Prog. Res. Rep.* No. 5. Washington, U.S. Gov. Printing Office, 1947.

HOLZINGER, K. *Student Manual of Factor Analysis.* Chicago, Dept. of Education, 1939.

HOTELLING, H. 'Analysis of a Complex of Statistical Variables into Principal Components.' *J. Educ. Psychol.*, 1933, **24**, pp. 417–41, 498–520.

KELLEY, T. L. *Crossroads in the Mind of Man.* Stanford, Calif., Stanford Univ. Press, 1928.

KOHS, S. C. *Intelligence Measurement.* New York, Macmillan, 1923.

KOUSSY, A. A. H. EL. 'The Visual Perception of Space.' *Brit. J. Psychol.*, Monogr. Suppl. No. **20**, 1935.

KOUSSY, A. A. H. EL. *Proceedings and Papers of the Twelfth International Congress of Psychology at Edinburgh, 1948.* Edinburgh, Oliver and Boyd, 1950, p. 82.

KOUSSY, A. A. H. EL. *The Directions of Research in the domain of Spatial Aptitudes.* Édition of the Centre National de la Recherche Scientifique, Paris, 1955.

LEFF, B. 'Technical Aptitude in boys and girls aged 12 years with special reference to Alexander's Performance Scale.' M.A. Thesis, Univ. of London, 1949.

LINE, W. 'The Growth of Visual Perception in Children.' *Brit. J. Psychol.*, Monogr. Suppl. No. **15**, 1931.

MCFARLANE, M. 'A Study of Practical Ability.' *Brit. J. Psychol.*, Monogr. Suppl. No. **8**, 1925.

MICHAEL, W. B. 'A suggested Research Approach to the Identification of Psychological Processes associated with Spatial Visualization Factors.' *Educ. Psychol. Measmt.*, 1954, **14**, 2, pp. 401–6.

MICHAEL, W. B., GUILFORD, J. P., FRUCHTER, B. and ZIMMERMAN, W. S. 'The Description of Spatial-visualization Abilities.' *Educ. Psychol. Measmt.*, 1957, **17**, pp. 185–99.

MILLS, L. F. 'Properties of a Space Test.' B.Ed. Thesis, Univ. of Edinburgh, 1947.

MORRISBY, J. R. 'Psychometric Theory of the Differential Test Battery.' Cyclostyled pamphlet available through the National Foundation for Educational Research, 1955.

MYERS, C. T. 'Some observations of Problem-solving in Spatial Relations Tests.' *Research Bulletin* RB–58–16, Educational Testing Service, New Jersey, 1958.

NORWOOD REPORT. *Curriculum and Examinations in Secondary Schools.* London, H.M.S.O., 1943.

PENROSE, L. and RAVEN, J. C. *Progressive Matrices.* London, H. K. Lewis, 1938.

PILLINER, A. E. G. *Personal Communication.* 1950.

PRICE, E. J. J. 'The Nature of the Practical Factor (F).' *Brit. J. Psychol.*, 1940, **30**, pp. 341–51.

RENSHAW, T. 'A Factorial Study of Two- and Three-Dimensional Space Tests.' Ph.D. Thesis, Univ. of Edinburgh, 1950.

REYBURN, H. A. and RAATH, M. J. 'Simple Structure: a Critical Examination.' *Brit. J. Psychol.* (Stat. Sect.), 1949, **2**, 3, pp. 125–33.

RODGER, A. 'A Borstal Experiment in Vocational Guidance.' *Indust. Health Res. Board Rep.* No. **78**, 1937.

ROFF, MERRILL. 'A Factorial Study of Tests in the Perceptual Area.' *Psychometric Monograph* No. **8**, 1952.

SLATER, P. 'Some Group Tests of Spatial Judgment or Practical Ability.' *Occup. Psychol.*, 1940, **14**, pp. 40–55.

SLATER, P. and BENNETT, E. 'The Development of Spatial Judgment and its relation to some Educational Problems.' *Occup. Psychol.*, 1943, **17**, 3, pp. 139–55.

SLATER, P. 'Evidence on Selection for Technical Schools.' *Occup. Psychol.*, 1947, **21**, pp. 135–40.

SLATER, P. Mr. Slater replies to Dr. Adcock. *Occup. Psychol.*, 1949, **23**, 2.

SMITH, G. MILTON. 'Group Factors in Mental Tests similar in Material or in Structure.' *Arch. Psychol.*, 1933, No. **156**.

SMITH, I. MACFARLANE. 'The Form-Perception Factor. A Study of a Variety of Form-Relations Tests, of the Existence of a Factor of Form-Perception and of its relation to success in School Subjects.' Ed.B. Thesis, Univ. of Glasgow, 1937. Summary in *Brit. J. Educ. Psychol.*, 1938, **3**, 1.

SMITH, I. MACFARLANE. 'Measuring Spatial Abilities in School Pupils.' *Occup. Psychol.*, 1948, **22**, 3, pp. 150–9.

SMITH, I. MACFARLANE. *Spatial Test I and Manual*. London, published for N.F.E.R. by Newnes, 1950.

SMITH, I. MACFARLANE. 'An Investigation into the problem of measuring Spatial Ability in pupils of 11 to 12 and of devising a reliable test for selecting for Technical Education, together with a study of the Personality Qualities of pupils so selected.' Ph.D. Thesis, Univ. of Manchester, 1952.

SMITH, I. MACFARLANE. 'The Development of a Spatial Test.' *Durham Res. Rev.*, 1954, **5**, pp. 19–33.

SPEARMAN, C. *The Abilities of Man*. London, Macmillan, 1927, p. 230.

SPEARMAN, C. and WYNN JONES, L. *Human Abilities*. London, Macmillan, 1950, p. 70.

STEPHENSON, W. 'Tetrad-differences for Non-verbal Sub-tests.' *Brit. J. Educ. Psychol.*, 1931, **22**, pp. 167–85.

STEPHENSON, W. 'Tetrad-differences for Verbal Sub-tests.' *Brit. J. Educ. Psychol.*, 1931, **22**, pp. 255–67.

STEPHENSON, W. 'Tetrad-differences for Verbal Sub-tests relative to Non-verbal Sub-tests.' *Brit. J. Educ. Psychol.*, 1931, **22**, pp. 334–50.

STRAUSS, A. A. and KEPHART, N. C. *Psychopathology and Education of the Brain-injured Child. Vol. II: Progress in Theory and Clinic*. New York, Grune and Stratton, 1955.

SULTAN, E. E. 'A Factorial Study in the domain of Creative Thinking.' M.A. Thesis, cf. abstract *Brit. J. Educ. Psychol.*, 1962, **32**, 1, pp. 78–82.

SWINEFORD, F. 'A Study in Factor-Analysis. The Nature of the General, Verbal and Spatial Bifactors.' *Supplementary Educational Monograph* No. **67**, Chicago, Univ. of Chicago Press, 1948.

TAYLOR, C. C. 'A Study of the Nature of Spatial Ability and its relationship to Attainment in Geography.' M.Ed. Thesis, Univ. of Durham. Abstract in *Brit. J. Educ. Psychol.*, 1960, **30**, 3, pp. 266–70.

THURSTONE, L. L. *A Factorial Study of Perception*. Chicago, Univ. of Chicago Press, 1944.

THURSTONE, L. L. 'Some Primary Abilities in Visual Thinking.' Chicago, *Univ. of Chicago Psychometric Lab. Report* No. **59**, 1950.

THURSTONE, L. L. 'An Analysis of Mechanical Aptitude.' Chicago, *Univ. of Chicago Psychometric Lab. Repotr*No. **62**, 1951.

VERNON, P. E. 'The Structure of Practical Abilities.' *Occup. Psychol.*, 1949, **33**, pp. 81–96.

VERNON, P. E. *The Structure of Human Abilities.* London, Methuen, 1950.

VERNON, P. E. and PARRY, J. B. *Personnel Selection in the British Forces.* London, Univ. of London Press Ltd., 1949.

WALTER, W. GREY. *The Living Brain.* Norton, New York, 1953.

WATTS, A. F. 'A Group Performance Test'. *Bulletin of the Nat. Foundation for Educ. Res.*, 1953, **2**, pp. 15–21.

WATTS, A. F. and SLATER, P. *The Allocation of Primary School Leavers to Courses of Secondary Education.* London, published for N.F.E.R. by Newnes, 1950.

WILLIAMS, H. S. 'Some Aspects of the Measurement and Maturation of Mechanical Aptitude in boys, aged 12 to 14.' Ph.D. Thesis, Univ. of London, 1948.

WITKIN, M. A. 'Individual Differences in ease of Perception of Embedded Figures.' *J. Pers.*, 1950, **19**, pp. 1–15.

WOLFLE, D. 'Factor Analysis to 1940'. *Psychometric Monograph* No. **3**, 1940.

ZIMMERMAN, W. S. 'The Influence of Item Complexity upon the Factor Composition of a Spatial Visualization Test.' *Educ. Psychol. Measmt.*, 1954, **14**, 1, pp. 106–19.

ZIMMERMAN, W. S. 'Hypotheses concerning the Nature of Spatial Factors.' *Educ. Psychol. Measmt.*, 1954, **14**, 2, pp. 396–400.

Chapter three

BALLARD, P. B. *Group Tests of Intelligence.* London, Univ. of London Press Ltd., 1922.

BARAKAT, M. K. 'Factors Underlying Mathematical Abilities.' Ph.D. Thesis, Univ. of London, 1950.

BARAKAT, M. K. 'A factorial study of Mathematical Abilities.' *Brit. J. Psychol.* (*Stat. Sect.*), 1951, **4**, pp. 137–56.

BETZ, W. 'Uber Korrelationen.' *Ztsch. fur ang. Psych*, 1911.

BLACKWELL, A. M. 'A Comparative Investigation into the factors involved in Mathematical Ability in Boys and Girls.' M.A. Thesis, Univ. of London, 1938.

BLACKWELL, A. M. 'A Comparative Investigation into the factors involved in Mathematical Ability in Boys and Girls.' *Brit. J. Educ. Psychol.*, 1940, **10**, pp. 143–53, 212–22.

BLADE, M. F. and WATSON, W. S. 'Increase in Spatial Visualization Test-scores during Engineering Study.' *Psychol. Monogr.* 1955, **69**, No. **397**.

BOTZUM, W. A. 'A Factorial Study of the Reasoning and Closure Factors.' *Psychometrika*, 1951, **16**, pp. 361–86.

BRONOWSKI, J. Chapter in *The Quality of Education.* (ed. Thompson, D. and Reeve, J.) London, Müller, 1947, p. 184.

BROWN, W. 'An Objective Study of Mathematical Intelligence.' *Biometrika,* 1910, **7**, p. 352 ff.

BROWN, W. 'The Psychology of Mathematics.' *Child Study,* 1913, **6**, p. 26.

BURT, C. 'The Relations of Educational Abilities.' *Brit. J. Educ. Psychol.,* 1939, **9**, pp. 45–71.

CAMERON, A. E. 'A comparative study of the Mathematical Ability of boys and girls in Secondary Schools.' *Brit. J. Psychol.,* 1925, **16**, 1, pp. 29–49.

CHURCHILL, B. D., CURTIS, J. M., COOMBS, C. H. and HASSELL, T. W. 'Effect of engineer school training on the Surface Development Test.' *Educ. Psychol. Measmt.,* 1942, **2**, pp. 279–80.

COLLAR, J. 'A statistical survey of Arithmetical Ability.' *Brit. J. Psychol.,* 1920, **11**, 1, pp. 135–58.

COOMBS, C. H. 'A factorial study of Number Ability.' *Psychometrika,* 1941, **6**, pp. 161–89.

DAHLGREN, O. H. 'De Konstitutionella Begåvningsanlagen för Olika Skolämnen.' *T.P.P.,* 1943–4, **2**, pp. 72–80. 'Bidrag till Språkfaktorernas Psykologi.' Ibid, 1947. Göteborg.

FAUBIAN, R. W., CLEVELAND, E. A. and HASSELL, T. W. 'The Influence of training on Mechanical Aptitude Test-scores.' *Educ. Psychol. Measmt.,* 1942, **2**, pp. 91–4.

FOURACRE, L. 'Psychological Tests of Mathematical Ability.' M.Ed. Thesis, Univ. of Leeds, 1925.

FOURACRE, L. 'Psychological Tests of Mathematical Ability.' *Forum of Education,* 1926, **4**, pp. 201–5.

GÄSTRIN, J. *Det intelligenta Lärandets problem.* Åbo, 1940.

HADAMARD, J. *The Psychology of Invention in the Mathematical Field.* Princeton University Press, 1945, Appendix II.

HAMLEY, H. R. *The Testing of Intelligence.* London, Evans, 1935.

HAMZA, M. 'A Study of Certain Aspects of Retardation in Mathematics amongst Secondary Grammar School Pupils by Factorial and Individual Methods.' Unpublished Ph.D. Thesis, Univ. of Leeds, 1951.

HAMZA, M. 'Retardation in Mathematics amongst Grammar School Pupils.' *Brit. J. Educ. Psychol.,* 1952, **22**, pp. 189–95.

HILLS, J. R. 'The Relationship between certain Factor-Analysed Abilities and Success in College Mathematics.' *Report from the Psychological Laboratory* No. **15**, Los Angeles, Univ. of Southern California, 1955.

HILLS, J. R. 'Factor-analysed Abilities and Success in College Mathematics.' *Educ. Psychol. Measmt.,* 1957, **17**, pp. 615–22.

HOLZINGER, K. J. and HARMAN, H. H. 'Comparison of Two Factorial Analyses.' *Psychometrika,* 1938, **3**, pp. 45–60.

HOLZINGER, K. J. and SWINEFORD, F. 'The relation of Two Bi-factors to achievement in Geometry and Other Subjects.' *J. Educ. Psychol.*, 1946, **37**, pp. 257–65.

HUNTER, I. M. L. 'An exceptional talent for Calculative Thinking.' *Brit. J. Psychol.*, 1962, **53**, 3, pp. 243–58.

KELLEY, T. L. *Crossroads in the Mind of Man.* Stanford, Cal., Stanford Univ. Press, 1928.

KOUSSY, A. A. H. EL. *Les Directions de Récherche dans le domaine des Aptitudes Spatiales. Symposium:* 'L'Analyse Factorielle et ses Applications.' Paris, 1955.

MCFIE, J. 'The effect of Education on African Performance in a group of Intellectual Tests.' *Brit. J. Educ. Psychol.*, 1961, **31**, 3, pp. 232–40.

MITCHELL, F. W. 'The Nature of Mathematical Thinking.' Ph.D. Thesis, Univ. of London, 1937.

MITCHELL, F. W. *The Nature of Mathematical Thinking.* Melbourne Univ. Press, 1938.

MÖBIUS, P. J. *Über die Anlage Zur Mathematik.* Leipzig, Barth, 1907.

MURRAY, J. E. 'Analysis of Geometric Ability.' *J. Educ. Psychol.*, 1949, **40**, 2.

MYERS, C. T. 'Some observations and opinions concerning Spatial Relations Tests.' *Research Memorandum* 57–7, Princeton, N.J., Educational Testing Service, 1957.

MYERS, C. T. 'Some observations of Problem Solving in Spatial Relations Tests.' *Research Bulletin* 58–16, Princeton, N.J., Educational Testing Service, 1958.

MYERS, C. T. 'The effects of Training in Mechanical Drawing on Spatial Relations Test-scores as predictors of Engineering Drawing Grades.' *R. and D. Rep.* No. 58–4, Princeton, N.J., Educational Testing Service, 1958.

NEWMAN, M. H. A. What is Mathematics? New Answers to an Old Question.' *Math. Gazette*, 1959, **43**, 345, pp. 161–71.

OLDHAM, HILDA W. 'An Investigation of School Mathematics.' Ph.D. Thesis, Univ. of Reading, 1936.

OLDHAM, HILDA W. 'A Psychological Study of Mathematical Ability.' *Brit. J. Educ. Psychol.*, 1937, **7**, pp. 269–86; ibid. 1938, **8**, pp. 16–28.

PARSLOW, L. C. 'The Factors contributing to Successful Mathematical Attainment in boys and girls of a Secondary School.' M.A. Thesis, Univ. of London, 1942.

RAPAPORT, D. *Diagnostic Psychological Testing. Vol. I,* Chicago, Year Book Publishers, 1950.

RIMOLDI, H. J. A. 'The Central Intellective Factor.' *Psychometrika,* 1951, **16**, pp. 75–101.

ROGERS, A. L. 'Experimental Tests of Mathematical Ability and their Prognostic Value.' *Teachers' College*, Columbia Univ., *Contributions to Education* No. **89**, New York, 1918.

SAAD, L. G. in collaboration with STORER, W. O. *Understanding in Mathematics.* Edinburgh, Oliver and Boyd, 1960.

SAYED, F. B. EL. 'The Cognitive Factors in Geometrical Ability'. Ph.D. Thesis, Univ. of Reading, 1951.

SCHILLER, B. 'Verbal, Numerical and Spatial Abilities of Young Children.' *Arch. Psychol.*, 1934, **161**.

SCHNECK, M. M. R. 'The measurement of Verbal and Numerical Abilities.' *Arch. Psychol.*, 1929, **107**.

SIEGVALD, H. *Experimentella Undersökningar rörande Intellektuella Könsdifferenser, I–II.* Lund, 1944.

SMITH, I. MACFARLANE. 'The Validity of Tests of Spatial Ability as predictors of success on Technical Courses.' *Brit. J. Educ. Psychol.*, 1960, **30**, 2, pp. 138–45.

SPEARMAN, C. *The Abilities of Man.* London, Macmillan, 1927.

THORNDIKE, E. L. 'On the Organisation of Intellect.' *Psychol. Rev.*, 1921, **28**, pp. 141–51.

VERNON, P. E. *The Structure of Human Abilities.* London, Methuen, 1950, p. 73.

WALTON, R. D. *Geometry Attainment Test.* London, Univ. of London Press Ltd., 1947.

WEBB, E. W. 'The relation of certain factors of Imagery and Immediate Memory to Geometrical Ability.' M.A. Thesis, Univ. of London, 1949.

WERDELIN, I. *The Mathematical Ability. Experimental and Factorial Studies.* Lund, Ohlsson, 1958.

WILSON, J. H. 'Group Factors among Abilities involved in a School Certificate Examination.' *Brit. J. Educ. Psychol.*, 1933, **3**, pp. 71–86, 99–108.

WRIGLEY, J. 'The Factorial Nature of Ability in Elementary Mathematics.' *Brit. J. Educ. Psychol.*, 1958, **28**, 1, pp. 61–78.

Chapter four

ALLEN, E. P. and SMITH, P. *Selection of Skilled Apprentices for the Engineering Trades.* 1st, 2nd and 3rd Reports to Birmingham Education Committee, 1931, 1934, 1939.

ANASTASI, ANNE. *Psychological Testing.* New York, Macmillan, 1954.

BRUSH, F. N. 'Mechanical Ability as a factor in Engineering Aptitude.' *J. Appl. Psychol.*, 1941, **25**, pp. 310–12.

COX, J. W. *Mechanical Aptitude.* London, Methuen, 1928.

COX, J. W. *Manual Skill. Its Organization and Development.* Cambridge, Cambridge Univ. Press, 1934.

CRONBACH, L. J. *Essentials of Psychological Testing.* New York, Harper, 2nd Edition, 1960, pp. 276–8.

FRISBY, C. B., VINCENT, D. F. and LANCASHIRE, R. *Tests for Engineering Apprentices. A Validation Study.* London, National Institute of Industrial Psychology, 1959.

GARSIDE, R. F. 'The Prediction of Examination Marks of Mechanical Engineering students at King's College, Newcastle.' *Brit. J. Psychol.*, 1957, **48**, 3, pp. 219–20.

GHISELLI, E. E. 'The Measurement of Occupational Aptitude.' *Univ. Calif. Publ. Psychol.*, 1955, **8**, 2, pp. 101–216.

HARRELL, W. 'A Factor-analysis of Mechanical Ability Tests.' *Psychometrika*, 1940, **5**, pp. 17–33.

HIMMELWEIT, H. T. 'Student Selection—an Experimental Investigation.' *Brit. J. Sociology*, 1950, **1**, pp. 328–46.

HOHNE, H. H. *The Prediction of Academic Success.* Report on the academic careers of students in the University of Melbourne Faculty of Arts. Australian Council for Educational Research, 1951.

HOLLIDAY, F. 'An Investigation into Selection of Apprentices for the Engineering Industry.' *Occup. Psychol.*, 1940, **14**, 2, pp. 69–81.

HOLLIDAY, F. 'The relations between Psychological Test-scores and subsequent proficiency of Apprentices in the Engineering Industry.' *Occup. Psychol.*, 1943, **17**, pp. 168–85.

KNIGHT, W. H. J. 'A Study of the Middlesex Junior Technical School Entrance Examination.' M.A. Thesis, Univ. of London, 1949.

MCMAHON, D. 'Selection and Follow-up of Engineering Apprentices.' *Occup. Psychol.*, 1962, **36**, 1 and 2, pp. 53–8.

MCMAHON, D., MONTGOMERY G. and ROSS, J. 'Symposium on Research on Engineering Apprentices.' Proceedings of the Annual Conference of B.P.S., Liverpool. *B.P.S. Quarterly Bulletin*, 1961, **44**, pp. A4–A5.

MONTGOMERY, G. W. G. 'Predicting Success in Engineering.' *Occup. Psychol.*, 1962, **36**, 1 and 2, pp. 59–68.

OXLADE, M. N. 'Further experience with Selection Tests for Power Sewing-machine Operators.' *Bulletin of Industrial Psychol. and Personnel Practice*, Australia, 1951, **8**, 1.

PATTERSON, C. H. 'Predicting Success in Trade and Vocational School Courses; Review of the Literature.' *Educ. Psychol. Measmt.*, 1956, **16**, pp. 352–400.

PETRIE, A. 'The selection of Medical Students.' *Lancet*, 1948, **255**, pp. 325–7.

RODGER, A. 'A Borstal Experiment in Vocational Guidance.' *Industr. Hlth. Res. Board. Rep.* No. **78**, 1937.

ROSS, JEAN. Predicting Practical Skill in Engineering Apprentices.' *Occup. Psychol.*, 1962, **36**, 1 and 2, pp. 69–74.

SANDERS, C. *Student Selection and Academic Success in Australian Universities.* Sydney, Commonwealth Office of Education, 1948.

SHUTTLEWORTH, C. W. 'Tests of Technical Aptitude.' *Occup. Psychol.*, 1942, **16**, pp. 175–82.
SLATER, P. 'Some group tests of Spatial Judgment or Practical Ability.' *Occup. Psychol.*, 1940, **14**, pp. 40–55.
STENQUIST, J. L. *Mechanical Aptitude Tests.* Yonkers, World Book Co., 1922.
SUPER, D. E. *Appraising Vocational Fitness by means of Psychological Tests.* New York, Harper and Bros., 1949.
UNITED STATES EMPLOYMENT SERVICE. *Estimates of Worker Trait Requirements for 4000 Jobs.* Washington D.C., U.S. Government Printing Office, 1957.
VERNON, P. E. 'Educational Abilities of Training-college Students.' *Brit. J. Educ. Psychol.*, 1939, **9**, pp. 233–50.
VERNON, P. E. *The Structure of Human Abilities.* London, Methuen, 1950.
VERNON, P. E. and PARRY, J. B. *Personnel Selection in the British Forces.* London, Univ. of London Press Ltd., 1949.

Chapter five

BURT, C. 'Validating Tests for Personnel Selection.' *Brit. J. Psychol.*, 1943, **34**, pp. 1–19.
EMMETT, W. G. *Prediction of Secondary School Success.* London, Univ. of London Press Ltd., 1942.
EMMETT, W. G. 'Evidence of a Space Factor at 11 plus and Earlier.' *Brit. J. Psychol.* (Stat. Sect.), 1949, **2**, 1, pp. 3–16.
HUSÉN, T. Paper to conference held in Sweden, June, 1961. Published in Report, *Ability and Educational Opportunity* (Edited by A. H. Halsey). Organisation for Economic Co-operation and Development, 1961.
LUBIN, A. 'Some Formulae for use with Suppressor Variables.' *Educ. Psychol. Measmt.*, 1957, **17**, pp. 286–96.
MCCLELLAND, W. *Selection for Secondary Education.* Publication 19 of the Scottish Council for Research in Education. London, Univ. of London Press Ltd., 1942.
SMITH, I. MACFARLANE. 'The Development of a Spatial Test.' *Durham Res. Review*, 1954, **5**, pp. 19–33.
VERNON, P. E. *The Measurement of Abilities.* London, Univ. of London Press Ltd., 1940.
WISEMAN, S. 'The use of an Interest Test in 11 plus Selection.' *Brit. J. Educ. Psychol.*, 1955, **25**, 2, pp. 92–8.
YATES, A. and BARR, F. 'Selection for Secondary Technical Courses—A Report of a Pilot Investigation.' *Educational Research*, 1960, **2**, 2, pp. 143–8.

Chapter six

ABERCROMBIE, M. L. J. *Perceptual and Visuomotor Disorders in Cerebral Palsy.* London, Spastics Society, Heinemann, 1964.

ALEXANDER, W. P. 'Intelligence, Concrete and Abstract.' *Brit. J. Psychol.*, Monogr. Suppl. No. **19**, 1935.

BENDER, L. *Visual Motor Gestalt Test.* American Orthopsychiatric Association, Inc., 1938.

BENSBERG, G. J. 'A test for differentiating Endogenous and Exogenous Mental Defectives.' *Amer. J. Ment. Deficiency*, 1950, **54**, pp. 502–6.

BENSBERG, G. J. 'Performance of Brain-injured and Familial Mental Defectives on the Bender Gestalt Test.' *J. Consult. Psychol.*, 1952, **16**, pp. 61–4.

BERG, E. A. 'A Simple Objective Technique for measuring Flexibility in Thinking.' *J. Genet. Psychol.*, 1948, **39**, pp. 15–22.

BIJOU, S. and WERNER, H. 'Language Analysis in Brain-injured and Non-brain-injured Children.' *J. Genet. Psychol.*, 1945, **66**, pp. 239–54.

BORSADA, E. C. 'A Comparative Study of Drawings of the Human Figure by Mental Defectives and Normal Children.' M.A. (Education) Thesis, Univ. of London, 1959.

BRAIN, W. RUSSELL. 'The Cerebral Basis of Consciousness.' *Brain*, 1950, **73**, pp. 465–79.

BURT, C. *Mental and Scholastic Tests.* London, Staples Press Ltd., 2nd. ed. 1947, p. 277.

BURT, C. 'The Structure of the Mind: A Review of the Results of Factor Analysis, Part 2.' *Brit. J. Educ. Psychol.*, 1949, **19**, 3, pp. 176–99.

BURT, C. *The Backward Child.* London, Univ. of London Press Ltd., 1950.

BUTT, A. S. 'The Differentiation of Reasoning Abilities at Adolescence.' Ph.D. Thesis, University of London, 1957.

CALDWELL, E. M. *A Case of Spatial Inability in a Cerebral Palsied Child.* Published by the British Council for the Welfare of Spastics, 1956.

CASSEL, R. H. 'Relation of Design Reproduction to the Etiology of Mental Deficiency.' *J. Consult. Psychol.*, 1949, **13**, pp. 421–8.

CASSEL, R. H. 'The effect of Mental Age and Etiology on two factors in Form Board Performance.' *J. Clin. Psychol.*, 1949, **5**, pp. 398–404.

CATTELL, R. B. *A Guide to Mental Testing.* London, Univ. of London Press Ltd., 2nd ed. 1948, p. 339.

CHOWDHURY, K. R. 'An Experimental Study of Imagery and its Relation to Abilities and Interests'. Ph.D. Thesis, Univ. of London, 1956.

CLARK, MARGARET. *Left-Handedness. Laterality Characteristics and their Educational Implications.* London, Univ. of London Press Ltd., 1957.

COSTA, L. D. and VAUGHAN, H. 'Verbal and Perceptual Performance in patients with Cerebral Lesions.' Reported at 68th Annual Conference of the American Psychological Association, Chicago, Sept. 1960.

COSTELLO, C. G. 'The effects of Prefrontal Leucotomy upon Visual Imagery and the Ability to perform Complex Operations.' *J. Ment. Sci.*, 1956, **102**, pp. 507–16.

CROWN, S. 'Psychological changes following Prefrontal Leucotomy. A review.' *J. Ment. Sci.*, 1951, **97**, pp. 49–83.

CRUICKSHANK, BICE and WALLEN. *Perception and Cerebral Palsy. A Study in Figure Background Relationship.* Syracuse University Press, 1957.

DOLPHIN, J. E. and CRUICKSHANK, W. M. 'Tactual Motor Perception of children with Cerebral Palsy.' *J. Pers.*, 1952, **20**, pp. 466–71.

DUNNE, J. W. *An Experiment with Time.* London, Black, 1927.

DUNSDON, M. I. *The Educability of Cerebral Palsied Children.* London, published for N.F.E.R. by Newnes, 1951.

EYSENCK, H. J. *The Scientific Study of Personality.* London, Routledge and Kegan Paul, 1952.

FREEMAN, W. and WATTS, J. W. *Psychosurgery.* Springfield, Illinois, 1942, p. 171.

GALLAGHER, J. J. *The Tutoring of Brain-injured Mentally Retarded Children.* Springfield, Illinois, C. C. Thomas, 1960.

GELB, A. and GOLDSTEIN, K. *Psychologische Analysen hirnpathologischer.* Fälle, Leipzig, 1920.

GOLDSTEIN, K. and SCHEERER, M. 'Abstract and Concrete Behaviour.' *Psychol. Monogr.*, 1941, **239**.

GOLDSTEIN, K. and SCHEERER, M. *Tests of Abstract and Concrete Thinking.* New York, Psych. Corp., 1941.

GRAHAM, F. K. and KENDALL, B. S. *Memory for Designs Test.* Dept. of Neuropsychiatry, Washington Univ. School of Medicine, 1948.

GRANIT, A. R. 'A study on the Perception of Form.' *Brit. J. Psychol.*, 1921, **12**, 3, pp. 223–47.

GREENBLATT, M., ARNOT, R. E., POPPEN, L. L. W. and CHAPMAN, W. P. 'Report on Lobotomy Studies at the Boston Psychiatric Hospital.' *Amer. J. Psychiat.*, 1947, **104**, p. 361.

HALPIN, V. G. 'Rotation Errors made by Brain-injured and Familial Children on Two Visual-motor Tests.' *Amer. J. Ment. Deficiency*, 1955, **59**, pp. 485–9.

HALPIN, V. G. and PATTERSON, R. M. 'The Performance of Brain-injured Children on the Goldstein-Scheerer Tests.' *Amer. J. Ment. Deficiency*, 1954, **59**, pp. 91–9.

HALSTEAD, W. C. Chapter in *Cerebral Mechanisms in Behaviour (The Hixon Symposium).* (Edited by Lloyd A. Jeffress.) London, J. Wiley & Sons, 1951.

HANFMANN, E. and KASININ, J. 'A Method for the Study of Concept Formation.' *J. Psychol.*, 1937, **3**, pp. 521–40.

HANFMANN, E. 'A Study of Personality Patterns in Intellectual Performance.' *Character and Pers.*, 1941, **9**, pp. 315–25.

HEBB, D. O. 'Intelligence in man after Removal of Cerebral Tissue.' *J. Genet. Psychol.*, 1939, **21**, pp. 73–87.

HEBB, D. O. 'The effect of Early and Late Brain Injury upon Test-scores and the Nature of Normal Adult Intelligence.' *Proc. Amer. Philosophical Soc.*, 1942, **85**, pp. 275–92.

HEIM, A. W. 'An Attempt to test High Grade Intelligence.' *Brit. J. Psychol.*, 1947, **37**, 1, pp. 70–81.

HUMPHREY, M. E. 'Consistency of Hand Usage. A preliminary enquiry.' *Brit. J. Educ. Psychol.*, 1951, **21**, 3, pp. 214–25.

HUMPHREY, M. E. and ZANGWILL, O. L. 'Cessation of dreaming after Brain-injury.' *J. Neurol. Neurosurg. Psychiat.*, 1951, **14**, pp. 322–5.

JARVIE, H. F. 'Problem-solving Defects following Wounds of the Brain.' Paper read at B.P.S. Conference, Hull. *Quarterly Bulletin, B.P.S.* **41**, 1960.

JONES, R. E. 'Personality Changes in Psychotics following Prefrontal Lobotomy.' *J. Abnorm. Soc. Psychol.*, 1949, **44**, pp. 315–28.

KEIR, G. 'The Progressive Matrices as applied to School Children.' *Brit. J. Psychol. (Stat. Sec.)*, 1949, **2**, 3, pp. 140–50.

KISKER, G. W. 'Perceptual Motor Patterns following Bilateral Prefrontal Lobotomy.' *Arch. Neurol. Psychiat.*, 1943, **50**, pp. 691–6.

LANE, M. *The Tale of Beatrix Potter.* London, Frederick Warne, 1946.

LOMBROSO, C. *The Man of Genius.* London, Walter Scott, 1891.

LORENZ, K. Z. 'The role of Gestalt Perception in Animal and Human Behaviour.' *Symposium on Aspects of Form.* (Edited by L. L. Whyte.) London, Lund Humphries, 1951.

LOVELL, K. 'A study of the Problem of Intellectual Deterioration in Adolescents and Young Adults.' *Brit. J. Psychol.*, 1955, **46**, pp. 199–210.

MCKELLAR, P. *Imagination and Thinking.* London, Cohen and West, 1957.

MCMURRAY, J. G. 'Visual Perception in Exogenous and Endogenous Mentally Retarded Children.' *Amer. J. Ment. Deficiency*, 1954, **58**, pp. 659–63.

MALMO, R. B. 'Psychological aspects of Frontal Gyrectomy and Frontal Lobotomy in Mental Patients.' *Res. Publ. Ass. Nerv. Ment. Dis.*, 1948, **27**, pp. 537–64.

PARTRIDGE, M. W. *Prefrontal Leucotomy.* Oxford, 1950.

PEEL, E. A. 'Evidence of a Practical Factor at the Age of Eleven.' *Brit. J. Educ. Psychol.*, 1949, **19**, pp. 1–15.

PEMBERTON, C. 'The Closure Factors related to the Cognitive Processes. *Psychometrika*, 1952, **17**, 3, pp. 267–88.

PETRIE, A. 'Personality Changes after Prefrontal Leucotomy. *Brit. J. Med. Psychol.*, 1949, **22**, 4, pp. 200–7.

PORTEUS, S. D. 'Q Scores, Temperament and Delinquency.' *J. Soc. Psychol.*, 1945, **21**, pp. 81–103.

PORTEUS, S. D. and PETERS, H. W. 'Maze Test Validation and Psychosurgery.' *Genet. Psychol. Monogr.* **36**, 1947.

RAPAPORT, D. *Diagnostic Psychological Testing. Vol. I.* Chicago, Year Book Publishers, 1950.

RUSSELL, W. RITCHIE. 'Functions of the Frontal Lobes.' *Lancet*, 1948, **1**, pp. 356–360.

RUSSELL, W. RITCHIE. *Brain, Memory, Learning. A Neurologist's View.* Oxford, Clarendon Press, 1959.

SEMEONOFF, B. and TRIST, E. *Diagnostic Performance Tests.* London, Tavistock Publications, 1958.

SPALDING, J. M. K. and ZANGWILL, O. L. 'Disturbance of Number Form in a case of Brain Injury.' *J. Neurol. Neurosurg. Psychiat.*, 1950, **13**, pp. 24–9.

SPEARMAN, C. *Psychology down the Ages. Vol. I.* London, Macmillan, 1937.

SPEARMAN, C. 'Theory of General Factor.' *Brit. J. Psychol.*, 1946, **36**, 3, pp. 117–31.

SPEARMAN, C. and WYNN JONES, L. *Human Ability.* London, Macmillan, 1950.

STRAUSS, A. A. and WERNER, H. 'Disorders of Conceptual Thinking in the Brain-injured Child.' *J. Nerv. and Ment. Diseases*, 1942, **96**, pp. 153–72.

SULTAN, E. E. 'A Factorial Study in the domain of Creative Thinking.' Abstract of M.A. Thesis, *Brit. J. Educ. Psychol.*, 1962, **32**, 1, pp. 78–82.

TAYLOR, C. C. 'A study of the Nature of Spatial Ability and its Relationship to Attainment in Geography.' M.Ed. Thesis, Univ. of Durham. Summary in *Brit. J. Educ. Psychol.*, 1959, **30**, 3, pp. 266–8.

TEUBER, H. L. 'Some Alterations in Behaviour after Cerebral Lesions in Man.' In *Evolution of Nervous Control.* Washington: Amer. Ass. Advanc. Sci., 1959, pp. 157–94.

THURSTONE, L. L. *A Factorial Study of Perception.* Chicago, Univ. of Chicago Press, 1944.

THURSTONE, L. L. 'Mechanical aptitude III. Analysis of Group Tests.' *Psychometric Lab. Report* No. **55**, Chicago, Univ. of Chicago Press, 1949.

UTTLEY, ALISON. *The Stuff of Dreams.* London, Faber and Faber, 1953.

VERNON, M. D. 'Different types of Perceptual Ability.' *Brit. J. Psychol.*, 1947, **38**, pp. 79–89.

VERNON, P. E. 'An application of Factorial Analysis to the study of Test Items.' *Brit. J. Stat. Psychol.*, 1950, **3**, 1, pp. 1–15.

VIDOR, M. 'Personality changes following Prefrontal Leucotomy as reflected by the M.M.P.I. and Psychometric Testing.' *J. Mental Science*, 1951, **97**.

WEDELL, K. 'The Visuo-spatial Perception of Cerebral-palsied Children.' Paper read to the South-West of England Branch of the British Psychological Society. *B.P.S. Quarterly Bulletin*, 1959, No. **39**, p. 24.

WEINSTEIN, S. and JOHNSON, L. 'The Bender-Gestalt Test in Differential Diagnosis of Temporal Lobectomy and Schizophrenia'. *Perceptual and Motor Skills*, 1964, **18**, pp. 813–20.

WERDELIN, I. *The Mathematical Ability. Experimental and Factorial Studies.* Lund, Ohlsson, 1958.

WERNER, H. 'Perceptual Behaviour of Brain-injured Mentally Deficient Children. An experimental study by means of the Rorschach technique.' *Genet. Psychol. Monogr.*, 1945, **31**, pp. 51–110.

WERNER, H. and STRAUSS, A. A. 'Pathology of Figure Background Relation in the Child.' *J. Abnorm. & Social Psychol.*, 1941, **36**, pp. 58–67.

WERNER, H. and THUMA, B. D. 'A deficiency in the Perception of Apparent Motion in children with Brain-injury. *Amer. J. Psychol.*, 1942, **55**, pp. 394–9.

YACORZYNSKI, G. K., BOSHES, B. and DAVIS, L. 'Psychological Changes produced by Frontal Lobotomy.' *Res. Publ. Ass. Nerv. Ment. Dis.*, 1948, **27**, pp. 642–57.

ZANGWILL, O. L. 'Psychological Research in the Field of Neurology.' Chapter in *Current Trends in British Psychology* (Edited by Mace, C. A. and Vernon, P. E.). London, Methuen, 1953.

Chapter seven

ABERCROMBIE, M. L. *The Anatomy of Judgment.* London, Hutchinson, 1960.

ARDIS, J. A. and FRASER, E. 'Personality and Perception: the Constancy Effect and Introversion.' *Brit. J. Psychol.*, 1957, **48**, 1, pp. 48–54.

BEECH, H. R. 'An investigation of the Performance on a Perceptual-Motor Task by Psychiatric Patients with special reference to Brain Damage.' Unpublished Ph.D. Thesis, Univ. of London, 1956.

BINGHAM, W. V. 'Personality and Vocation.' *Brit. J. Psychol.*, 1926, **16**, 4, pp. 354–62.

BLACK, D. A., WALTON, D. and STEVENS, J. S. 'Differences between Dysthymics, Hysterics and Psychopaths in Intelligence-vocabulary Ratio.' Paper read to Annual Conference of the B.P.S., Liverpool, 1961.

BOLDRINI, M. and MENGARELLI, C. *Comit. Ital. Stud. Prob. Popol. Atti. Roma,* 1933, **195**, pp. 3–27.

BRADFORD, E. J. G. 'Symposium on the Selection of Pupils for different types of Secondary Schools. IV: An experimenter's point of view.' *Brit. J. Educ. Psychol.*, 1948, **18**, 2, pp. 67–86.

BRATTGARD, S. O. 'Personality, Attitude and Physical Make-up.' *Acta Psychiat. Neurol. Scand.*, 1950, **354**, pp. 339–54.

BURNS, C. L. C. 'Psychosis in Children.' Paper read to the Midland Branch of the British Psychological Society. Reported in *B.P.S. Quarterly Bulletin*, 1950, **1**, 10, pp. 389–90.

BURNS, C. L. C. 'Maladjusted Children of High Intelligence.' *Brit. J. Educ. Psychol.*, 1949, **19**, 2, pp. 137–41.

BURT, C. 'The Structure of the Mind. A review of the results of factor-analysis.' *Brit. J. Educ. Psychol.*, 1949, **19**, 3, pp. 176–99.

CAMERON, N. *The Psychology of Behaviour Disorders.* Boston, Houghton Mifflin, 1947.

CATTELL, R. B. 'Temperament Tests.' *Brit. J. Psychol.*, 1934, **24**, pp. 20–49.

CATTELL, R. B. 'Personality Traits associated with Abilities. II: With verbal and mathematical ability.' *J. Educ. Psychol.*, 1945, **102**, pp. 475–86.

CATTELL, R. B. *A Guide to Mental Testing.* London, Univ. of London Press Ltd., 2nd ed. 1948, p. 339.

CATTELL, R. B., BELOFF, J., FLINT, D. and GRUEN, W. *Junior Personality Quiz (I.P.A.T.).* Urbana, Illinois, U.S.A., 1953.

CATTELL, R. B. *Personality and Motivation Structure and Measurement.* London, Harrap, 1957.

CATTELL, R. B. and DREVDAHL, J. E. 'A comparison of the Personality Profile of eminent Researchers with that of eminent Teachers and Administrators and of the General Population.' *Brit. J. Psychol.*, 1955, **46**, pp. 248–61.

CHRISTENSEN, P. R. and GUILFORD, J. P. 'An experimental study of Verbal Fluency Factors.' *Brit. J. Stat. Psychol.*, 1963, **16**, 1, pp. 1–26.

DELLAERT, R. 'L'Intelligence des Anormaux du Caractère.' *L'Année Psychol.*, 1934, **34**, pp. 200–16.

DREVDAHL, J. E. 'An exploratory study of Creativity in terms of its relationships to various Personality and Intellectual Factors.' Unpublished Ph.D. Thesis, Univ. of Nebraska, 1954.

EARL, C. J. C. 'Some methods of assessing Temperament and Personality.' *The Study of Society.* (Edited by Bartlett et al.) London, Kegan Paul, 1939, pp. 230–56.

EKMAN, G. 'On the Number and Definition of Dimensions in Kretschmer's and Sheldon's Constitutional Systems.' *Essays in Psychology.* Uppsala, Almquist, 1951.

ENKE, W. 'Experimentalpsychologische Studien zur Konstitutionsforschung.' *Z. ges. Neurol. Psychiat.*, 1928, **114**, pp. 770–94.

ENKE, W. 'The affectivity of Kretschmer's Constitutional Types as revealed in Psycho-galvanic Experiments.' *Char. and Pers.*, 1953, **1**, pp. 225–33.

EYSENCK, H. J. 'Comment on the relation of Neuroticism and Extroversion to Intelligence and Educational Attainment.' *Brit. J. Educ. Psychol.*, 1963, **33**, 2, p. 192.

EYSENCK, H. J. 'Cyclothymia and Schizothymia as a dimension of Personality. I: Historical Review.' *J. Pers.*, 1950, **19**, 2, pp. 123–53.

EYSENCK, H. J. *The Scientific Study of Personality.* London, Routledge and Kegan Paul, 1952.

EYSENCK, H. J. and GILMOUR, S. L. L. 'The Psychology of Philosophers—a Factorial Study.' *Char. and Pers,.* 1944, **12**, pp. 290–8.

EYSENCK, H. J., GRANGER, G. W. and BRENGELMANN, J. C. *Perceptual Processes and Mental Illness.* Maudsley Monograph Series. London, Chapman and Hall, 1957.

EYSENCK, H. J. *The Structure of Human Personality.* London, Methuen, 2nd ed. 1960, p. 186.

FITZPATRICK, T. F. and WISEMAN, S. 'An Interest Test for use in selection for Technical Education.' *Brit. J. Educ. Psychol.,* 1954, **24**, 2, pp. 99–105.

FOULDS, G. A. 'The ratio of General Intellectual Ability to Vocabulary among Psychoneurotics.' *Internat. J. Soc. Psychiat.,* 1956, **1**, pp. 5–12.

FRENCH, J.W. *Comparative Prediction of Success and Satisfaction in College Major Fields, Part I.* Princeton, New Jersey, Educational Testing Service, 1959.

FREYD, M. 'Introverts and Extraverts.' *Psychol. Rev.* 1924, **5**, pp. 74–87.

FRUCHTER, B. 'Nature of Verbal Fluency.' *Educ. Psychol. Measmt.,* 1948, **8**.

FURNEAUX, W. D. 'Universities and students: the value of psychological research in a specialized context.' Chapter in *Research and Experiment in Education* (pp. 19–33). Dept. of Education, King's College, Newcastle-upon-Tyne, 1962.

GEHLMANN, F. 'Performance on Objective Tests as Indicators of Temperament and other Personality Traits.' Unpublished Ph.D. dissertation, Dept. of Psychology, Univ. of Chicago, 1951 (quoted by Pemberton).

GETZELS, J. W. and JACKSON, P. W. *Creativity and Intelligence.* New York, Wiley, 1962.

GEWIRTZ, J. L. 'Studies in Word Fluency.' *J. Genet. Psychol.,* 1948, **72**.

GRANGER, G. W. 'Dark Adaptation in Neurotic Patients.' *J. Ment. Sci.,* 1955, **101**, pp. 354–62.

HALSTEAD, H. and SLATER, P. 'An experiment in the Vocational Adjustment of Neurotic Patients.' *J. Ment. Sci.,* 1946, **92**, pp. 509–15.

HANFMANN, E. and KASININ, J. 'Conceptual Thinking in Schizophrenia.' *Nerv. and Ment. Disease Monogr.,* **67**, 1942.

HARGREAVES, H. L. 'The "Faculty" of Imagination.' *Brit. J. Psychol.,* Monogr. Suppl. **10**, 1927.

HARPER, E. A. 'Discrimination between matched Schizophrenics and Normals by the Wechsler-Bellevue Scale.' *J. Consult. Psychol.,* 1950, **14**, pp. 351–7.

HEBRON, M. E. 'The Mental and Scholastic Status of pupils in various streams of Secondary Modern Schools.' Univ. of Hull, Institute of Education, *Studies in Education,* 1957, **2**, p. 5.

HIMMELWEIT, H. T. 'The Intelligence-vocabulary Ratio as a measure of Temperament.' *J. Pers.,* 1945, **14**, pp. 93–105.

HOLZINGER, K. R. *Preliminary Report on Spearman-Holzinger Unitary Trait Study.* Chicago, Statist. Lab., Dept. Educ., Univ. Chicago, Nos. **2** and **4**, 1934, 1935.

HOWELLS, W. W. 'Factors of Human Physique.' *Amer. J. Physiol. Anthropol.*, 1951, **9**, pp. 159–91.

HOWELLS, W. W. 'A Factorial Study of Constitutional Type.' *Amer., J. Physiol. Anthropol.*, 1952, **10**, pp. 91–118.

HUDSON, L. 'Arts/Science Specialisation: a Study of Differential Aptitude'. Unpublished Ph.D. Thesis, Univ. of Cambridge, 1961.

JASTAK, J. *Variability of Psychometric Performances in Mental Diagnosis.* New York, 1934.

JAY, R. L. 'The Relation between some Perceptual Factors and some Personality Categories.' Unpublished M.A. Thesis, Dept. of Psychology, Univ. of Chicago, 1950 (quoted by Pemberton).

KEEHN, J. D. 'An Experimental Investigation into the Validity of the use of Attitude to Colour and Form in the Assessment of Personality.' Ph.D. Thesis, Univ. of London, 1953.

KIBLER, M. 'Experimental Psychologischer Beitrag zur Typenforschung.' *Z. ges. Neurol. Psychiat.*, 1925, **98**, pp. 524–44.

LAMBERT, C. M. 'A survey of Ability and Interest at the Stage of Transfer.' *Brit. J. Educ. Psychol.*, 1949, **19**, 2, pp. 67–79.

LINDBERG, B. J. 'Experimental studies of Colour and Non-colour Attitudes in School Children and Adults.' *Diss. Acta Psychiat. et Neurol.*, Suppl. **16**, 1938.

LINDBERG, B. J. *Experimental studies of Colour and Non-colour Attitudes in School Children and Adults.* Copenhagen, Levin and Munksgaard, 1938.

MEUMANN, E. *Vortrag Z. Einf. in der experimentalischer Pädagogik.* 1907, **1**, pp. 499 f.

MISIAK, H. and PICKFORD, R. W. 'Physique and Perseveration.' *Nature*, 1944, **153**, p. 622.

MONS, W. *Principles nad Practice of the Rorschach Personality Test.* London, Faber and Faber, 1947.

MORGAN, G. A. V. 'Verbal Abilities in Primary School Children.' Durham Res. Rev., 1956, **7**, pp. 97–107.

NORTH, R. D. 'An Analysis of the Personality Dimensions of Introversion-extroversion.' *J. Pers.*, 1949, **17**, pp. 352–67.

NOTCUTT, B. 'Perseveration and Fluency.' *Brit. J. Psychol.*, 1943, **33**, pp. 200–8.

OESER, O. A. 'Some experiments on the Abstraction of Form and Colour.' *Brit. J. Psychol.*, 1932, **22**, pp. 200–15, 287–323.

PAYNE, R. W. 'An Investigation into the Possibility of Defining "Dissociation" as a Personality Trait by Means of Objective Tests.' Unpublished Ph.D. Thesis, Univ. of London, 1954.

PAYNE, R. W. and HEWLETT, J. H. G. Chapter in *Experiments in Personality. Vol. II: Psychodynamics and Psychodiagnostics.* (Edited by H. J. Eysenck.) London, Routledge and Kegan Paul, 1960.

PEEL, E. A. 'Assessment of interest in Practical Topics.' *Brit. J. Educ. Psychol.*, 1948, **18**, 1, pp. 141–7.

PEMBERTON, C. L. 'The Closure Factors related to Temperament.' *J. Pers.*, 1952, **21**, pp. 159–75.

PILLSBURY, W. B. 'Body Form and Introversion-extraversion.' *J. Abnorm. (Soc.) Psychol.*, 1939, **34**, pp. 400–1.

PRAK, J. LUNING. *Mathematical and Technical Tests.* London, Harrap, 1948.

RAPAPORT, D. *Diagnostic Psychological Testing.* Chicago, Year Book Publishers, 1950.

REES, L. 'Constitutional Factors and Abnormal Behaviour.' Chapter in *Handbook of Abnormal Psychology.* (Ed. H. J. Eysenck.) London, Pitman, 1960.

REES, L. and EYSENCK, H. J. 'A factorial study of some Morphological and Psychological Aspects of Human Constitution.' *J. Ment. Sci.*, 1945, **91**, pp. 8–21.

ROE, ANNE. 'A psychological study of eminent Psychologists and Anthropologists and a comparison with Biological and Physical Scientists.' *Psychol. Monogr.* 76, No. **352**, 1953.

SCHOLL, R. 'Theorie und Typology der teilinhaltlichen Beachtung von Form und Farbe.' *Ztsch. Psychol.*, 1927, **101**, pp. 281–320.

SEMEONOFF, B. and TRIST, E. *Diagnostic Performance Tests.* London, Tavistock Publications, 1958.

SHAPIRO, M. B. 'The effects of Mental Disorder on the Drawing of Abstract Designs.' Paper read to B.P.S., 25th May 1957.

SHELDON, W. H. *The Varieties of Human Physique.* New York, Harper, 1940.

SILLS, F. D. 'A factor analysis of Somatotypes and their relationship to Achievements in Motor Skills.' *Res. Quart.*, 1950, 21, pp. 424–37.

SMITH, FRANCES E. 'Word Reactions and Temperament.' Unpublished Ph.D. Dissertation, Dept. of Psychology, Univ. of Chicago, 1951 (quoted by Pemberton).

SMITH, I. MACFARLANE. 'The relationship between Spatial Ability and Temperament.' Paper read to the Annual Conference of the British Psychological Society. Abstract in the *Quarterly Bulletin*, 1952, **3**, 16, pp. 43–4.

SMITH, I. MACFARLANE. 'The Development of a Spatial Test.' *Durham Res. Rev.*, 1954, **5**, pp. 19–33.

SMITH, H. C. and BOYARSKY, S. 'Relationship between Physique and Simple Reaction Time.' *Char. and Pers.*, 1943, **12**, pp. 46–53.

STEPHENSON, W. *Testing School Children.* New York, Longmans Green & Co., 1949.

SULTAN, E. E. 'A Factorial Study in the domain of Creative Thinking.' M.A. Thesis, Univ. of London. Abstract in *Brit. J. Educ. Psychol.*, 1962, **32**, 1, pp. 78–82.

TERMAN, L. and MILES, C. *Sex and Personality.* New York, McGraw Hill, 1936.

THOULESS, R. H. 'Individual differences in Phenomenal Regression.' *Brit. J. Psychol.*, 1932, **22**, pp. 216–41.
THURSTONE, L. L. *A Factorial Study of Perception*. Chicago, Univ. of Chicago Press, 1944.
THURSTONE, L. L. 'Primary Mental Abilities.' *Psychometr. Monogr.* **1**, 1938.
THURSTONE, L. L. 'An Analysis of Mechanical Aptitude.' Chicago, *Univ. of Chicago Psychometric Lab. Report* No. **52**, 1951.
UHLER, C. 'Wide-span Psychometric Patterns.' *Delaware State Medical J.*, 1937, **9**, pp. 1–6.
VENABLES, E. C. 'A comparative study of Part-time Day-release Students.' Paper read to Annual Conference of the B.P.S., Reading, 1963.
VERNON, P. E. *Personality Tests and Assessments*. London, Methuen, 1953.
WELLS, F. L. 'Verbal Aptitudes versus Attitudes. Case Studies XI-XIV.' *J. Genet. Psychol.*, 1948, **72**, pp. 185–200.
WELLS, F. L. 'Quantitative Spatial Aptitudes and Motivation. Case Studies XV-XVIII.' *J. Genet. Psychol.*, 1948, **73**, pp. 119–40.
WILLIAMS, E. M. 'An investigation of the Value of Higher School Certificate Results in predicting performance in First Year University Examinations.' *Brit. J. Educ. Psychol.*, 1950, **20**, 2, pp. 83–98.
WISEMAN, S. 'The use of an Interest Test in 11 plus Selection.' *Brit. J. Educ. Psychol.*, 1955, **25**, 2, pp. 92–8.
WITKIN, H. A. 'Individual differences in Ease of Perception of Embedded Figures,' *J. Pers.*, 1950, **19**, pp. 1–15.
WITKIN, H. A., LEWIS, H. B., HERTZMAN, M., MACHOVER, K., MEISSNER, P. B. and WAPNER, S. *Personality through Perception*. New York, Harper, 1954.
WITKIN, H. A., DYK, R. B., FATERSON, H. F., GOODENOUGH, D. R. and KARP, S. A. *Psychological Differentiation. Studies of Development*. New York. Wiley and Sons, 1962.

Chapter eight

CATTELL, R. B. *Personality and Motivation Structure and Measurement*. London, Harrap, 1957.
CATTELL, R. B. and TINER, G. B. 'The varieties of Structural Rigidity.' *J. Pers.*, 1949, **17**, pp. 321–41.
CHOWN, SHEILA M. 'The effect of Age on the Relationship between different types of Rigidity.' Paper read to B.P.S., reported in *Quarterly Bulletin*, 1961, **44**, p. A12.
EYSENCK, H. J. *The Structure of Human Personality*. London, Methuen, 2nd Edn. 1960.
LANKES, W. 'Perseveration.' *Brit. J. Psychol.*, 1915, **7**, pp. 387–419.

LOVELL, K. 'Intellectual deterioration in Adolescents and Young Adults.' *Brit. J. Psychol.*, 1955, **46**, 3, pp. 199–210.

MCMURRAY, J. G. 'Rigidity in conceptual thinking in Exogenous and Endogenous Mentally Retarded Children.' *J. Consult. Psychol.*, 1954, **18**, pp. 366–70.

MORRISBY, J. R. *The Differential Test Battery*. Duplicated notes available through the N.F.E.R., London, 1955.

PINARD, J. W. 'Tests of Perseveration. I. Their relation to character.' *Brit. J. Psychol.*, 1932, **23**, pp. 5–19.

PRATT YULE, E. 'The classification of Motor Perseveration Tests; some Criticisms and Deductions.' *Brit. J. Psychol.*, 1952, **43**, 1, pp. 42–52.

RIM, Y. 'Perseveration and Fluency as measures of Introversion-extraversion in Abnormal Subjects.' *J. Pers.*, 1954, **23**, pp. 324–34.

STEPHENSON, W. *Testing School Children*. New York, Longmans Green, 1949.

WALKER, K. F., STAINES, R. G. and KENNA, J. C. 'P-tests and the Concept of Mental Inertia.' *Char. and Pers.*, 1943, **12**, pp. 32–45.

WERNER, H. 'Abnormal and Subnormal Rigidity.' *J. Abnorm. and Social Psychol.*, 1946, **41**, pp. 15–24.

Chapter nine

BARRATT, P. E. 'Use of the E.E.G. in the study of Imagery.' *Brit. J. Psychol.*, 1956, **47**, 2, pp. 101–14.

BIESHEUVEL, S. 'The measurement of the Threshold of Flicker and its value as a Perseveration Test.' *Brit. J. Psychol.*, 1938, **29**, pp. 27–38.

BUHLER, R. A. 'Flicker Fusion Threshold and Anxiety Level.' Unpublished Ph.D. Thesis, Columbia University, 1953.

CHYATTE, C. 'The relation of Cortical Potentials to Perceptual Functions.' *Genet. Psychol. Monogr.*, 1954, **50**, pp. 189–266.

CLARIDGE, G. 'The Excitation-inhibition Balance in Neurotics.' Chapter in *Experiments in Personality, Vol.* 2. (Edited by H. J. Eysenck.) London, Routledge and Kegan Paul, 1960, pp. 107–54.

DREVER, J. 'Some observations on the Occipital Alpha Rhythm.' *Quart. J. Exp. Psychol.*, 1955, **7**, pp. 91–7

EYSENCK, H. J. *The Scientific Study of Personality*. London, Routledge and Kegan Paul, 1952.

EYSENCK, H. J. 'Cortical Inhibition, Figural After-effect, and the Theory of Personality.' *J. Abnorm. & Social Psychol.*, 1955, **51**, pp. 94–106.

FRIEDL, F. G. 'Anxiety and Cortical Alpha in Normal Subjects.' *Studies in Psychol. and Psychiat.*, Cath. Univ. Amer., 1954, 9, No. **2**.

GALLESE, G. J. 'Spiral After-effect as a test of Organic Brain Damage.' *J. Clin. Psychol.*, 1956, **12**, pp. 254–8.

GASTAUT, H. Chapter in Symposium on *Brain Mechanisms and Consciousness.* (Edited by Delafresnaye.) Oxford, Blackwell, 1954.

GLUECK, S. and GLUECK, E. *Unravelling Juvenile Delinquency.* New York, Commonwealth Fund, 1950.

GOLDSTONE, S. 'Flicker Fusion Measurements and Anxiety Level.' *J. Exper. Psychol.*, 1955, **49**, pp. 200–2.

GOLLA, F., HUTTON, E. L. and WALTER, W. GREY. 'The objective study of Mental Imagery. I. Physiological concomitants.' *J. Ment. Sci.*, 1943, **89**, pp. 216–23.

HOLLAND, H. C. and BEECH, H. R. 'The Spiral After-effect as a test of Brain Damage.' *J. Ment. Sci.*, 1958, **104**, pp. 466–71.

JAFFE, R. 'Kinaesthetic After-effects following Cerebral Lesions.' *Amer. J. Psychol.*, 1954, **67**, pp. 668–76.

KELTY, E. J. 'Normal Electrocortical Activity in relation to Personality Factors.' Summary of Paper presented at American Psychological Association Annual Convention, Chicago, September, 1960.

KLEIN, G. S. and KRETCH, D. 'Cortical Conductivity in the Brain-injured.' *J. Pers.*, 1953, **21**, pp. 118–48.

KRUGMAN, H. E. 'Flicker Fusion Frequency as a function of Anxiety Reaction. An exploratory study.' *Psychosom. Med.*, 1947, **9**, pp. 269–72.

MAGOUN, H. W. 'Caudal and Cephalic Influences of the Brain-stem Reticular Formation. *Physiol. Rev.*, 1950, **30**, pp. 459–74.

MUNDY-CASTLE, A. C. 'Electrophysiological Correlates of Intelligence.' *J. Pers.*, 1958, **26**, pp. 184–99.

PRICE, A. C. and DEABLER, H. L. 'Diagnosis of Organicity by means of the Spiral After-effect.' *J. Consult. Psychol.*, 1955, **19**, pp. 299–302.

SHEVACH, B. J. 'Studies in Perseveration. I: A survey of researches in perseveration.' *J. Psychol.*, 1937, **3**, pp. 223–30.

SHORT, P. L. and WALTER, W. GREY. 'The relationship between Physiological Variables and Stereognosis.' *E.E.G. Clin. Neurophysiol.*, 1954, **6**, pp. 29–44.

SMITH, I. MACFARLANE. 'The Relationship between Spatial Ability and Temperament.' Paper read to annual conference of B.P.S., 1952.

SMITH, I. MACFARLANE. 'The Educational Significance of individual differences in Imagery.' *Education Papers*, King's College Ed. Soc., Newcastle upon Tyne, 1955, **8**, 2, pp. 33–40.

STEWART, C. A. and SMITH, I. MACFARLANE. 'The Alpha Rhythm, Imagery and Spatial and Verbal Abilities.' *Durham Res. Rev.*, 1959, **2**, 10, pp. 272–86.

WALTER, R. D. and YEAGER, C. L. 'Visual Imagery and Electroencephalographic Changes.' *E.E.G. Clin. Neurophysiol.*, 1956, **8**, pp. 193–9.

WYNN JONES, L. 'Temperament and the Threshold for Flicker.' *Brit. J. Psychol.*, 1939, **29**, pp. 422–6.

Chapter ten

ASHBY, SIR ERIC. *Technology and the Academics*. London, Macmillan, 1959.
BOYD, W. *History of Western Education*. London, Black, 1921, p. 85.

Appendices

BELL, E. T. *Men of Mathematics*. London, Gollancz, 1937.

BERRY, A. J. *Henry Cavendish*. London, Hutchinson, 1960.

BLAKE, P. *The Master Builders*. London, Gollancz, 1960.

CARNEGIE, A. *James Watt*. Famous Scots Series. London, Oliphant, Anderson and Ferrier, 1906.

CLIFFORD, W. K. *The Common Sense of the Exact Sciences*. (Originally published 1885, republished in new edition with introduction by J. R. Newman.) New York, Alfred Knopf, 1946.

CROWTHER, J. G. *Famous American Men of Science*. London, Routledge & Kegan Paul, 1937.

CROWTHER, J. G. *British Scientists of the Nineteenth Century*. London, Penguin Books, 1940, p. 91.

CROWTHER, J. G. *British Scientists of the Twentieth Century*. London, Routledge & Kegan Paul, 1952.

DAVIDSON, M. A., MCINNES, R. G. and PARNELL, R. W. 'The distribution of Personality Traits in Seven-year-old Children: a combined Psychological, Psychiatric and Somatotype Study.' *Brit. J. Educ. Psychol.*, 1957, **27**, 1, pp. 48–61.

DICK, STEWART. *Master Painters*. Edinburgh, Foulis, 1911.

ELLIS, HAVELOCK. *A Study of British Genius*. London, Hurst and Blackett, 1904.

EYSENCK, H. J. '"Type" factors in Aesthetic Judgments.' *Brit. J. Psychol.*, 1941, **31**, pp. 262–70.

FINE, R. *The World's Great Chess Games*. London, Deutsch, 1952.

FLEMMING, W. 'Thoughts on the Training of the Mathematics Teacher'. *Mathematical Gazette*, 1955, **39**, 327, pp. 20–30.

FRANK, P. *Einstein, His Life and Times*. London, Jonathan Cape, 1948.

GHISELIN, B. (Ed.) *The Creative Process. A Symposium*. New American Library, 1955.

GALTON, F. *Enquiries into Human Faculty and its Development*. London, Dent, Everyman Edn., 1907, p. 78.

HADAMARD, J. *The Psychology of Invention in the Mathematical Field*. Princeton Univ. Press, 1945.

HANSON, L. and E. *Portrait of Vincent. A Van Gogh Biography*. London, Chatto and Windus, 1955.

HUXLEY, A. *The Doors of Perception*. London, Chatto and Windus, 1954.

JONES, E. *Essays in Applied Psycho-Analysis.* London, Hogarth Press, 1951.
KRETSCHMER, E. *The Psychology of Men of Genius.* London, Kegan Paul, 1931.
LENARD, P. L. *Great Men of Science.* London, Bell, 1933.
LOMBROSO, C. *The Man of Genius.* London, Walter Scott, 1891.
MAYER-GROSS, W. 'Experimental Psychoses and other Mental Abnormalities produced by Drugs.' *Brit. Med. J.*, 1951, **2**, p. 317.
MÖBIUS, P. J. *Über die Anlage zur Mathematik.* Leipzig, Barth, 1907.
MURRAY, P. and L. *A Dictionary of Art and Artists.* London, Penguin Books, 1959.
NISBET, J. F. *The Insanity of Genius.* London, Ward and Downey, 1891.
PARNELL, R. W. 'Physique and Choice of Faculty.' *Brit. Med. J.*, 1953, **1**, pp. 1506–10.
PEARSON, H. *Doctor Darwin.* London, Penguin Books, 1943, p. 76.
REITMANN, F. 'Goya—A medical study.' *Char. and Pers.*, 1939, **8**, 1.
RESHEVSKY, S. *Reshevsky on Chess.* New York, Chess Review, 1948.
ROGERS, C. A. 'A Factorial Study of Verbal Fluency and Related Dimensions of Personality.' Ph.D. Thesis, University of London, 1952.
RUSSELL, J. *British Portrait Painters.* London, Collins, 1944.
SNOW, C. P. *The Two Cultures and the Scientific Revolution.* (Rede Lecture.) Cambridge University Press, 1958.
STEWART, A. G. *The Academic Gregories.* Famous Scots Series, New York, Scribner, 1896.
TURNBULL, H. W. *The Great Mathematicians.* London, Methuen, 1929.
WALTER, W. GREY. *The Living Brain.* London, Duckworth, 1953.
ZERBE, E. 'Seelische und soziale Befunde bei verschiedenen Körperbautypen.' *Arch. Psychiat.*, 1929, **88**, pp. 705–51.

Subject Index

Name Index

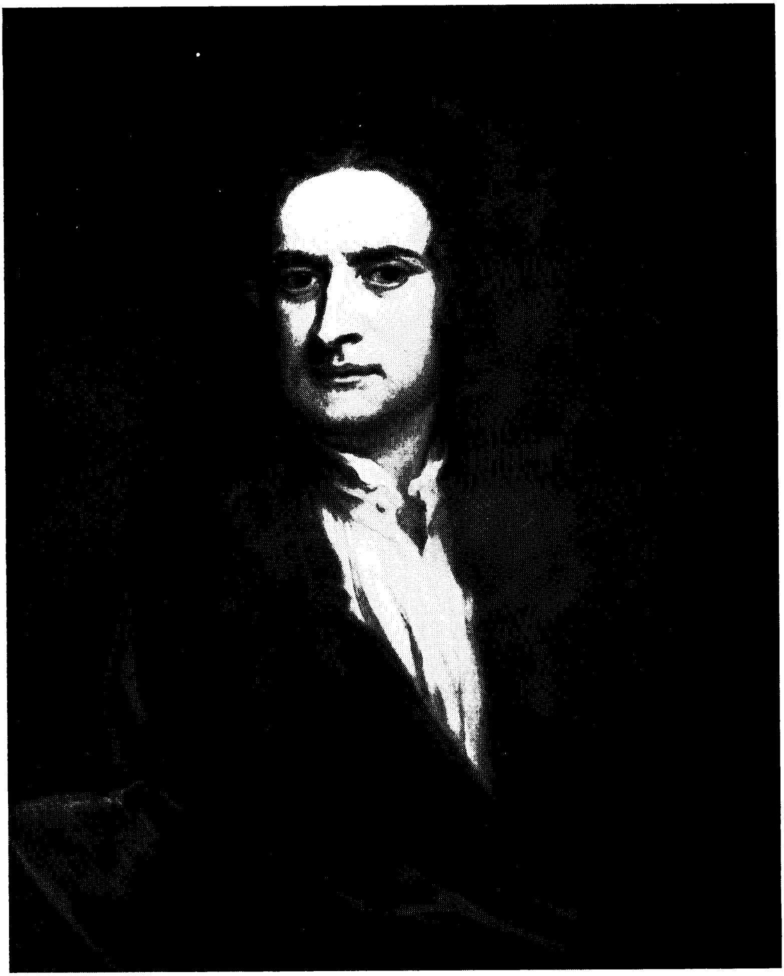
M. ANNETT (MRS)

SPATIAL ABILITY *Its Educational and Social Significance*

"The degree of exactness of the intuition of space may be different in different individuals, perhaps even in different races. . . .
"A full investigation of this subject, somewhat on the lines suggested by Francis Galton in his researches on heredity, might be interesting."

Felix Klein

(The Evanston Colloquium Lectures on Mathematics, New York, 1894, p. 46.)



Isaac Newton, mathematician (1642–1727)
'Qui genus ingenio superavit'
National Portrait Gallery

frontispiece