



Durham E-Theses

Spatial ability, sex, and handedness at 10/11 years of age

Densham, Raymond

How to cite:

Densham, Raymond (1983) *Spatial ability, sex, and handedness at 10/11 years of age*, Durham theses, Durham University. Available at Durham E-Theses Online: <http://etheses.dur.ac.uk/7157/>

Use policy

The full-text may be used and/or reproduced, and given to third parties in any format or medium, without prior permission or charge, for personal research or study, educational, or not-for-profit purposes provided that:

- a full bibliographic reference is made to the original source
- a [link](#) is made to the metadata record in Durham E-Theses
- the full-text is not changed in any way

The full-text must not be sold in any format or medium without the formal permission of the copyright holders.

Please consult the [full Durham E-Theses policy](#) for further details.

SPATIAL ABILITY, SEX, AND HANDEDNESS AT
10/11 YEARS OF AGE.

SPATIAL ABILITY, SEX, AND HANDEDNESS AT

10/11 YEARS OF AGE.

Raymond Densham.

ABSTRACT.

The importance of spatial ability is argued and the difficulties in defining and assessing it discussed. These questions are asked: are the suggested relationships between spatial ability and sex, and between spatial ability and handedness still evident when spatial ability and handedness are more carefully defined than usual and when children of 10/11 are studied?

The Edinburgh Handedness Inventory (E.H.I.) was modified and administered to 519 children. E.H.I. score and writing hand were compared as criteria of handedness. All 57 left handers and 57 right handers matching them in degree of handedness, age, and school experience were selected. The Spatial Test II (Watts) was administered to these 114 children.

No evidence was found of any relationship. The implications of this are discussed.

SPATIAL ABILITY, SEX, AND HANDEDNESS AT
10/11 YEARS OF AGE.

RAYMOND DENSHAM

THESIS FOR M.Ed.

UNIVERSITY OF DURHAM

EDUCATION FACULTY

1983.

The copyright of this thesis rests with the author.
No quotation from it should be published without
his prior written consent and information derived
from it should be acknowledged.



27 APR 1984

STATEMENT OF COPYRIGHT.

The copyright of this thesis rests with the author.
No quotation from it should be published without
his prior written consent and information derived
from it should be acknowledged.

LIST OF CONTENTS.

Pages	
	ACKNOWLEDGEMENTS.
	LIST OF TABLES AND FIGURES.
1-4	INTRODUCTION.
5-25	SPATIAL ABILITY
	a) Its Educational and Social Significance.
	b) The Problem of Definition.
	c) The Inadequacy of some Previous Works and a Definition of Acceptable Criteria.
26-51	SPATIAL ABILITY AND SEX
	Possible sex-based Factors Effective to Spatial Ability
	a) Genetic Factors.
	b) Maturational Rate.
	c) Sex Role - Interpersonal Relationships.
	d) Personality Traits.
52-75	HANDEDNESS
	a) Problem of Comparison of Criteria for Handedness.
	b) Problem of Definition.
	c) Comparison of Tests.
76-98	HANDEDNESS AND SPATIAL ABILITY
	a) Academic Interest in Handedness and Cerebral Dominance.
	b) Practical Interest in Relationship of Handedness and Spatial Ability.
	c) How Use of Atypical Subjects and Differing Instruments Can Lead to Inaccuracy of Definition of Relationship of Handedness to Spatial Ability.

Pages

99-103 DESIGN.

104-135 METHODS

a) Instruments

(i) Handedness Questionnaire.

(ii) Spatial Ability Test.

b) Subjects.

c) Procedure.

d) Analysis.

136-161 RESULTS

Question 1 How Accurate is Writing Hand as a Criterion of Handedness.

Question 2 Current Incidence of Handedness.

Question 3 Sex Differences in Spatial Ability.

Question 4 Relationship of Spatial Ability to Handedness.

a) For All Subjects.

b) For Varying Degrees of Handedness.

c) For Each Sex.

162-183 DISCUSSION OF RESULTS

a) Comparison of Criteria.

b) Incidence of Handedness.

c) Relationship Between Spatial Ability and Sex; All Subjects.

d) Spatial Ability and Handedness

(i) For All Subjects.

(ii) For More and Less Lateralised Subjects.

(iii) By Sexes.

184-190 CONCLUSION.

REFERENCES.

ACKNOWLEDGEMENTS.

I would like to express my sincere gratitude to all those who have assisted in the preparation and presentation of this work, in particular the following:

MR. H.M. STONE for his invaluable guidance in the organisation of this work.

The Headteachers of the primary schools in which the research was conducted for their cooperation and assistance.

MR. J.R. HUTCHISON for his encouragement and forbearance.

MISS V. NICHOLS for her assistance in the presentation of this text.

Without their unstinting help and support, this work would not have been possible.

R. Densham, A.C.P., B.Ed.

LIST OF TABLES AND FIGURES.

<u>Page</u>	<u>TABLES</u>	
115	Table 1	Test and Retest Results for the Verion of E.H.I. Used Here.
120	Table 2	Results of Spatial Ability Pilot Study.
136	Table 3.1	Agreement Between the Two Criteria of Handedness.
136	Table 3.2	Proportion of Children Identified as Left Handed by the Different Criteria.
139	Table 4.1	Incidence of Reported Handedness.
142	Table 4.2	Incidence of Handedness - E.H.I.
148	Table 5.1	Mean Raw Scores on Spatial Ability Test.
151	Table 6.1	Correlation by Pearsons Product Moment Coefficient 'r' of Scores on E.H.I. and Standardised Scores of Spatial Test II, All Subjects.
154	Table 6.2	Correlations of Progressively Refined Handedness.
154	Table 6.3	't' Tests of Statistical Significance.
158	Table 6.4	Product Moment Correlation Coefficient 'r' Scores on E.H.I. and Standardised Scores, Spatial Test II, Males.
159	Table 6.5	Two Tailed 't' Tests of Statistical Significance, Performance on Spatial Test II, Males.
158	Table 6.6	Product Moment Correlation Coefficient 'r' Scores on E.H.I. and Standardised Scores, Spatial Test II, Females.
159	Table 6.7	Two Tailed 't' Tests of Statistical Significance, Performance on Spatial Test II, Females.

FIGURES

Page

- 105 Figure 1 Oldfield's Original Questionnaire (1970).
- 107 Figure 2 First Modified Questionnaire.
- 111 Figure 3 Second Modified Questionnaire.
- 120 Figure 4 Spatial Test II (Watts).
- 127 Figure 5 Instructions for Completion of Handedness Questionnaire.
- 129 Figure 6 Instructions for Administration of Spatial Ability Test.
- 144 Figure 7 Graph of Distribution of Quotient Scores.
- 146 Figure 8 Graph of Incidence of Handedness as a % of All Subjects.
- 150 Figure 9 Graph of Distribution of Spatial Ability Test Scores: Males and Females.
- 157 Figure 10 Scattergram of E.H.I. Quotients and Spatial Test Scores.
- 180 Figure 11 Comparison of Expectations of Correlations by Previous Hypotheses and the Present Work.

INTRODUCTION.

For a long time the mental abilities of children tended to be assessed by instruments predominantly verbal in content, and the element of non-verbal intelligence, including spatial ability, went largely untapped.

Since the realisation that spatial ability is closely associated with not only mechanical and technical understanding but with mathematics, chemistry and other high-level cognitive skills (Baker and Talley '74) and due to the educational and social significance of undervaluing spatial abilities (Macfarlane Smith '64) there has been greater interest in these specific abilities and in related effective factors.

One major factor which seems to effect cognitive skills, or at least the attempts to measure cognitive skills, is that of sex. Many studies have found males to be superior to females or vice versa in the performance of differing tasks, and the direction and size of these differences vary with the task and the subjects. Many of the works considering spatial abilities in particular find a male superiority in this domain while some do not. It is important that this confused picture be considered, for the problems surrounding sex roles and sex expectations and perceptions are complex enough, and any clarification of the relationship between sex and a major cognitive area such as spatial ability must be welcomed.

Another factor which has been the cause of much work is handedness and its connection with all manner of abilities. The social and educational beliefs and preconceptions about "sinistrality" are rooted deeper in history than the interest in spatial ability, but since the link between handedness and spatial ability has been studied, there has been remarkably little consensus as to what that link might be. An ad hoc observation of these people who are engaged in what might be considered spatially oriented tasks - such as painters, architects, professional tennis players and the like - certainly seems to reveal an abnormally large proportion of left handed participants.

The indication of left handed superiority are, however, contrary to the theory of Levy ('69) who believes that, due to the nature of the means by which the cerebellum processes information, right handed subjects ought to have an inherent advantage at spatial functioning.

It is obvious that this is another important area, like that of sex effect, which is seriously in need of clarification so that further work may proceed on a firmer foundation than that at present available.

The probability seems large that much of the confusion described here is from a combination of three factors.

The first of these is a lack of a stable definition of spatial ability, and use of sometimes unspecified or unsuitable instruments for assessing it. A second problem is that of definition of handedness. In many works the method of assessing handedness is not specified, or left handedness is defined by use or reported use of writing hand. The treatment of handedness as discrete and dichotomous is also unsuitable, for there are many degrees of handedness, and "mixed handers" may well effect results.

A third problem is the frequent use of atypical subjects used in experimental work. Adults or, even worse, highly selected students such as university undergraduates or institutionalised or cerebrally disturbed patients have been the subjects of work from which much wider generalisations have been allowed to generate.

For these reasons, it can be considered that many previous works are inadequate, and a clearer understanding of these problems is needed as an underpinning to further work. To this end, the aim of this work is to help to clarify the position regarding spatial ability, and sex and handedness in children. This will be attempted by the application of a spatial test which complies to well defined criteria, to children in school whose handedness has been determined by a reliable and sensitive instrument.

The questions to be posed are as follows:

1. Is the use of writing hand a reliable criterion of handedness.
2. What is the incidence of handedness at the present time among pupils of 10/11 years of age.
3. What is the relationship between spatial ability and sex for all subjects.
4. What is the relationship between spatial ability and handedness for all subjects, for subjects of particular degrees of handedness, and for each sex separately.

1. SPATIAL ABILITY.

- a) Its Educational and Social Significance.
- b) The Problem of Definition.
- c) The Inadequacy of some previous works, and definition of acceptable criteria.

1 a) Spatial Ability - Its Educational and Social Significance.

Whenever the concept of mental ability is discussed, or used as a criterion for compartmentisation of people into groups for one purpose or another, the general term "mental ability" often distils into meaning "verbal ability". This may have some historical precedent, for when "intelligence tests" were first promulgated and designed they tended to be heavily verbal in nature, for even when the questions asked by the test purported not to be about verbal material, the test itself relied upon the subjects' ability to read the test. A person who could not do so, and who therefore scored poorly on such tests was labelled as being of poor "intelligence" despite the fact that he or she might have considerable mental powers which were simply not being tapped by the test used.

This anomaly has persisted for some while, and even after the disclosure of an area of ability not strictly verbal, and now usually defined as "non-verbal" or "visuo-spatial", the principle of equating mental ability with verbal ability still abounds.

In educational terms, this often shows itself in the practice of streaming or banding where pupils are allocated

to groups which may well be offered differing levels or content of syllabus for all subjects in the curriculum on the basis of their verbal, or sometimes verbal and numerical, abilities. It has been realised, however, (Baker and Talley '74) that the area of visuo-spatial intelligence is not only closely connected with performance in mechanical and other obviously spatially oriented tasks, but to mathematics, chemistry and other high-level cognitive skills.

It is quite possible that in many cases children are never specifically tested for this particular ability, although they are often tested and re-tested for verbal skills. Because of this lack of awareness of another large and important area of intelligence, much potential of pupils' ability is being lost. Macfarlane Smith ('64) argues that such "spatial" ability is undervalued in education, and proposes that it ought to be accorded a status of consideration at least equal to that of verbal ability, and suggests that it could be even more important.

The same argument can be carried from the educational to the occupational level. Many areas of work which require a well developed spatial intelligence including the mechanical industries and occupations such as architect, designer, draughtsman and the like often

make selections on the basis of their own 'performance' tests which are heavily loaded in spatial factors. This in itself is another condemnation of an education system which fails to provide this information to people requiring it above or as well as the traditional verbal and verbally based abilities. It may also be viewed in a more complex situation where prospective candidates don't even get to the selection stage because of their inferior verbal abilities so once again what may be considerable mental potential is left undiscovered and unused.

In an age which is evermore preoccupied with and enmeshed in a mechanical and technological revolution it is surprising and perhaps wasteful in potential terms that greater efforts are not being made to find and develop this specific latent mental ability. The arguments proposed by Smith twenty-years ago are even more valid and pressing today. The need for spatial abilities to be recognised as the equal to verbal abilities is important to the realisation of educational potential, the discovery and use of specific talents and abilities for further education and occupational requirements, and for the maximisation of life-chances in general.

The true value of using non verbal abilities will not be and can not be realised until it is possible to consider such abilities in the same theoretical detail as that now afforded to verbal abilities. Due to the earlier start and larger amounts of time and effort spent on refining and understanding concepts of verbal ability, its effective factors and relationship with other abilities, the theoretical picture is somewhat clearer for verbal than the non verbal areas of "intelligence."

It is necessary to improve the understanding of such non verbal abilities so that reliable and valid instruments can be consistently applied to quantify the ability, and thereby developing and directing the ability and its application in the same way and with the same status as has long been possible for verbal abilities.

1 (b) Spatial Ability - Problems of Definition.

When considering reports of work undertaken in the area of psychology which deals with various mental abilities, it is usual to encounter two difficulties. The first of these is definition; when claiming to test "spatial ability" it is as well to be precise about what is meant by "spatial ability". The problem of definition of such terms seems to have become more acute in recent years as methodology has become more rigorous. When tests of mental abilities were first promulgated, almost any test was accepted as testing what it claimed to test - thereby leading to the neat definition that "intelligence is what intelligence tests measure". As criticism of such tests lead to more refined attempts to quantify these concepts, the precision of the definitions of what was being measured became somewhat blurred and now such tests or attempted qualifications are perhaps too nebulous or are too loosely applied, as the definitions of such abilities become ever more amoebic.

The problem of definition is even more acute when dealing with spatial ability, for as a part, however large or small, of total human mental ability, it is difficult to separate it from other abilities to an extent where it is worthy of a definition in its own right as a discrete

ability. Although not physically possible, it is conceptually convenient to categorise such an ability as if it were separate and separable, while still recognising that an unspecified degree of overlap and interdependence between spatial and other abilities exists. The second of the two difficulties mentioned is that of designing and applying a valid instrument of measurement of whatever has been accepted as an adequate definition of the specified ability.

In one report (Manuel and Rorshel '52) over one hundred and forty tests claiming to measure "spatial ability" were listed. As many of these tests are quite different, can they all be measuring the same ability? Although this particular ability may well be wide and devious, it would not be unreasonable to suggest that there must be some "essence" or essential quality which could be considered mandatory in presence in order to assess whether a particular test validly measures that which has been defined as spatial ability.

In his major work "Spatial Ability - its Educational and Social Significance" Macfarlane Smith ('64) offers a very comprehensive survey of the development of the paper and pencil type of tests of

spatial ability since 1917. Many of these, he claims, originated as written forms of earlier manipulated tests such as practical, mechanical or formboard tests. These were originally intended as instruments of measurement of general intelligence for people of low education or poor verbal expression. Much time and energy has been spent, he reminds us, on trying to resolve the question as to whether these tests actually measured some special aptitude over and above the "general" ability "g" - the concept of Spearman (1927) - in the same way that verbal tests had been found to involve a large group factor additional to "g".

There were many who claimed to have isolated such a group factor (Earle, Milner et al 1929, Cox 1928, Truman Kelly 1928) while as many refuted its existence (Line 1931, Fortes 1930) claiming that their analysis of the data simply showed measurement of the general factor "g". Eventually, the evidence offered by Brown (1933) and Alexander (1935) among others began to clarify the situation in favour of a "factor of practical ability" usually referred to as the F factor, when an outstanding contribution, now considered as one of the seminal works in this area, was presented by El Koussy (1935). He applied 28 tests covering a wide range of abilities to 162 boys attending a Kent school.

The battery of tests included the following spatial or mechanical tests:-

1. Area discrimination. (El Koussy)
2. Memory for designs. (N.I.I.P.)
3. Form Relations. (N.I.I.P.)
4. Fitting Shapes. (Stephenson)
5. Form Equations A. (El Koussy)
6. Form Equations B. (El Koussy)
7. Form Equations C. (El Koussy)
8. Overlapping Shapes. (Stephenson)
9. Overlapping Shapes. (Abelson)
10. Pattern Perception. (Stephenson)
11. Spatial Analogies. (Modified from Stephenson)
12. Classification of areas, directions, lines. (Spearman)
13. Band Completion. (El Koussy)
14. Correlate Eduction A. (El Koussy)
15. Correlate Eduction B. (El Koussy after Spearman)
16. Mechanical Explanations. (Cox)

Using Spearman's tetrad-difference technique he concluded there was evidence of the existence of the factor in eight of the spatial tests, but not in the others. He stated his main conclusion

"...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 (his 'k' probably coming from 'kurtosis')."

The eight tests having the significant 'k' loadings mentioned proved to be those numbered 2, 3, 4, 5, 10, 11, 13 and 14 above, and after obtaining reports of introspections from many of the subjects of these tests El Koussy decided that the explanation of the 'k' factor consisted in "the ability to obtain and the facility to utilise visual, spatial imagery."

In the year following El Koussy's work, Clarke ('36) reported the findings of an even larger survey than that of El Koussy, but using female subjects exclusively. The interpretation she offered of the results seemed to oppose the findings of El Koussy, but re-examination of her tests and analyses showed that the work did, indeed, support El Koussy's findings, but to a lesser extent, possibly due to the sex of the subjects.

At the same time ('36) Macfarlane Smith was himself submitting a thesis on the same topic. When devising

the battery of tests for his investigation, Macfarlane Smith had been perturbed by the fact that he had found very great individual differences in pupils' ability to reproduce by drawing, accurate, well proportional sketches of simple objects. Pupils who produced sketches obviously grossly out of proportion seemed to find nothing amiss with their efforts. Macfarlane Smith believed that if the special aptitude he wished to measure existed at all, it should be manifest in the ability to observe and reproduce shape and dimensions in their true proportions. He accordingly included drawing tests of simple objects such as Bunsen burners and milk bottles in his test battery. He has maintained that any test claiming to test spatial ability should depend critically for success on the perception of the correct proportions of a figure or pattern - a conception obviously close to El Koussy's contention that 'k' factor consists of obtaining and utilising visual imagery, and is puzzled and, one suspects, disappointed by the fact that other research workers seem unaware of this principle or see fit not to refer to it in their work.

Meanwhile the field was becoming much more complex because of developments of new test material and of ever more exhaustive factorisations made possible by new

computing devices, and an attempt was made in 1957 by Michael, Guilford, Frucher and Zimmerman to 'filter' the similarities and differences between the factors so far isolated and to propound three areas of ability which they believe to be fairly well established as representational of spatial ability.

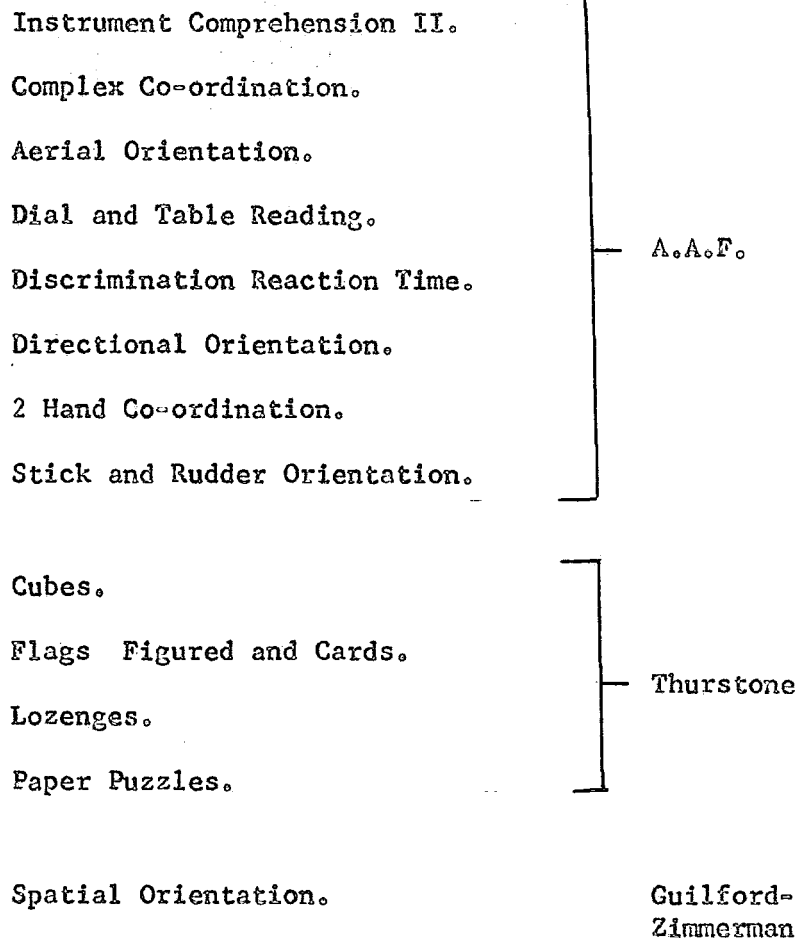
These three groups of factors were listed as

1. SR-0 Space relations and orientation.

This is considered to be the ability to comprehend the nature of the arrangements of elements within a visual stimulus pattern, primarily with the examinee's body as the frame of reference. In a typical test of this factor, as the entire configuration or principle component of it is moved into a different position, the objects within the pattern hold essentially the same relationship to one another.

The tests used to discern the factors

are:-



2. Vz Visualisation.

This factor is 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 to mentally rotate, twist, turn or invent 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 recognise 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.

Again the tests used to define this area are largely those of the Army Air Force psychologists listed and are:-

Directional Plotting.	}	A.A.F.
Spatial Visualisation - Paper Folding.		
Mechanical Principles.		
Mechanical Movements.		
Pattern Comprehension.		
Punched Holes.	}	Thurstone
Formboard.		
Spatial Visualisation.		Guilford-Zimmerman

3. K - Kinaesthetic Imagery.

This, the most tentative of the three is 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.

The only two tests for this factor are,
indeed

Hands	}	Thurstone
Bolts		

It will be noticed that the first of these factors - Spatial Relations and Orientation - bears similarity to Macfarlane Smith's contention. It requires that the subject first of all has the correct perception and then the mental manipulation of shapes as a whole. It also includes the use of the testee's own body as a reference frame - a concept closely allied to the field-dependence field-independence structure outlined by Witkin et al ('62), especially in the use of his classic R.F.T.

An interesting point to be noticed here is that many researchers have concluded that at tasks of spatial ability, males tend to be superior to females; while Witkin found that females also tend to be significantly more field dependent in general than do males. If tests of spatial ability require an independence of mental

reference from the body, then those who demonstrate field independence may well, by definition, have an inbuilt advantage at these tests normally called tests of spatial ability and a positive causal link may exist between the tendency for males to be more often field independent and superior at measurable spatial ability.

Although among the huge battery of spatial ability tests now available many are of the three-dimensional type requiring the subject to manipulate parts of mechanical apparatus, or else to fit pre-formed shapes into formboard and the like, El Koussy showed quite conclusively that these three-dimensional tests are not superior to the two-dimensional type of test; in fact for most of the tests considered to be heavily loaded in spatial factors, the two-dimensional or 'paper and pencil' type of test are in fact superior. The conclusion has been that probably the heaviest loading could be seen in those tests which require mental manipulation of three-dimensional objects in space - the Vz factor.

Macfarlane Smith points out, however, that many of the tests devised and used to test spatial ability do not,

in fact, use this type of mental manipulation. Some tests require only identification of different position, or the noting of details or recognition of pattern - and those tests are criticised by Macfarlane Smith on the grounds that they can be completed successfully by subject who do not have a high degree of spatial ability, but simply a mental facility for noting detail or recognising shape - a function of memory in fact. He is quite adamant that 'spatial' ability requires recognition and manipulation of organised wholes in three dimensions - and shape or pattern recall may be only a part of this ability.

As the available tests for spatial ability become more refined more specialised and their results better interpreted and understood, it would appear that if the definitions of constituent spatial ability by El Koussy and Macfarlane Smith are to be accepted, then the most reliable kind of test are those involving visualisation (Vz). The tests themselves could be two rather than three dimensional and need not be complex in the sense which implies much detail, but they may be complex in another sense, in the respect that the relationships between the parts of a configuration cannot easily be grasped explicitly. The relationship 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 organised whole.

It is this definition which is found acceptable for the purposes of this work; the nature of the test should require the subject to perceive, retain, and mentally manipulate in three dimensional space an organised whole, the parts of which must be grasped implicitly.

The orientation element (SR-0) should be minimised, as a major factor in its definition is liable to sex-bias in relation to the field dependence variable, and in order to facilitate analysis of sex differences on the test, it should be as sex-fair as possible.

1 c) The Inadequacy of some previous works and definition of acceptable criteria.

As discussed earlier, the problem of defining, let alone measuring spatial ability does not lend itself to easy solution. It is possible that many abilities combine to constitute that which is called spatial ability, but most researchers agree that its predominant cerebral location is the right hemisphere. This particular hemisphere seems to be most adept at a 'gestalt' grasp of problems of a spatial and motor-kinesthetic type and operates in an holistic manner, while the more analytical approach to problem solution is usually the domain of the left hemisphere (Bogen & Bogen '69, Levy '72, Cohen '73).

The suggestion that spatial factors are best processed by the hemisphere which uses holistic methods of processing tends to confirm the opinions of El Koussy and Macfarlane Smith who consider that the problems most heavily loaded with a discernable spatial factor are those which require a complete and almost "intuitive" grasp of the problem rather than an ordered and analytical approach. Highly loaded spatial tasks are those which require the subject to perceive the problem or image as an organised whole, and to visualise its manipulation

in three dimensional space, or to recognise the object or image when rotated to a different position. This task is not quickly or easily done by analytical methods, if it can be so done at all.

In order to select a spatial test which will involve the subject in this particular type of mental activity, the items in the available tests needed to be analysed for the type of mental processes they would be likely to involve.

Some of the better-known tests of spatial abilities (including some that have been used as the indicator of spatial ability in certain large and influential studies) do not altogether conform to the criteria imposed by the author. Such tests include the Minnesota Spatial Relations Test which dates from 1930 but is still in use in one form or another and consists of fitting blocks into preformed holes in boards. It is basically a speed test, and since it is of a practical nature, is not easy to administer to large groups of subjects simultaneously. It measures two-dimensional form recognition, and has no element of combining or integrating necessary to three dimensional rotation. The Minnesota Paper Formboard Test of 1941, in which subjects make multiple choice

responses to the re-assembly of cut-ups geometrical figures, is once again two dimensional and much of its completion can be credited to facility in shape recognition and memory rather than to spatial rotational elements.

The widely used Wechsler Intelligence Scale for Children (WISC) of 1949 is a battery of ability tests often applied in psychological research only three of which can be considered to have a spatial element. The battery yields three scores - Verbal, Performance and Total, but there is no definition of precisely what the "performance" score relates to, and the whole battery has been described (Delp. H.A.) as too difficult for the lower age brackets, and not effective for subjects at either end of the intelligence distribution.

Spatial Test I designed by Macfarlane Smith and published by NFER in 1950 is a better instrument, but of the six subtests none is three dimensional in principle - a curious fact considering the designer's work and findings in this area. Much use is also made of the Differential Aptitude Test (1958), a battery the "space relations" subtest of which is based on the unfolded paper boxes surface development technique. This does, at least, have some element of three dimensional mental

manipulation, but the test as a whole is rather too large to be a likely candidate for the use of measuring spatial ability exclusively.

A more recent test of spatial ability is the Spatial Test II designed by A.F. Watts and published by NFER (1979). This particular test is based upon material which complies quite closely to the required criteria, for, as Watts explains "The items of the test have been deliberately restricted to three-dimensional material. This has been done on the hypothesis that some difference may possibly exist in the ability to deal mentally with two dimensional and three dimensional problems respectively.."

The function of the test requires the subject to mentally manipulate a shape by imagining its rotation in space - being turned about in different ways, back to front, upside down, through 90 degrees; seen as part of a larger whole, or as containing a number of smaller parts and so on. This particular test also contains a minimum of written and verbal instruction, so minimising any handicap pertaining to the slow or poor reader. This test appears to the best available instrument at this time for assessing spatial ability as defined by the criteria listed above.

2. SPATIAL ABILITY AND SEX.

Possible sex-based factors effective to spatial ability.

- a) Genetic factors.
- b) Maturation rate.
- c) Sex role - interpersonal relationships.
- d) Personality traits.

2. Spatial Ability and Sex.

The whole issue of the sex of the subjects used is worth considering, for of all the areas of cognitive functioning to which sex differences have been linked, verbal abilities (Maccoby and Jacklin '74, Waber '75) and spatial abilities (Hype Geringer and Yen '75, McDaniel and Guay '76, McGlone and Davidson '73) rank among the most common.

Reasons for such noted differences in measurable performances in these skills (particularly spatial skills) are offered by large numbers of reseaches in various areas, some of which appear contradictory, and many of which are possibly interactionary. It is pertinent at this point to examine each of the main areas thought to be contributory to the reported differences in performance in order to consider their relevance to the subjects of this work.

2 a) Genetic Factors.

When considering any facet of ability demonstrated by a person or persons, a commonly asked question is to what extent that ability or predisposition for ability is inherited as part of the human genotype. The question is, however, impossible to answer for the abilities demonstrated by an individual are not purely genotype but phenotype. The arguments over heritability of such traits as "intelligence" have ranged long and bitter in the past, and may well continue to do so between inheritance theorists and committed environmentalists.

Nevertheless it is reasonably clear that such arguments may only really be about the degree of effect that inheritance or environment may play in the production of a personal phenotype, and not the fact that one or the other is uniquely responsible for it. For these reasons it is extraordinarily difficult to "get at" the evidence for or against genetic factors influencing spatial ability.

One recent attempt to show that demonstrated differences between the sexes in visuospatial domain is due to genetic factors, namely a recessive gene influence

is the work of Stafford ('61). He points out that although it is difficult to investigate heredity components of behaviour due to inevitable environmental influence, transmission by genes on the X chromosome is unique to a family. His investigation involved 104 fathers and mothers, 58 sons and 70 daughters. The correlations he found were statistically significantly close enough to correlations predicted by gene frequency to uphold his hypothesis. This work was replicated by Hartlage at a later date (1970) with different populations and different tests of visuospatial ability yet gave very similar results to those of Stafford, whose genetic theory was thereby supported. Further investigation of this hypothesis, however, has not been as supportive as may have been expected.

As suggested by Vandenberg and Kuse ('79), abnormalities of inheritance often provide insights when considering genetic hypotheses. They report the work of McClearn ('67) who noted the impaired performance of women with Turner's syndrome. In this condition, cases typically have only one sex chromosome (XO). If spatial ability is sex-linked, then these sufferers from Turner's Syndrome ought to demonstrate the same level of spatial skill as normal males, whose X chromosome complement is the same (XY). This hypothesis was not

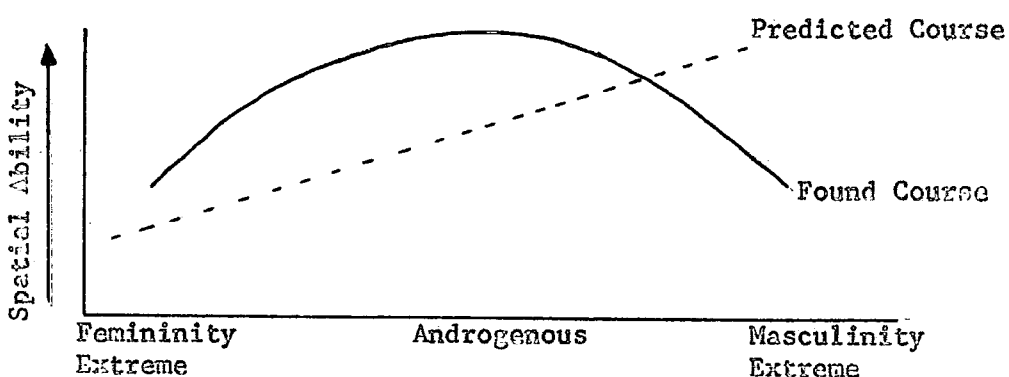
upheld (Garron '70), which would tend to discredit the X chromosome link theory. Similar evidence of refutation of the theory has been offered by researchers dealing with much larger samples than did Stafford or Hartlage. De Fries et al ('76), Spuhler ('76) McGee ('78) and Locklin et al ('78) all report familial correlations on spatial tests which do not display the unique pattern of correlation expected by a gene on the X chromosome.

There is, however, counter-criticism of these works (Vandenberg and Kuse '79) which reports that in the case of these latter studies there is some disparity in the types of tests used to measure "spatial abilities", and that indeed for some subtests the scores are remarkably consistent even though the populations differed widely in geographic location. As for the Turner's syndrome cases, Money and Mitterthal ('70) suggest that the unexpected depression of spatial ability scores may be due to the infantilizing treatment of many of these cases by their parents and teachers. Bock and Kolakowski ('73) also suggest that the expression of the sex-linked spatial gene may depend on a normal hormonal environment typically absent from Turner's syndrome patients.

The introduction of the possibility of hormonal influence discloses yet another area of research which links spatial ability to sex hormone levels (Klaiber, Broverman, Vogel and Kobayaski '74). In this work an inverse relationship has been suggested between male spatial scores and chemical and somatic signs of androgenicity. In a review of this research, Peterson ('79) recalls the work of the Brovermans and their colleagues over the last decade. Through increasingly sophisticated measures of hormonal influence they have repeatedly reported correlations between testosterone production rate (though not testosterone level) with measures of proficiency on the E.F.T. (Witkin '50) and two Wechsler subtests - block design and object assembly (Wechsler '55) both thought to be 'spatial' in character.

Peterson herself ('76) found confirmation of the inverse relationship for males; in females, however, she found that external signs of androgenicity correlated positively with spatial scores. If the relationship between spatial ability and testosterone levels is negative for males, however, then it is surprising that both spatial scores and testosterone levels show significant simultaneous increase during adolescence. Vandenberg and Kuse suggest that either powerful factors

operate in the opposite direction to overcome the increased androgen levels, or the negative relationship is not constant throughout life. Peterson ('79) delineates the present findings in her summarising article which shows that at extremes of androgenicity, spatial ability actually contradicts the predicted directions.



She concludes that "...it seems rational that any biological and sociocultural influences on sex-related differences should be acting in concert, that they should be mutually reinforcing. The results just presented are difficult to combine with a socialization hypothesis...these results remain confusing and require further research."

The evidence, then, is quite complex. The trait seems to show a definite developmental pattern. A

recessive gene on the X chromosome has been suggested, but disputed; the effects of hormones on various cognitive performances has been demonstrated, but the evidence is somewhat contrary to expectations and further work is being undertaken at present to attempt clarification of this issue. All of this work, of course, does not take into account the effects of culture and experience upon these biological factors which might magnify any measurable differences between the sexes.

The doubt also remains whether the different results obtained by researches using measures of spatial ability are not in part caused by the use of differing types of subtest which are labelled as "spatial ability" tests. Vandenberg and Kuse remind us that comparability of studies is somewhat confounded by the fact that there is no psychometric definition of "spatial visualisation" which is generally accepted (Macfarlane Smith '64) - a factor which is discussed elsewhere.

The consideration of these reported findings is an important factor in the design of the present work, for the suggestion that hormonal differences may account for measurable discrepancy in proficiency on E.F.T. and block design tests, may be instrumental in the selection of the spatial tests to be used; and the choice of pre-adolescent

children may assist in reducing reported testosterone-
production related differences in spatial ability.

2 b) Maturational Rate.

As the human being matures physically and mentally, it is quite possible that if the sexes mature at different rates (Tanner '62) then the differing maturational rates may be connected to differing performances between sexes. This phenomenon has been demonstrated in monkeys (Goldman, Cranford, Stokes, Galkin and Rosvold '74) and research has led towards the conclusion that in humans, too, the disparate maturational rates between the sexes may be an important factor in the measurable performance differences.

Research undertaken by Waber ('75, '76) has led her to the conclusion that maturational timing might be a factor in the observable differences of performance between sexes, particularly in the areas of verbal and spatial ability. She has found that early maturers were better at verbal skills and were less cerebrally lateralised, while late maturers performed better at spatial tasks and were more cerebrally lateralised; and the conclusion was drawn that a critical factor in psychological differences is not gender per se but differing rates of maturation between the sexes.

It has been suggested that, as sex related differences often seem to appear and disappear at various ages, the differences themselves may reflect different organisational systems and loci which give one sex an initial advantage at some specific ability which eventually disappears as the other catches up. An example of this is the observation that, on verbal tasks given to children between five and eleven years of age females are invariably superior (Denckla and Rudel '74) but after that age males catch up - possibly due to ceiling effect. Only in the area of word fluency do females maintain their superiority into adolescence or adulthood (Herzberg and Lepkin '54).

Developmentally, both linguistic and fine motor skills show the same pattern; that females are consistently more advanced in early age while as puberty is approached males catch up. The data suggest that a common neurological substrate may underly the development of linguistic and fine motor skills, and that its maturation proceeds more quickly and more smoothly in females than in males.

The picture is quite different when considering spatial abilities, for many of the works studying this area report male superiority, particularly noticeable

and tenacious when the instrument for measuring spatial ability includes or is based on embedded figures, block design and mazes (Maccoby '67). It would seem possible that if differences are to be noted as more discernable at certain very specific tasks, then these differences may be affected by mental strategy as much as differential maturational rates.

An important point to establish here is whether male superiority in spatial tasks, as so often reported, appears to persist when the test of spatial ability is devoid of items such as embedded figures and block design. Whether or not females are more or less lateralised, or use different mental strategies to respond to spatial items in a test has little bearing on the responses they actually make in practical terms, and the results of this work might help to clarify the picture of how the performance of the sexes relate when in the pre-adolescent stage, and using three dimensional material exclusively as a spatial instrument.

2 c) Sex Role.

In an interesting paper Fox, Tobin and Brody ('79) review the situation currently in vogue which relates the relative abilities of males and females on verbal and mathematical performance scales. Although their review is concerned with mathematical ability in particular, this work is in no way irrelevant to the present interest in spatial ability, for spatial and mathematical abilities have long been considered alike and in opposition to verbal skills. It is not inappropriate to substitute the word "spatial" for "mathematical" in much of the following text.

Fox, Tobin and Brody see the current literature as favouring two major hypotheses as important in the area of demonstrable sex-related differences in mathematical performance. The first of these is the adoption of a masculine psychological identification as a prerequisite for the interest in the study of mathematics; the second being the differential social reinforcement which conditions males more than females to pursue the study of mathematics.

The masculine-identification hypothesis (Plank and Plank '54, Elton and Rose '67, Aitken '75, '76)

argues that boys and girls who identify with their fathers or a generalised masculine sex-role are better at maths than those who have a feminine identification - or at least are better mathematically than verbally. An often cited supporting study to this hypothesis is that of Carlsmith ('64) in which boys and girls from homes from which the father was missing during early childhood showed higher verbal than mathematical aptitude scores. Such a high-verbal, low-mathematical pattern is defined as feminine, while the reverse pattern is defined as masculine.

This series of findings was replicated later (Landy, Rosenberg and Sutton-Smith '69), when decreased quantitative scores for both sexes were found in father-absent homes. As Ferguson and Maccoby ('66) remind us, however, stress and tension interfere differentially with functions underlying performance, and as the lack of a parent in the home would probably lead to stress and tensions, then the reduction of performance on verbal and mathematical tests is hardly surprising.

At present, then, the masculine identification hypothesis is not impressive, but the second theory - that of the sex-typing of mathematics as masculine

and the differential conditioning of sex role appropriate behaviour does have some merit. The argument behind the sex role theory is basically that girls tend to favour "feminist" pursuits, which include mostly verbal attributes, while boys favour those areas such as maths, science and spatial topics which are usually perceived as "masculine". The theory is, however, more complex and subtle than this.

While it is comparatively easy to show that more boys than girls choose mathematics and maths related courses in schools and colleges (even girls with high ability in these subjects don't choose them as often as do males) as reported by Casserly (1975), Ernest (1976) and Fennema (1977); it is more difficult to decide why this should be so, and how these sex-role constraints relate to the theories of inherent mental superiority in these domains.

Attitude is obviously one effective area concerned with performance, and the fact that maths is seen as a male domain by boys (Kilton and Berglund 1974, Sherman and Fennema 1977) improves their attitude and hence their performance in this direction. Girls also perceive mathematics as a male domain (Warley 1969) and their perception of this leads to the "fear of

success" syndrome; for apparently high achievement females relate success in mathematical areas as being in direct conflict with social success, particularly with males! This negative attitude of females compared to the positive attitude of males towards the same perception of mathematics as a male domain would naturally lead to diverse measurable attainment between the sexes.

A second dimension of how attitude towards a particular subject or area of cognitive functioning differs is shown by Nash ('79) who recalls the work of Montemayer ('74) wherein even six to eight year olds monitored their performance in accordance to the sex label assigned to the task. This was shown when girls' performance was highest when playing a game "for girls"; while boys' performance at the same game was highest when the game was labelled as being "for boys". When given a choice of tasks, eleven year old boys chose to work longest on "male" tasks, less long on "neutral" tasks, and least on "female" tasks, although girls spent equal time on all three tasks. (Stein, Pohly and Mueller '71)

Nash believes that between the ages of two and four years the child establishes "a fixed, irreversible

'gender identity' based on a physical reality judgement" (Kohlberg '66). This identity becomes the organiser of the child's sex-role attitudes, as the child strives for consistency in sex-role development. She cites many works (Fagot and Patterson '69, Hartley, Hardesty and Gorfein '62, Kuhn, Nash and Brucken '78, Schell and Silber '68) which support the findings that between ages three to five years children show sex-typed preferences for certain toys, objects and activities; and that preschool children prefer same-sex peers and claim their own sex as "better". This type of evidence demonstrates that even at the ages below which one might expect school students to be conscious of the effects of the choices of subjects, or even to relate such choices to the way they perceive them as useful to their future careers (Haven '71, Sherman and Pennema '77), the tendency exists to increase performance in a way which seems to be predicted by the sex-role theories.

When, to these seminal attitudes towards and perceptions of sex-role, the further complications of social influences are added it is not surprising that Nash concludes "The relationship between sex role and intellectual functioning is a complex one -

and not subject to simple generalisations." The pressures of peer-group support, or lack of it, can effect the conflict between sex concept and innate ability (Hurley '64, '65) as can the educational practices of "segregating" certain subjects in the curriculum: examples such as Home Economics and Technical Studies being but two of the more obviously "covertly" segregated areas. Not only the pupil, but significant adults in the pupils life will also hold beliefs and values about the appropriateness of various activities and academic subjects to specific sexes.

Parents may well believe that certain areas of study are more appropriate to boys or girls, and positively or covertly direct their children, or at least by their beliefs (accurate or otherwise) transmit an expectation of preference.

Teachers are another group of people who either deliberately or inadvertantly may influence pupils' beliefs or attitudes towards specific activities. By their vocabulary, tone of voice, or even by non-verbal signals, teachers can effectively alter pupil's perception of and performance on certain academic

areas (Rosenthal and Jacobson '63) and such an influence, whether intentional or not, may also strengthen in children a sex-role or sex-appropriate stereotype.

There is little doubt that employers also do, or at least did, perceive some areas of knowledge as more appropriate to males or females, and base selection of employees on their perception of sex appropriateness. Were this not the case, the Equal Opportunities Commission would be a redundant institution.

All of these beliefs and attitudes are observed by the child, or are applied to the child, and thereby help to form or strengthen his beliefs about sex-role and sex stereotyping. Whether these beliefs are accurate or false is of no consequence, for it is the belief and not the reality which impinges upon the child's conscience.

The sex-role stereotypes, once adopted by the child, are usually reinforced by social experiences such as children's literature, textbooks, television programmes, and even tests, and there is little doubt that such a constant bombardment of "sexist" media presentation

must have some mediating effect upon sex-role stereotyping and therefore on attitudes and therefore on cognitive performance.

2 d) Personality Traits.

Compared to the efforts of many to delineate cognitive differences between sexes as a function of genetic heredity, or of sex-role identity, there is another perspective on the topic which proposes that many of the differences may be environmental in cause.

As many of the factors to be considered here are effected by socialisation, the findings tend, by nature, to be less definitive than the more "clinical" investigations. This does not imply that conclusions drawn are less accurate or important, but it does often mean that the results of such works are more open to interpretation. In the discipline of sociology, methodological issues are a constant source of discussion and dissension; for, depending on the perspective or ideology adopted, the same events can be interpreted in quite different ways.

There is little doubt, however, that the way a person perceives a task can affect the level of performance on that task as discussed elsewhere in this work and as summarised by Maccoby and Jacklin (1972) "The emergence in early adolescence of views about the possible nature of their future lives may

have a good deal to do with the rapid sex differentiation in intellectual interests and skills that occurs at that age."

Effects on performance are even detectable through expectation - the well known "halo effect" documented by Rosenthal and Jacobson ('65) and Lacey ('70). If a subject can be seen to perform better without an actual increase in "knowledge", then the explanation must lie in the fact that a greater proportion of latent potential is being used or realised; and that this increased potential realisation is a factor of some social and or personality variable.

One personality trait which has been long established as effective in the spatial domain of cognitive functioning is that defined as Field Dependence or Field Independence, by Witkin ('49). Further work (Witkin, Dyk, Faterson, Goodenough and Karp '62) considered stimulus modes, and concluded that subjects did not differ in the basic way they perceive space, but rather that "...they differ in their choice of alternatives when several possibilities for perception are open, i.e. when the process of spatial perception is ambiguous...the outcomes will be

influenced by attitudes, motives, and even by social background" (Gibson '57).

The establishment that females are generally inferior to males in the "rod and frame" and "embedded figures" tests which are often used as measures of field dependence closely parallels the reports that females tend to be consistently inferior to males on many tests of spatial ability, and some sort of connection between these tendencies has been suggested. Gibson's comments on social background do not go unnoticed, for Dawson's ('67) investigation of the Temne and Mende tribes of Sierra Leone considered child-rearing practices. She found that within the Temne tribe, who tend to subject their children to authority, conformity and strict discipline, the males were more field dependent than males of the Mende tribe, who practice a more permissive child-rearing milieu. Such findings support the hypothesis of a positive relationship between field dependence scores for mother-son pairs (Witkin et al '67).

The work of Berry ('66) extended this work to consider Eskimo children who are reared in an atmosphere of unconditional love and approval. It was found that,

not surprisingly, Eskimo subjects demonstrated much greater field independence than the "dominated" Temne subjects. With regard to sex-related differences, it was interesting to note that among the Temne, who exercise even stricter control over females than males, males were on average more field independent than females. Among the Eskimos, females are allowed considerable autonomy, and Berry (1966) and MacArthur (1967) found no significant sex-related differences in field independence among Eskimo children.

Sex related differences in field independence seem to be largely a function of social role influence (Kagan and Kogan 1970), "The cross-cultural evidence available to date is consistent with the hypothesis that child-rearing practices, and the social roles assigned to the two sexes affect the degree to which the sexes differ in spatial ability" (Nash 1979).

While there are many personality traits propounded by the "trait" theorists of personality, and an individual may lie on continua between the extremes, the overall "profile" of any one person's personality remains unique, and therefore subject to different amounts and directions of change after

exposure to the same experience. As the bewildering array of social experiences encountered by a person are so inter-related, it is difficult to even consider any one of them as separable for conceptual purposes. It is not surprising, therefore, that several other studies of personality factors which may affect spatial or spatially-linked cognitive abilities are less than definitive. Bieri ('60) and Oetzel ('61) have suggested that high level analytical thinking is associated with cross-sex typing; while Maccoby ('67) suggests modelling and opportunities to learn as causal factors of sex differences in abilities. These latter suggestions are appealing, for they would answer the questions of why girls seem superior at verbal skills while boys seem to excel in spatial and analytical tasks. She offers that girls tend to spend more time in the home with their mothers, whom they model, thereby acquiring improved language use; while boys play more with constructional or "three-dimensional" toys which enhances their spatial concept, as does their modelling on their fathers. Maccoby readily admits, however, that there is no firm evidence for either theory, and they are both criticised by Fox, Tobin and Brody ('79), who briefly summarise the complexity of the issues thus:- "It appears that girls

and boys differ with respect to attitudes, self-confidence, values, and career aspirations and expectations...and such differences are learned behaviours. The socialisation agents are the family, teachers, counsellors, the peer group, the school, the media, books..."

The exact nature of each factor, its degree and direction of influence and its amount of interaction with other factors are not particularly germane to this work; it suffices to demonstrate that some of the measurable sex differentiation of cognitive ability can be attributable to personality, the appropriateness of the task, and the individual's opportunity to learn.

An interesting observation leading from these investigations is that if some or all of these factors are learned behaviours, then it follows that they can be unlearned, or changed by re-directing the behaviour or attitudes. Such findings have, indeed, been demonstrated by Sherman ('74) who discovered that performance on several tests of "spatial" bias could be changed (improved) by practice. It may be that what differences are apparent between the sexes may be genetic in a marginal sense, and that these small

differences are magnified by later experiences. This would allow for the findings that differences between sexes' performances seem to expand and contract with age differences, and that in some cultures they are less marked than in others.

3. HANDEDNESS.

- a) Problem of Comparison of Criteria
for Handedness.
- b) Problem of Definition.
- c) Comparison of Tests.

3 a) Problem of Comparison of Criteria for Handedness.

The same definition problem also occurs in the area of lateral dominance - this time of defining handedness and the establishment of criteria for categorising subjects. The term handedness is so commonly used, and so widely "understood" that it may well seem superfluous to define it further, yet no deep study of the work on handedness (which itself is burgeoning) is necessary to discover that the simple definition of "right or left" handed is hopelessly inaccurate and inadequate. The fact is soon discovered that while virtually everybody can be easily classified into one of the two camps of handedness, in truth very few of the population are absolutely and totally one handed. The vast majority of people (and even animals) fall into a category of "mixed" handedness; where one hand may be preferred for the operation of some tasks, while the other hand is naturally preferred for the operation of others.

This state of mixed handedness as defined by Annett ('74) is not the same as true ambidexterity where either hand carries equal facility for all tasks, and is extremely rare in occurrence. Various estimates have it that the proportion of people who are absolutely

and exclusively handed may be around six or seven percent of the population, while true ambidexters account for less than one percent of the remainder.

This leaves a very large majority of people who are, in fact, mixed-handed, and it is this portion of the population which provides the major problems of definition.

The causal relationship which might be thought to exist between cerebral dominance and overt handedness for various tasks is discussed elsewhere, but suffice it for now to consider the classification into left or right handedness by performance criteria only. Very often this classification is established by the simple expedient of observing with which hand the subject writes, or the even simpler expedient of asking the subject with which hand he writes. While it is admitted that writing is a very important and much used skill, it may possibly be the only task performed by that subject with that hand - he may be otherwise almost totally contra-cerebrally dominant, or "handed" the other way. This incidence was not unknown when the practice of encouraging children not to write left-

handedly was still common, and some apparent right-handers are, indeed, changed left-handers for writing, while retaining their left-handedness for virtually all other tasks.

It can be seen, therefore, that hand observation for writing alone might be misleading, and this type of mis-classification has been thought in the past to have been the cause of inaccurate conclusions about handedness and other abilities due to dilution of samples with mixed or changed handers.

As many works have held differing criteria for the selection and specification of handedness, some using reported handedness from each subject, some using observation of writing hand, some using unspecified means, it is easy to understand the difficulties encountered in making meaningful comparisons between various works, or of being able to rely upon conclusions drawn about the effects of reported handedness.

3 b) The Problem of Defining Lateral Dominance.

Lateral dominance - that is the dominance of preference of use of one side of the body over the other - commonly called handedness, is one of the oldest areas of psychomotor investigation in man and as Margaret Clarke humourously complains .."only one who has embarked upon investigation of hand preference can realise the extent of the data available on the subject."

In many areas of activity, one hand plays an important part, and as this hand acquires more efficiency with use, there is advantage in using this hand. It might be expected on this basis that humans would be roughly divided into equal numbers of left and right hand users by chance; but even casual observation shows that this is not so.

Not only are the right handed in a large majority, but this has become accepted as "right" and "correct", and superstition and unjustified connotations about "sinistrality" abound. It could even be considered as surprising under the circumstances that roughly one person in ten remains determinedly left-handed despite the prejudice in some quarters and the downright physical

inconvenience this brings in a right-handed society. Similar tendencies can be detected in the consistently preferred use of one eye or one foot over the other, and many theories have been propounded for the cause of this dominance.

One of the earliest explanations of right handedness is accredited to Thomas Carlyle (1795-1881) and is referred to as the primitive warfare theory. This holds that primitive man used his right hand to hold his weapons in order to leave his left free to hold a shield over his heart. Left-handedness was accounted for as being the result of some kind of "natural mistake" or freak occurrence. Another early work which tried to consider left handedness in a more positive light - probably because of his own left-handedness - was that of Wilson (1891) who claimed that education was the key. His theory was that very few people are naturally strongly handed by preference, and so right-handedness must be the result of education in a predominantly right handed society. Many of these people, claimed Wilson, could as easily have been left-handed had that been the social preference of the time. This theory does not, however, account for the fact that virtually all other societies, educated or not, human

and animal, show very similar patterns of right side dominance.

Around the turn of the century, attention was drawn to the possible genetic influences on handedness. Early work by Jordan (1911) and Ramaley ('13) considered Mendelian recessiveness as a cause, but of course, this would mean that a left with left mating would produce all left-handed children which is patently not the case. Trankell ('50) believes that Mendelian dominance is the cause of left-handedness, but cannot say what happens in the absence of the dominant factor. Another difficulty in comparing early researches, and even more recent work for that matter, is that of ensuring that all cases of left-handedness have been selected by a standard (or even vaguely similar) criterion.

Many years ago left-handedness was actively suppressed in schools, and as a result surveys of writing hand used would detect only about two percent of the population so performing, while more recent enquiries can find about eight percent of left-handed writers. There is evidence that left-handedness is more common among males than females, by about eight

percent to six percent, and that it is also more common in twins than in single born offspring by about eleven to seven percent respectively, (Clarke '57, Wilson and Jones '32) but there is no concensus as to why this should be so. The current situation is assessed by Clarke as follows; "...genetic studies have revealed that the development of handedness preference has an hereditary basis, in other words, that ones chances of being left handed are greater if there are instances of left-handedness in the family. Few would deny, however, that factors other than genetic help to determine whether any particular individual will be right or left handed..."

If the genetic effects of handedness are not clear-cut, then neither is the picture of developmental effects. It has been found that the developmental stages of laterality are highly individual and are related to quite definite age ranges. Gessell and Ames ('47) have reported that early infancy is characterised by bilaterality or considerable use of the non-dominant hand. By the age of two a relatively clear-cut dominance occurs, mostly the right hand. The age of two and a half sees a shift back into a period of bilaterality which once again gets towards the dominant hand. It is not unusual to find

schoolchildren using one hand for several tasks without that hand being the "dominant" one - they may be in a transitional bilaterality stage. Hildreth ('48) found that acts subject to training - the use of cutlery, throwing and scribbling for example - become stereotyped earlier than seldom practiced acts, and it is believed that the earlier a dominance appears, the stronger it becomes.

In a large majority, a lateral dominance is apparent and virtually fixed by the age of two, while a small minority show alternate use of left and right hands up to early school age, by which time any preference shown is likely to be less stable than that of those who "stabilized" earlier.

If there is a physiological tendency towards a lateral preference, and such a preference has been demonstrated in rats and other animals as well as man (Tsai and Maurer '30, Peterson '31) then such a tendency is towards a preponderance of dextrality. The work of Peterson supports the theory of physiological basis of laterality, for he found he could affect the "hand" preference of rats by destruction of areas of the cerebral cortex.

As with so many other areas of human behaviour, it would be no surprise to find that lateral preference is the product of indeterminate genetic endowment and a multitude of environmental factors.

It is possible that genetically, one is born with a predilection of hand usage rather than a fixed ability to use that hand only, and that predilection is strengthened or not as the case may be by sociological or socializing influences. It has been mentioned elsewhere that at some times in some societies left-handedness is positively suppressed, and this factor allied to the physical inconvenience that left-hand usage can cause in a complex society ergonomically committed to right-hand usage may well exert enough early influence upon an individual who is not strongly left-handed to change his preference to the right. The game of golf presents an example of a situation where many natural left handers have learned to play the "right way round" simply through lack of suitable left-handed equipment, or of any instructor who could teach them to play left handedly.

This concept of handedness being the product of genetic and sociological factors would explain why

there appears to be so many disparate degrees of handedness, and why an individual's position on a handedness continuum can shift according to age, circumstance, and type of test used. The problem of identifying positively the direction of lateral preference in humans, and the degree of that preference has been one of the greatest stumbling blocks to the efforts of designing reliable measuring instruments which in turn has caused some of the vast proliferation of which Clarke complains and which makes accurate comparisons of different research projects difficult.

Provins and Cunliffe (1972) and Rigal (1974) rightly question the validity of determining handedness by questionnaire, for, they argue, no matter how comprehensive and sophisticated the questionnaire may be, subjects sometimes perform differently from how they report that they perform. The volume and level of language use involved in some questionnaires could also influence the accuracy of response of younger or less verbally able subjects.

Barnsley and Rabinovitch (1970) also warn that questionnaires of hand preference cannot adequately represent the full range of handedness or degrees of

differential manual proficiency. In their view, hand performance tests are preferable, but adequate performance tests of many different tasks by many subjects could well be simply too slow and cumbersome to be of use to a researcher "in the field."

This researcher is left, therefore, in having to rely upon the administration of a large assembly of observances of subjects actually performing a range of tasks or of applying one of the available questionnaire type of test - the only "practical" hand preference test, that of Van Riper (⁰31) having been found to be inordinately clumsy to administer and unreliable to boot - and the written type of test at least lends itself to accurate record of results, and can be re-applied by others with equal accuracy. This latter course seems at this time to be the preferable one bearing in mind the possible shortcomings of such tests, and taking all possible precautions to minimise them.

Most works which study lateral dominance consider only which hand is preferred for usage at any given task, and tend to ignore the acuity with which the preferred hand is used. Often the main criterion of

determination of lateral dominance is the observation of which hand is preferred for writing - and indeed Provins and Cunliffe ('77) have found that of the tests of dexterity, the best test-retest scores are those for handwriting, but as Clarke discusses, a person found choosing the right hand for writing may well be a "changed" left-hander. The consideration of acuity in use rather than preference of use is often more easily discernable in other areas of lateral dominance than handedness; such other areas are "footedness" and "eyedness".

While footedness, especially kicking foot preference, is found to be highly correlated to handedness, the effects of eyedness are not so. Usually tested by observing which eye the subject uses to look down a tube, through a hole, or to "aim" a toy rifle eyedness shows nowhere near the same degree of correlation with handedness. Clarke has found correlations between eyedness and handedness ranging from almost zero to over ninety percent. The fact that performance of vision is not the same as eye preference may account for some of the noted variance, for while aiming a gun may well depend upon the hand normally preferred to hold

the weapon, and use of the corresponding eye, there is no such clear-cut advantage to looking through a hole cut in a piece of card with one eye or the other.

In this instance acuity of vision with one eye or another may well be the controlling factor. There appears to be no evidence that sight 'belongs' to either one of the cerebral hemispheres, let alone to the same 'dominant' side which contralaterally controls handedness (Clarke). As hand, eye, foot and even ear preference are all functions of lateral dominance, can it be considered that examination of hand usage alone is proof enough of a dominance of lateral acuity? Consideration of the low correlations between eye and ear preference with other chosen uses such as hand and foot leads to the suspicion that while eye and ear preference may be somewhat arbitrary, the almost unchanging selection of one hand or foot for some specific task and the high correlation between the selection of hand and foot lead one to answer in the affirmative.

To summarise the findings on lateral dominance as they pertain to and affect this work, it would be

reasonable to conclude that use of hand, foot and observed writing hand are most permanently dominant one way or the other. While quite high correlations between hand and foot are recorded, the correlations between hand and eye, hand and ear, eye and ear, are much less clearly demonstrable. More males (8%) than females (5.9%) are left-handed writers, but some left-handed writers are not largely "left-handed" in that they may have a right hand preference for almost all other tasks but writing, while a not inconsiderable number of right handed writers may be "changed" left handers.

Handedness is not a discrete ability, but each individual lies on a continuum between the extremes of handedness. The individual may also shift along the continuum depending upon which one or ones of a flexible set of criteria is used to determine handedness at that time.

Annett reminds us that, "This range (of handedness) is sufficient to account for the widely discrepant incidences reported in the literature. Reviews such as those of Bingley (1958) and Hecaen and de Ajuriaguerra (1964) amply demonstrate the confusion of contrary evidence and opinion that attends studies of

left-handedness" and she warns that, "The use of measures of differences between the hands in skill which are continuously distributed may make it easier to avoid the pitfalls attending the treatment of right and left as if they were discrete."

The physiological basis for handedness may be genetically determined or predilected, but is also obviously influenced to a greater or lesser extent by environmental factors which may not be a regular and constant force but ever changing and evolving, thereby constantly changing the nature and magnitude of their effect. The resultant position of an individual on a continuum joining the two extremes of handedness is therefore probably a combination of genetic endowment, parental influences, school and peer group pressures and expectations, social prejudices, and ergonomics in a complex culture.

It would appear, then, that one of the available handedness questionnaires would present the most accurate definition and measure of handedness, bearing in mind the inherent dangers of a questionnaire compared to a performance test.

The quantification so obtained must then be compared to that established by other criteria to verify whether or not there is any meaningful relationship between present and past works.

3 c) Comparison of Handedness Questionnaires.

Of the many available tests of hand preference, some are of the three dimensional practical type where the subject is observed performing manual tasks, while others are "paper and pencil" questionnaires.

This latter type, being the most suitable for ease of accurate application to large numbers of subjects were considered for use in this work.

Among such questionnaires, two works appear to the investigator to be not only easy to administer and accurate to assess, but are widely used and therefore well known to researchers in the field. These two are Annett's Hand Preference Questionnaire (Annett 1970) and the Edinburgh Handedness Inventory (Oldfield 1971). On examination the tests appear to be quite similar as they are comprised of a series of questions requiring the subject to indicate which hand, if either, is preferred for particular physical activities. Annett's questionnaire consists of twelve questions, while Oldfield's has ten, seven of which are common to both tests.

Annett's questions are divided into primary and secondary questions, to which the subject responds with 'R' (for right hand preference) 'L' (for left hand preference) or 'E' (for either hand). From these responses the degree of handedness is obtained, and scoring takes into account the differential weighting of responses to the 'primary' and 'secondary' questions.

Annett is quite adamant that handedness is not discrete in two dichotomous poles, but is a place somewhere on a continuum between the extremes where very small proportions of the population reside. She also believes that as there are only two main terms (left and right) with which to categorise lateral differences, some of the problems concerning handedness and cerebral dominance may have arisen from failure to recognise and separate what she calls "mixed handers" from consistent handers, both right and left.

Annett likens speaking of 'left' and 'right' handedness in the same light as describing a person's height as being 'tall' or 'short'. If these remain the only descriptive terms, then it is not possible to appreciate the continuity of size between them.

Annett's questionnaire has enabled her to isolate no less than twenty-three types of handedness, although many of these are more conceptual than practical divisions. There remain, however, six quite practical types of handedness which she groups as follows:-

- C.R. Consistent right handers.
- I.R. Inconsistent right handers.
- R.A. Right ambidexters.
- L.A. Left ambidexters.
- I.L. Inconsistent left handers.
- C.L. Consistent left handers.

For most practical test-result applications, Annett concedes that even these six categories can be condensed into only three; these being left, right, and mixed handers, each category relating to the first two, middle two, and last two groups correspondingly.

The measure gives a very detailed picture of a subjects' handedness, especially when all other facets of the test, such as analysis of the subjects, responses to individual questions, and consideration of skill as well as preference of hand, are taken into account; but the quantitative element of the results is somewhat vague and difficult to manipulate statistically.

On the other hand, the E.H.I. by Oldfield, although very similar in its face format and in its administration, varies significantly in the method of scoring the tests.

To each of the questions, the subject is asked to place a plus (+) in a column headed 'left' or 'right' accordingly. Should no other but the preferred hand ever be used for that task, two plus signs (++) are placed in the appropriate column; and should neither hand consistently dominate the other for that particular task, then a plus can be placed in both the 'left' and 'right' hand columns. From these more quantitative responses, it is possible to calculate a numerical "Laterality Quotient" which varies from +100 which indicates total right handedness to -100 which indicates total left handedness, while scores around zero would reflect either complete ambidexterity or a degree of mixed handedness.

This system of 'scoring' the results gives the investigator a numerical representation of the degree of hand usage which can be more easily manipulated statistically, while a certain degree of 'individual profile' on each subject is sacrificed.

In a useful and timely comparison of the two tests, with a retest trial of both, McKeckan and Lishman (1975) found that the retest reliability of both tests was quite high, the Amett test yielding a Kappa Coefficient of agreement (Everitt 1968) of +0.80, while the Edinburgh Inventory showed a product moment correlation of +0.97. It is pointed out, however, that direct comparison between the two tests is not really too meaningful as slightly different methods of assessment were used, and the figure for the Edinburgh Inventory is perhaps somewhat inflated due to statistical reasons for computation. Even so, the figures remain quite impressively high for a retest of a "paper and pencil" type of questionnaire, and neither one of the test seems superior to the other in terms of reliability.

It has been reported (Barnsley and Rabinovitch 1970) that because subjects often seem to perform in a manner different or contrary to the way in which they report that they behave, written questionnaires are somewhat unreliable. The retest coefficients of both the Amett and the Edinburgh Inventory would not seem to support this notion, but the point about relying on questionnaires could be well taken, and it behoves the

investigator to be wary of the responses given without some form of check being undertaken (such as observation of the tasks being enacted) to ensure that the validity of the responses is as high as possible.

In their comparison of the tests, McMeekan and Lishman found that each had its advantages and disadvantages. The Edinburgh Inventory gave a greater spread of hand preference, possibly due to the influence of the wording of the questions as Annett's questionnaire asks merely "which hand do you use" - which may direct the subject to answer "right" or "left" rather than give the response "either", while the Edinburgh Inventory allows "if in any case you are really indifferent put + in both columns."

McMeekan and Lishman also point out that the allocation of numerical scores on a continuum, as with the Edinburgh Inventory, might appeal in certain situations, particularly where these data need to be correlated to other data. The actual method of scoring, however, comes under criticism, for it is questionable whether the placing of two plus signs in one column may lead to the valid assumption that twice the amount of hand preference is indicated,

yet this is how the total score is tabulated. Secondly, Oldfield gives equal weight to all questions in deriving the eventual score, while there is no empirical evidence for such equivalence. Amett found it necessary to divide her questions into "primary" and "secondary" type, with the former carrying more "weight" in the scoring system than the latter.

The Laterality Quotient produced by the Edinburgh Inventory ought to be viewed as an arbitrary score rather than a definitive interval of measurement - a point conceded by Oldfield himself. The conclusion of McMeekan and Lishman's work is that the two tests have little to commend either above the other, the main criterion of choice being, perhaps, the purpose for which the test is to be used.

Accordingly, as the purpose of this work is to consider the effects of handedness on spatial ability, it is considered that the Edinburgh Handedness Inventory may prove to be the more suitable test for this purpose. The numerical data provided by this test are more suitable for statistical analysis, and while it is understood that the scores obtained are

in no way definitive, they do provide a means of comparison between subjects which is at least stable. The reported fact that the Inventory offers a wider spread of handedness scores with fewer scores bunched at either end and than with Annetts Questionnaire may also prove a useful asset, for in comparing one ability with another, the wider the spread of the abilities, the more delicate becomes the measuring instrument.

4. HANDEDNESS AND SPATIAL ABILITY.

- a) Academic Interest in Handedness and Cerebral Dominance.
- b) Practical Interest in Relationship of Handedness and Spatial Ability.
- c) How Use of Atypical Subjects and Differing Instruments can lead to Inaccuracy of Definition of Relationship of Handedness to Spatial Ability.

The interest in clarifying the position with regards to accuracy of quantification and comparison of handedness, and the problems surrounding the definition and measurement of spatial abilities, along with the possible sex effect on such abilities is twofold.

First, the academic interest linked by studies of lateral dominance and cerebral dominance and the possibility of any causal connection, and secondly the practical interest in terms of those who deal with subjects whose handedness and abilities are important educationally.

4 a) Academic Interest in Handedness and Cerebral Dominance.

In terms of academic pursuits, the area of spatial ability and handedness is particularly interesting, for the work on lateral dominance has a very direct and relevant bearing on cerebral dominance, the study of the function of the two cerebral hemispheres of the brain.

While the two hemispheres which comprise the cerebral cortex appear symmetrical in that both contain sensory, motor, visual and auditory areas of function, there are quite large differences between the psychological functions of the two hemispheres. Many of these differences have been disclosed by surgical severance of the corpus callosum in attempts to alleviate severe epileptic seizures in patients. Once the hemispheres have been so divided, there remains no neural communication between them and the subjects of such separation demonstrate "split-brain" performances.

After devising tests to consider how the cerebral hemispheres operate when separated, (Sperry '70, Nebes and Sperry '71) and as a result of extensive

research using split-brained animals, the functional differences of the hemispheres have been clarified and the basic principles can be stated fairly simply. The left hemisphere - often called the major hemisphere - which controls motor activities of the right side of the body also governs the major part of language usage, sequential and analytic activities, and mathematical computations.

The right-minor-hemisphere comprehends and responds only to simple language and mathematical concepts. It does, however, appear to have a highly developed spatial and pattern sense, and is superior to the left in geometrical and design function (Hilgard and Atkinson '75) and there is also evidence that the right hemisphere is the centre for musical ability (Milner '62) and "artistic appreciation."

Much work has been directed towards refining these somewhat crude and unsophisticated compartmentations of cerebral functioning, but the basic concept of language being centred in the left hemisphere while spatial control is centred in the right has usually been upheld (Gazzaniga '72, Ornstein '72).

Hilgard and Atkinson state "the fact that right handedness is the norm for human beings is probably connected with the occurrence of speech in the left hemisphere. Some left-handed people have their speech areas in the right side of the brain, but indications are that most have the same dominant hemisphere (the left) as right-handed people."

This idea that left-handed subjects are less often consistently lateralised in the areas of "speech centre" location has been propounded, as has the concept that familial left-handedness tends to indicate the likelihood of right-hemispheric location of speech function (Gilbert ⁰74, Bryden ⁰65). Sex differences are also noted in cerebral lateralisation, females being reported as being less often lateralised for spatial abilities than males (McGlone and Kertesz ⁰73, Levy ⁰72, Kimura ⁰69). It is as well to remember when considering such evidence, that females may demonstrate a greater degree of cross modal transfer and use verbal mediation to complete traditionally non-verbal tasks than their male counterparts (O'Callaghan ⁰77); and Bryden (⁰79) warns that "one must always be sensitive to the fact that any differences found may represent differences in strategy rather than true differences in cerebral organisation."

Examination of such works shows that they are primarily concerned with the location of the specified ability within the cortex, and the degree of laterality it seems to present in one sex or another, or in subjects with a particular degree of lateral dominance. In a review of literature dealing with such topographical differences in brain organisation, Marshall ('73) points out that many of the claims made are, in fact, contradictory.

Two of the more evident theories will illustrate the conflicting thoughts on this matter. The first of these, commonly known as the Levy-Sperry Hypothesis (Levy and Sperry '68) postulates that some degree of bilateral representation for language skills will be found in a substantial proportion of left-handed subjects. This right-hemisphere component of linguistic ability will, it is claimed, "interfere with" visuo-spatial processing normal to the right hemisphere and thereby deter these latter skills. In contrast, right-handed subjects are claimed to have a "purer" representation in each hemisphere of the skills for which that locale is specialised. Support for this hypothesis is offered in the form of evidence of poorer performance on non-verbal tests and visuo-spatial

tasks known to be right hemisphere dependent by left-handed subjects. This hypothesis can only be as strong as its original assumptions about the bi-laterality of left-handed subjects, and evidence is that not more than 20% of left-handers have an appreciable degree of such laterality (Pratt, Warrington, Halliday '71) and in fact the majority of these subjects demonstrate normal left-hemisphere language control. The supporting evidence does not show how homogeneous the test groups were, and if the groups were "diluted" by mixed as well as pure left-handers, or by familial as well as non-familial left-handers, then the direction of the results could be distorted. Such a distortion could cast doubt upon the validity of the hypothesis until more control can be exercised over the specified degree of handedness of the subjects, and also of the validity of the tests of visuo-spatial ability used.

The alternative theory of relationships between performance and noted cerebral dominance is the Buffery-Gray Hypothesis (Buffery and Gray '72) which is again framed in topographical fashion. The postulation is that males have a relatively bilateral representation for visuo-spatial tasks in contrast to

Females who demonstrate a more positively lateralised structure into left and right hemisphere for verbal and visuo-spatial abilities respectively. Bilaterality is then claimed to be the most effective mode for spatial processing, and this provides an explanation of the claimed male superiority in this domain. Data to support this theory are currently rather sparse, as many pertinent results from normal subjects are infrequently analysed for sex differences. Furthermore, the stated superiority of males over females on such tasks has been questioned (Kimura '69, Mayo and Bell '72, Bogen et al '72) and the evidence for biologically determined sex differences in visuo-spatial ability is far from conclusive. McGlone and Davidson ('73) conclude that "...visual non-verbal cerebral dominance may be more left-hemisphere dependent in females than in males", while their results of work with left-handed subjects contrasts with the "competition" theory of Levy, thereby failing to support that particular hypothesis.

It is possible that the type of visuo-spatial task may affect the apparent male superiority reported by Buffery and Gray or the right handed superiority

considered by Levy and Sperry, and the whole area of measurement instruments and degree of laterality are called into question yet again.

In general, the left-hemisphere of the cerebellum seems to be the predominant processor of verbal concepts, while the right-hemisphere is predominantly the processing centre of visuo-spatial concepts. Bakan ('69) and De Witt and Averill ('76) suggest that lateral eye movement of a subject dealing with a problem is related to the functional specialisation of the cerebral hemisphere. They noted that given a spatial type of problem, subjects tend to gaze left (right hemisphere actuation) while they gazed right (left hemisphere actuation) when tackling verbal problems. Although Weiten and Etaugh ('74) and Kinsbourne ('74) upheld this theory, Croghan ('75) tends to dispute it, but conceded that right eye-movers were superior to left eye-movers at all cognitive functioning - suggesting that the left hemisphere is dominant for high-level abstract thinking.

Hines and Martindale ('74) found that induced left-looking enhanced performance on a spatial

relations test, and that females exhibit less consistent spontaneous lateral eye movement than males. This could be because females are less lateralised than males for spatial processes (contrary to the Buffery-Gray Hypothesis) or it could also be interpreted that females more often use verbal mediation to work in a "spatial mode" - using less of a Gestalt grasp and more of a verbal type of analytical approach thereby accounting for less consistency in eye shift during the problem solving process.

Another method of assessing hemispheric function is to measure Alpha rhythms emitted by each cerebral hemisphere during specific brain tasks. Because Alpha rhythms decrease as positive brain activity increases, a lowering of Alpha rhythms is considered to be an indication of increased mental activity in the corresponding hemisphere. Such a study has been undertaken by Butler and Glass ('74) who tested by E.E.G. Alpha rhythms in both hemispheres during several modes of cerebral functioning from eyes closed relaxation to the computation of mental arithmetical problems. All of their subjects exhibited lower E.E.G. Alpha activity in the left hemisphere. Their conclusion is that the left hemisphere specialises in verbally mediated tasks in contrast.

Flanery (1979) supports this theory by his work on children of various school grades, and adults. He found that on a tactile spatial task, the left hand (right hemisphere) was significantly better. Although he expresses concern that "Developmental research is lacking in the area of non-linguistic functions and functions that should be lateralised in the right hemisphere", he concludes that his findings are consistent with the hypothesis that hemispheric asymmetry, at least for spatial abilities, develops during middle childhood. The term "middle childhood" could be interpreted from his results as being about the age of 11 years, for his 5th graders (mean age 11-3) had stabilized in a significantly superior pattern of left-hand performance.

It is tempting to suppose, then, that if the two halves of the brain perform differently on different tasks to give the well documented hemispheric asymmetry, and the two sides of the body perform differently on different tasks of skill and acuity of eye, hand, foot and ear as the lateral dominance literature indicates, then some connection between the two specialisations may be discernible.

Clarke ('57) has mentioned the possibility of a connection between the relationship of the two hemispheres of the brain and the dominance of one hand. She cites the work of Wilson who believed that there was some anatomical or physiological difference in the structure and functioning of the hemispheres resulting in one or the other becoming dominant and leading in turn to contra-lateral hand preference. It was believed that one hemisphere would prove to be larger, heavier, be provided with a better blood supply and many other absolute differences; a theory which Wilson "proved" by demonstrating that the right hemisphere of a known left-handed acquaintance of his was in fact heavier on post-mortem examination.

Carter-Saltzman ('79) has traced the recognition of a relationship between handedness and hemisphere specialisation for cognitive processes to over a century ago. Broca (1865) she reports, noted that while almost all right-handed aphasics had suffered injury to the left hemisphere exclusively, left-handed subjects were more likely to lose linguistic capacity after right hemisphere lesions. More recent work, however, seems to show that while nearly all right-handed subjects have left hemisphere superiority for processing linguistic information, only two thirds

of the left-handed population has this pattern. The remaining third have either right hemispheric superiority or bilateral representation of the linguistic function (Milner, Branch and Rasmussen '64).

It would appear, then, that while nearly all right-handers have "normal" hemispheric lateralisation of cerebral functioning, not all left-handers are opposite. Many left handers have the same lateralisation as right handers, while familial left handedness is more likely to be related to contra-lateral specialisation. The degree of specialisation difference between males and females is undecided, as is the actual mode of use made by differing subjects on the same tasks.

Although it is not within the scope of this work to attempt to specify the degree of hemispheric lateralisation, or to investigate the cerebral strategies employed in tackling problems by different subjects, the results must be analysed with these differences in mind. While evidence abounds to show that hemispheric asymmetry exists, and to demonstrate the directions in which the various abilities lie there is less certainty about the relationships between

cerebral dominance and lateral dominance or the effects one may have upon the other. Similarly the evidence relating to sex effect on cerebral dominance or lateral dominance is inconclusive, and it is a matter of some importance to establish whether or not such differences in a major cognitive area exist in normal schoolchildren, at an important age educationally, and within an ordinary school environment.

4 b) Practical Interest in Relationship of Handedness
and Spatial Ability.

The need to clarify the current situation goes further than the academic interest in the matter, important as this may be. It is necessary to appreciate the effects which may be perpetrated upon pupils either overtly or covertly by teacher expectations.

Educational practice, especially at the classroom level, is primarily concerned with person to person situations, and in such personal relationships expectation and attitude can be a very subtle yet important factor.

It is difficult to determine the factors which influence the pedagogical and ideological approaches of the teacher in a classroom situation, but one possible such factor would be what the teacher has, through training or subsequent study, come to believe about his charges from research or from work or theories emanating from research on educational matters. The theories evolved about learning strategies, social behaviour and the like must in some way influence the way in which the teacher perceives his task, his role

and his pupils, and there must be little doubt that what is believed will be an equally strong determinant of behaviour as that which is empirical. The belief that left-handedness was the 'cause' of retarded learning or other educationally unsound practices may well have been a major factor in attempts to eradicate left handedness in children by teachers in the past.

The positive influence of teacher beliefs and attitudes upon pupil performance has been well documented by Rosenthal and Jacobson ('68) who discovered that randomly selected pupils "spurted" academically when their teacher was led to expect such a spurt. Nothing was altered in the children's educational programme except the teacher's attitude, and Rosenthal and Jacobson speculate that "by what she said, by how and when she said it, and by her facial expressions, postures, and perhaps her touch, the teacher may have communicated to the children of the experimental group that she expected improved intellectual performance." By the same reasoning they also conclude that when teachers have a low opinion of the children's learning ability, the children seldom exceed these expectations.

Two years later, a similar conclusion was drawn by Barker-Lunn ('70) in her work on streaming in primary schools. Teacher attitudes, she reports, seemed to be at least as important as the organisation of the school to the child's academic and social performance; and that "these influences (referring to teacher attitudes) operate strikingly on children of average and below average ability." It would appear, then, that simply changing the way in which the teacher perceives the pupils can affect their performance in class.

Such perceptions, whether based on facts or mere presumptions, can and do affect pupil performance and the observation of a pupil writing or performing in a manner indicating left-handedness could lead to a set of assumptions or preconceptions of the potential abilities (or lack of abilities) "associated" with left handedness.

Should the overall effects of these assumptions or perceptions prove to be beneficial to the pupil - the so called "halo effect" of improved performance as recorded by Rosenthal and Jacobson, - then it is doubtful if any objections would be raised or harm be

done. On the other hand if the assumptions or preconceptions about handedness as related to other cognitive abilities are negative, then the results could be quite damaging. In his study "Hightown Grammar" ('70), Lacey relates several case history incidents illustrating this point. In one perhaps extreme but illuminating case, Lacey describes an incident of a maths teacher who asked a question of one of the poorer pupils in the class, who gave a wrong answer. The teacher railed at the child severely for his mistake, and Lacey noted that the tension generated by such an incident paralysed the child's ability to think, rendering him incapable of concentration and thereby exacerbating the situation. Several other similar instances are cited by Lacey, showing how the confidence, self-esteem and performance of the pupil can be shattered by the teacher's perception of, reaction to and attitude towards him.

When considering spatial ability, an important area of cognitive functioning, there have been reports that right handed subjects are superior performers in such tasks (Levy '69, Miller '71) which could lead to adverse assumptions about the expected performance of left handers. Conversely, there are works which report left handed superiority of spatial functioning (Peterson and Lensky '74, McGee '76) which could lead to an opposite syndrome.

It is important to determine which, if either, of these hypotheses is correct, so that unfounded assumptions about abilities can be refuted, thereby preventing damaging expectations and attitudes from developing.

It is believed that any attempt to so determine must involve the use of a spatial test which carries a heavy loading towards the spatial visualisation factor V_2 , which is possibly the "purest" representation of this form of mental imagery, while at the same time minimising these factors which may be demonstrably sex-biased. It is also necessary that the subjects of the work should be a relevant sample of the population to which any results might be generalised, in this case a sample of "normal" schoolchildren whose laterality has been determined by the best available method, and who have been minimally exposed to such possibly effective but controllable factors as hormone production and differential practice at spatially oriented tasks.

4 c) How the Use of Atypical Subjects and Differing Instruments can lead to Inaccuracy of Definition of Relationship of Handedness to Spatial Ability.

Much of the information recorded about the effects of handedness or performance on various manual and cognitive tasks is of interest to educationists, among others, in their attempts to understand and benefit their pupils by the discovery and nurture of some inherent possibly latent talent, or conversely by the eradication of erroneous preconceptions about the student's personalities, abilities and predilections.

This type of interest in psychological research could be deemed to be a practical interest engendered for the reasons stated, but much of the work undertaken by researchers tends to be of a more clinical interest, with no specific locus of practical implication intended. Such a mis-match of intentions between reader and writer could lead to dangerous assumptions, for the subjects used by researchers in their works may not be typical of the subjects to whom the reader wishes to apply the findings. An educationist, for example, may well be interested in the abilities or potential abilities of his students who are, for want

of a more accurate phrase, "normal subjects", of "average" abilities.

The practice of applying or generalising findings specific to one population of subjects to a different population need hardly be denounced here; yet some of the population or samples of individuals used by many researches can hardly be described as average or normal. In some cases, the research is undertaken using university undergraduates (often those engaged on psychology courses) as apparently convenient captive subjects by the experimenter. While such subjects may well be convenient and indeed willing, they can hardly be described as average or typical for, by definition, university undergraduates are chosen as a result of highly selective academic processes. It is quite probable that many such students have studied mathematics and other non-verbally biased subjects for long periods of time and at great depth. Such a study might well artificially inflate the spatial scores of those subjects when given a spatial test.

Other atypical subjects are those used by clinical researchers when investigating the functioning of the cerebellum. Much of this work has, by necessity, been

conducted on brain damaged subjects, or those on whom cerebral surgery has been performed, many of these being the inmates of hospitals or other institutions. It is allowed that these subjects may well be the best, or indeed only, available source for this type of work, but it is doubtful whether the responses given by these subjects under these conditions would be typical of a more 'normal' population. It remains uncertain what effects may ensue from brain damage or surgical trauma in the way of psychological functioning, but it is a distinct possibility that scores given by subjects who have long been institutionalised may well be depressed by the trivialising effects of institutionalisation (Money and Mittenhal '70).

The final example of the use of subjects not relevant to educational interpretation although not irrelevant as such is the tendency to use adult subjects rather than children in school. This may not seem such an odd choice of subjects as the two previously cited examples, yet there is no reason to suppose that either laterality or spatial ability remain unchanged from childhood. Again it is arguable that as persons grow to adulthood, they may undergo social or occupational experiences which may well improve their spatial ability and thereby alter their response to a spatial task.

It would appear, then, that for the reasons of lack of precise definition of what is being measured under the broad umbrella term of spatial ability allied to often questionable selection of criteria of handedness both of which terms then applied to subjects not directly relevant to those in whom readers of such work may well be interested, these works may be considered inadequate.

It is typical that Levy ('69) found that left-handers were inferior to right handers on "performance" (visuo-spatial) tests using postgraduate students from Cal. Tech. whose "performance" tests were the W.A.I.S. subtests, and whose laterality was self-styled.

Miller ('71) also used psychology students who were given N.I.I.P. relations tests and whose laterality was decided by observation of the hand used for writing.

The work of McGee ('76) concluded that left handed males were superior to right handed males by testing 46 university psychology students on the Mental Rotations Test (Shepard and Metzler '71), but did at least determine laterality by using Annett's hand preference questionnaire.

It may be possible from such brief examples to realise that quite different criteria are used for the selection of handers in the first place - little account of the possible effects of mixed handers seems to have been considered; in all cases fully mature and very highly selected subjects were used, and the applied tests of spatial performance differ quite widely in age, form and type. There is no evidence to support the theory that these instruments are measuring substantially the same ability in the same subjects, so their conclusions cannot be used to either support or refute a specific hypothesis. Much work is now being done which, due to its incompatibility of standards and definitions, is not assisting in the clarification of the overall picture, but is refracting it into ever smaller fragments.

DESIGN.

The four questions to be asked by this work will be as follows:-

Question 1.

How accurate is the use of writing hand as a criterion of handedness in an objective sense?

It may be presumed that, due to the state of the art, a specifically designed and correctly applied and interpreted handedness questionnaire might give the most accurate available assessment of handedness; yet because many past works have not used such a criterion, comparison of such works becomes difficult.

This question is necessary, therefore, because of the differing criteria used - often simply the reported writing hand - and considers whether the use of writing hand is a valid criterion of handedness by asking what proportion of left-handers are found using each criterion separately, and by finding what percentage of left handed writers are found to be left handed by the criterion of handedness questionnaire.

Question 2.

What is the incidence of handedness in the present sample, and how does this compare with the reported handedness from previous works?

This follows from the first question, and considers what the present incidence of handedness is. Accurate assessment of handedness will depend upon the use of children who, by nature of their age, have stabilised in their handedness, yet have been minimally effected by educational and social influences.

When the validity of the use of writing hand has been considered as a handedness criterion, and the works from the past placed in that perspective, then the comparison of past works with the present work may be useable in the attempts to define whether or not the incidence of handedness is a stable trait, or whether changes in the proportion of left handedness can be detected.

Question 3.

What is the relationship of sex to spatial ability for all subjects?

This third question is concerned with the reported male superiority on spatially oriented tasks, and asks whether there is a sex based difference in mean score and shape of distribution of scores on a test of spatial ability which does not involve the following complications.

It has been demonstrated frequently that the personality trait of Field Dependence can effect sex differences on psychological tasks, and the perceived sex role of the task can similarly be effective in this way. The intention is to control for both of these factors by the use of a spatial test which is as far as possible devoid of field dependant controlled items, and which is considered to be neutral in terms of perceived sex role.

The children who are to be the subject of this work must be of an age which permits their ability to properly comply with instructions and complete the set tests, yet which will minimise hormone production effects and the possibility of different educational experiences.



This question will also be posed for left and right handed pupils separately, as well as for left and right handers together, in order to determine whether any sex effect found is specific to either left or right handed children.

Question 4.

What is the relationship of handedness to spatial ability a) for all subjects

b) for various ranges of handedness

c) for each sex separately.

a) The controls imposed for this part of the question will be the same for the pupils and for the spatial ability test as those mentioned in question 3 above, and the handedness of the pupils will be determined by the application of a reliable handedness questionnaire.

b) The correlations between handedness and spatial ability will be explored for differing ranges of handedness. This will be achieved by using a test of handedness which will allow varying degrees of handedness to be identified, so that the spatial ability of more and less definitely handed pupils can be calculated.

- c) This section of the question deals with the relationship between handedness and spatial ability for each sex separately, for yet again the ever-present possibility of sex-differences must be considered.

In order that these questions can be considered, the pupils will be of an age at which their spatial ability and their handedness will be fully developed, yet at which the well documented pre-adolescent "academic spurt" by females may be minimal, as will the pupils' hormonal production rates. It is also necessary, insofar as is possible, that the pupils should have undertaken broadly similar educational experience, and that neither sex nor handedness group will have been subjected to specifically differentiated experiences which could be construed as "practice" in the academic sense. Such pupils will be those who are in their final year of primary education.

When considering differences between left and right handed groups, all other possibly effective factors must be controlled, so for this purpose the pupils will be matched in pairs - one right handed pupil with one left handed, of the same degree of handedness, the same age, and with similar educational experience. The test used to assess spatial ability must be devoid of items which may be sex-biased, and the instrument used to define handedness must be capable of locating varying degrees of handedness.

METHODS.

- a) INSTRUMENTS.
 - (i) Handedness Questionnaire.
 - (ii) Spatial Ability Test.
- b) SUBJECTS.
- c) PROCEDURE.
- d) ANALYSIS.

INSTRUMENTS.(i) Handedness Questionnaire.

For the reasons stated earlier, namely the reliability of the test, the spread of scores offered and the convenience for statistical purposes of obtaining a numerical quotient for handedness, the instrument chosen for definition of handedness is the E.H.I. (Oldfield '70).

As Oldfield's work was applied to University undergraduates, and the original text of the questionnaire contains vocabulary which, while suited to Oldfield's subjects may not be functionally legible to younger or less linguistically able pupils, I decided to alter the level of vocabulary used without loss of meaning in the text.

This work intends to use, as subjects, pupils of the highest age range in primary schools, that is of about ten to eleven years of age, and also to use pupils from across the whole range of mental ability. For such pupils, phrases in Oldfield's original text such as "In those cases the part of the task, or object, for which hand preference is wanted is indicated

Figure 1

OLDFIELD'S ORIGINAL QUESTIONNAIRE (1970)

Medical Research Council Speech & Communication Unit.

EDINBURGH HANDEDNESS INVENTORY

Surname Given Names

Date of Birth Sex

Please indicate your preference in the use of hands in the following activities by putting + in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put ++. If in any case you are readily indifferent put + in both columns.

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all of the object or task.

	LEFT	RIGHT
1 Writing		
2 Drawing		
3 Throwing		
4 Scissors		
5 Toothbrush		
6 Knife (without fork)		
7 Spoon		
8 Spoon (upper hand)		
9 Striking Match (match)		
10 Opening box (lid)		
11 Which foot do you prefer to kick with?		
12 Which eye do you use when using only one?		

in brackets", or even the words "appropriate column" may render the text illegible. (see Fig. 1)

In view of the unknown nature of the test when applied to young children, and to the fact that some of the wording of the text was to be changed, it was decided that a pilot study should be conducted to note the efficacy of the test and to verify that the text changes were suitably legible and understandable to the children involved. Furthermore, as some studies have indicated a possible connection between familial handedness and lateral dominance (Gilbert '74, Bryden '75) I decided to add to the questionnaire at this design stage, questions specific to the handedness of the subjects' parents. This information, it was thought, may shed some light on the incidence of "inherited" handedness, and of any indication of increased polarity of left-handedness among familial left-handers.

This amended text questionnaire (Fig. 2) was given to 27 children, 12 boys and 15 girls, all members of the same class in a semi-rural primary school in North-West Durham, and all between 10 and 11 years of age.

FIRST MODIFIED QUESTIONNAIRE.

FIG. 2

SURNAME OTHER NAMES

DATE OF BIRTH

IS YOUR MOTHER LEFT-HANDED? YES/NO

IS YOUR FATHER LEFT-HANDED? YES/NO

Please show which hand you would use for each of these activities by putting a plus sign (+) in the "left" or "right" column. If you would never try to use the other hand unless you were forced to, put two plusses (++) in that column. If you really don't care which hand you use for that activity, put a plus (+) in BOTH columns.

Try to answer all the questions.

- WHICH HAND DO YOU USE
1. FOR WRITING.
 2. FOR DRAWING.
 3. FOR THROWING A BALL TO HIT A TARGET.
 4. TO CUT WITH SCISSORS.
 5. TO HOLD A TOOTHBRUSH WHILE CLEANING YOUR TEETH.
 6. TO HOLD A KNIFE (WITHOUT A FORK).
 7. TO HOLD A SPOON.
 8. AT THE TOP OF A BROOM WHILE SWEEPING.
 9. TO HOLD A MATCH WHILE STRIKING IT.
 10. TO OPEN THE LID OF A BOX.

LEFT	RIGHT

L.Q.

These children were therefore members of the same class and from one of the schools to be used in the main work, but due to the timing of the test the pupils used in the pilot study had transferred to secondary school, to be replaced by a different class of pupils who were the subjects of the main work.

In this way similar subjects were used in both the pilot study and the main work, but were not, in fact, the same pupils. The results demonstrated that despite the simplified text, of the 27 subjects only 4 completed the questionnaire in full accordance with the meaning of the instructions. One outstanding example was the fact that, due to apparent misunderstanding of the instructions, many pupils had put a total of three 'x' signs in the columns for each activity instead of a maximum of two.

Two further problems emerged from an analysis of the results, one of these being relevant to the clarity of the instructions, the other not. The first of these problems concerns question number 10 on the questionnaire relating to the opening of a box. The instructions asked "Which hand do you use to open the lid of a box?". As this task is often accomplished by both hands, one holding the box while the other opens

the lid, it is possible to misunderstand which hand preference is being requested. Having interpreted the answers given (incorrectly) by "common sense" interpretations, this particular question seemed to indicate choice of hand contrary to the obviously predominant hand in 7 out of 25 cases (28%).

The second problem was that of the questions about familial handedness. Many of these were left unanswered, or in the case of the "yes/no" choice, both alternatives were deleted.

A logical conclusion of these results was that although the instructions of the questionnaire had been simplified, some of the semantics had been lost, for there appeared to be some confusion about, or room for misinterpretation of, these instructions. The instructions were re-written for a second trial questionnaire, in an attempt to clarify the meaning without complication of the language used. The opportunity was taken to re-phrase question 10 to make clearer the direction of the hand usage required. The questions were also separated by horizontal lines across the questionnaire to enable the filling in and reading of the questionnaire to be accomplished with greater facility. The decision was taken to allow

the questions about familial handedness to remain on the questionnaire to determine whether any further information could be elicited.

The revised questionnaire (Fig. 3) was now administered to 12 pupils, 3 girls and 9 boys, all of whom were of the same age as the original children and were all in one class (although a different class to the original children) in the same school as was used for the first test.

All of the revised questionnaires were completed correctly; that is without apparent misunderstanding of the instructions, for all questions were answered in the correct manner.

As a means of checking the test/retest reliability of the questionnaire in this form when given to pupils of this age, a retest of the same 12 subjects was undertaken some four months after the first test. The subjects were given the same modified questionnaire and the same instructions, and again the questionnaires were completed without problem or ambiguity. Of the 24 responses (12 subjects, 2 tests) only one showed an indication of change from the predominant hand. This one "odd" response (4.16%) contrasts with the 20% of "odd" responses found on the originally modified

SECOND MODIFIED QUESTIONNAIREFIG. 3

SCHOOL

SURNAME OTHER NAMES

DATE OF BIRTH TODAY'S DATE

IS YOUR MOTHER LEFT-HANDED? YES/NO

IS YOUR FATHER LEFT-HANDED? YES/NO

Please show which hand you use for each of these activities by putting a plus sign (+) in either the "left" or "right" column.

If you would never use the other hand unless you were forced to, put two plus signs (++) in the column of the hand you do use.

If you really don't care which hand you use, put a plus sign (+) in both the "left" and the "right" columns.

WHICH HAND DO YOU USE

	LEFT	RIGHT
1. FOR WRITING.		
2. FOR DRAWING.		
3. FOR THROWING A BALL TO HIT A TARGET.		
4. TO CUT WITH SCISSORS.		
5. TO HOLD A TOOTHBRUSH WHILE CLEANING YOUR TEETH.		
6. TO HOLD A KNIFE (WITHOUT A FORK).		
7. TO HOLD A SPOON.		
8. AT THE TOP OF A BROOM HANDLE WHILE SWEEPING.		
9. TO HOLD A MATCH WHILE STRIKING IT.		
10. TO HOLD THE LID OF A BOX WHILE OPENING THE BOX.		

L.Q.

questionnaire, and seemed to indicate that the intended meaning of question 10 (box opening) had now been clarified.

The questions relating to familial handedness were all completed, although no method of verifying the accuracy of these responses was available to the tester.

Comparison of the test and retest questionnaires showed that of the twelve subjects, only two completed identical responses. Two more ended with identical handedness quotients due to making two "balancing" alterations on the second questionnaire. The remaining eight pupils ended with different laterality quotients on the second (retest) questionnaire. In fact the laterality quotient mean on the first test was 68.3, which altered to 63.3 for the mean quotient of the retest, a change of the magnitude of some 5% overall. A product moment correlation coefficient between the test and retest scores was calculated at 0.77, which is significant at the 0.01 level. A t^0 test of significance showed no statistical difference between the test and retest scores.

While the correlations between test and retest scores are quite high, it could be considered as mildly surprising that they are not higher still; for when asked the same question about which hand one uses, it is not unexpected that one will elicit the same answer - even if the questions are posed four months apart. This lack of perfection of fit between the two sets of scores ought to serve as a timely reminder of the imperfection of such questionnaires; and of the danger of extrapolating too freely from their results.

Because of the success attained by the second modified questionnaire in its legibility and clarity as displayed in the way subjects of the required age and ability range could make sensible and repeated responses to the questions, it was decided to utilise this particular version of the questionnaire without further alteration.

It was also decided that, as different instructions given to different groups of subjects may lead to different types of responses, the instructions on how to complete the questionnaire should be uniform. At the same time, in an attempt to minimise the likelihood of false reporting of actions, the danger of which was

(1970)

cited by Barnsley and Rabinovitch, subjects were to be asked to "act out" any of the actions about which uncertainty pertained; and to carry out random "spot checks" on subjects by noting their written response to a particular question and then ask them to perform it under observation.

Table I
 Test-Retest Results for the
 Version of the E.H.I. Used Here.

SUBJECT NO.	TEST I SCORE	TEST II SCORE	CHANGE OF SCORE
1	+60	+80	+20
2	+90	+70	-20
3	+90	+80	-10
4	+70	+50	-20
5	+60	+60	0
6	+60	+50	-10
7	+100	+100	0
8	+40	+40	0
9	+50	+60	+10
10	+60	+40	-20
11	+80	+80	0
12	+60	+50	-10
MEAN SCORE	+68.3	+63.3	

Subjects 7 and 11 recorded identical pairs of questionnaires.

(ii) Spatial Ability Test.

Because of its meeting the spatial criteria stated above, its low reliance on verbal skills and comparatively short administration time, (given the age and ability of the subjects), it was decided to use Spatial Test II (Watts) (Fig. 4).

This particular test was specifically written for children, and is standardised for the age range 10 years 7 months to 11 years 6 months which is precisely the age range of the intended subjects of this work. The test was, however, unfamiliar to the author who would administer it. Furthermore, although the working time of the test totals 26½ minutes, each section of the test allows the subjects to practice an unmarked response, and then ask questions to clarify any misunderstandings they may have. This "unworked" portion of the test is not, of course, timed; yet adds to the total administration time of the test. Because the actual length of time engaged in administering the test is important from the points of gaining permission from schools to engage their pupils for this amount of time, and of the concentration span of younger children added to the authors

unfamiliarity of and lack of experience in administering this test, it was decided to conduct a small pilot study.

Ten pupils were selected from the same class of the same school as used in the pilot study of the handedness instrument, and were selected by age criterion alone, no other factor being considered. They were, in fact the ten oldest pupils available in that class. The test was administered by the author according to the manual of instructions provided with the test, and the children were observed carefully during the working of the test, while the non-working aspects of the test such as explanations and practices were carefully timed.

As the written instructions of the test are few and simple, no severe problems should be encountered, and this proved to be the case. Most of the instructions for the subjects are verbal, opening the possibility of miscomprehension, but as plenty of opportunity is given in the test for explanation and the asking and answering of questions along with a practice test (unmarked) of each subtest before the actual marked examples are worked, this possibility is minimised.

The test was completed by all pupils with no apparent difficulties and as each subtest is relatively short, the author could observe no limitation to correct completion of the work due to boredom or lack of concentration span.

The time allowance for the aggregate of the subtests is 26½ minutes, but the explanation and practice element swells this to approximately 44 minutes in total.

As stated, this small pilot study detected no problems with the nature, material or completion of the test, and the results obtained, when standardised revealed a spread of 94 to 140 with a mean of 116.2 S.D. 18.4.

Raw scores gave a mean of 55 for all pupils; a mean of 50.2 for males and a mean of 59.8 for females. (see Table 2)

In his standardisation trials, Watts obtained mean raw scores for boys and girls of 37.9 and 34.6 respectively. It will be noticed that not only were the scores of the trial pupils higher than those of Watts' subjects, but the boys scored lower than the girls, a reversal of Watts findings. Little attention

is paid to this apparent anomaly, for only 10 pupils were tested, and one or two unusual scores could cause disproportionate distortion of the results, compared to the 1,754 subjects used by Watts.

Nevertheless the pilot study has confirmed the test as being a viable instrument to use for the subjects envisaged in this work.

Table 2

Results of Spatial Ability Pilot Study.

Female Subjects (n = 5)

Raw Scores	Standardised Scores
88	140
28	94
31	100
90	140
62	121
m = 59.8	m = 119

Male Subjects (n = 5)

Raw Scores	Standardised Scores
55	117
27	96
59	120
24	94
86	140
m = 50.2	m = 113.4

All Subjects (n = 10)

Raw Scores	Standardised Scores
m = 55	m = 116.2

NATIONAL FOUNDATION FOR EDUCATIONAL RESEARCH IN ENGLAND AND WALES

THIS TEST IS COPYRIGHT

SPATIAL TEST 2

(THREE-DIMENSIONAL)

By

A. F. WATTS M.A., D.Lit.

with the assistance of

D. A. PIDGEON, B.Sc., and M. K. B. RICHARDS, M.A., M.Sc., Ph.D.

DO NOT TURN OVER OR OPEN THIS BOOK UNTIL YOU ARE TOLD TO DO SO

FILL IN THE FOLLOWING PARTICULARS:—

SURNAME

CHRISTIAN NAME(S)

NAME OF YOUR SCHOOL

YOUR AGE YEARS MONTHS

TO-DAY'S DATE DATE OF BIRTH

READ THE FOLLOWING CAREFULLY:—

Not to be filled in by the Scholar

PAGE	ITEM Nos.	SCORE
5	1-20	
8	21-40	
12	41-50	
13	51-60	
16	61-70	
17	71-80	
20	81-100	
	TOTAL	
Age	Years	Completed Months
Standardised Score	...	

1. Do not open this book until you are told to do so.
2. The test is in sections. You will be told how much time is allowed for each section.
3. When you come to the end of a page, FOLLOW THE INSTRUCTIONS given at the bottom.
4. Each time you are told to stop, STOP WORKING AT ONCE.
5. Work as quickly and as carefully as you can.
6. If when you try a question you find you cannot do it, DO NOT WASTE TIME BUT GO ON TO THE NEXT.
7. Make any alterations in your answers CLEARLY.
8. ASK NO QUESTIONS AT ALL DURING THE TEST.
9. If you should require another pencil, put up your hand.

©
1951

National Foundation for Educational Research in England and Wales

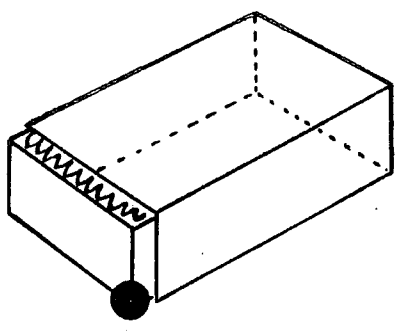
79, Wimpole Street, London, W.1

Printed by BRIGHTON HERALD, LTD., Pavilion Buildings, Brighton, 1,
and Published by
Newnes Educational Publishing Co., Ltd., Tower House, Southampton St., London, W.C.2,
for the
National Foundation for Educational Research in England and Wales.
Test No. 6. JN. 36270. 40M: 45M/5/61

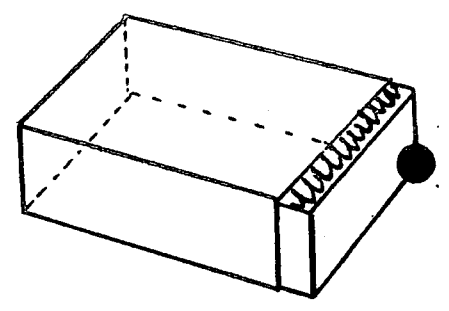
PRACTICE TEST I

MATCH BOX CORNERS

This match box has a black spot on one corner.



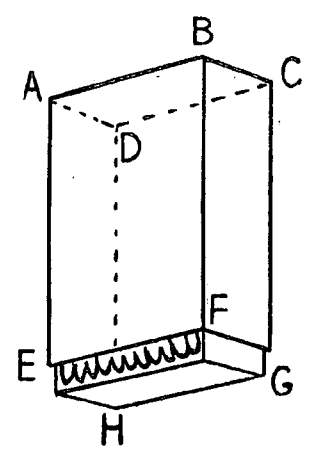
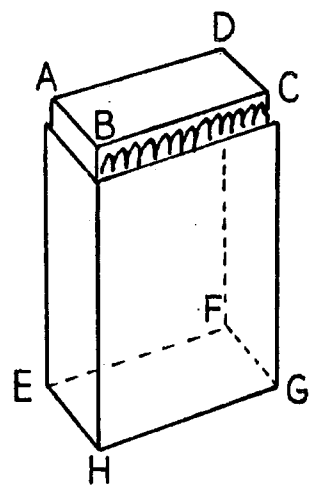
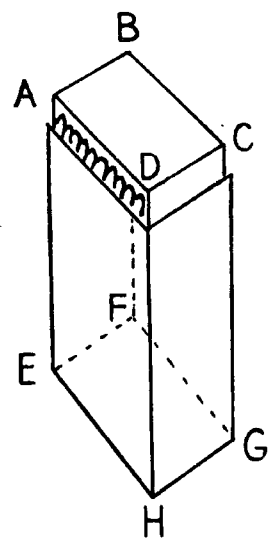
This is the same match box turned round.



The dotted lines show the edges out of sight.

The same match box is shown turned round to three different positions. Where should the black spot be now?

Put a black spot on to the correct corner on each box.



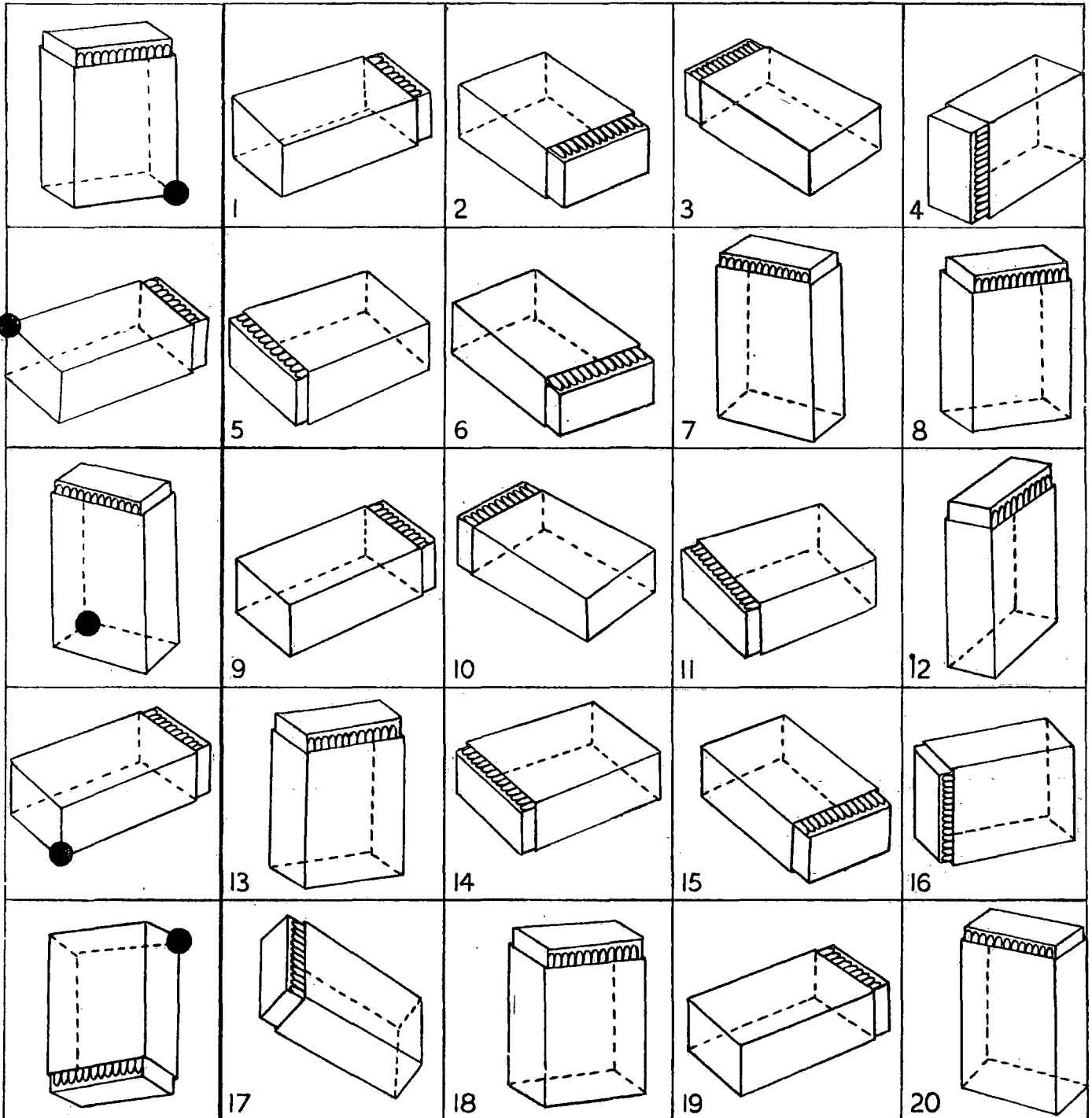
Do NOT turn over until you are told to do so

Do NOT turn back to earlier pages

TEST I MATCH BOX CORNERS

Time allowed—3½ mins.

Put a spot on the boxes so that all five boxes in each row have their spots on the same corner.



Do NOT turn over until you are told to do so

Do NOT turn back to earlier pages

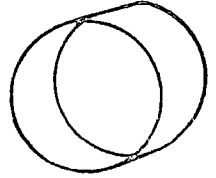
PRACTICE TEST 2

SHAPES AND MODELS

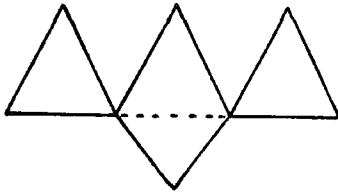
This shape



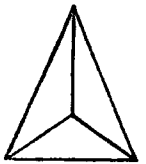
can be cut out and folded
to look like this:



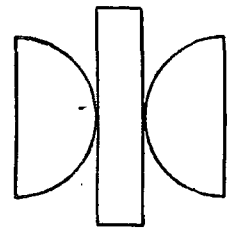
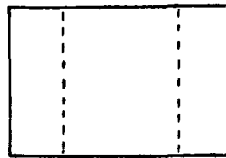
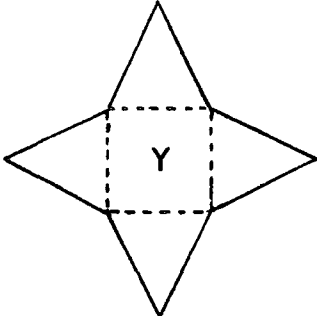
This shape



can also be cut out and
folded at the dotted line
to make this model:



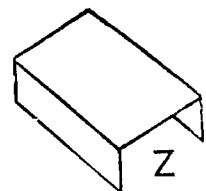
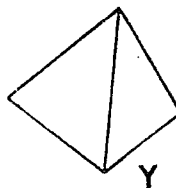
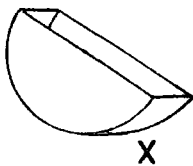
Now look at these three shapes:



They can be cut out and folded to make the models X, Y, and Z below.

Put a letter on each shape to show which model can be made from it.

The first has been done for you.

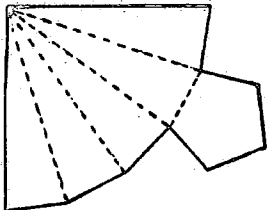
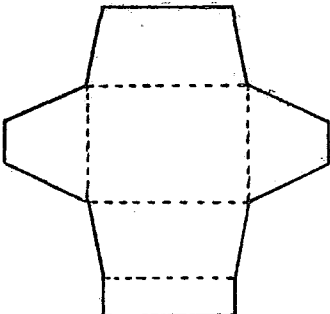
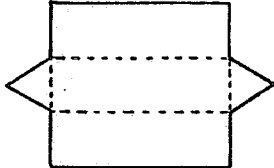
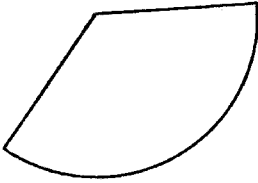
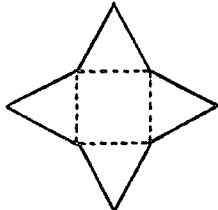
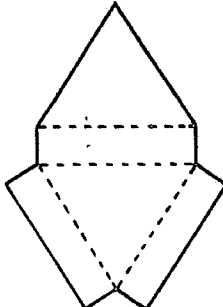
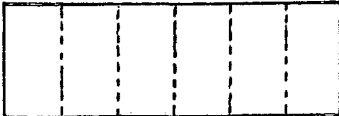
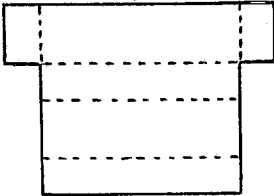
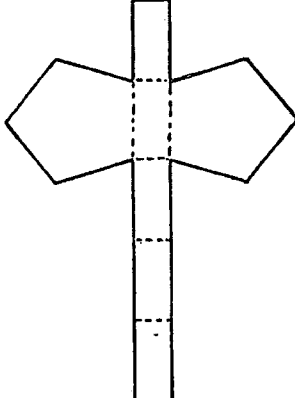


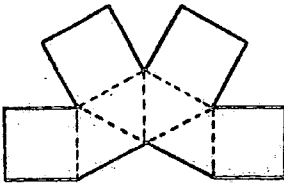
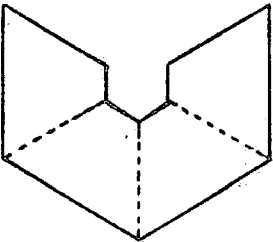
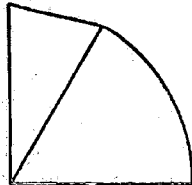

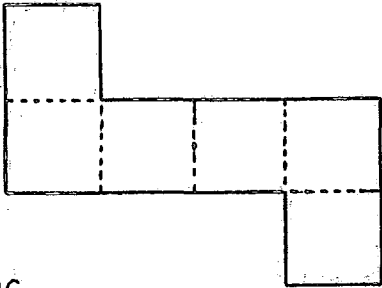
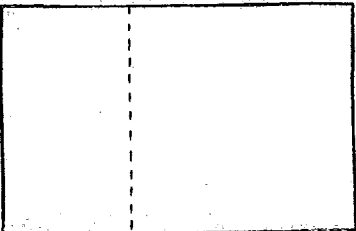
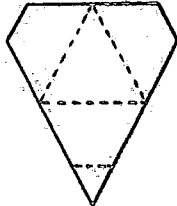

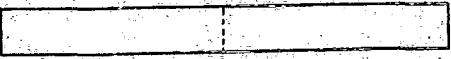


Do NOT turn over until you are told to do so

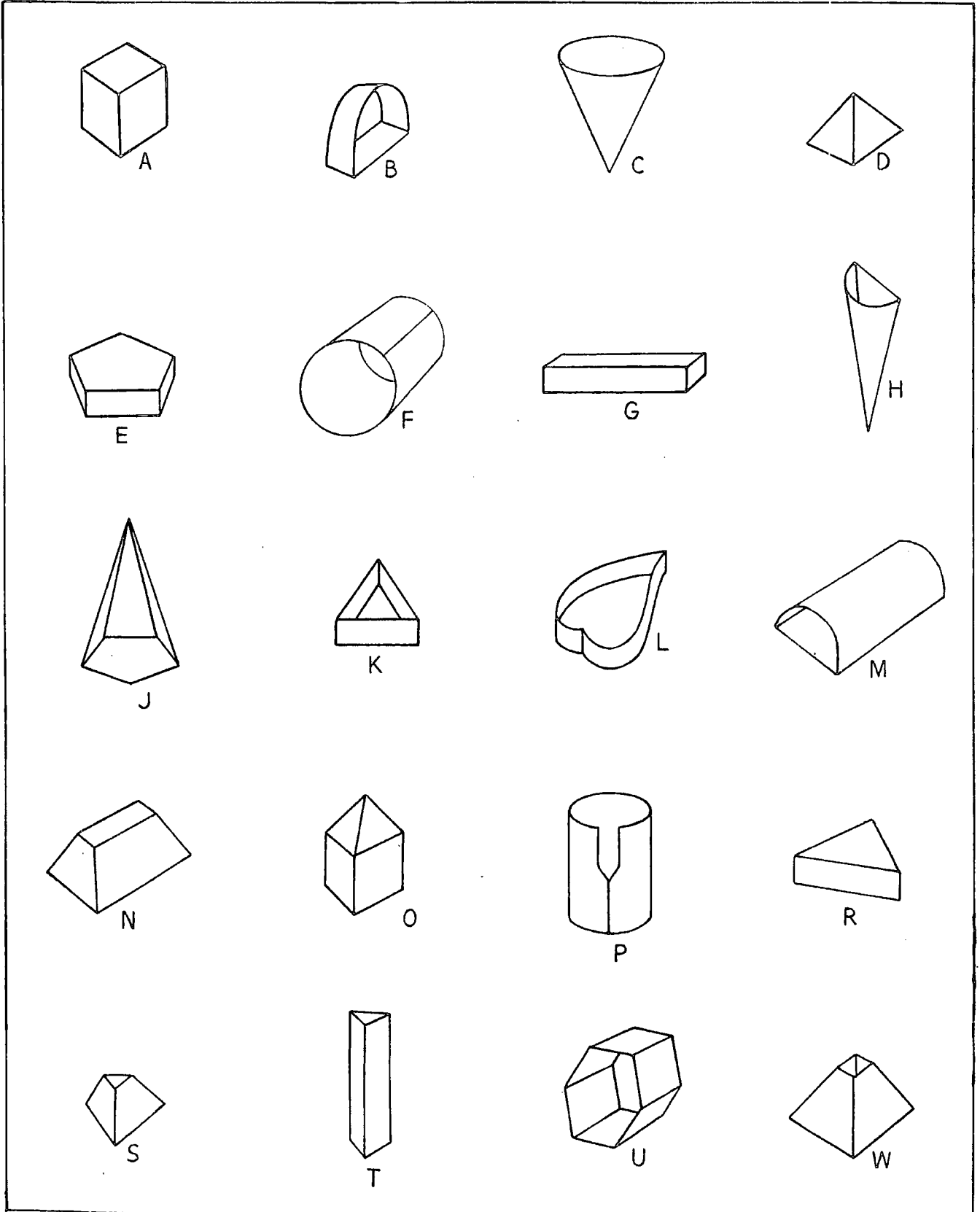
TEST 2 SHAPES AND MODELS

Time allowed—10 mins.

PUT A LETTER ON EACH SHAPE TO SHOW THE MODEL THAT CAN BE MADE FROM IT.

21 	28 	35 
22 	29 	36 
23 	30 	37 
24 	31 	38 
25 	32 	39 
26 	33 	40 
27 	34 	

THESE ARE THE MODELS WHICH CAN BE MADE FROM THE SHAPES ON THE OPPOSITE PAGE.

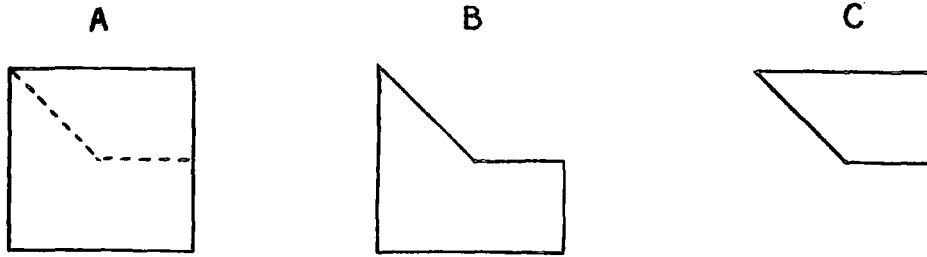


Do NOT turn over until you are told to do so

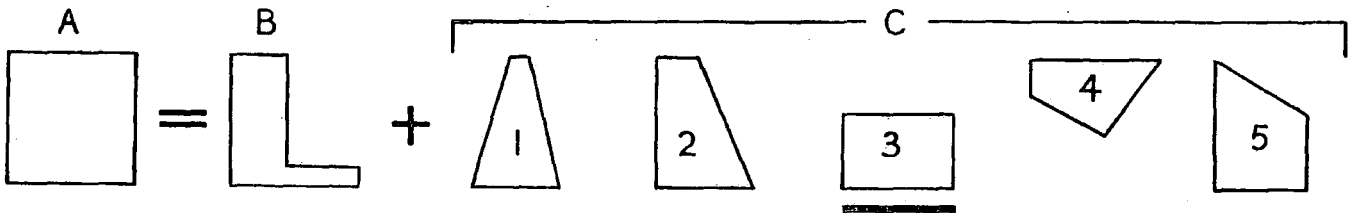
Do NOT turn back to earlier pages

PRACTICE TEST 3

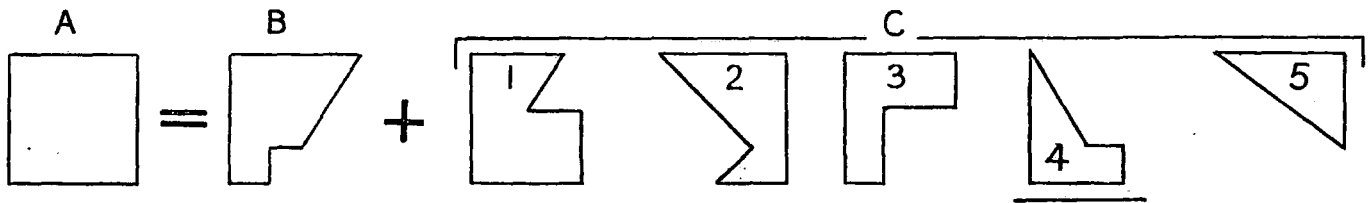
SQUARE COMPLETION



The figures shown under B and C are like pieces of a jig-saw puzzle. When put together, they make the square under A.

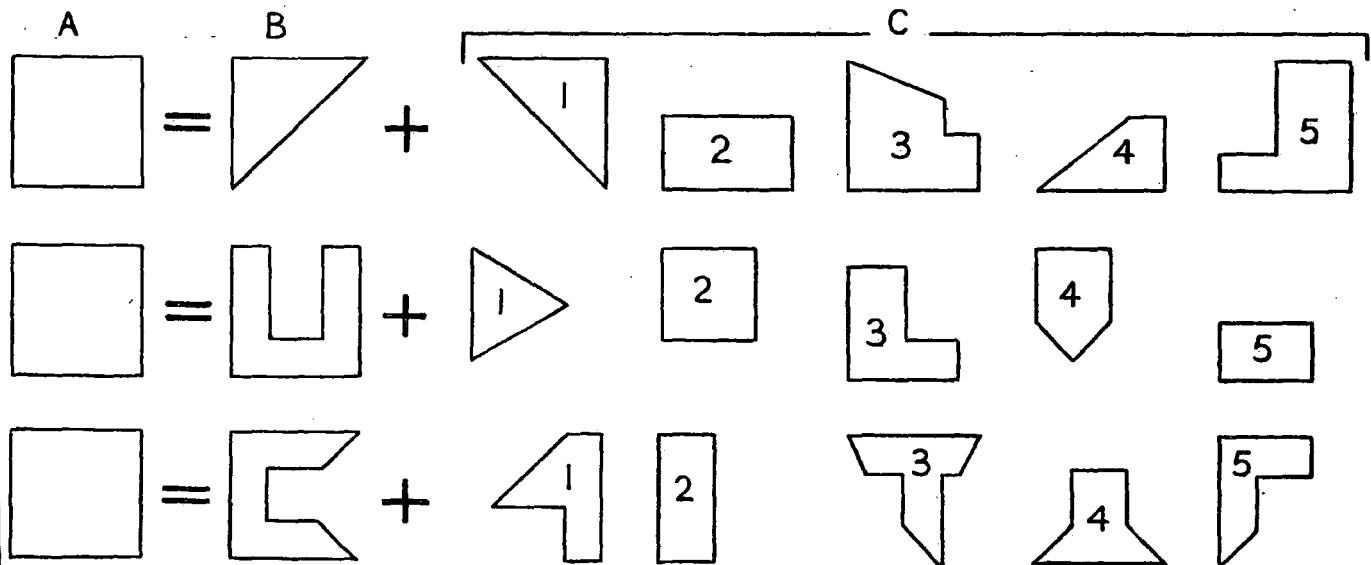


Which of the five pieces under C has to be added to B to make the square A? It is number 3, so it has been underlined. Notice that it has been turned round, but it still fits.



Here, number 4 fits, although it has been turned over this time.

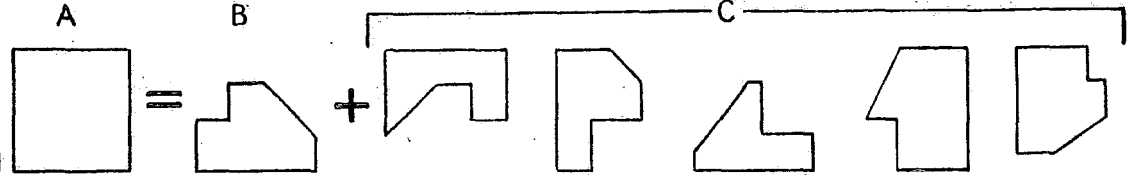
Now do the three others below—underline the figure under C which when added to B will make the square A. Remember, it might be turned round, or turned over, or both.

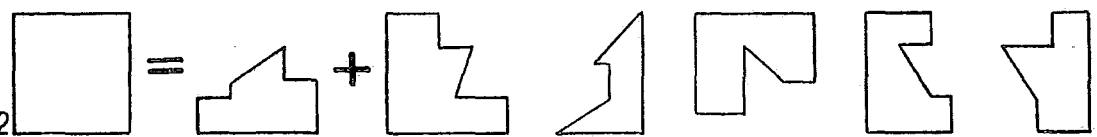



Do NOT turn over until you are told to do so

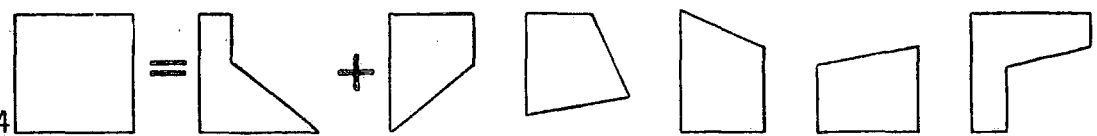
TEST 3 SQUARE COMPLETION Time allowed—6½ mins.


UNDERLINE THE FIGURE UNDER C WHICH WHEN ADDED TO B WILL MAKE THE SQUARE A.


41 


42 

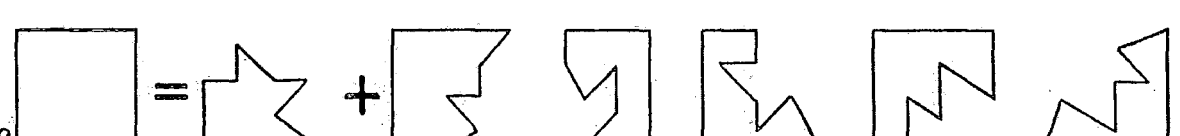
43 


44 

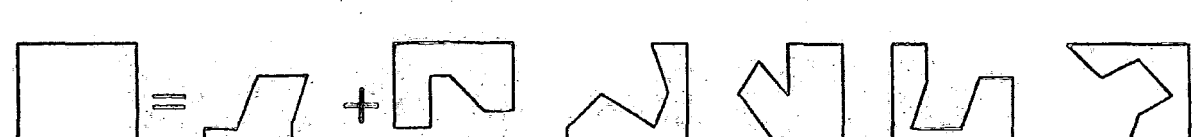
45 

46 

47 

48 

49 

50 

Go Straight On To The Next Page

DO THESE IN THE SAME WAY.

51 $A = B + C$

52 $A = B + C$

53 $A = B + C$

54 $A = B + C$

55 $A = B + C$

56 $A = B + C$

57 $A = B + C$

58 $A = B + C$

59 $A = B + C$

60 $A = B + C$

Do NOT turn over until you are told to do so

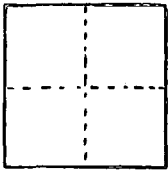
Do NOT turn back to earlier pages

PRACTICE TEST 4

PAPER FOLDING

Here is a square

A



It is folded in half.



And then in half again.

B



The dotted lines show the folds.

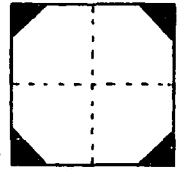
Suppose you cut away a piece from the folded square B, it might look like this:

The shaded part is the cutaway part.



What would it look like if you unfolded the whole square again?

Like this:

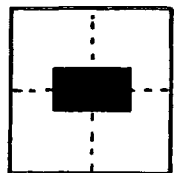
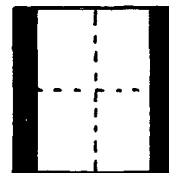
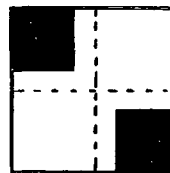
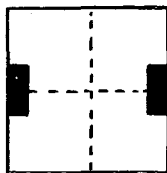
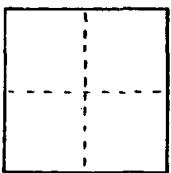


Now look at this one.

When the folded square B has a piece cut off one side as shown by the shading, and it is then unfolded again, it will look like . . . number 3. Therefore number 3 has been underlined.

A

B



1

2

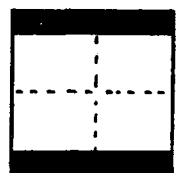
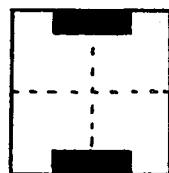
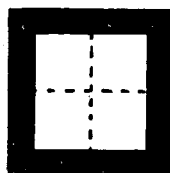
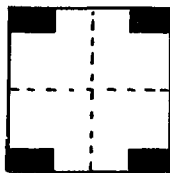
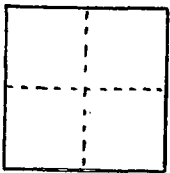
3

4

Now try this one. Underline the square on the right of B that gives you the answer.

A

B



1

2

3

4

Do NOT turn over until you are told to do so

TEST 4 PAPER FOLDING

Time allowed—3½ mins.

Underline the square on the right that looks like the small square unfolded.

61						
62						
63						
64						
65						
66						
67						
68						
69						
70						

Go Straight On To The Next Page

Do NOT turn back to earlier pages

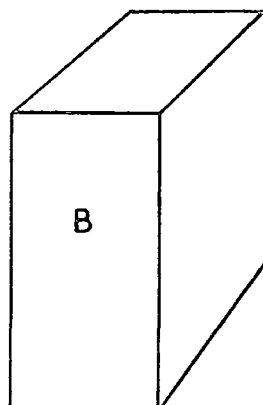
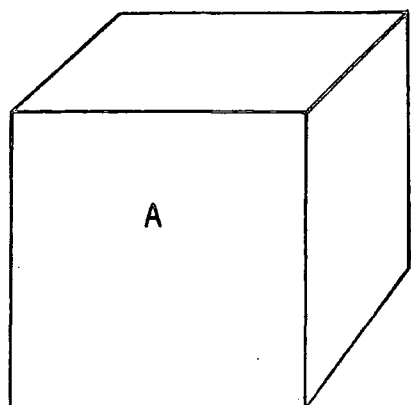
Here the square A has been folded from CORNER TO CORNER to get the shape B. Underline the square on the right that looks like " B " unfolded.

	A	B				
71						
72						
73						
74						
75						
76						
77						
78						
79						
80						

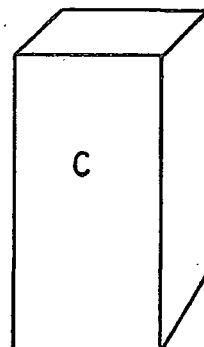
Do NOT turn over until you are told to do so

PRACTICE TEST 5

BLOCK BUILDING



(2)

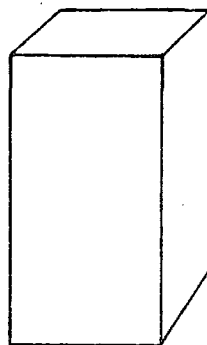
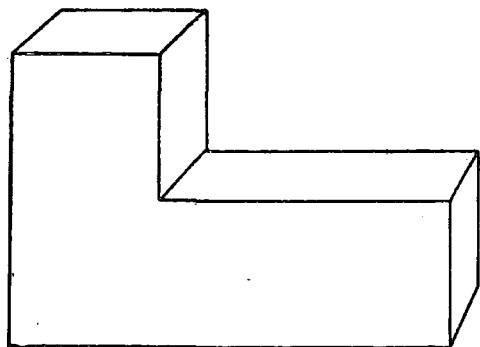


()

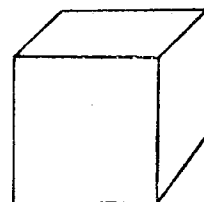
How many of the block B are needed to build the large block A?

We should need two B's put together to make A, so the figure 2 has been put in the brackets underneath B.

How many of block C should we need to build A? Put the answer in the brackets underneath.



()



()

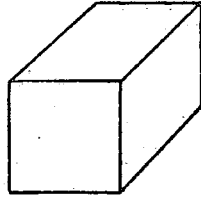
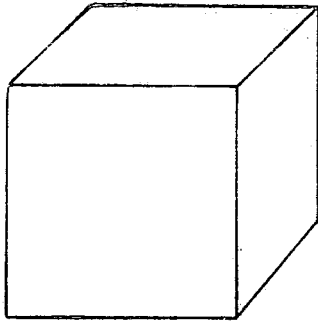
Here is another large block. Put in the brackets under each smaller block the number of that kind needed to build the large one.

Do NOT turn over until you are told to do so

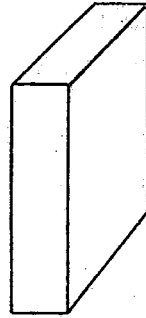
TEST 5 BLOCK BUILDING

Time allowed—3 mins.

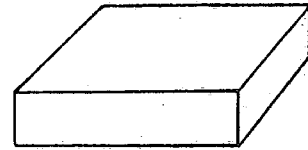
How many of the smaller blocks in the rows below are needed to build the larger one on the left?



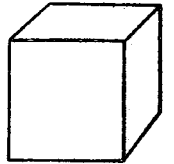
81 (.....)



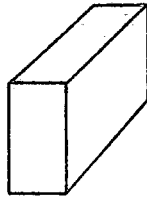
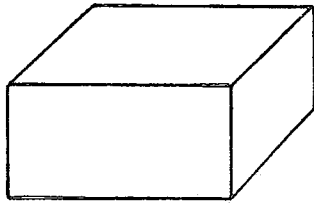
82 (.....)



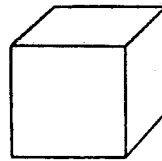
83 (.....)



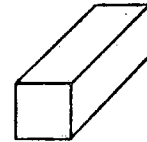
84 (.....)



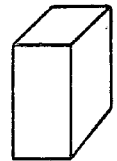
85 (.....)



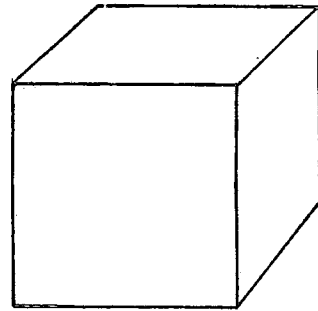
86 (.....)



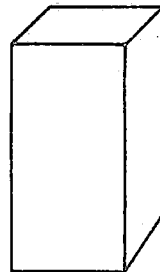
87 (.....)



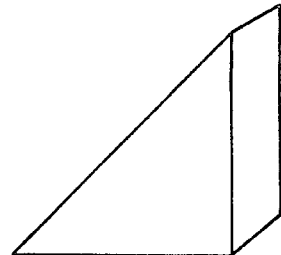
88 (.....)



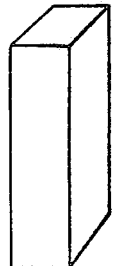
89 (.....)



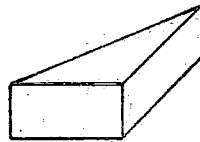
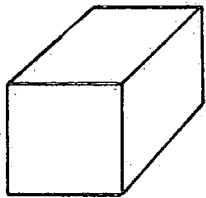
90 (.....)



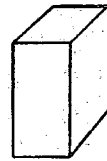
91 (.....)



92 (.....)



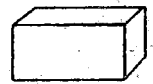
93 (.....)



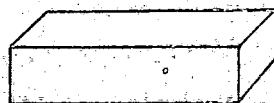
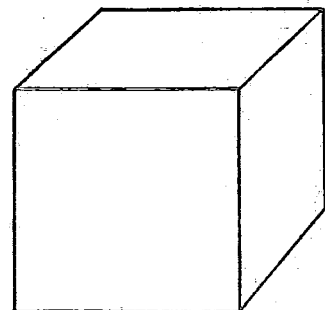
94 (.....)



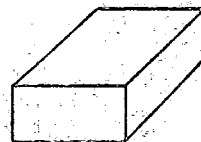
95 (.....)



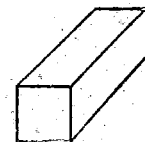
96 (.....)



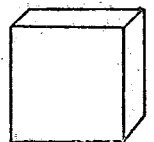
97 (.....)



98 (.....)



99 (.....)



100 (.....)

LOOK OVER THIS PAGE UNTIL TIME IS UP

METHODS

b) Subjects.

The subjects of this work were, at the time of the work, all receiving full-time education in the schools of one area of one Local Education Authority situated in North East England, within an area of about twenty square miles comprising semi-rural areas with centres of heavy and some lighter industry. The decision to use schools within one geographical locality and within the same Local Education Authority was taken in order to minimise regional differences, and to maintain the homogeneity believed to exist in terms of educational policy within one authority.

For reasons stated elsewhere, the pupils required were those who were, at the time of the tests, as old as possible without being subjected to secondary education. This naturally means those pupils in the upper classes of primary school or, where the "top" class contains pupils of varying ages, that section of the class which contains the oldest pupils.

All fourteen primary schools in this particular area were contacted for permission to use their pupils as subjects, and of the fourteen only one school refused to co-operate for reasons of re-organisation and re-decoration at the time of the tests. The thirteen schools used were of similar type, for while they ranged in size from about four hundred pupils to approximately one quarter of that size, none could

be described as uniquely "village" or "inner city" in character. The schools themselves were broadly representative of schools within the Authority, for the Authority itself is comparatively small and contains a large majority of semi-rural schools of the type used in this work, as no large areas of urbanisation exist within its boundaries.

From the thirteen schools used, the number of pupils of the required age totalled 519, with females slightly outnumbering the males by 270 to 249 respectively. The age range of pupils in the most senior classes or sections of classes in the primary schools was between ten years eight months and eleven years nine months with a mean age of eleven years two months.

The ages for each sex was quite similar, proving to be ranged from 10.8 to 11.9, mean age eleven years one month for males, and from 10.10 to 11.9, mean age eleven years three months for females; having chosen at the time of the tests to limit pupils by the criterion of having a date of birth between September 1st, 1969 and August 31st, 1970.

The handedness inventory was given to these 519 pupils, all of whom were, at the time of the tests old enough to comprehend and complete the tests, and yet young enough to be minimally subjected to possible hormone production rate

differences, and due to the similarity of their educational experiences were minimally effected by differing lesson content often encountered in secondary education.

The results of all 519 pupils will be utilised to study the first two questions posed by this work.

Some 59 of those 519 pupils (31 females and 28 males) were found to be left-handed, using as a criteria a negative quotient on the handedness inventory.

As mentioned elsewhere, the pupils must be controlled for the factors of age, sex, handedness and educational experience. This control was achieved by matching each of the left handed pupils discovered with a right handed pupil. The pair were so matched by finding all the right handed children whose handedness quotient exactly corresponds to that of the left hander (except, of course, that the quotient be positive instead of negative) and from these, selecting the children who are members of the same class as the left handed child. If more than one right hander fulfils both of these criteria, then the right hander who is most nearly the same age as the left handed one was selected.

In this way each pair of pupils had identical but reciprocal handedness quotients, belonged to the same class within the same school, and were closely matched for age (within two months).

These 59 matched pairs will have their spatial ability scores utilised for the consideration of questions three and four of this work.

METHODS.

c) Procedure.

The thirteen schools used in this work were visited within a period of three weeks by the author for the administration of the handedness inventory. At each school visited the pupils were separated from the normal classroom environment, facility being provided to use an empty classroom or hall space. Only the author was present during the administration of the test. The pupils were given a copy of the modified questionnaire which, for convenience of separating the responses of each sex, were printed on different coloured papers. Because the two paper colours available to the author were blue and pink, the decision was made to utilise the somewhat sexist convention of using blue copies for male children and pink copies for females. It is believed that such a distribution would have no effect upon the nature of the responses, for the questionnaire were in all other respects identical and could not be considered as being a task "for girls" or "for boys"; a later check revealed that very few of the children involved were aware of the convention of associating blue with boys and pink with girls.

The pupils were told that they were assisting the author to study handedness, and that no social nor academic connotations would be incurred in the completion of the questionnaire, nor were there any specifically right or wrong answers.

The questionnaire was then completed in accordance to the printed instructions (Fig. 5), with the exception that at each school two or three subjects selected at random by the tester were asked to perform all the responses while these were compared to their written responses on the completed questionnaires. The number of pupils so selected varied as a representative sample of the number of pupils being tested at that school, smaller schools providing two checks, while larger samples provided three. All of these randomly chosen pupils completed the action of the tasks exactly as reported.

Although the responses to the questionnaire are not timed, completion of all the responses was completed within approximately thirty to forty minutes, during which time the children appeared well motivated to complete the task, and enjoyed doing so. In no case could the author detect boredom or carelessness.

Having, by analysis of the handedness questionnaires, discovered 59 left-handed pupils and having matched these with 59 right-handed ones as described elsewhere, the schools were informed of the names of the pupils involved and asked permission for these 118 children to be tested further using the Spatial Test II. Accordingly the schools were visited over a period of four weeks, this period being some two months after the handedness tests. At each school the pupils

Figure 5

Instructions for Completion of Handedness Questionnaire.

1. Distribute blue copies to boys taking part in questionnaire.
2. Distribute pink copies to girls taking part in questionnaire.
3. Ask pupils to complete headings in pencil or ink, as follows:
 - (a) Name of school.
 - (b) Child's surname.
 - (c) Child's forename(s).
 - (d) Date of Birth (day, month, year).
 - (e) Today's date.
4. Ask each child to delete "yes" or "no" for questions about parent's handedness. (For this purpose "handed" means hand of usual use, e.g. writing).
5. Read through instructions, making clear that for each response they may put one plus sign + in R or L column to show preference, two plus signs ++ in R or L column to show unique preference, or one plus sign + in both columns to show no preference for hand used. (do example on blackboard)
6. Ask pupils to think carefully about answers - they may "act out" use of either hand to check.
7. Read each question in turn to pupils, leaving time after each one for pupils to make response.
8. Ask pupils to check the total number of plus signs + used; if correctly completed, the columns should sum not less than 10, and not more than 20 plus signs.
9. Collect papers.

selected were once again afforded the privacy of a separate room from their classmates, and the test was administered by the author alone. This time the pupils were told that the purpose of the test was to ascertain the level of their spatial ability - this was explained in simplified terms - and once again were reassured that no connection was to be made to their academic ability.

The test was administered in each case according to the manual of instructions general directions (Fig. 6) except that it was not possible to use two invigilators as recommended by the directions.

Due to the very small numbers of children at each school, however, no problem was encountered in careful invigilation, and because of the space available oversight of other papers by any pupil was rendered impossible.

Each test was strictly timed as required, and when added to the non-worked time for practices and explanations the whole application took, on average 44 minutes. Once again, the children seemed well motivated to complete the work, and seemed to enjoy the stimulation of the questions and, possibly, the change from normal school routine.

Figure 6

Instructions for Administration.

General Directions.

1. It is **ESSENTIAL** that the procedure here outlined should be followed **EXACTLY**. No deviations, however slight, from the oral instructions are permissible. Also, the greatest care must be taken to ensure that the five sub-tests are correctly timed. For this purpose it is necessary to make use of a watch with a seconds hand. **ON NO ACCOUNT** must a watch or clock without a seconds hand be used. If a stop-watch is used, its accuracy should first be checked by comparing it with an ordinary watch with a seconds hand, as serious errors in timing sometimes occur when stop-watches are used. It is desirable to have a spare watch in case of accidents.
2. The pupils must write their answers in **PENCIL**. The supervisor should ensure that each child has two sharpened pencils before the test begins. If it is not possible to arrange for this, a supply of spare pencils should be kept at hand in case any pupil should break his pencil during the test. No materials other than pencils should be provided. Pens, rulers, erasers, must **NOT** be used.
3. It is desirable that there be two invigilators to each room. One of these, the supervisor, should be responsible for the timing of the sub-tests. He should stand at the desk, facing the children, reading the instructions as here outlined, and keeping time with a watch. He should guard against having his attention distracted in any way whatever. The times allowed for each sub-test are short, and it is very easy to overrun the allotted periods inadvertently.

The second invigilator should patrol the room quietly. He should be responsible for the prevention of copying and for ensuring that the children follow the instructions at the foot of each page, and turn over the pages correctly.

contd..

4. Since copying is comparatively easy with a test of this type, the supervisor should arrange that the children are seated at separate desks, and as far away from one another as possible. While the test is being worked, the second investigator should see that they write the answers in the correct places and in the correct way. Thus, if he sees that a child is using a wrong METHOD of answering, for example, crossing out, instead of underlining, he should correct the child by pointing to the words in the instructions at the top of the page. **ADMIN FROM THIS, NO ASSISTANCE WHATSOEVER SHOULD BE GIVEN DURING THE ACTUAL WORKING OF THE TEST.** An opportunity for asking questions will be given at the end of each Practice Test. The supervisor should answer these **BRIEFLY IF THEY ARE RELEVANT.** He should not allow himself to be drawn into a discussion, or to prolong the time taken to administer the test.
5. There are five sub-tests, each preceded by a practice test. The timing is as follows:

Test 1. Match Box Corners	Page 5	3½ minutes
Test 2. Shapes and Models	Pages 8 & 9	10 minutes
Test 3. Square completion	Pages 12 & 13	6½ minutes
Test 4. Paper folding	Pages 16 & 17	3½ minutes
Test 5. Block building	Page 20	3 minutes

The total working time, including the time required for the practice tests is approximately 45 minutes.

It is believed that the ease of administration of the test was greatly assisted by the practice gained in the pilot study for the complete instructions must be read to the children verbatim, and prior knowledge of the types of questions likely to be asked by the pupils, and of the amount of time required to complete the trials and question sessions proved valuable in the smooth organisation of the pupils' time.

METHODS

- d) Analysis
 - (i) Handedness Questionnaire.
 - (ii) Spatial Ability Test.

(1) Handedness Questionnaire.

The responses recorded by each pupil on the Bell.I. were converted into a Laterality Quotient as Oldfield terms it by the following method. All plus signs '+' in the "left" column are summed, as are all the plus signs in the "right" column.

The quotient is then obtained by application of the formula

$$LQ = \frac{(\sum R - \sum L)}{(\sum R + \sum L)} \times \frac{100}{1} \%$$

Where R is the sum of responses in the right column and L is the sum of left column responses. Where $\sum L$ exceeds $\sum R$, the quotient will have a negative dimension.

The analysis of the handedness inventory also revealed that the question pertaining to parental handedness was very poorly completed, or in many cases, was left uncompleted. This was thought to be due to a lack of specific knowledge of the handedness of their parents on the part of the children. Furthermore due to the belief that a considerable proportion of children may well come from one parent families and are therefore unable to respond to questions about the missing parent; no particular pressure was applied to the children to complete this part of the questionnaire.

In either case, no really useful information could be elicited from the responses given, rendering the opportunity to investigate the incidence and effects of familial handedness no longer available.

The data relevant to the Laterality Quotient of each subject were tabulated, as were the responses to question one of the inventory relevant to writing hand used; the responses for each sex being noted separately.

The first question to be posed by this work, the comparison of criteria of handedness, can be considered by computing the percentages of responses meeting each criterion, and the incidence of handedness can be discovered through the percentages of the sample in each handedness classification.

(14) Spatial Ability Test.

The responses on the Spatial Test II were marked in accordance with the marking key and the general principles laid down in the manual of instructions. When the marking is totalled, a raw score for each pupil is produced.

The raw scores so obtained are converted to standardised scores using the conversion tables provided with the test. This standardisation is based upon the criterion of age in years and completed months of the child at the time of taking the test, younger children, being given a larger standardised score than older ones having the same raw score. In fact the age advantage is quite small, resulting in an advantage of only five marks between the ages of 10 years 7 months and 11 years 6 months, and as the age range of the present subjects is quite small, the relative amounts of change in standardising the scores is minimal.

Nevertheless, the raw score and standardised score for each pupil were recorded for each sex separately.

The raw and standardised scores on the spatial test for those 118 pupils so tested were appended to

their laterality quotient scores and tabulated so that the handedness scores and the spatial test scores were available for each sex separately.

The third question, directed to sex differences on the spatial tasks, will be considered by comparison of the mean scores, for each sex separately, of the spatial test. Checks will be made for the statistical significance of any differences found by the application of two-tailed t^0 tests. Distribution of scores will be examined graphically, and double checked for significant difference using χ^2 tests.

The fourth question is concerned with the relationships between spatial ability and handedness for all subjects, for various degrees of handedness, and for each sex separately. The overall pattern of correlation will be examined graphically for linear regression or homocendacity using a scattergram of scores on the spatial test with handedness quotients.

The other relationships will be examined using Pearson's product moment correlation coefficient r^0 , the use of which in these circumstances has been justified by Hovliceck and Peterson (077), and the statistical significance will be double checked by t^0 tests.

RESULTS.

- Q.1 How Accurate is Writing Hand as a Criterion of Handedness.
- Q.2 Current Incidence of Handedness.
- Q.3 Sex Differences in Spatial Ability.
- Q.4 Relationship of Handedness to Spatial Ability.
 - a) For All Subjects.
 - b) For Varying Degrees of Handedness.
 - c) For Each Sex.

Table 3.1

Agreement Between the Two Criteria of Handedness.

Proportion of Left Handed Writers Who Have L.Q. < 0	93.3%
Proportion of Right Handed Writers Who Have L.Q. > 0	99.1%

Table 3.2

Proportion of Children Identified as Left Handed by the Different Criteria.

Criterion Used	Boys	Girls	All Subjects
E.H.I. Quotient < 0	11.24%	11.56%	11.41%
Reported Writing Hand (Left)	12.04%	11.19%	11.60%

Question 1.

How Accurate is Writing Hand as a Criterion of Handedness.

Tables 3.1 and 3.2 show the differences to be found when differing criteria are applied to define left handedness.

When the criterion used is the application of the E.H.I., considering all those with negative laterality quotients to be "left handed", the overall incidence of left handedness for the 517 pupils of this study was 11.4%.

If the criterion for left handedness is simply the subject's reported use of writing hand - in this case the left hand - the incidence of left handedness among the same pupils was calculated at 11.6%.

Although it may seem that reported writing hand is a much less precise criterion for the definition of handedness than the application of a vigorous inventory, it appears that in terms of broad classification at least, the use of reported writing hand and questionnaire results give remarkably close degrees of incidence.

In answer to question 1, then, it would appear that the reported use of writing hand is a quite valid method of selecting left handers. Such a criterion does not, of course, take any account of degree of laterality which, in many cases is very important; but it does demonstrate that past works using such a criterion to define left handers are, in broad terms at least, worthy of comparison.

Table 4.1

Incidence of Reported Handedness.

Criterion Used	Work	Reported % L.H.
Writing Hand	Clarke 1957	7%
E.H.I.	Oldfield 1970	7.4%
Writing Hand	Annett 1970	10.7%
E.H.I.	Present Work	11.4%
Writing Hand	Present Work	11.6%

Question 2.

Current Incidence of Handedness.

As can be observed from Table 4.1 a sample of large-scale works of previous years show that, when comparable criteria are used, an increase of observed left handedness can be detected.

The work of Margaret Clarke, published in 1957 found about 7% of subjects to be left handed. Two major works concerned with the definition and quantification of handedness, both published in 1970, found a larger proportion of subjects to be left handed. Using the same criterion as Clarke, namely writing hand, Annett discovered 10.7% of left handedness while Oldfield used his newly defined quotient to find 7.4% of his subjects in this category.

The present work has used the same quotient as Oldfield and an overall percentage of 11.4 of left handedness is reported. Because the first question on Oldfield's questionnaire asks the subject to report on which hand is used for writing, it is comparatively easy to discover the incidence of reported writing hand. By this criterion, the percentage of left handedness rises very slightly to 11.6% of all children used.

Question 2 asks what the incidence of handedness is; the answer as defined by this work is that left handedness is the state of more than eleven percent of the children tested, and this figure seems to represent an increase in the incidence of left handedness since a decade ago, and a considerable increase over figures from twenty-five years ago. This increase could be because of an increase in the left handed population due to genetic factors, as uncovering of a larger proportion of natural left handers who were formerly repressed into right handedness by social pressures, or simply the increasing accuracy of determination of left handedness. For whatever reason, it appears that left handedness is increasing, or the reported incidence of left handedness is increasing, as each successive work has discovered a larger percentage of left handers within its sample.

INCIDENCE OF HANDEDNESS E.H.I.

Range of Laterality Quotient	Handedness	BOYS			GIRLS			ALL SUBJECTS	N		
		Incidence as % of L.H. Boys	Incidence as % of R.H. Boys	Incidence as % of All Boys	Incidence as % of L.H. Girls	Incidence as % of R.H. Girls	Incidence as % of All Girls	Incidence as % of All Subjects	D.	G.	ALL
-100	Left	17.8%		2.0%	9.6%		1.1%	1.5%	5	3	8
-80 to -99		25.0%		2.8%	29.0%		3.3%	3.0%	7	9	16
-60 to -79		14.2%		1.6%	19.3%		2.2%	1.9%	4	6	10
-40 to -59		17.8%		2.0%	29.0%		3.3%	2.7%	5	9	14
-20 to -39		14.2%		1.6%	9.6%		1.1%	1.3%	4	3	7
- 1 to -19		10.7%		1.2%	3.2%		0.3%	0.7%	3	1	4
+ 1 to +19	Right		1.8%	1.6%		0.4%	0.3%	0.9%	4	1	5
+20 to +39			9.0%	8.0%		2.9%	2.6%	5.2%	20	7	27
+40 to +59			17.6%	15.6%		16.8%	14.9%	15.2%	29	60	79
+60 to +79			30.7%	27.3%		28.2%	25.0%	26.1%	68	67	135
+80 to +99			23.0%	20.4%		33.3%	29.4%	25.1%	51	79	130
+100			17.6%	15.6%		18.1%	16.0%	15.8%	39	43	82

1910/11

Table 4.3 shows a breakdown of the incidence of handedness among children tested by the E.H.I. It will be noticed that for both boys and girls there is a much larger percentage of left handers near to the central or "mixed handed" zone.

For males, it is noticeable that the "very slightly left handed" areas of -1 to -19 and -20 to -39 on E.H.I. quotient are occupied by 10.7% and 14.2% respectively; while the reciprocal "very slightly right handed" areas of +1 to +19 and +20 to +39 quotients show only 1.8% and 9.0% respectively.

For females, the difference is even more marked, for the lowest polarity classifications have 3.2% and 9.6% of left handers, but the reciprocal right handed zones have only 0.4% and 2.9% of female pupils.

The overall profile of the distribution of the subjects across the full continuum of quotients from +100 to -100 can be observed in the "all subjects" column of Table 3. It is obvious that the distribution of left handers across the negative quotient sector is comparatively even, each class being occupied by between 0.7% and 3% of all subjects, while the right handers show progressively larger proportions of subjects gathering towards the polarity extreme.

Figure 7 represents graphically the distribution of quotient scores from the F.H.I. For ease of assimilation the scores on each half of the quotient continuum are divided into three broad "bands", from 0 to plus or minus 25 representing those subjects who demonstrate low polarity or considerable mixed handedness. The group within the classification of 26 to 50 can be considered as being moderately polar in their laterality, while those who score plus or minus 51 to 100 must be considered definite in their polarity, having scored in excess of fifty-percent of the possible quotient score.

The graph demonstrates that many more left handers are grouped towards the central zone than are right handers, who tend to be more definitely grouped towards the high polarity scores.

The indication from this presentation is that left handers are "less left handed" than right handers are right handed.

Figure 8

Graph of Incidence of Handedness as a Percentage of All Subjects.

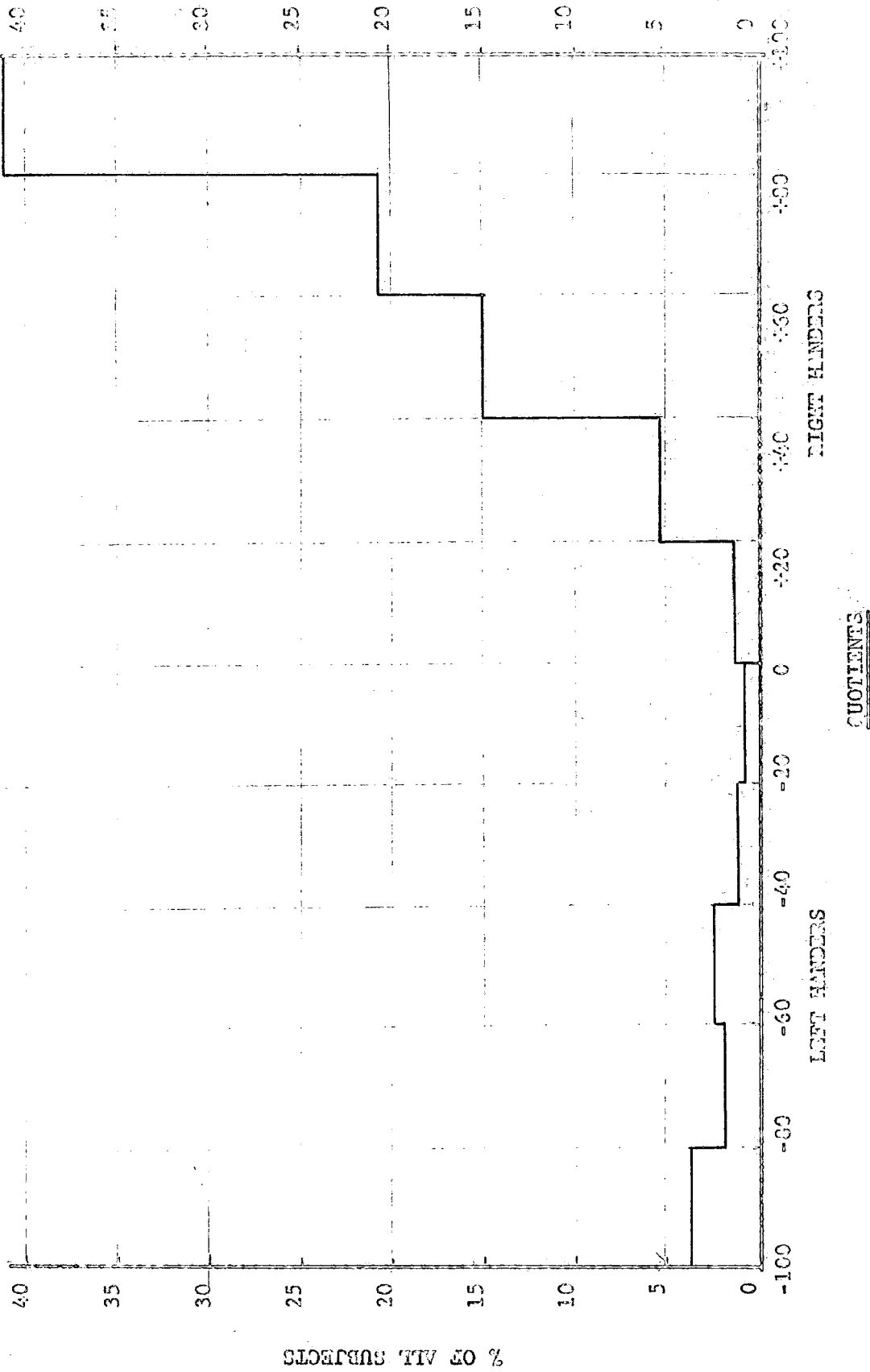


Figure 6, a graph of the incidence of handedness as a percentage of all subjects is of interest relevant to Question 2 about the incidence of handedness. The 'bold' figures which report the percentage of left and right handers within a group of subjects don't reveal the whole picture - that of the spread of laterality within each group.

The pictorial representation of the data (given in more detail in Table 4.2) shows that not only do left handers make up a smaller proportion of the subjects than right handers - as to be expected - but that the spread of their polarity is much more even. Dividing the polarity quotient continuum into quintiles, it will be found that for left handers each quintile is occupied by not less than 0.7% and not more than 4.5% of the whole sample. The corresponding group of right handers, however, congregate in ever larger proportions towards the extreme of polarity. Each progressive quintile from the central tendency contains a larger proportion of pupils rising steadily from 0.9% to 40.9% of all pupils.

Question 3

Sex Differences in Spatial Ability.

The third question relevant to this work is addressed to the relation of sex to spatial ability.

Table 5.1 shows the mean raw scores of the children on the spatial ability test listed by sexes. It can be seen from this table that females consistently outscored males, for all the subjects tested, and when considered as left and right handers separately.

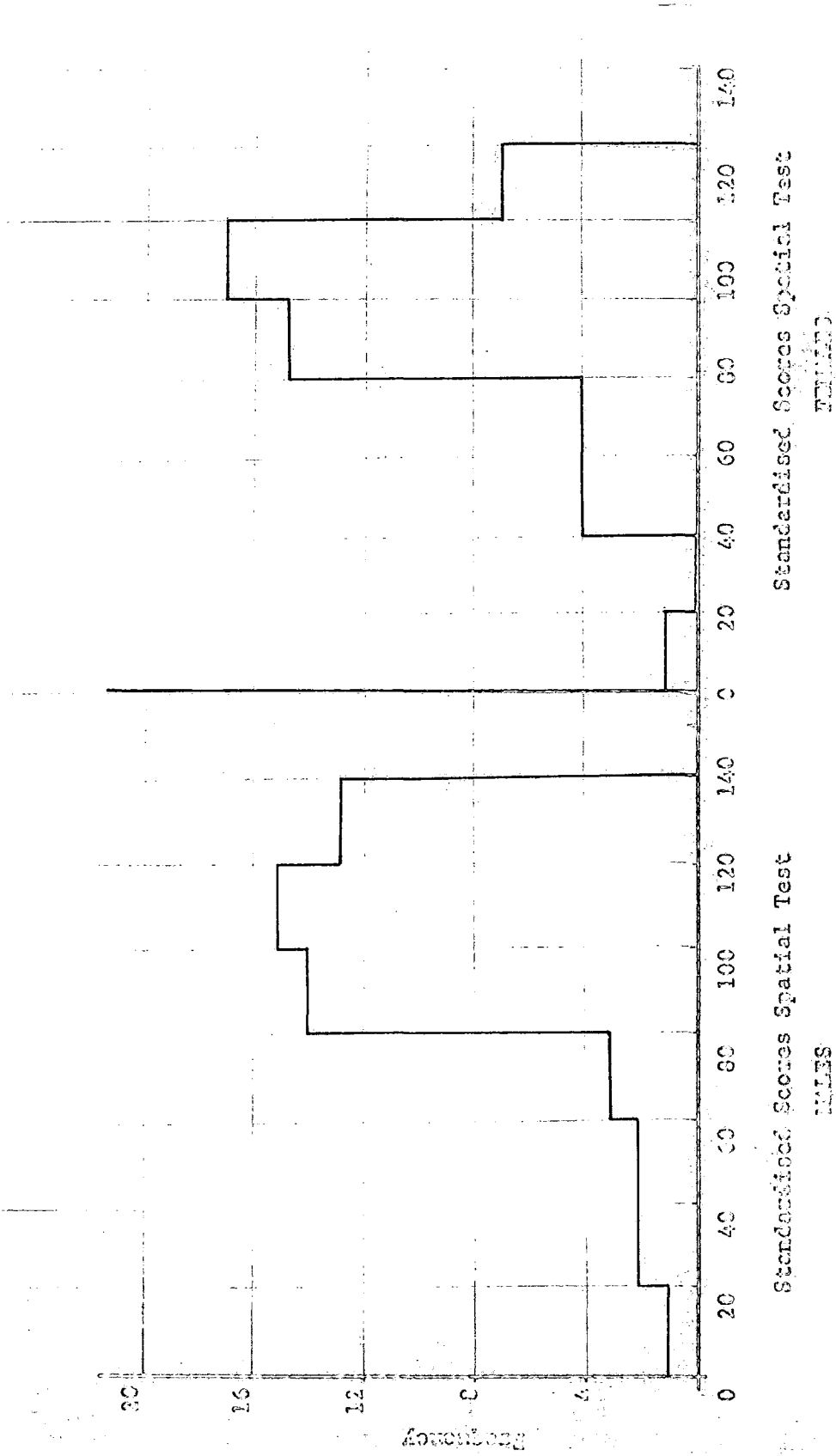
The differences found are very small, and do not reach statistical significance; and it would not be suggested that females are consistently superior to males on spatial tasks, but the often reported and frequently expected male superiority at such tasks is conspicuously absent.

Furthermore, this absence of any significant differences between the sexes can be found throughout this work.

Figure 9 demonstrates the similarity in the distribution of scores on the spatial ability test for males and females. A χ^2 test reveals no significant difference in the distribution.

Figure 9

Graph of Distribution of Spatial Ability Test.



Question 4

Relationship of Handedness to Spatial Ability.

The fourth and final question posed by this work is of the relationship of handedness to spatial ability, and is considered under three subsections.

- a) The first of these is to examine the stated relationship for all the pupils of the test, the second is to analyse this relationship across varying degrees of handedness, and the third will consider the relationship for each sex separately to determine any inter-sex differences.

Table 6.1 refers to the first of these three sections, namely the correlation between handedness and spatial ability. All the left handed pupils of the test, that is all those whose E.H.I quotient was negative and a matched sample of right handed (positive quotient) pupils were tested for spatial ability using Spatial Test II (Watts.)

As can be seen from Table 6.1 the correlations between handedness and spatial ability were low; left handed correlating about +0.05 while right handed⁰ correlation

coefficient reached just over 0.2. It would appear, then, that right handers may be more able at spatial tasks than left handers, but a two tailed 't' test shows that the group differences do not attain statistical significance.

The answer to the first part of Question 6 is that there is no significant difference in the correlation of handedness with spatial ability between left and right handed subjects.

- b) The second part of Question 4 is directed at the analysis of the relationship between handedness and spatial ability scores varying degrees of handedness.

Table 6.2 shows the correlations between these two factors for moderately and more extremely handed children. When the subject's handedness is considered in progressively refined groups by removing from the calculations the lowest twenty percent of quotients, there is no progressive pattern of correlations increase.

The correlations for right handed pupils remain quite consistent at about +0.2 with the exception of the +80 to +100 quotient group, while the left handed pupils' correlations were all quite close to zero except for the -100 only group. Throughout, the correlations are not significantly different from the hypothesis that r will be greater than zero.

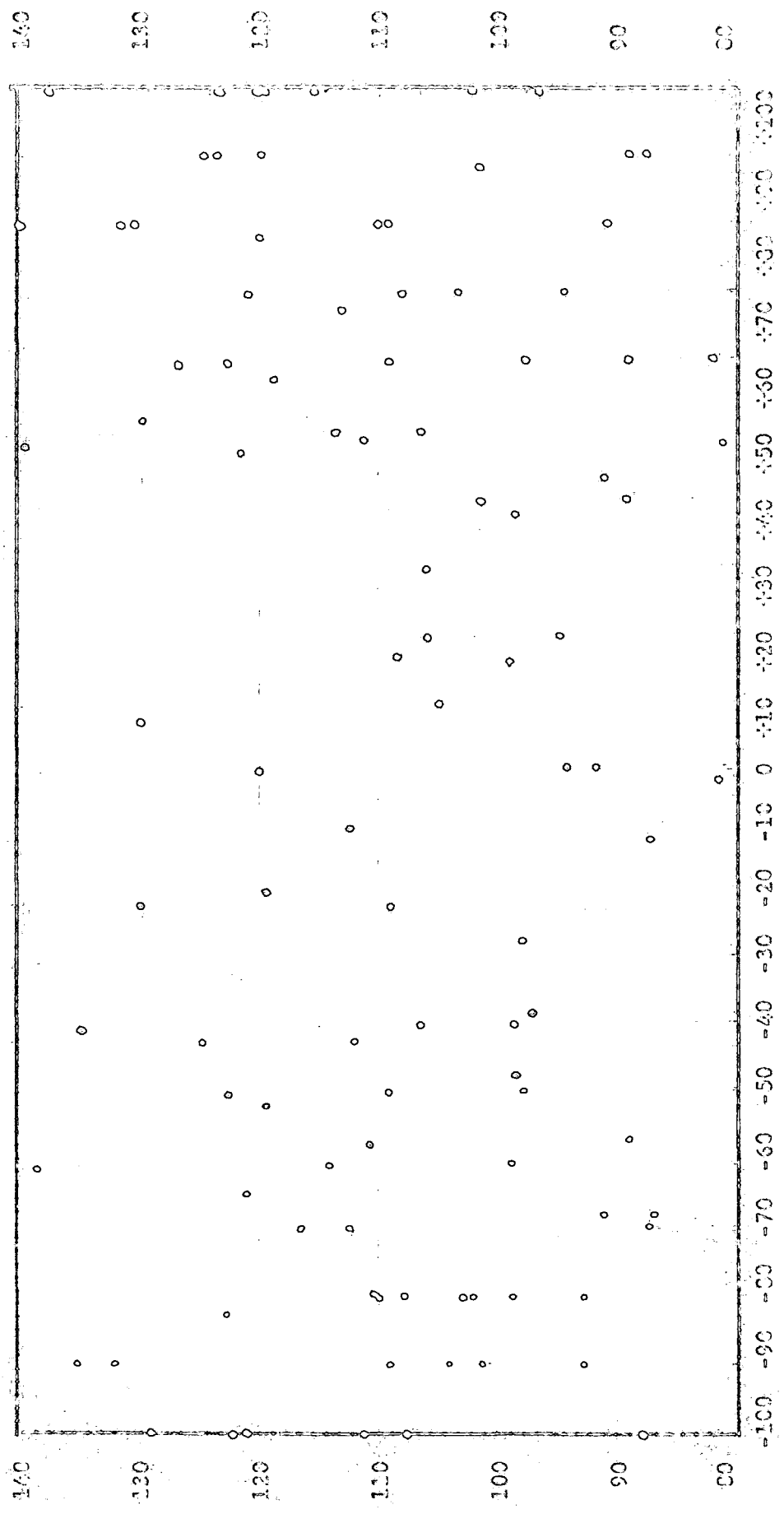
Using a broader consideration of handedness (after Annett) into three groups of extreme right handers, extreme left handers and mixed handers, again any significant difference from the null hypothesis fails to emerge.

Table 6.3 further demonstrates that no significant difference exists between any two of these three groups.

Such a pattern would deny any theory that "pure" handedness is associated with higher spatial ability, for if this were the case a progressively higher correlation should be evidenced as the low or mixed handers are gradually removed from the sample.

A further check on any possible linear or non-linear relationship across all the scores was prepared on Figure 10 which again demonstrates a lack of any such correlation.

Scattergram of S.H.I. Quotient and Spatial Test Scores.



S.H.I. QUOTIENTS

Standardized Scores Spatial Test

Standardized Scores Spatial Test

Product Moment Correlation Coefficient r^2
 Scores on E.H.I. and Standardised Scores
 Spatial Test II (Watts) by Sexes.

Table 6.4 Males

Subjects	r^2	Sig. 5%
All	+0.002	N/S
Right Handed E.H.I. Score < 0	+0.32	N/S
Left Handed E.H.I. Score > 0	-0.036	N/S

Table 6.6 Females

Subjects	r^2	Sig. 5%
All	+0.229	N/S
Right Handed E.H.I. Score < 0	+0.210	N/S
Left Handed E.H.I. Score > 0	+0.272	N/S

Two-Tailed 't' Tests of Statistical Significance,
Performance on Spatial Test II (Platts).

BY SERIES.

Table 6.5 Males

Subjects	Sig. 5%
Left-Handed Boys vs Right-Handed Boys	N/S

Table 6.7 Females

Subjects	Sig. 5%
Left-Handed Girls vs Right Handed Girls	N/S

- c) The third and last part of Question 4 refers to the correlation of handedness and spatial ability for each sex separately.

Table 6.4 shows the correlations determined for males. It is apparent from this table that while right handed males proved to have a higher correlation than left handed ones, none of the correlations computed reached a level of statistical significance. Table 6.5 also demonstrates that there is no significant difference between the two sub-groups of male subjects.

Table 6.6 shows that a similar picture emerges for female subjects, for again although the correlations overall are a little higher than those of the males, no significant difference from a null hypothesis exists. Table 6.7 again confirms lack of any difference between the left and right handed subgroups of females.

Two conclusions emerge from these tabulated results. The first of these is that even when considered as separate groups by sex, neither right nor left handers appear to enjoy an advantage over the other in terms of

spatial ability. The second, perhaps even more interesting conclusion, is that not only is the well reported male advantage at spatial tasks missing from the results, but the marginally higher spatial scores and correlations come from the females, although not to a significant degree.

While it is granted that with comparatively small numbers of subjects statistical significance is difficult to attain, nevertheless a correlation for females in excess of ± 0.2 compared to that of males at less than ± 0.1 does not lend evidence to a male superiority theory, for although dealing here with correlations, it must be recognised that as each group consists of pairs of subjects who are matched for handedness quotient, an increased correlation coefficient must be closely associated with increased spatial score.

DISCUSSION OF RESULTS.

- a) Comparison of Criteria.
- b) Incidence of Handedness.
- c) Relationship between Spatial Ability and Sex, all Subjects.
- d) Spatial Ability and Handedness.
 - (i) All Subjects.
 - (ii) More and Less Lateralised Subjects.
 - (iii) By Sexes.

a) Comparison of Criteria.

In an attempt to determine whether or not use of writing hand is a meaningful criterion for determination of handedness, the absolute laterality as determined by the E.H.I. has been compared to the handedness as determined by the reported writing hand only.

This question is important in order to determine how heavily it is possible or prudent to rely upon figures produced by past works which have used writing hand or reported writing hand only as a handedness criterion. Despite the complexity of the question of handedness, and bearing in mind the fact that handedness is not dichotomous, there seems to be good correspondence between handedness as defined by the criterion of positive or negative quotient and handedness as defined by observation of writing hand.

Although the fit is not perfect, as might be expected at first thought it is certainly high enough to make use of past works viable for comparison with works using a more specific criterion. These findings have more recently been supported by the work of Roszkowski Smalbecker and Sacks ('82) who have

considered the reported use of hand and performance in 5-9 year olds. They conclude that writing is the best single index of self assessed performance at this age.

Unfortunately there still remains a number of works the criteria of which are unstated - simply reporting that "left-handers" performed in a certain way.

b) Incidence of Handedness.

The picture framed by these results regarding handedness incidence is that nearly 11.5% of tested subjects were left handed using the E.H.I. as a measure. Slightly more girls than boys were found to be left handed (11.6% to 11.2%).

Due to the confirmation, discussed elsewhere, that criteria from other works are still justifiably useable for comparison with the present work, a progressive evolution of reported handedness can be discerned.

In 1957 Margaret Clarke declared that she had found 8% of males but only 6% of females left handed, her criterion being writing hand used. She also defined 2.4% of her population as "true left handers" - criterion unspecified. Miller (1971) found 4% of the population to be "true left handers", but again no criterion for this deduction is offered. The present work, using a criterion of handedness quotient -100 to be absolute left handedness, disclosed only 1.5% of subjects in that position.

Amott (1970) using her questionnaire as a criterion, discovered 10.7% of her subjects to be left handed, with 3% at the "left extreme". Also in 1970 Oldfield published his E.H.I. which found 10% of males and 5.9% of females to be left handed - that is with a laterality quotient less than zero as a criterion. Of all subjects tested, he found 7.4% of his subjects to be left handed by this definition.

Comparison of these past works with the present results seems to indicate a small but noticeable and progressive increase in the reported use of the left hand. The reasons for such an increase, if true increase there be, are not immediately apparent. It is possible that relaxation of some of the social constraints which once repressed left handedness is responsible for 'uncovering' a larger number of natural left handers. There is also the possibility that left handedness is indeed on the increase perhaps through some genetic basis. Should this be the case, then a matter of some importance could be looming, for society in general, from preconceptions to ergonomics still seems ill prepared for the fact that perhaps one person in eight (and this figure may be increasing) performs "the wrong way round."

The classification of handedness into narrow bands of laterality quotients proved to be revealing, for it demonstrated that in the classes nearest to the central zero or "mixed handed" zone, there are proportionately many more left than right handers. It is clear that although the percentages of each hand at the extremes of the continuum are quite similar (13.5% to 17.8% left to right respectively), there are proportionately many more left handers than right handers in the low scoring quartiles. It seems that, in general, left handers are less left handed than right handers are right handed.

There appears to be no simple explanation for this observation, but if left handers perform a relatively larger number or proportion of activities with their right hand than right handers do with their left hands, then several alternatives for why this might be could be suggested.

One of these would be social in nature; the pressures of social constraints and norms may well lead to the habit of performing contra-handedly on a number of specific tasks, such as the use of knife and fork at table.

Another constraint which may lead left handers to adopt a comparatively large proportion of right handed activities is that of ergonomics. Many circumstances and implements in modern society simply do not take account of handedness, and left handed people are faced with having to adopt, perhaps from quite early age, to performing these tasks or using these implements as right handers do.

A third possibility is that cerebral organisation may effect the direction and magnitude of hand use.

It has been noted that while almost all right handed subjects have 'normal' hemispheric lateralisation of cerebral functioning, not all left handers are opposite, for many left handers have the same type of lateralisation as right handers (Milner, Branch and Rasmussen '64) and this variance of cerebral lateralisation may be effective upon the various tasks used to measure handedness.

A more specific theory of the cause of left handedness is propounded by Ashton ('82) who suggests that left handedness results from a combination of genotype, birth experience and maternal example; and believes that handedness is determined by genetic and environmental factors in an approximate ratio of 10% to 90% respectively.

c) Relationship between Spatial Ability and Sex, all Subjects.

In a large majority of studies which analyze spatial performance for sex differences, males are shown to outperform females at such tasks. The fact remains, however, that when a large number of such works are studied, the difference in performance seems to shift in direction and magnitude and it is the contention of the present work that such shifts, or indeed the actual differences noted may be the product of the age of the subjects tested and the nature and content of the tests themselves.

The results of this work refute the widely accepted theory that boys perform better at spatial tasks than girls, for no statistically significant differences could be found. Indeed girls scored slightly higher than boys on the spatial task, having a mean raw score of 50.3, compared to the boys mean raw score of 46.8. Girls also very slightly outperformed their male counterparts when each handedness group was considered separately; for among right handers, girls scored better than boys by 53.1 to 49.0 (mean raw scores) and among left handers the female superiority showed again with scores of 47.6 to 44.7 respectively.

Although there is no statistically significant difference to these figures, there is sound indication that males do not demonstrate superior spatial ability, a conclusion also reached by Villaneta et al (1981) in a comparison of the spatial abilities of males and females aged about 13 years, for they also found no significant differences in spatial performance between the sexes of their subjects. As comparative numbers of each sex of the subjects was very close (48 to 52) and as the subjects were matched as carefully as possible to minimise possible extraneous affective factors, it is suggested that the remarkable lack of male superiority found by this work is due to one of, or a combination of, the following three factors.

The first of these is the age of the subjects, which was chosen specifically to avoid, as far as possible, maturation and hormonal effects. At the age tested (mean age 11 years 2 months), the well documented differences in maturational rate, with girls usually demonstrating superior intellectual performance, will have lost most if not all of the effect usually reported, for it would seem that by the age of the present subjects males have caught up on the maturational spurt of their female counterparts. At the same time, however,

any sex differences which are or may be attributable to hormonal production in adolescent males should be at a minimal level.

The second of the factors mentioned, is that of the type of education undergone by the subjects. At the time of testing, none of the subjects, male or female, had been subjected to any educational experiences which differed significantly from the others. Boys have not, at this stage of their education in this specific system, had discriminatory experiences in such academic areas as geometry, spatial or practical skills or other experiences which could be directly contributable to "practice" in a spatial sense; or even to any subject material which could be perceived as male role oriented. The importance of this factor has been suggested by Turcu ('79) in finding a significant improvement in spatial relations tasks by students of 9 - 12 years old who had been directed in spatial tasks over a control group who had not.

The third factor and, it is suggested, possibly the most influential, is the nature of the items in the spatial test used in this work. Because none of these items is of a type which relies upon pattern recognition, embedded figures, or other material which

can be shown to be affected by the personality trait of field dependence or field independence as defined by Witkin, then the test as a whole becomes relatively free of this particular trait. As boys are almost always superior at items which require field independence for their correct completion, the elimination of this factor may well be solely responsible for the disappearance of male superiority on the spatial test used in the present work.

This is, of course, a speculation which is in need of verification by further work in this direction. Perhaps much of the presently confusing situation regarding male versus female performance on such tasks could be clarified by a closer and more thorough investigation of this specific factor.

d) Spatial Ability and Handedness.

(1) All Subjects.

Despite the results of many other significant works in this area which demonstrate differences of performance at spatial tasks between left and right handed subjects, this work could detect no such differences.

In fact right handed subjects were found to have a slightly higher mean score on the spatial task (51.1) than left handers (46.1), but the difference does not reach statistical significance. While it is admitted that the numbers of subjects involved (51 of each, left and right handed) may be smaller than would be desirable for the safe postulation of a generalisation, it is also necessary to remember that some of the works which claim to find such differences have done so with even fewer subjects.

In this work it is believed that the classification of subjects as left or right handed has been very carefully done, as the definition was not reliant upon observed writing hand alone, but subject pairs were watched for degree of handedness.

The suggestion is also offered that the instrument used for measuring spatial ability was selected to conform to the closest definition of the criteria of spatial ability, discussed elsewhere; and that by application of careful analysis the emergent picture is as clear as can be obtained at the present time using the available parameters of definition.

There is no evidence to suggest that there is any measurable difference in performance on a spatial task performed by normal schoolchildren of ten to twelve years of age, between left and right handed subjects. Some studies seem to indicate that, due to cerebral location and composition of abilities, cerebral dominance of one sort or another which is usually associated with the overt signs of lateral dominance carries with it a predilection to perform better at spatial tasks, or those non-verbal tasks usually associated with one cerebral hemisphere as being the processing centre for those tasks.

The work of Peterson and Lansky (1974), for example, found a disproportionately large number of left handed subjects in an architectural school, and that these left handers performed better on a spatial maze task than their right handed colleagues. Their conclusion was, broadly, that right hemisphere "goes with" left handedness and high levels of spatial ability. If this is the case, then the more left handed a subject is, the better should be his score on a spatial task, and therefore the correlation between a spatial task score and a laterality quotient should increase towards the negative end of the laterality continuum.

On the other hand, alternative theories such as that of Levy and Sperry (1968) suggest that left handers have to process spatial information cross-modally, while right handers have a "purer" representation of spatial processing in the cerebellum. This would allow a reversal of Peterson and Lansky's expectations - that a spatial task score and laterality quotient correlation should increase towards the positive end of the laterality continuum.

In fact, the results of this work can uphold neither hypothesis, for the correlations between laterality quotient and spatial task score were uniformly low across the whole continuum, from complete right handedness to complete left handedness. The right handers did, in fact, score slightly higher in this respect, but the overall figure is low, and not significantly different to the correlations of left handers.

d) (ii) More and Less Lateralized Subjects.

As discussed elsewhere, handedness itself tends not to be a discrete and unique ability, but a somewhat fluid and often mixed set of abilities or predilections which, for convenience of labelling, is usually referred to by its major constituent. A person labelled "left handed" may be so called because he either writes with his left hand, or because he performs a majority of common tasks with his left hand. This label conveniently forgets or disregards the fact that he may perform a significant minority of other tasks with his right hand, eye or foot, and that his "cerebral make up" may not be as right hemisphere dominant as suggested.

When, to this unknown quantity is added the imperfectly understood processes of cerebral processing of psychomotor information, the resultant performance of an individual on a specific task is not easily predicted.

So far, for the purposes of this work "left handed" has been used to refer to those subjects whose laterality quotient on the D.H.I. is less

then zero, while the term "right handed" has referred to those with a positive laterality quotient. As it is understood that each of these broad classifications will contain a wide spectrum of degree of handedness, the results were prepared to examine the correlations of spatial ability and handedness for both the less lateralised and ever more exclusively lateralised subjects available. To this end, correlations were prepared for the entire right and left handed groups, and these correlations were compared with the correlations of progressively more polarised subjects.

This was achieved by removing the 20% of each hand nearest to the central zero position on the laterality continuum, and then calculating a new spatial task - laterality correlation. Eventually the extremes of each pole was checked by computing the correlations of +100 and -100 laterality subjects only.

If being more polar in handedness combines with a superior performance on a spatial task, then the correlations should increase in magnitude towards one or both of the polar extremes of the continuum.

The work of Peterson and Lensky would predict an improvement of spatial ability towards the negative pole, while the Levy-Sperry Hypothesis would have the opposite to be the case. In fact the results of this work would uphold neither of these expectations, for the correlation rate was almost uniformly low, with a very slight improvement of scores for right handers over left, but there is no upswing of improvement of spatial scores towards either pole.

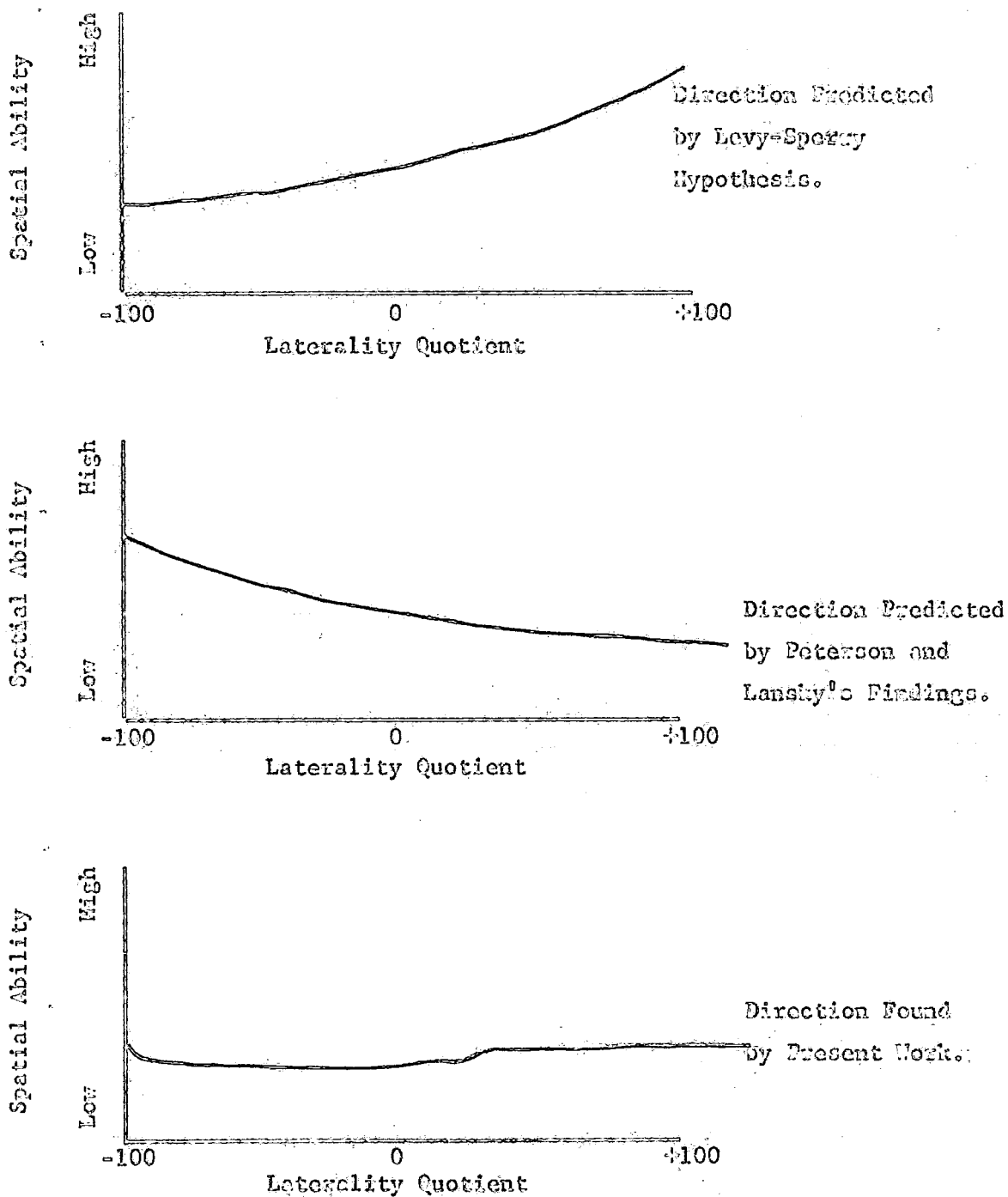
A careful analysis of the results will, indeed, reveal a slight increase of correlation among the -100 laterality subjects, but due to the very small sample size ($n = 7$) it is dangerous to assume that this may be more than a "freak" result.

Nevertheless it would be beneficial and interesting to verify this result, for the possibility exists, no matter how remote, that some affective factor is at work here. One such factor could be familial left handedness, for the research has shown that children of left handed parents tend to be more positively lateralised than average, and that they more often process spatial information by contra-lateral methods which may have some

depending upon their measurable performance on spatial tasks. The reasons for the failure of this work to accurately acceptata information about familial handedness are mentioned elsewhere yet it is considered that this aspect of laterality could be important and worthy of further work.

Figure 11

Comparison of Expectations of Correlations by
Previous Hypotheses and the Present Work (Not to Scale)



d) (iii) By Sexes.

When the results showing correlations between handedness and spatial ability are analysed by sexes, an interesting picture emerges. The most noticeable feature of the table of correlations is that all the classifications of females show a remarkable consistency of magnitude, all females correlating at $+0.22$, while left and right handed females correlated at $+0.27$ and $+0.21$ respectively.

When this is compared to the male classifications of the table, quite a converse is found. All males correlated at $+0.08$, while left and right handed males' correlations were -0.08 and $+0.3$ respectively.

It could be that females show a more consistent correlation between spatial ability and handedness than their male counterparts because, as O'Callaghan ('77) suggests, they process spatial information by different processes than males. It is not within the scope of this work to determine whether females process such information analytically or holistically, but it would seem that the method used is used by all classes to give such consistent results.

Males, in contrast, have a very low correlation overall, actually reaching negative dimension for left handed boys. The right handed boys, in contrast, show the largest correlation of all at +0.3. This may well indicate that males are indeed using different or various methods of spatial processing. This suggestion is reinforced by the work of Bagnara and Simion ('81) who suggest that there is much support for the theory that males are more lateralised for spatial tasks.

The second factor to be noticed is the overall low correlations of all groups. The highest correlation of all is only +0.3, and several of the others are virtually zero - not an impressively high set of correlations at all.

In comparing the performances of each sex separately, although the females show a correlation consistently above that of males, the size of the correlation is so low, and the numbers of subjects is such that no statistically significant difference can be detected.

There is no evidence found by this work that either males or females are superior to the other in their correlation of handedness to spatial ability. This may not be surprising in the light of the results which show no sex superiority on the spatial task, but a slight indication can be detected that, for reasons suggested, females produce a more consistent correlation between their laterality and their spatial ability.

CONCLUSION.

This work was undertaken to investigate spatial ability in children and whether this ability is in any way associated with the handedness of the pupil, or their sex.

Because of the somewhat confused picture in this area, with some works purporting to show that left handed subjects are superior at spatial tasks while others claim quite the reverse, and with males being quoted as superior or not at these abilities, and due to the importance of spatial ability in the cognitive structure of children an attempt to clarify this picture was considered desirable.

It was discovered that some factors contributing to the confusion mentioned were those of problems of definitions of the tests and terms used to specify spatial abilities and handedness, the unsuitability of the design or application of these tests, and the often poor selection of subjects for works from which generalisations relevant to schoolchildren could be extrapolated.

Many works used widely differing and sometimes poorly defined tests of spatial ability. There being no generally accepted criterion for the definition or measurement of spatial ability, all types of instruments have been used - those of

three-dimensional material, two dimensional items, or the "spatial relations" subtests of large battery tests. In similar vein, the handedness of the subjects tested has been determined by various methods ranging from observation of writing hand to acceptance of the subjects' stated laterality, or in some cases without any specification of the criterion at all.

The individuals to whom these tests have been applied have in some cases been university undergraduates, adults, or brain-damaged and institutionalised patients which has in no way aided the clarification of the situation regarding normal schoolchildren in an educational context.

Any attempted resolution of these problems would require that a satisfactory test of spatial ability which would, by stated criteria, fulfill a realistic definition of spatial skills be applied to subjects whose handedness had been determined by means of a precise criterion; and that such subjects should be normal schoolchildren performing in a school context.

To this end, the present work undertook to test as large a sample of schoolchildren as possible for handedness, using the E.H.I. which had been modified to be more functionally legible to younger children. Having discovered by this

method, a sample of left handed subjects, these and a matched sample of right handed subjects were tested using Watts' Spatial Test II which had been selected for its three-dimensional items which fulfill the required criteria for spatial material.

The results of the tests were analysed to show the incidence of handedness, the level of spatial ability and its relation to the sex of the subjects. The relationship between spatial ability and handedness was also studied in the case of all subjects, and for each sex, and for differing degrees of handedness.

The conclusions reached are that the incidence of left handedness or at least left hand writing seems to be increasing, and that there is no measurable difference in the level of spatial ability between the sexes. This lack of measurable difference of spatial abilities has also been noted by Waber ('82) when using as subjects children of this age.

The study of the relationship between spatial ability and handedness also failed to discover any significant difference in performance between left and right handed subjects, whether considered as separate sexes, or as varying degrees of handedness.

The reasons why it is felt that some of the previously reported differences fail to appear in this work are discussed elsewhere, but suffice it to say that when handedness is determined by a reliable criterion, and spatial ability is measured by a "pure" instrument, there is no reliable evidence to support the theory that either right or left handed subjects are spatially superior to their corresponding opposites.

At the age tested (mean age 11.2 years) there was also no evidence of difference between the sexes, and it is believed that this is due to test material free of sex-biased items and the fact that the subjects were young enough not to have undergone either possibly effective hormonal changes, or discriminatory educational experiences.

The same conclusions have recently been reached by Bagnara and Simion ('82) who conclude "sex differences are more infrequent than common, and most sex differences have not been replicated".

The lack of detectable spatial superiority found here for either sex or between people of different handedness carries implications for four areas

- a) Theories of the brain.
- b) Assessment design.

- c) Education.
- d) Psychological research.

a) Theories of the brain.

Cerebral organisation which has been the underpinning of brain theories such as those of Buffery and Gray and Levy and Sperry among others may be less different between sexes or handers than has been previously thought, or any such differences may be less significant than supposed. It is suggested that if no difference in a cognitive area such as spatial ability can be found in schoolchildren of the age 10/11, then theories accounting for differences may be premature, or else such cerebral organisation modes must occur at a later age when differences might emerge.

b) Assessment Design.

The lack of consensus of opinion about spatial abilities, and in some cases the lack of replication of findings between different works can perhaps be accredited to the use of often very different instruments to assess the ability. The necessity still exists of reaching some general agreement about the nature of

spatial ability and the criteria for assessing it and for the development of instruments which are free of material performance on which is believed to be sex-related.

Better definition of handedness and more refined means of assessing it in all its varying degrees could still be sought, and the relationship between handedness and cerebral organisation is clearly not yet fully understood and is in need of further specific attention. This will only be possible when a method of definitively assessing modes of cerebral organisation has been devised.

c) Education.

If the present conclusions pertaining to school-children of a specific age are correct, then educationists need to be wary of forming or adhering to preconceptions about the relative performances of males and females, or left versus right handers at specific cognitive tasks. Such preconceptions, once formed, are difficult to eradicate and may lead to sex role stereotyping and self fulfilling prophecies which will perpetuate the original preconceptions. Indeed it is quite possible that such beliefs held by teachers could

cause or contribute to the differences reported in some works between sexes or handers at such tasks.

d) Psychological Research.

The results of this work suggest that what is most specifically required to improve the understanding of the precise effects of the factors discussed is a longitudinal study of children from the age of those children studied in this work to post adolescence.

As mentioned above, cerebral organisation may alter with age, as might the effects of maturational hormone production rate and level. The effects of different educational experiences over a period of time could also be studied in this manner. It is argued here that at the age of 10/11 there is no difference in performance on a spatial ability test between left and right handers, or between sexes. Whether this remains so as children age is in need of verification, and the reasons for any changes detected need explanation.

BIBLIOGRAPHY.

- AITKEN, L.R. "Some Speculations and Findings Concerning Sex Differences in Mathematical Abilities and Attitudes" in *Mathematical Learning: What Researchers Say About Sex Differences* Fennema E. (Ed) Science & Environment Ed. Clearing House, 1975.
- AITKEN, L.R. "Update on Attitudes and Other Affective Variables in Learning Mathematics". *Review of Educational Research* 46, 293-311, 1976.
- ALEXANDER, W.D. "Intelligence, Concrete and Abstract". *British Journal of Psychology, Monog.Supp.* 20, 1935.
- ANASTASI, A. "Psychological Testing." Macmillan Pub. Co., New York, 1976.
- ANNETT, M. "Handedness in the Child of Two Left Handed Parents", *British Journal of Psychology*, v.65, 129-131, 1974.
- ANNETT, M. "A Classification of Hand Preference by Association Analysis", *British Journal of Psychology*, v.61.3, 303-321, 1970.
- ASHTON, G.C. "Handedness - An Alternative Hypothesis", *Genetics*, v.12, 125-147, 1982.
- BAGNARA, S. and SIMION, F. "Possible Differences in the Hemispheric Specialisation of Men and Women", *Italian Ricerche di Psicologia*, v.5, 181-203, 1981.
- BAKAN, P. and PUTNAM, W. "Right-Left Discrimination and Brain Lateralisation Sex Differences", *Archives of Neurology*, v.30, 334-335, 1974.
- BAKER, R.S. and TALLEY, L.H. "Visualisation Skills as a Component of Aptitude for Chemistry - A Contrast Validation Study", *Journal of Research in Science Teaching*, 11, 95-97, 1974.
- BANKER-LINN, J.C. "Streaming in the Primary School", N.F.E.R., 1970.

- BARNESLEY, R.H. and RABINOVITCH, M.S. "Handedness - Proficiency Versus Stated Preference", *Perceptual and Motor Skills*, v.30, 343-362, 1970.
- BELMONT, T.L. and BIRCH, H.G. "Lateral Dominance and Left-Right Awareness in Normal Children", *Child Development*, 34, 257-271, 1963.
- BERRY, J.W. "Temne and Eskimo Perceptual Skills", *Internal Journal of Psychology*, 1, 207-229, 1966.
- BIERI, J. "Sex Differences in Perceptual Behaviour", *Journal of Perception*, 26, 1-12, 1958.
- BOCK, R.D. and KOLAKOWSKI, D. "Further Evidence of Sex-Linked Major Gene Influence on Human Spatial Visualizing Ability", *American Journal of Human Genetics*, v.25, 1-14, 1973.
- BOCK, R.D. and VANDENBERG, S.G. "Components of Heritable Variation in Mental Test Scores", in "Progress in Human Genetics", S.G. Vandenberg (Ed.), Johns Hopkins, Baltimore, 1968.
- BOGEN, J.E. and DEZURE, R. and TENHOOTEN, W.D. and MARSH, J.F. "The Other Side of the Brain" in "The A/P Ratio", *Bull. L.A. Neurol. Soc.*, 37, 49-61, 1972.
- BROVERMAN, D.M. and KLAIBER, E.L. and KOBAYASHI, Y. and VOGEL, W. "Roles of Activation and Inhibition in Sex Differences in Cognitive Ability's", *Psychology Per.*, 75, 23-50, 1968.
- BROWN, W. and STEPHENSON, W. "A Test of the Theory of Two Factors", *British Journal of Psychology*, 23, 1933.
- BRYDEN, M.P. "Tachistoscopic Recognition and Cerebral Dominance", *Perceptual and Motor Skills*, 19, 1964.
- BUFFERY, A.W.H. and GRAY, J.A. "Sex Differences in the Development of Spatial and Linguistic Skills", in "Gender Differences: Their Antogeny and Significance", Ounsted, C. and Taylor, D.C. (Eds), Williams and Wilkins, 1972.
- BUTLER, S.R. and GLASS, A. "Asymmetries in E.E.G. Associated With Cerebral Dominance". *Electroencephalography and Clinical Neurophysiology*, v.36, 1974.

- CARLSMETH, L. "Effect of Early Father Absence on Scholastic Aptitude."
Harvard Ed. Review, 34, 3-21, 1964.
- CARTER-SALTZMAN, L. "Patterns of Cognitive Functioning in Relation to Handedness and Sex Related Differences" in 'Sex-Related Differences in Cognitive Functioning', Wittig, M.A. and Peterson, A.C. (Eds), Academic Press, 1979.
- CASSERLY, P.L. "An Assessment of Factors Affecting Female Participation in Advanced Placement Programmes in Maths., Chemistry and Physics."
Report to National Science Foundation, July, 1975.
- CLARKE, G. "The Range and Nature of Factors in Perception Tasks." Ph.D. Thesis, U. London, 1936.
- CLARKE, M.M. "Left Handedness", U.L.P., 1957.
- CONNOLLY, K. and STRATTON, P. "Developmental Changes in Associated Movements."
Developmental Medicine and Child Neurology, 10, 49-56, 1968.
- CORKIN, S. "Tactually Guided Maze Learning in Man."
Neuropsychologia, v.3, 339-351, 1965.
- COX, J.W. "Mechanical Aptitude." Methuen, 1928.
- CROGHAN, L.M. "Relationship Between Conjugate Lateral Eye Movement and Verbal and Spatial Abilities."
D.I.A., v.35, 913, 4644-4645, 1975.
- CROVITZ, H.F. "Laterality and Sex."
Perceptual and Motor Skills, v.37, 520, 1973.
- DAWSON, J.L.M. "Cultural and Physiological Influence Upon Spatial Perceptual Processes in West Africa."
Int. Journal of Psychology, 2, 115-185, 1967.
- DeFRIES, J.C. and ASHTON, G.C. and JOHNSON, R.C. and KUSE, A.R. and McCLEARN, G.E. and MI, M.P., and RASHAD, M.N. and WANDENBERG, S.G. and WILSON, J.R. "Parent-Offspring Resemblance for Specific Cognitive Abilities in Two Ethnic Groups."
Nature, 261, 131-133, 1976.

- DeFRIES, J.C. and VANDENBERG, S.G. and McCLEARN, G.E.
 "The Genetics of Specific Cognitive Abilities."
 Ann. Review of Genetics, 10, 179-207, 1976.
- DENCKLA, M.B. and RUDEL, R. "Rapid 'Automatized' Naming of
 Pictured Objects, Colours, Letters and
 Numbers by Normal Children."
 Cortex, 10, 186-202, 1974.
- DeWITT, G. and AVERILL, J.R. "Lateral Eye Movements and
 Field Dependence."
 Perceptual and Motor Skills, v.43, 1179-1184, 1976.
- DURNFORD, M. and KUMURA, D. "Right Hemisphere Specialisation
 for Depth Perception in Visual Field Differences."
 Nature, 231, 394-395, 1971.
- DWYER, C.A. "The Role of Tests and their Construction
 in Producing Apparent Sex-Related Differences."
 in 'Sex-related Differences in Cognitive
 Functioning', Wittig and Petersen (Eds), 1979.
- ELLIOTT and McMICHEL "Effects of Specific Training on
 Frame Dependence."
 Perceptual and Motor Skills, v.17, 363-367, 1963.
- ELTON, C.F. and ROSE, H.A. "Traditional Sex Attitudes and
 Discrepant Ability Measures in College Women."
 Journal of Counselling Psychology, 14, 538-543, 1967.
- ERNEST, J. "Mathematics and Sex."
 Santa Barbara, University of California, 30, 1976.
- EVERITT, B.S. "Moments of the Statistics Kappa and Weighted Kappa."
 British Journal of Maths. Statistical Psychology,
 21, 97-103, 1968.
- FAGOT, D.I. and PATTERSON, G.R. "An In Vivo Analysis of
 Reinforcing Contingencies for Sex-Role Behaviour
 in the Pre-School Child."
 Developmental Psychology, 11, 563-568, 1969.
- FARLEY, S.M. de C. "A Study of the Mathematical Interests,
 Attitudes and Achievement of 10th and 11th
 Grade Students." Doctoral Dissertation
 University of Michigan, D.A.I., 29, 3037A, 1969.
- FENNELL, L. "Mathematics Learning and the Sexes: A Review."
 Journal for Research in Mathematics Education, 5,
 126-129, 1974.

- FENNEMA, E. "Influence of Selected Cognitive, Affective and Educational Variables on Sex Related Differences in Maths Learning and Studying." in 'Women and Mathematics: Research Perspectives for Change', J. Shoemaker (Ed.), Washington D.C. National Institute of Education, U.S. Department of Health, Education and Welfare, 1977.
- FERGUSON, L.R. and MACCOBY, E. "Interpersonal Correlates of Differential Abilities." Child Development, 37, 549-571, 1966.
- FLANERY, R.C. and BALLING, J.D. "Developmental Changes in Hemispheric Specialization for Tactile Spatial Ability." Dev. Psychology, 15, 364-372, 1979.
- FOX, L.H. and TOBIN, D. and BRODY, L. "Sex Role Socialisation and Achievement in Mathematics" in 'Sex Related Differences in Cognitive Functioning' Wittig and Petersen (Eds.), 1979.
- GAZZANIGA, M.S. "One Brain - Two Minds?" American Scientist, 60, 311-317, 1972.
- GEFFEN, G. and BRADSHAW, J.L. and NETTLETON, N. "Hemispheric Asymmetry, Verbal and Spatial Encoding of Visual Stimuli." Journal of Experimental Psychology, v.95, 25-31, 1972.
- GESSELL, A. and AMES, L.B. "The Development of Handedness." Journal of Genetic Psychology, LXX, 1947.
- GILBERT, C.D. "Relations Among Handedness, Hemispheric Localisation and Perceptual Skills of the Right Hemisphere." D.A.I., v.34 (12b), 6237, 1974.
- GOLDBERG, J. and MEREDITH, W. "A Longitudinal Study of Spatial Ability." Behaviour Genetics, 5, 127-135, 1975.
- GOLDMAN, P.S. and CRAWFORD, H.T. and STOKES, L.P. and GALKIN, T.W. and ROSVOLD, H.E. "Sex Dependent Behavioural Effects of Cerebral Cortical Lesions in the Developing Rhesus Monkey." Science, 186, 540-542, 1974.
- GOODENOUGH, D.R. and KARP, S.A. "Field Dependence and Intellectual Functioning." Journal of Abnormal and Social Psychology, 63, 241-246, 1961.

- HARRIS, L.J. "Neurophysiological Substrates of Spatial Development."
Paper to Society for Research in Child Development, Philadelphia, 1973.
- HARTLAGE, L.G. "Sex Linked Inheritance of Spatial Ability."
Perceptual and Motor Skills, v.31, 610, 1970.
- HARTLEY, R.E. and HARDESTY, F.P. and GORFEIN, D.
"Children's Perception and Expression of Sex Preference."
Child Development, 33, 221-227, 1962.
- HAVEN, E.W. "Factors Associated with the Selection of Advanced Academic Mathematics Course by Girls in High School."
Doctoral Dissertation, University of Pennsylvania, 1971.
- HEIM, A.W. and WATTS, K.P. "Handedness and Cognitive Bias."
Quarterly Journal of Experimental Psychology, v.28, 335-360, 1976.
- HERZBERG, F. and LEPKIN, M.A. "A Study of Sex Difference in the PMAT."
Educational and Psychological Measurement, 14, 687-689, 1954.
- HILTON, T.L. and BERGLUND, G.W. "Sex Differences in Mathematics Achievement - A Longitudinal Study."
Ed. Testing Service Research Bulletin, 1971.
- HINES, D. and MARTINDALE, C. "Induced Lateral Eye Movements and Creative and Intellectual Performance."
Perceptual and Motor Skills, v.39, 153-154, 1974.
- HURLEY, J.F. "Report of Projective Evaluation: Instructional Grouping by Sex at 5th Grade Level - a Study of All Boy and All Girl Groups."
Fairfax Va., Office of Psychological Services, 1964.
- HURLEY, J.F. "Report of Project Evaluation: A Study of All Boy and All Girl Groups at the 3rd and 5th Grade Levels and an Evaluation after Two Years in Same Sex Classes."
Fairfax Va, Co. School Board, 1965.
- JOHNSON, O. and HARLEY, C. "Handedness and Sex Differences in Cognitive Tests of Brain Laterality."
Cortex, v.6, 73-82, 1980.

- JORDAN, H.E. "Hereditary Left-Handedness With A Note on Twinning."
Journal of Genetics, v.IV, 1914.
- KAGAN, J. and KOGAN, N. "Individuality and Cognitive Performance" in Carmichael's Handbook of Child Psychology, P. Mussen (Ed.), v.1, Wiley, New York, 1970.
- KAMMERER, B.L. "The Development of Hemispheric Asymmetry and Somesthesia."
D.A.I., v.36(2b), 889, 1975.
- KARNOVSKIY, A.P. "Sex Differences in Spatial Ability - A Developmental Study."
D.A.I., v.34(12-A), 7586, 1974.
- KELLEY, T.L. "Crossroads in the Minds of Man."
Stanford University Press, 1928.
- KIMURA, D. "Cerebral Dominance and the Perception of Verbal Stimuli."
Canadian Journal of Psychology, 15, 166-171, 1961.
- KIMURA, D. "Dual Functional Asymmetry of the Brain in Visual Perception."
Neuropsychologia, v.4, 275-285, 1966.
- KIMURA, D. "Spatial Localisation in L and R Visual Field."
Canadian Journal of Psychology, 23, 445-458, 1969.
- KINSBOURNE, M. "Direction of Gaze and Distribution of Cerebral Thought Processes."
Neuropsychologia, v.12, 279-281, 1974.
- KLAIBER, E.L. and BROVERMAN, D.M. and VOGEL, W. and KOBAYASHI, Y. "Rhythms in Plasma MAO Activity EEG Behaviour During the Menstrual Cycle." in Biorhythms and Human Reproduction, Ferin, Halberg (Eds), Wiley, New York, 1974.
- KOHLBERG, L. "Cognitive Development Analysis of Children's Sex Role Concepts and Attitudes." in The Development of Sex Differences, E. Maccoby (Ed), Stanford University Press, 1966.
- KOHN, D. and NASH, S.C. and BRUCKEN, L. "Sex Role Concepts for Two and Three Year Olds."
Child Development, 49, 445-451, 1978.
- KOUSSY, A.H.H.El "The Visual Perception of Space."
British Journal of Psychology, 20, 1935.

- LACEY, C. "Hightown Grammar."
University Manchester Press, 1970.
- LANDY, F. and ROSENBERG, B.G. and SUTTON-SMITH, B.
"The Effects of Limited Father Absence on
Cognitive Development."
Child Development, 40, 941-944, 1969.
- LEVY, J. "Possible Basis for the Evolution of
Lateral Specialisation of the Brain."
Nature, 224, 614-615, 1969.
- LEVY, J. "A Review of Evidence for a Genetic Component
in the Determination of Handedness."
Behaviour Genetics, v.6, 429-453, 1976.
- LEWIS, D.G. "Statistical Methods in Education."
University London Press, 1967.
- LINE, W. "The Growth of Visual Perception in Children."
British Journal Psychology, Monog. Supp. 15, 1931.
- LOCKHEED, H. "Sex Bias in Educational Testing, A Sociologists
Perspective."
Princeton, N.J., Educational Testing Service,
ETS RM 74-13, 1974.
- MACARTHUR, R.S. "Sex Differences in Field Dependence for
the Eskimo."
International Journal of Psychology, 2,
139-140, 1967.
- MAGCOBY, E.E.(Ed) "The Development of Sex Differences."
Tavistock, 1967.
- MAGCOBY, E.E. and JACKLIN, C.N. "The Psychology of Sex
Differences."
Stanford University Press, 1974.
- MACFARLANE, M. "A Study of Practical Ability."
British Journal Monog. Supp. 8, 1925.
- MARSHALL, J.C. "Some problems and Paradoxes Associated with
Recent Accounts of Hemispheric Specialisation."
Neuropsychologia, v.11 463-470, 1973.
- MAYO, P.R. and BELL, J.M. "A Note on the Taxonomy of
Witkin's Field Independence Measures."
British Journal Psychology, 63, 225-256, 1972.
- MCGEE, M.G. "Laterality, Hand Preference and Human Spatial
Ability."
Perceptual and Motor Skills, v.42, 781-782, 1976.

- McGEE, M.G. "Interfamilial Correlations and Heritability Estimates for Human Spatial Abilities in a Minnesota Sample." Behaviour Genetics, 8, 77-80, 1978.
- McGLONE, J. and DAVIDSON, W. "The Relationship Between Cerebral Speech Laterality and Spatial Ability with Special Reference to Sex and Hand Preference." Neuropsychologia, 11, 105-113, 1973.
- McGLONE, J. and KERTESZ, A. "Sex Differences in Cerebral Processing of Visuospatial Tasks." Cortex, v.9, 313-320, 1973.
- McMENAMAN, E.R.L. and LISHMAN, M.A. "Retest Reliabilities and Inter-relationships of the Annett Hand Preference Questionnaire and the E.H.I." British Journal of Psychology, 66, 53-59, 1975.
- MILLER, E. "Handedness and Patterns of Human Ability." British Journal of Psychology, 62, 111-113, 1971.
- MILNER, B. "Laterality Effects in Audition" in Interhemispheric relations and Cerebral Dominance, Mountcastle, V.B. (Ed.), John Hopkins Press, Baltimore, 1962.
- MILNER, B. and BRANCH, C. and RASMUSSEN, T. "Observations on Cerebral Dominance" in Disorders of Language, DeRueck, A.U.S. and O'Connor, M. (Eds), Churchill, London, 1964.
- MONEY, J. and MITTENTHAL, S. "Lack of Personality Pathology in Turner's Syndrome." Behaviour Genetics, 1, 43-56, 1970.
- MONTMAYOR, R. "Children's Performance in a Game and Their Attraction to it as a Function of Sex Typed Labels." Child Development, 45, 152-156, 1974.
- MOORE, T. "Language and Intelligence: a Longitudinal Study at the First Eight Years." Human Development, 10, 83-106, 1967.
- MURPHY, R.J.I. "Sex Differences in Examination Performance: Do They Reflect Differences in Ability or Sex Role Stereotypes?" Paper to International Conference on Sex Role Stereotyping, Cardiff, July, 1977.
- NASH, S.C. "The Relationship Among Sex Role Stereotyping, Sex Role Performance and Sex Differences in Spatial Visualisation." Sex Roles, 1, 15-32, 1975.

- NASH, S.C. "Sex Role as a Mediator of Intellectual Functioning" in Sex Related Differences in Cognitive Functioning. Wittig and Petersen (Eds), Academic Press, 1979.
- NEDES, R. and BRIGGS, G. "Handedness and Retention of Visual Material." Cortex, v.10, 209-214, 1974.
- NEDES, R. and SPERRY, R.W. "Cerebral Dominance in Perception." Neuropsychologia, 9, 247, 1971.
- NEHCORDE, F. and RATCLIFFE, G. "Handedness, Speech Lateralisation and Ability." Neuropsychologia, 11, 399-407, 1973.
- O'CALLAGHAN, S. "Influences of Laterality Training Upon Visual Discrimination of Direction." D.A.I., v.38(3b), 1445, 1977.
- OETZEL, R.M. "Sex Typing and Role Adoption." Unpublished Manuscript, Stanford University, 1961.
- OLDFIELD, R.C. "The Assessment and Analysis of Handedness." Neuropsychologia, v.9, 97-113, 1971.
- ORLOFF, L.J. "Sex Differences in Cognitive Differentiation." D.A.I., v.37(12b), 6342-6343, 1977.
- ORNSTEIN, R.E. "The Psychology of Consciousness." Freeman, San Francisco, 1972.
- PENROSE, L. and RAVEN, J.C. "Progressive Matrices." H.L. Lewis, 1938.
- PETERSEN, A.C. "Physical Androgyny and Cognitive Functioning in Adolescence." Developmental Psychology, 12, 524-533, 1976.
- PETERSEN, A.C. "Hormones and Cognitive Functioning in Normal Development" in Sex Related Differences in Cognitive Functioning, Wittig and Petersen (Eds), Academic Press, 1979.
- PETERSON, G.M. "A Preliminary Report on Right Handedness and Left Handedness in the Rat." Journal of Comparative Psychology, XII, 1931.
- PETERSON, J.M. and LANSKY, L.M. "Left Handedness Among Architects - Facts and Speculation." Perceptual and Motor Skills, v.38, 549-550, 1974.

- PLANK, E.N. and PLANK, R. "Emotional Components in Arithmetical Learning as Seen Through Autobiographies." *Psychoanalytic Studies of the Child*, 9, 274-296, 1954.
- POOLE, C. and STANLEY, G.A. "A Factorial and Predictive Study of Spatial Abilities." *Australian Journal of Psychology*, 24, 317-320, 1972.
- PRATT, R. and MARRINGTON, E. and HALLIDAY, A.M. "Unilateral ECT as a Test for Cerebral Dominance with a Strategy for Treating Left Handers." *British Journal of Psychiatry*, 119, 79-83, 1971.
- PROVINS, K.A. and CUNLIFFE, P. "The Reliability of Some Performance Tests of Handedness." *Neuropsychologia*, 10, 199-206, 1972.
- RAMALEY, F. "Inheritance of Left Handedness." *American Naturalist*, v.XLVII, 1913.
- RIGAL, R.A. "Determination of Handedness Using Hand Efficiency Tests." *Perceptual and Motor Skills*, v.39, 253-254, 1974.
- RODGER, A. "A Dorstal Experiment in Vocational Guidance." *Ind. Health Board, Report 78*, 1937.
- ROSENTHAL, R. and JACOBSON, L. "Pygmalion in the Classroom." Holt, Reinhart, Winston, 1968.
- ROSKOWSKI, M.J. and SNELBECKER, G.E. and SACKS, R. "Young Childrens' Subjective Reports of Manual Preference: Internal Consistency and the Selection of Most Representative Activity on the Basis of Item-Total Correlations." *Clinical Neuropsychology*, v.4, 35-37, 1932.
- RUDEL, R. and DENCKLA, M. and SPALTENE, E. "The Functional Asymmetry of Braille Letter Learning in Normal, Sighted Children." *Neurology*, 24, 733-738, 1974.
- SCHNELL, R.E. and SILBER, J.W. "Sex Role Discrimination Among Young Children." *Perceptual and Motor Skills*, 127, 379-389, 1968.
- SCHUCK, R. and VAN EGMOND. "Sex Differences in the Relationship of Interpersonal Perceptions to Academic Performance." *Psychology in the Schools*, 2, 32-40, 1965.

- SCHEIDT, N. and ELIOT, J. and GREENFIELD, S.
 "Consistency of Lateral Eye Shift Related
 to Performance on Analytical Perceptual Tasks."
 Perceptual and Motor Skills, v.42, 634, 1976.
- SEMEL, J.
 "Hemispheric Specialisation - A Possible Clue
 to Mechanism."
 Neuropsychologia, v.6, 11-26, 1968.
- SHERMAN, J.
 "Problem of Sex Differences in Space
 Perception and Aspects of Intellectual
 Functioning."
 Psychology Review, 74, 290-299, 1967.
- SHERMAN, J.
 "Field Articulation, Sex, Spatial Visualisation,
 Dependency, Practice Laterality of Brain,
 Birth Order."
 Perceptual and Motor Skills, v.38, 1223-1225, 1974.
- SHERMAN, J. and FENNEMA, E. "The Study of Mathematics by
 High School Girls and Boys: Related Variables."
 American Educational Research Journal, 14,
 51-71, 1977.
- SMITH, I. MACFARLANE. "Spatial Ability."
 University of London Press, 1964.
- SPERRY, R.W.
 "Perception in the Absence of Neocortical
 Commissures," in Perception and its Disorders,
 Res. Publ. A.R.N.M.O., v.48, 1970.
- STAFFORD, R.E.
 "Sex Differences on Spatial Visualisation
 as Evidence of Sex Linked Inheritance."
 Perceptual and Motor Skills, v.13, 428, 1961.
- STEIN, A.H.
 "The Effects of Sex Role Standards for
 Achievement and Sex Role Performance on Three
 Determinants of Achievement Motivation."
 Developmental Psychology, 4, 219-231, 1971.
- STEIN, A.H. and POHLY, S.R. and MUELLER, E.
 "The Influence of Masculine, Feminine and
 Neutral Tasks on Children's Achievement
 Behaviour, Expectancies of Success and Attainment
 Values."
 Child Development, 42, 195-207, 1971.
- TANNER, J.M.
 "Growth of Adolescence."
 Blackwell, London, 1962.
- TERRANOVA, C.
 "The Relationship Between Test Scores and
 Test Time."
 Journal of Experimental Education, 40,
 81-83, 1972.

- FRANKELL, A. "The Genetics of Left Handedness."
Paper to 13th International Congress of
Psychology, Stockholm, 1951.
- TSAI, L.Z. and MAURER, S. "Right Handedness in White Rats."
Science, LXXII, 1930.
- TUCKER, D.M. "Hemispheric Differentiation and Integration
EEG Studies on Differences in Brain Function."
D.A.I., v.35(12B), 6126, 1975.
- TUCKER, D.M. "Sex Differences in Hemispheric Specialisation
for Synthetic Visuospatial Functions."
Neuropsychologia, 14, 447-454, 1976.
- TURCU, A. "Developing the Ability of Operating with
Spatial Relations." (translation from French)
Revista de Psihologie, v.25, 9-27, 1979.
- UMILTA, C. and RIZZOLATTI, G.S. and MARZI, C. and ZAMBONI, G. and
FRANZINI, C. and CAMARADA, C. and BERLUCHI, G.
"Hemispherical Differences in Discrimination
of Line Orientation."
Neuropsychologia, v.12, 165-174, 1974.
- VANDENBERG, S.G. and KUSE, A.R.
"Genetic Determinants of Spatial Ability"
in Sex Related Differences in Cognitive
Functioning. Wittig and Petersen (Eds),
Academic Press, 1979.
- VANDENBERG, S.G. and KUSE, A.R.
"Spatial Ability: A Critical Review of the
Sex Linked Major Gene Hypothesis" in Sex
Related Differences in Cognitive Functioning.
Wittig and Petersen (Eds), Academic Press, 1979.
- VAN RIPPER, C. "A New Test of Laterality."
Journal of Experimental Psychology, v.17, 1934.
- VILLARCTA, C. and SMIRNI, P. and LEPIRA, F. and ZAPPALA, G.
"Verbal, Visual and Spatial Learning in
Adolescence: Sex Differences."
Italian Journal of Psychology, v.8, 81-85, 1981.
- WABER, D.P. "Development Trends and Biological Basis of
Gender Differences in Mental Abilities."
D.A.I., v.36(1B), 429-430, 1975.
- WABER, D.P. "Sex Differences in Cognition: A Function of
Maturation Rate?"
Science, 192, 572-573, 1976.

- WABER, D.P. "Sex Differences in Mental Abilities, Hemispheric Lateralisation and Rate of Physical Growth of Adolescence." *Developmental Psychology*, 13, 29-38, 1977.
- WABER, D.P. and CARLSON, D. and MANN, M. "Developmental and Differential Aspects of Mental Rotation in Early Adolescence." *Child Development*, v.53, 1614-1621, 1982.
- WEITEN, H. and ETAUGH, C. "Lateral Eye Movements Consistency is Related to Academic Aptitude." *Perceptual and Motor Skills*, v.38, 1203-1206, 1974.
- WILSON, D. "The Right Hand: Left Handedness." London Nature Series, The Macmillan Co., 1991.
- WILSON, D.T. and JONES, H.E. "Left Handedness in Twins." *Genetics*, XVII, 1932.
- WILSON, J.R. and DeFRIES, J.C. and McCLEARN, G.E. and VANDENBERG, S.G. and JOHNSON, R.L. and RASHAD, M.N. "Cognitive Abilities: Uses of Family Data as a Control to Assess Sex and Age Differences in Two Ethnic Groups." *Int. Journal Aging Human Development*, 6, 261-276, 1975.
- WITKIN, H.A. "Sex Differences in Perception." *Transactions of the New York Academy of Science*, 12, 22-26, 1949.
- WITKIN, H.A. "A Cognitive Style Approach to Cross-Cultural Research." *International Journal of Psychology*, 2, 233-250, 1967.
- WITKIN, H.A. and DYK, R.B. and FATERSON, G.E. and GOODENOUGH, D.R. and KAPP, S.A. "Psychological Differentiation: Studies of Development." Wiley, New York, 1968.
- WITTIG, H.A. "Genetic Influences on Sex Related Differences in Intellectual Performance: Theoretical and Methodological Issues." in *Sex Related Differences in Cognitive Functioning*. Wittig and Petersen (Eds), Academic Press, 1979.

- YEN, W.M. "Sex Linked Major Gene Influences on Human Spatial Ability."
D.A.I., v.34(11B), 5567, 1974.
- YEN, W.M. "Sex Linked Major Gene Influences on Selected Types of Spatial Performance."
Behaviour Genetics, v.5, 281-298, 1975.
- ZURIF, E.B. and BRYDEN, M.P. "Familial Handedness and Left-Right Differences in Auditory and Visual Perception."
Neuropsychologia, v.7, 179-187, 1969.

