A STUDY OF HANDEDNESS AND ITS RELATION TO VERBAL AND SPATIAL ABILITY

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SUMMARY

The concept of handedness is reviewed, encompassing environmental, developmental and genetic aspects. Particular attention is paid to the measurement of laterality variables and the clarification of techniques involved in handedness assessment.

Following a study of previous work pertaining to cerebral dominance, an attempt is made, through the literature, to establish a relationship between handedness and cerebral dominance. The clarification of such a relationship is a prerequisite for the association of specific ability levels with patterns of cerebral dominance, where handedness is employed as an index of such patterns. Subsequently a model relating mixed-handedness to good visuo-spatial ability is envisaged. This contrasts with earlier studies which reveal inferior 'performance' abilities for left or mixed-handers.

Three investigations bearing on this model are reported. First a laterality survey was conducted amongst Artists, Engineers and Linguists, to test the hypothesis that more mixed-handedness would be found in Artists and more strong handedness in Linguists. Results upheld both this hypothesis and further predictions concerning other laterality variables. Secondly an experiment was conducted which sought to relate various questionnaire and performance measures of handedness, and which produced handedness distributions for 144 subjects. Thirdly, a further experiment employed this data to select independent groups on stringent handedness criteria. In this experiment, male and female groups of left, mixed and right-handers were compared over a series of tests. Males, in particular, tended to produce significant results in the expected directions. A possible relationship was demonstrated between, on the one hand, mixed-handedness and good performance on a test of spatial ability, and, on the other hand, strong handedness and relatively superior performance in sequencing aspects of linguistic ability. Females, however, performed somewhat differently and reasons for this are suggested.

The final discussion, in addition to summarising the main findings, sets the results in the context of the probable relationship between handedness and specific reading retardation (dyslexia). An overview of sex differences in handedness found in the experiments is also presented.

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NOTES ON THE TEXT

Figures and Tables

There are no separate indices for figures and tables, which are integrated into the text. The first number of each figure or table heading indicates the Chapter in which the figure or table is found (e.g. Table 7.21 is the 21st Table in Chapter 7).

Appendices

Individual references to the appendix are not made in the text. The appendices contain a short note on the terminology employed in the thesis in addition to items arranged in chapter sections. Thus, for example, material relating to Chapter 6 of the thesis is collected under subsection 6 of the appendices.

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1. HANDEDNESS

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1.1 Concept of handedness

As a comprehensive definition of handedness, that of Ludwig (see Kovac, 1973) is acceptable as any:

"A disposition to perform finely co-ordinated movement with one of the extremities more easily, faster and better." (p.235)

Within this definition both objective and subjective elements of handedness are encompassed, measurable by performance tests and preference questionnaires respectively.

All cultures appear to include a majority of right-handers (Barsley, 1970) and this right-hand dominance is believed to have been present at least since the Bronze Age (Goldberg and Schiffman, 1972). The handedness of primitive man has been deduced from clues such as the shapes of tools and weapons and from pictures showing men using such implements. It is interesting to note that right-handed people find it easier to draw profiles facing left, a fact that also facilitates an assessment of the handedness of ancient man (Gardner, 1967).

The simplest of theories concerning the emergence of right-handed man is that which relates to the asymmetrical distribution of internal bodily organs. While the heart and stomach are displaced to the left of the body, the liver and appendix are found on the right. The primaeval warrior may therefore have used a shield with his left hand to protect his heart, leaving his right hand free to manipulate more lethal weapons with great skill (Corballis and Beale, 1970). With respect to the lateralisation of functions within the brain other more complex theories have superceded this (see, for example, Levy, 1969). Such theories appear just as speculative as the simple theory of handedness above and in fact they cannot explain the emergence of right-handedness in particular.

Right-handedness is now regarded as the norm, deviation from which may still not meet with acceptance in certain educational, religious or social contexts (Barsley, 1970). This picture may be changing but persistent difficulties remain for the left-hander.

1.1.1. Concepts of left and right

Where do our ideas of 'left' and 'right' originate? Are they embedded in the world we perceive or in the language we use? Perhaps the first clue to this problem is the observation that nothing is perfectly symmetrical. Meredith (1972) points out that although the words 'left' and 'right' are themselves conventional, the fact that we require two words is not. Since perfect symmetry exists only in the mind, we require, in order to comprehend and organise our world, the concepts, which we label 'left' and 'right'.

In particular, 'left' and 'right' may be regarded as inherent properties of the class of objects which possess a basic asymmetry in one vertical plane (see Gardner, 1967 for discussion). Thus objects such as cars, chairs and human beings which possess inherent 'tops, bottoms, backs and fronts' are thought to possess a right and a left side, while a table, which has no intrinsic back or front, does not in itself have claim to such properties (Skinner, 1973).

'Right' and 'left' appear to be concepts firmly grounded in human experience. Animals, on the other hand, do not in general consistently demonstrate knowledge of left and right. Pavlov (see Tschirgi, 1958) found that dogs were unable to discriminate between stimuli to the right and left sides of their bodies, while Corballis and Beale (1970) report that animals find it difficult or impossible to truly discriminate between mirror-imaged stimuli (such as 0 and θ).

Asymmetry appears to be a quality present in every living thing. The Carbon compounds found in living organisms possess a basic asymmetry due to the presence in the compound of asymmetric ('right or left-handed') carbon atoms (Gardner, 1967). Further, in any carbon compound, where there are more than two different atoms or groups of atoms attached to the central carbon atom, the molecule is asymmetrical.

Asymmetry is therefore present on at least three levels:

1. The molecular and atomic structure of carbon and its compounds.
2. The asymmetrical distribution of certain internal bodily organs.
3. The intrinsic right and left-sidedness of a certain class of objects.

1.1.2 Left-handedness

Left-handedness has traditionally been associated with ideas of evil or hell, where "sinistral Satan dwelt with the goats" (Barsley, 1970). Right up to this day the left-hander is faced with physical disadvantages and with social pressures to conform to the right-handed norm.

Burt (1937) sees handwriting as one major problem for the left-hander. If the sinistral writer is not pressurised at school into learning to write with his non-preferred hand, then he may still find it difficult to accommodate to the act of writing which, in left-to-right script, is easier performed with the right hand. The most natural action of the left-hander is a sweep with the pen from the bottom right to the top left of the page.

This movement is rarely used in handwriting, unlike the converse movement with the right hand (bottom left to top right). Specific difficulties such as this are thought to account for much of the mirror-writing which is found more frequently among sinistrals.

The left hander, is, then, in a minority. Figures demonstrating the proportion of left-handers in the population vary almost as widely as the different techniques used to classify right and left-handedness. Wile (1934) referred to sixteen independent studies, a selection of which produces proportions of left-handers in the population ranging from 1% to 30%. The unweighted average of these estimates is 11.3% which conforms closely to figures expected or found by contemporary authors (Barsley, 1970, and from figures of Oldfield, 1971; Annett, 1964 and others). Such widely discrepant figures as those presented by Wile may arise, according to Annett (1973) due to left-handedness being scored as either all or as any 'left' responses to items of a preference questionnaire. They could also be due to different male-female ratios in the groups under investigation, or, more probably, to totally diverging methods of classification. For example, Woo and Pearson (1927) took handedness to be equivalent to superiority on tests of hand strength, while Parson (1924) based figures on cases of eye preference.

Connections between left-handedness and cerebral dominance will be referred to in Chapter 3 and here it suffices to note that sinistrality is often associated with suspected or diagnosed brain dysfunction (Quinn, 1972; Ingram, 1959; Burt, 1957;Touwen, 1972). According to the simple model of Gordon (1921) two sorts of left-hander may be envisaged: first the natural left-hander who is the complete 'flip-over' of the right-hander, (ie right cerebral dominance for language); secondly the pathological left-hander, naturally a right-hander, who has adopted a sinistral appearance due to a shifting of brain organisation caused by injury or defect, (ie still left cerebral dominance for language).

Left-handedness, while presenting practical difficulties, is also considered to be followed by 'a marked slowing up of thought and reaction' (Gerhardt, 1959). Gerhardt was led to investigate the problem of left-handedness in pilots, after it was noted that a greater proportion of left-handed than of right-handed pilots were involved in air crashes. Left-handed pilots facing instruments designed for right-handers are confronted with more than a mere manipulative problem, it seems. They are often unable to distinguish left from right in the reading of dials or in the operation of controls, and may be forced to identify the left side by noting, for instance, which hand their wedding ring is on (Gerhardt). The relationship of perceptual abilities to handedness will form much of the discussion in Chapter 4.

In the majority of instances 'left-handedness' is referred to as if it represented a discrete class of individuals. In fact the various measures used are likely to render widely diverging versions of left-handedness. Some measures rely on subjective assessment while others rest on a more stringent measurement of differential hand skill. Even within each of these two approaches the methods employed are by no means consistent from one author to another.

1.1.3 Subjective and objective measures of handedness

Preference questionnaires normally require the individual to list his preferences (right, left or either) for performing certain every-day activities. When questions are answered by the subject himself without observation by an experimenter then the method employed is, to a certain extent, a subjective one. The simplest subjective measure of handedness is a reply to the question: "Which hand do you write with?" or a simple typological classification such as "I am right-handed".

Performance tests which compare each hand quantitively on a given task provide a more objective measure. The distributions yielded by (a) preference questionnaire data and (b) performance test scores are of a different nature. (a) produces a typically J-shaped distribution, whether scores are determined by number of actions performed with the right hand (Annett, 1972) or by a laterality quotient based on 'right', 'left' and 'either' answers (Oldfield, 1971). (b) are typically normally distributed with the mean displaced to the right of zero (ambidexterity), when a measure of relative hand skill is used. (Annett, 1972; Woo and Pearson, 1927).

Difficulties and inadequacies arising from the use of different tests of handedness are pointed out by Annett (1970) and by Bannatyne (1968) who remarks that most existing laterality tests are inadequately measuring a complex set of heterogeneous variables which call for 'a much more detailed examination in terms of function.' To discover adequate handedness measures we might consider the more general aspects of motor and psychological development in which handedness is grounded (Palmer, 1964). Palmer suggests that such factors as family handedness and change of handedness in childhood should be taken into consideration in addition to observed or reported handedness. Experimentation has confirmed that familial handedness may indeed be an important variable in the categorisation of left-handers (see, for example Bryden, 1965).

1.1.4 Distinction of handedness

Handedness is not truly represented by discrete categories such as Right, Left or Either, but is better considered as a continuum with 'consistent right', and 'consistent left' as the two poles between which all individuals are placed. Most handedness questionnaires will differ slightly in their placement of individuals into categories, the critical scores by which individuals fall into one or other of the categories being determined solely by the experimenter. Any theory of 'absolute laterality' (distinct categories) rests therefore to a large extent on subjective assessment.

In a similar fashion, if results from performance tests are thought to best represent the spread of handedness, there are no valid grounds for segmenting any resultant distribution into discrete categories (although 'right' and 'left' are often employed to distinguish subjects with better right-handed scores from those with better left-handed scores). Woo and Pearson (1927) contest that hand-grip strength constitutes a true test of handedness and that the normal distribution of scores on this test contradicts any absolute laterality theory.

As will become apparent at a later stage, however, it is often advantageous to study different regions of a distribution while still recognising a continuum to be the true picture of events. In doing this, consistent and intelligible criteria for classification must be sought (Annett, 1970). Various classifications of handedness have been employed by different authors up to date: subjects can be classified as Right, Left, Mixed

(Annett, 1964) as Strong Right, Moderate Right, Mixed, Moderate Left or Strong Left (Harris, 1957), or can be distinguished as Consistent Right/ Left or Inconsistent. Palmer (1964) draws finer distinctions between left-handers, ambilateral (lack of differentiation of hand preference) and ambidextrous (high grade skill with both hands) subjects. His general distinction of differentiated/undifferentiated compares with that of consistent/inconsistent handers.

The two basic variations in the categorisation of handedness may be represented as:

(i) a Right - Mixed - Left-handed classification, and

(ii) a similar classification without reference to the direction of handedness, that is a simple Consistent - Inconsistent distinction.

1.1.5 Eye, ear and foot laterality

The best documented modality preference other than handedness is that of the eye. It is generally assumed that at least right-handedness and right eye dominance are closely related, while recent results show ear dominance to be more closely associated with handedness (Touwen, 1972).

Although causal relationships between modality preferences are rarely hypothesised, Parson (1924) suggests that eyedness may be the cause with handedness the effect. Goldberg and Schiffman (1972) also see man as primarily right or left-eyed and only secondarily right or left-handed. Such theories may be encouraged by the greater incidence (Goldberg and Schiffman - 30%) of left-eyedness than left-handedness (less than 10%). There are also approximately one third of all right-handers who are not right-eyed (see Annett, 1967).

Tests which have been used as measures of eye preference include observation of eye preferred for monocular sighting and aiming (Parson, 1924; Harris, 1957; Berman, 1971) and for looking through a telescope (Harris, Berman). Tests of visual acuity and of the dominant eye in binocular sighting have also been employed as eye dominance measures (Woo and Pearson, 1927; Berman, 1971). A further measure, tachistoscopic visual hemi-field preference appears to be related to Cerebral Dominance rather than to occular dominance, in that it is dependent on the type of stimuls projected (eg verbal or non-verbal). This will be discussed in Chapters 2 and 3.

Tests of ear preference, which are rarely used, may involve observing with which ear the subject listens to a centrally placed watch or radio. This is normally only employed with children (Newton, 1974; Berman, 1971). Dichotic listening tests, used to detect the superior recall of one ear when material is presented simultaneously to both ears, tend, as with tachistoscopic tests, to be reported as measures of Cerebral Dominance rather than of ear dominance. Right or left ear superiority appears to depend on the type of stimulus used. (Again see Chapters 2 and 3)

Simple tests of foot preference usually involve observation of either kicking, stamping or stepping (first foot forward) (Harris, 1957; Hanvik and Kaste, 1973; Berman, 1971). More elaborate measures do not appear to exist.

1.2 Development of handedness

While hand preference can be assumed to manifest itself at some time after birth, very young infants are often described as demonstrating symmetrical movements of arms and legs, showing no consistent preference for right or left (Washburn, 1929). The distinction then arises between (a) the age at which handedness emerges and (b) the age at which this pattern of handedness becomes established for life.

In keeping with general maturational trends it is commonly assumed that handedness develops earlier in females than in males (Goldberg and Schiffman, 1972). A study by Cohen (1966), however, fails to confirm this. Cohen obtained simple handedness scores for eight-month old infants - if the infant grasped objects placed before him consistently with one hand then he was described as possessing a preferred hand (left or right). These scores were then related to the developmental status of the infants as measured by the Bayley Mental Development scales. Babies classed as 'developmentally advanced' demonstrated a greater abundance of hand preference (92.3%) compared to 'normal' (45.2%) or 'suspect' (50.0%). A secondary finding was that sex and hand preference were not significantly related in this group of infants.

Further to this, Palmer (1964) suggests that the roots of handedness may lie in general motor development, and that the same initial influences operate over both aspects of development. Genetic, pre-natal and early environmental factors may all contribute to the emergence of a given handedness or laterality pattern in the individual. Handedness is envisaged therefore, as a process of gradual differentiation of function and of greater 'hierarchic integration' rather than as an absolute acquired or inherited phenomenon.

Since inconsistent hand preference is frequently observed in the early stages of a child's development (about 55% of 'normals' in Cohen's study were inconsistent) mixed hand preference in later life is often interpreted as a sign of developmental immaturity (Sand and Taylor, 1973). An alternative explanation seeks to demonstrate the class of mixed handers as representing a basic biological variant along with right and left handers (Annett, 1964), although as stated in section 1.1.4 such a class may not represent a truly discrete category. The latter explanation is more appealing in that distributions of hand dominance (on performance tests) are found to be normal in nature, while frequencies of right, mixed and left handers do not change noticeably after early childhood.

1.2.1 Age at which handedness is established

Various experiments involving the use of a dynamometer to measure hand strength have demonstrated that neither the size of hand difference nor the distribution of such differences varies over the age range 6 to 80 years (Annett, 1972). Annett (1970) demonstrated that school-children ranging in age from 5 to 15 years do not differ significantly with respect to age on a task involving right-left differences of manual speed. Such differences tend to remain fairly constant throughout the age range, and, indeed, compare with those of an undergraduate population sample.

The instances cited above support the notion that handedness is established by age 5 or 6. A modification of this theory is supplied by Belmont and Birch (1963), who studied normal children aged from 5 to $12\frac{1}{2}$ years. The children were given a handedness test comprising of throwing a ball, turning a door knob, cutting with scissors and writing. A classification of 'right' ('left') was used if all four items were performed with the right (left) hand, all remaining children being 'mixed'. The conclusion reached from this investigation is that not until the tenth year of life does a high level of consistency in preferential hand usage become established, although preference may appear to be established at age 5.

1.2.2 How does handedness change with age?

Weintraub (1968) claims that in all populations (including the educationally retarded) hand preference becomes better established with age. The individual stages of such a development may, however, be quite complex.

The study by Belmont and Birch reveals the possible nature of this complexity. They looked at the incidence of consistent and inconsistent handedness in children and discovered that mixed handedness was found to be relatively stable at age 5 and at ages over 9 (0-11%), but was much more prominent (15-28%) at ages 6, 7 and 8. A significant difference was found between the younger (9-) and older (9+) children with respect to incidence of mixed handedness. These results conform to observations of Gesell and Ames (1947) that preferential hand usage is subject to 'peaks and troughs' with unilaterality firmly established only at age 8, and perhaps further implications might be considered with regard to the intensive learning (reading) processes which the child of 6-8 years must face.

Harris (1957) found a steadier decline in mixed handedness with age. Proportions of his clinical sample of mixed handers decreased from 37% to 12% in children aged 7 to 11 years, while an unselected sample of children progressed with age to greater right-handed proportions.

Sand and Taylor (1973) found that within the three age groups, 10-14 years, 15-19 years and 6-19 years, observed and predicted frequencies of handedness differed significantly. However, while mixed handedness tended to decrease significantly from age 6 to age 19 years, it was found in far greater excess in all adult subjects (aged 20-59 years). 'Left-handedness' did, however, decrease from the children to the adults (approximately 8.5% down to 3%).

Kovac (1973) discovered a remarkably similar decline in left-handers (approximately 8.5% compared to 2.25%) from age 8/9 to age 18/19.

Further support for the alternative (to Harris') hypothesis that mixed handedness actually increases with age, while left handedness decreases, comes from Annett (1964) and Annett and Turner (1974) who compared groups of children under 8 years (5-8) and over 8 years (8-11). The percentage of mixed handers rose from 43 in the younger group to 50 in the older group.

1.2.3 Development of eye and foot preferences

Harris (1957) found that both eyedness and footedness, unlike handedness, do not become better lateralised with age. Belmont and Birch (1963) also failed to detect a relationship between age and preferred foot, while a detailed analysis by Kovac (1973) yielded little more information. Although an increase with age in the frequency of 'moderate' right-footedness is noted, there is a corresponding slight decrease in 'Pronounced' left-footedness. Certain insignificant trends towards greater mixed footedness with age also emerge.

Kovac, with the same subjects as above discovered that left-eyedness increased with age, while Belmont and Birch revealed, unlike Harris, a non-significant increase in both left and right eyedness from age 10. A resulting decline in the numbers of crossed (eye and hand) lateral children was also found.

Measures of modality preference other than handedness are so varied that it is hardly surprising that little agreement or relevance is found in any studies concerned with the development of such preferences,

1.3 Measures of handedness

1.3.1 Preference questionnaires

Preference questionnaires represent the easiest and cheapest method of measuring degree of handedness. They are also the measures most readily applicable to large numbers of subjects (Kovac, 1973).

In general, such questionnaires can be answered individually without the need for an observer or experimenter. When dealing with children, however, group tests are more common, where the teacher or observer notes which hand the child uses in manipulating relevant objects (Ingram, 1959; Gates and Bond, 1936; Gordon, 1921; Harris, 1957).

A self-report ("I am right-handed") represents the most common measure of absolute handedness and, together with more discriminating questionnaires, often assumes that a reliable estimate of differential manual skills has been obtained (Satz, Aschenback and Fennell, 1967). Can such an assumption be made?

Palmer (1964) rejects the above assumption, since a preference questionnaire reflects consistency of handedness and is not a behavioural measure of differences in hand skill. Further comparison between questionnaires and tests of manual skill is made in Chapter 1.3.2.4.

1.3.1.1 Examples of questionnaires

Annett (1967) devised two questionnaires with the aim of obtaining a large number of responses from various population samples. Completed forms were returned either by hand or by post.

Answers of 'Right', 'Left' or 'Either' were required to the question: "Which hand do you habitually use for each of the following activities?" To the eight activities of the first questionnaire were added four extra items to create the best possibility for the differentiation of mixed from consistent handers. These four items were: dealing cards, hammering a nail, cleaning teeth and unscrewing the lid of a jar, while the original eight items consisted of writing, throwing, using a racket, sweeping (upper hand on broom), striking a match, using scissors and threading a needle.

The 12-item questionnaire was then used on subsequent occasions.

Provins and Cunliffe (1972a, 1972b) invented a 31-item questionnaire to discriminate strong right-handed from strong left-handed subjects. Subjects were required to answer 'right', 'left', or 'either' to each question.

Harris (1957 and see Olson, 1973) required the same response to each of ten questions - writing, throwing, rubbing out, combing hair, brushing teeth, opening a door, hammering a nail, cutting with a knife, using scissors and winding a watch. However, since his questionnaire was designed primarily for children, instructions were included for the observation of mimed activities by an examiner.

Kovac (1973) set up two forms of an O.L.P. (Orientation in Lateral Preference) scale, designed for individual and group assessment. In addition to preference items, sections are included on education, parental occupation and handedness, physical and functional disorders and development of handedness.

Thirty-eight unspecified items comprise an inventory of hand, eye, foot and ear preferences. Subjects' answers are coded as 'R', 'r', 'o' 'l' 'L' which represent the subjects' opinion of relative preference strength. This measure of handedness is also used by Arbet (1973) in another study.

Crovitz and Zener (1962, see Crovitz, 1973) also used a 5-point classification with a 14-item test for assessing hand dominance. The items included were writing, hammering, throwing, unscrewing a lid, drawing, peeling a potato, holding a pouring jug, using scissors, cutting with a knife, threading a needle, holding a drinking glass, cleaning teeth, wiping with a duster and using a racket. The subject is required to ring which of six choices he considers most appropriate for each item ("imagine yourself performing the activity described"):

1. Ra (right hand always)
2. Rm (right hand most of the time)
3. E (both hands equally often)
4. Lm (left hand most of the time)
5. La (left hand always)
6. X (don't know which hand)

The Edinburgh Inventory of Handedness, devised by Oldfield (1971) and used by others (McKeever, Deventer and Suberi, 1973; Raczkowski, Kalat and Nebes, 1974), represents much exploratory work in the choice of test items. As in other tests, subjects have a choice of five responses to each item of the inventory, although the method of answering is different. Here the subject must place, in the appropriate column - 'right' or 'left' - either

(a) a single + to indicate preference in the use of a hand

(b) a double ++ "where preference is so strong that you would never try to use the other hand unless absolutely forced to."

(c) a + in each column "where you are really indifferent."

The ten items used by Oldfield are: writing, drawing, throwing, using scissors, using a toothbrush, a spoon, a broom (upper hand), striking a match and opening a box lid. The inventory, like that of Annett, is designed for use with large numbers of subjects who fill in and return the forms themselves.

The more appealing visual format of this questionnaire and possible responses to it may attract subjects to respond using all possible alternatives, thus leading to a more 'left-handed' distribution of scores than on other questionnaires.

1.3.1.2 Unimanual performance tasks

Very often small batteries of items, similar to those found in preference questionnaires, are used as practical tests with children and sometimes with adults (Raczkowski et al, 1974). The child may, for example, be required to throw a ball, point at an object, draw a design, write a word and cut with scissors (Woody and Phillips, 1934). The classification of the subject would then be decided by how many of the actions were performed with one hand (see Gates and Bond, 1936). Alternatively the responses could be entered on a preference questionnaire form and a classification determined from the pattern of responses (see Harris, 1957). Complex scores could be obtained by either having the child mime or perform a larger number of items (for example, 10 items - see Harris) or presenting a small number of common activities for the child to perform two or three times each. For example, Ingram (1951) observed which hand the child used for turning a door handle, breaking a stick, throwing and catching a ball, each three times.

Although the relationship between observation of simple activities and self-report of preference is not a perfect one, the high correlation (0.95) suggested by Benton (1962) indicates that the two procedures may often be safely interchangeable.

Berman (1971) constructed a thirty-item questionnaire, termed an I.C.D. (Index of Cerebral Dominance), which included items of hand, foot, eye and ear preference. The test battery is supposed to delineate finely between subjects with respect to overall dominance, and involves as one item a pegboard test, a performance measure of relative dexterity. The thirty items were administered by a psychologist to children of all levels of intelligence, including two groups of brain-damaged subjects.

1.3.1.3 Scoring and classification

Annett (1967, see also 1970, 1972) suggests a two-fold classification of subjects. First, on a 13-point scale, subjects can be ranked according to how many of 12 items are performed with the right (or left) hand. Secondly, subjects can be placed into categories 'Right', 'Mixed' and 'Left' according to the following criteria:

Right : subjects using the left hand for none of the 12 items

Left : subjects using the right hand for none of the 12 items

Mixed : subjects reporting a mixture of right and left preferences.

'Either' responses alone are not considered sufficient for 'mixed' classification and do not detract from 'right' or 'left' classifications. Thus, as has happened in the writer's experience, when a subject answers 'right' to only three items and 'either' to the remaining nine items, he is classified as right-handed, while professing, with some apparent justification, to be ambidextrous.

Annett's 'mixed' classification may, however, be intended to refer to specifically mixed (using right hand for some activities and left hand for others) rather than equal (using right or left hand for individual activities) use of hands, but nonetheless little margin for error appears to be allowed in respect of correct classification, when only one inconsistent reply renders the subject 'mixed-handed'.

Authors who base classification not on patterns of response but on segmentation of a Laterality Quotient Score (Oldfield, 1971) do not distinguish in this way between 'mixed' and 'ambidextrous' subjects. For example, Harris (1957) computes a simple Laterality Quotient Score for his ten items by scoring 10 for each 'R' answer, 5 for each 'E' answer and 0 for each 'L' answer. Thus quotients range from 0 (totally left-handed)to 100 (totally right-handed). A score of 50 may be comprised of 10 'E's (ambidexterity), 5 "R's and 5 'L's (mixed handed) or any other combination of answers yielding this score. Classification of subjects is then made according to the scale (a) below:

(a) Harris

R = 100
r = 75 - 95
M = 30 - 70
l = 5 - 25
L = 0

Crovitz and Zener (1962) also score for each answer, see table (b) below,

(b) Crovitz and Zener

Ra	= 1
Rm	= 2
E	= 3
Lm	= 4
La	= 5

and arrive at handedness scores ranging from 14 (strong right-handed) to 70 (strong left-handed) over 14 items.

A similar procedure is adopted by Kovac (1973) who converts resultant scores into percentages ranging from -100% (strong left-handed) to +100% (strong right-handed). This approach bears similarities to the procedure used by Annett in that 'either' answers "add to the predominant trend in lateral preference" rather than detract from it. Kovac scores as in table (c) below.

(c) Kovac

-3	for an 'L' response
-2	for an 'l' response
-1 or +1	for an 'e' response
+2	for an 'r' response
+3	for an 'R' response

The score for 'e' responses becomes -1 if the subject tends to be sinistral overall and +1 if he or she is predominantly right-handed.

Oldfield (1971) uses a Laterality Quotient (L.Q.) to rank subjects on his inventory. The L.Q. is calculated as:

$$100 \quad x \quad \frac{\sum_{i=1}^{10} X(i,R) - \sum_{i=1}^{10} X(i,L)}{\sum_{i=1}^{10} X(i,R) + \sum_{i=1}^{10} X(i,L)}$$

where X(i,R) is the number of +'s for the i^{th} item in the 'right' column, and X(i,L), similarly, for +'s in the 'left' column. This formula is a variation of the simple one used by Provins and Cunliffe (1972):

$$100 \times \frac{R - L}{R + L + E}$$

where R, L, and E refer to the number of 'right', 'left' and 'either' response respectively. Again subjects are placed on a scale ranging from -100% to +100%.

1.3.1.4 Results obtained from Preference Questionnaires

Apart from the J-shaped distribution of individual scores (Annett, 1972; Oldfield, 1971; Crovitz and Zener, 1962) interest also lies in the frequency of occurrence of right, mixed and left-handers.

On the basis of a simple genetic model, Annett (1964, 1967) expected to obtain right, mixed and left-handers in the proportions 64%, 32% and 4% respectively. In none of seven different population samples did the observed and predicted frequencies differ significantly:

	RIGHT	MIXED	LEFT
Total observed	827	352	47
Expected numbers	784.64	392.32	49.04

Ingram (1951) studied speech-defective and normal children using a simple measure of handedness. Children were classed as strongly lateralised if at least 9 (out of 12) activities were performed with the same hand. Due to diverging methodological approaches and widely discrepant age-groups it is not surprising that Ingram's figures differ from those of Annett. For 200 normal children aged 4-7 years, results were:

Right	78%
Not strongly lateralised	14%
Left	8%

Gates and Bond (1936) using a even simpler grade of classification (all 5 tasks performed with the same hand constituted consistent handedness) found the following frequencies among a group of 65 normal children (average age $8\frac{1}{2}$):

Right	89%
Mixed	6%
Left	3%

Oldfield (1971) divided scores into two groups: right and left-handed, where a positive L.Q. indicates a right-hander, and a negative L.Q. a left-hander. His figures, which unlike those of Annett show striking sex differences, are as follows:

	L.Q. +	L.Q. -
Males	360	40 (10.0%)
Females	667	42 (5.92%)

Subjects in general tended to underestimate degree of departure from strong right-handedness. For example, of those subjects who scored between +31 and +41 L.Q., which represents a considerable deviation from truly right-handed behaviour, only about 50% admitted some tendency towards left-handedness.

Crovitz and Zener (1962) also noted a sizeable overlap in L.Q. scores for self-confessed right-handers (score 14-44) and self-confessed left-handers (score 23-70). Again, more inconsistency was found in the latter group, distributed over 48 points of the L.Q. scale compared to 31 points in the group of self-confessed dextrals. The relationship found between confessed and test-rated handedness can be seen more clearly from the following table.

	Handedness by self-report	
Test Scores	RIGHT	LEFT
14-20	67%	0%
21-30	31%	2%
31-40	2%	8%
41-50	0%	15%
51-60	0%	35%
61-70	0%	40%

Kovac (1973) presents a table for the 'frequency response analysis in self-judgement of overall handedness'. This table displays age and sex as separate factors, and a summary of the data is presented here:

	Self-classification				
	R	r	o	l	L
Males	66-76%	13-24%	2-6%	1-2%	0-2%
Females	72-77%	14-20%	2-6%	0-3%	0-1%

These figures differ considerably from those expected by Touwen (1972), thus further demonstrating the discrepancies to be anticipated from diverging techniques in assessing handedness. Touwen claims the expected frequencies of handedness to be:

Purely right-handed	25%
Predominantly right-handed	33%
Mixed	25%
Predominantly left-handed	17%
Purely left-handed	1%

It is, however, not abundantly clear to whom these figures are attributable or by what rationale they are produced.

From the above selection of results from preference questionnaires it can be quickly ascertained that, apart from detecting only a small minority of left-handers, there is little obvious agreement on frequencies of right, mixed and left-handers. Oldfield's figures of approximately 6% (females) and 10% (males) left-handers represent the clearest and possibly the most accurate estimate of sinistrality where strength of left-handedness is not considered.

1.3.1.5 Item analysis and rationale

It is assumed that man is conscious of his lateral preferences and is thus able to give information about them (Kovac, 1973). Further, we must ask of the subject who fill in a preference questionnaire:

1. Does he really use the hand he says he does?
2. Does he have an accurate memory?
3. Is a halo-effect being produced? i.e. does the subject tend to answer items in the same way, rather than treating each item individually? (Raczkowski et al 1974)

Such problems represent one aspect for consideration when questionnaires are being developed. Apart from the subject's approach to the test much can be done to ensure that the items selected are those most likely to give a true representation of hand preference.

Raczkowski et al (1974) see the need for items which true left-handers may often perform with their right hand. This need to seek qualitative distinctions not only between left-handers, but between all subjects is recognised by Oldfield (1971) who claims that items for his inventory should be chosen not only as a result of quantitative analysis but also for the requirements of qualitative portrayal.

The same hand may invariably be used for two (or more) activities, for example writing and drawing, thus creating a case for omitting one as redundant from the questionnaire. If, however, individual profiles of handedness are of particular interest, then it may be desirous to retain both items in order to spot the very few 'odd men out' who employ different hands for each task.

Oldfield refers to difficulties associated with item selection as:

1. The weighting of items: are some more important than others? (in general, items are not weighted)
2. The redundancy of items: do certain items usually produce identical responses? If so, should some be deleted?
3. Fair sample of questions: how do we know that the best or most valid items have been selected from every-day experience?

In general it would seem that a questionnaire of some 10 or 12 items is favoured where items are carefully selected both on analytic and subjective grounds. While certain authors (Berman, 1973; Kovac, 1973; Provins and Cunliffe, 1972a and 1972b) may feel it better to include a large number of novel items the general trend (Touwen 1972, Oldfield 1971) is to believe that confusion increases with the number of test items.

Items should take account of cross-cultural and sex-differences (Oldfield), making it as easy as possible for all members of the required population to fill in the same questionnaire. Few females have had much experience of digging with a spade (see Annett, 1967) although most males may know how they sweep with a broom!

Other items may require justification for inclusion on different grounds. Opening a door (see Harris 1957 and others) may depend to a large extent on the position and movement (inward and outward) of the door, while threading a needle may also depend on which eye is dominant (following the thread through with the eye).

Oldfield (1971) performed a correlational analysis on his inventory items and discovered that while throwing is possibly a good single indicator of handedness (relates closely to L.Q. score), dealing cards is performed with the left hand by a surprising number of right-handers (and does not relate closely to L.Q.). Oldfield omits this last item - dealing cards - from his inventory, although others (see Annett, 1967) retain it. The question remains open: are we discovering something essentially interesting about a right-hander who perform s actions such as dealing cards with his left hand? Has this subject a left-handed tendency or is this result a product of the task itself? Certainly by including such items finer distinctions of (right) handedness <u>will</u> emerge.

Annett (1970) subjected her data to an association analysis and observes the various profiles of handedness which emerge. She also found that dealing cards was the action performed most often with the left hand (17.02%) (compared with writing - 10.60%). Six items were highly associated with all others: writing, throwing, striking a match, hammering, using a racket and cleaning teeth, and in fact hammering proves to be the item with the highest sum of associations with other questions, while unscrewing a jar has the least.

A table is presented below which reveals the items with the highest frequency of occurrence in the questionnaires of Annett (1967), Provins and Cunliffe (1972), Harris (1957), Crovitz and Zener (1967), Oldfield (1971) and Berman (1971). Those items occurring in at least 3 of the 6 questionnaires are included. The total number of different items used is 41.

Frequency	3	4	5	6
	unscrew lid sweep with broom strike match	use racket brush teeth cut with knife drawing	hammer nail	writing throwing ball using scissors

Finally, it is interesting to note a small study by Bannatyne (1968) which demonstrated that items of 'learned' and 'unlearned' handedness are not significantly correlated. With such items as folding or clasping hands we may be measuring different laterality functions than with such learned items as writing and clapping. Although learned and unlearned aspects of tasks do not appear clearly distinguishable, they must clearly be taken into account in any notions of validity of preference questionnaires.

1.3.1.6 Reliability and validity of questionnaires

Annett (1967) used two questionnaires on different samples and found similar distributions of handedness frequencies in both cases. This suggests that the expected distribution was not an artifact of the experimental situation but was in fact being validly measured by the questionnaires.

With 23 items adapted from Hull and Oldfield questionnaires, Raczkowski et al (1974) tested 47 subjects on two occasions a month apart. Subjects were presented with the first questionnaire (Q1) then a later questionnaire (Q2) involving the same items, and immediately prior to Q2 performance test (T) with observation of the questionnaire activities by an examiner. The results show good reliability (Q1 - Q2) and validity (Q1 - T) while also indicating the greater inconsistency of left-handers:

	percentage disagreement of test items	
	Q1 - T	Q1 - Q2
Right-handers	6.6	4.2
Left-handers	10.2	11.2

Using a split-half technique Harris (1957) found a co-efficient of contingency of 0.74 and a Spearman co-efficient of 0.85 for his handedness tests. General problems are envisaged in the reliability testing of questionnaires since one performance probably alters the nature of performance on a re-test. Also, correlational methods assuming a normal distribution cannot be employed with the J-shaped distribution obtained from handedness scores.

Harris proposes three criteria of validity:

1. Are the content and nature of the tests appropriate for the purpose for which they were intended?
2. Do the tests compare favourably with other measures of the same characteristics?
3. Do the tests differentiate groups known to be different in the relevant characteristics?

Such questions are thought to remain largely unanswered due to the lack of knowledge of the underlying nature of handedness.

1.3.1.7 Distribution of eye, ear and foot preferences

Using a group test of binocular sighting, Crovitz and Zener (1962) discovered 18.3% of subjects to be ambiguous with respect to eyedness (less than 6 out of 8 trials consistent). No indication is given of right/left-eyed ratios.

Ingram (1959) used two tests of eye dominance in a clinical study with children. These two tests, telescope sighting and sighting through a hole in a card, were each performed three times. A child was classed as 'right' or 'left', if he showed consistent eye preference on at least 5 of the 6 trials. The ratio of right and left eye preference can be seen in the table below. Results for foot preference were obtained in similar fashion using kicking and stepping with leading foot as the two measures:

	Preference	
	eye	foot
Right	75%	76%
Left	4%	10%
Not strongly lateralised	21%	14%

Results from Kovac's O.L.P. tests produced the following results in terms of distributions of eye, ear and foot preferences (10-19 years old):

	Preference		
	eye	foot	ear
Right	16%	61%	9%
r	7%	19%	5%
o	65%	10%	76%
l	3%	3%	2%
Left	4%	4%	4%

As previously mentioned, these are results of self-assessment questionnaires the exact details of which are not given. From the results available the measures do not appear to be very discriminative, failing to distinguish amongst the large majority (65% and 76%) having mixed eye and ear preference.

1.3.2 Performance tests of handedness

If, as Provins (1967) maintains, "handedness is simply attained by the development of motor skill, in as much as the potential to acquire skill would be expected to be equal on the two sides - at least initially", then by studying the performance of hands on motor tasks and bearing in mind the experience and training of the subject, a better understanding of handedness might be reached.

When each hand is required alternately to perform a given uni-manual function scores of relative right or left hand superiority can be obtained. Such scores might simply be expressed in terms of difference in performance between the hands (Annett 1967, Wood and Pearson 1927, Benton 1962) or by a ratio measure - r/l for right hand superiority and l/r for left hand superiority. An alternative measure is represented by the ratio of hand difference to total performance, i.e. (r-1)/(r+1) (Satz et al, 1967). Finally the difference between hand performance can be assessed on subjective grounds, where quality of performance is judged according to pre-set criteria (Benton, 1962).

1.3.2.1 Performance items

The use of simple performance items is exemplified by Benton (1962) and Benton, Myers and Polder (1962) who required subjects to cut lengths of paper with scissors, first along a straight line and secondly along a wavy line. The quality of each performance was rated by judges on a 7-point scale from which measures of relative hand superiority could be assessed. A second measure involving length of time to complete the task was used for each hand.

Marcel et al (1974) used an even simpler task. Subjects were asked to draw a circle and to then repeat the performance with the other hand. First choice (right or left) hand and superiority in skill were noted and used as classifications of handedness.

Tests involving the manipulation of pegs from one location to another are commonly employed to assess handedness. Benton et al (1962) used Crawford's Small Parts Dexterity test, in which the subject is required to pick up small pins with a tweezer, place them in holes and then pick up and place a small metal collar on the pin. Such a test involves fine co-ordination of finger and hand movements in addition to control of arm movements. The Small Parts test was also used by Satz et al (1967) as part of a battery of tests to assess manual strength and dexterity.

Trieschman (1968) used both a large and a small pegs test: in the first instance subjects moved ten large pegs from one hole to an adjoining one, while in the second test ten nails were picked up and placed in adjoining holes. An additional steadiness measure was calculated by measuring the total contact time between the sides of a small hole and a stylus held in the hole, away from the sides, by the subject.

Annett (1970) devised a task similar to that of Trieschman, which she employed as a single measure of manual speed. Her test involved the movement of ten dowelling pegs from a row of holes (½" in diameter, 1" apart) to another row 8" below. The test was timed and performed by each hand in turn, half the subjects beginning with the left hand and half with the right hand.

Tests of hand-grip strength (using a dynamometer) are often used to gauge relative hand performance. Woo and Pearson (1927) completed a major study with nearly 5,000 subjects employing this technique. They concluded that:

"grip difference really does closely indicate the total number of manual sinistrals in the population, and that no correction is needful here as when handedness is determined by verbal inquiry." p.180

- a suggestion refuted by Satz et al (1967) who might claim that unwarranted uniqueness is placed on the dynamometer test as the one true test of handedness. They demonstrated that left-handers perform very ambiguously on this task, showing no clear or consistent left hand dominance. A-priori there seems to be no reason why hand-grip strength should represent a unique and accurate measure of overall handedness, since fine motor control would appear to be at least an equally important aspect of handedness, one which is ignored in such a test.

An index of handedness can be calculated from the use of a number of performance tests on the same subjects. Such a battery was employed by Satz et al (1967) who subjected 54 self-classified left-handers and 69 self-classified right-handers to three tests:

1. Two trials with each hand on a dynamometer, the averages of which were computed and a mean right-left difference score obtained.
2. A finger-oscillation tapping test, in which the number of finger taps on a key were counted over three trials of 10 seconds.
3. The Crawford's Small Parts Dexterity Test.

Provins and Cunliffe (1972a, b) employed a larger battery of seven motor performance tests of handedness. These were:

1. Dexterity - Crawford's Small Parts Dexterity Test
2. Handwriting - timed writing of the alphabet with each hand
3. Darts - throwing 10 darts at a target with each hand
4. Tapping - two trials of tapping a key for ten seconds (each hand)
5. Ratchet - number of turns made in each of two five-second periods with a football-type rattle held in each hand alternately.
6. Hand-grip strength - three attempts with each hand (Dynamometer)
7. Grip-strength endurance - length of time a grip of 80% (maximum on test, 6) could be maintained.

Knowledge of results was given to subjects after each trial, and the tests were administered to subjects in the same order (1-7) for each, half starting with the left hand and half with the right.

Finally, a small study by Syed (1973) suggests a very simple test of handedness. If a subject is asked to separate jointly his second and third fingers as far as possible from his fourth and fifth fingers, a measurement can be made at the point of maximum separation. Simple analysis on a small number of results demonstrates that the measurement is greater in the non-preferred hand. No possible explanations are given but wide-ranging medical implications are envisaged for such a test - to detect strokes and 'aid in the diagnosis of psychiatric problems'. However, the notion of preferred hand still has to be explained!

1.3.2.2 Reliability and correlation of performance items

In general only low correlations are to be found between (relative hand) performance scores on different tests. Strong preference on a practised task may well not be related to strong preference on a more simple and novel task (Provins, 1967).

A relationship is found, however, between separate hand performances on one task. Good performance with the preferred hand will in general be accompanied by good performance with the non-preferred hand. Provins and Cunliffe (1972a) aimed to determine the consistency of performances of both preferred and non-preferred hands on seven motor tests. The tests were administered to 20 subjects on two occasions at least three days apart. Product-moment test-retest correlations were carried out for each task and each hand, demonstrating high reliability ($p<0.01$) for the preferred hand for all tasks except one (grip-endurance). Results for the non-preferred hand show less reliability although four of the seven tests still have r values significant at the 1% level.

The tests of handwriting demonstrated the greatest consistency from one test session to the next, and is claimed to represent in some ways the best single measure of handedness. (Note also that it is probably the most practised.)

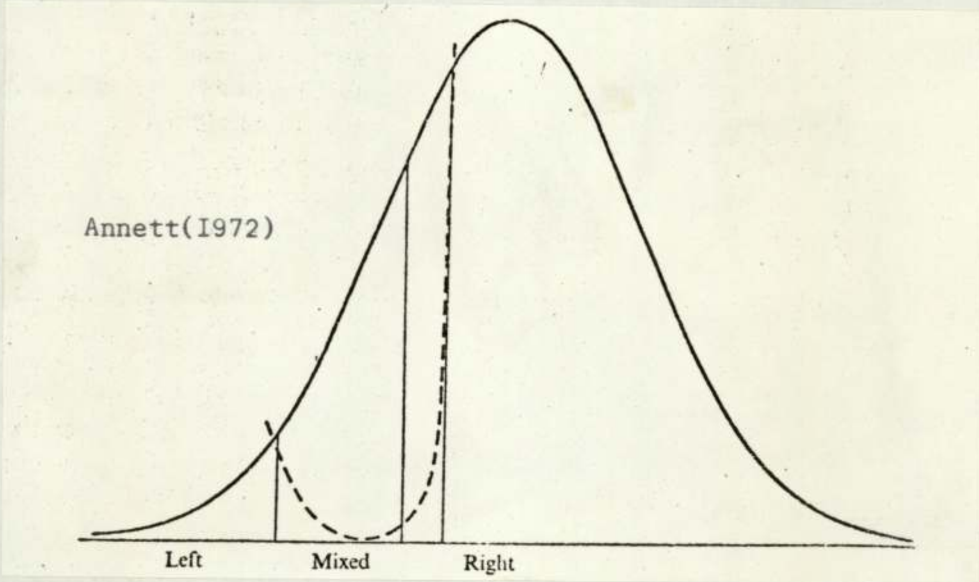
Although Provins and Cunliffe conclude that the degree of preferred hand superiority varies from task to task, and from performance to performance, their figures are based on simple 'r-l' (right-left difference) scores and do not reflect the relative superiority of hands (such as (r-l)/(r+l)) which may have yielded less inconsistent results.

1.3.2.3 Relationship between performance tests and preference questionnaires

If all handedness tests are presuming to measure one common underlying variable, then some degree of correlation would undoubtedly be expected between results from performance tests and results from preference questionnaires. The extent of such a relationship will depend partly on the accuracy with which such tests can measure relative <u>degrees</u> of handedness, especially amongst the majority of the population who fall in the right-hand sector of questionnaire rankings. Rating agreement for left-handers may be equally important, however, especially for clinical purposes (Raczkowski et al, 1974).

Bearing the desire for agreement in mind, Newcombe and Ratcliffe (1973) find it discouraging that conflicting reports exist as to the association between performance in dexterity tests and hand preference for familiar activities. (The writer, however, has failed to discover results that are conflicting to any great extent, since, in general, <u>some</u> positive relationship is found between results on the two types of measure.)

Annett (1972) proposes a theoretical relationship between these two aspects of handedness, based on her own work with questionnaires and peg-moving tasks. The distribution of all (male and female) scores on the manual speed test can be represented by a normal curve with the point of no difference between the hands 0.8z below the mean. If this point is taken to be best representative of those subjects classed as 'M' (mixed) by questionnaire then the projected relationship between the two distributions (questionnaire and manual speed) can be envisaged thus:

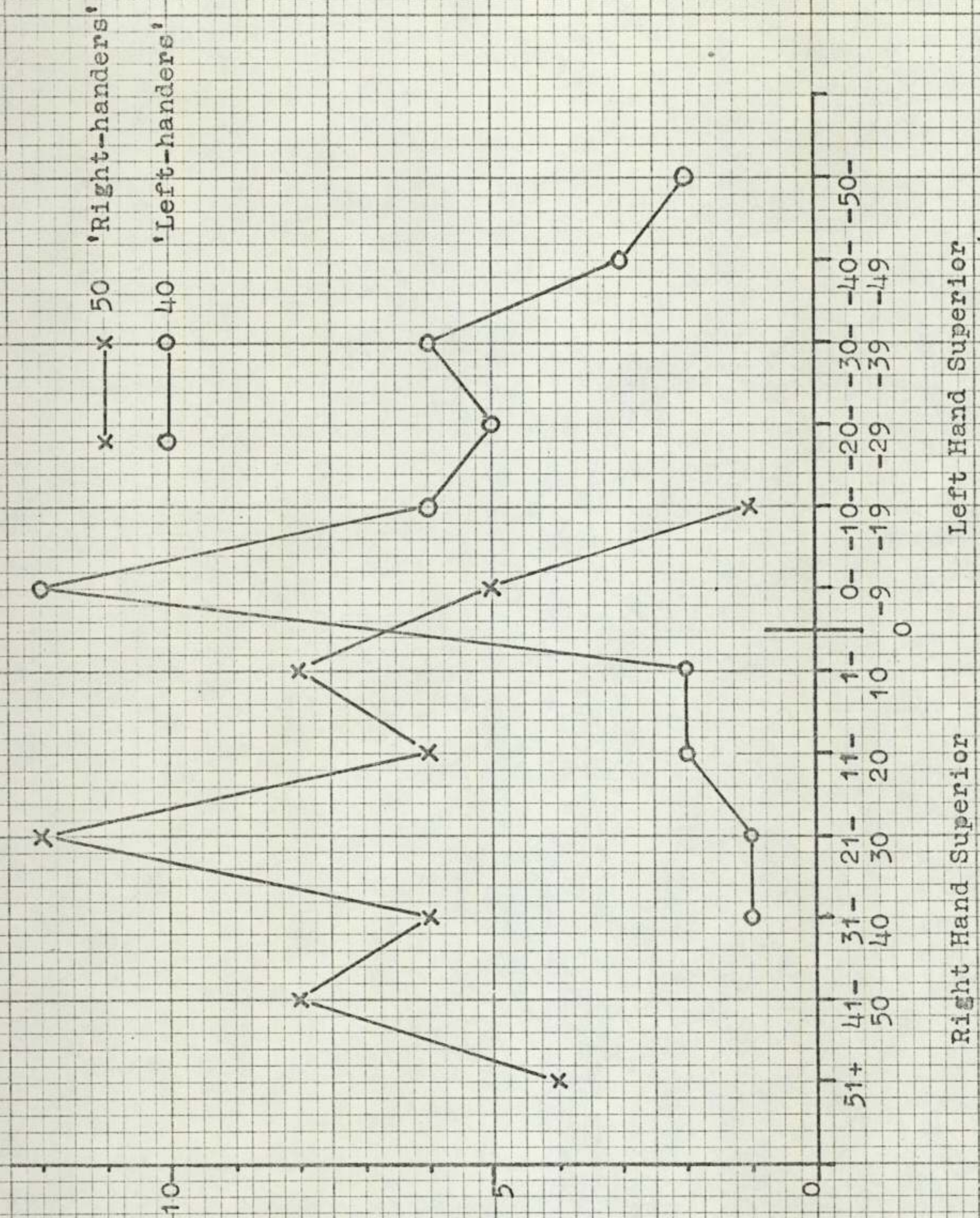


'the probably relationship between assymetry skill and the J-shaped preference distribution in man'

Benton (1962) compared 50 self-classified right-handers with 40 self-classified left-handers on the Small Parts Dexterity test. Using a performance score of mean difference between the hands, two points arose:

1. For the right-handed group: mean dexterity score of +25 but considerable variation of scores (12% equal or left dexterity scores).
2. For the left-handed group: mean dexterity score of -16 but individual variation in performance very pronounced (15% superiority with the right hand).

The margin of overlap between the two groups on performance scores can be seen in Figure 1.1.



A Comparison of Dexterity Scores for Self-classified Right and Left-handers (Benton 1962)

Figure I.I.

Elsewhere Benton et al (1962) set out to determine the degree of association between performance and hand preference scores. The two performance tests used were the Small Parts Dexterity Test and a scissor-cutting tasks (see Chapter 1.3.2.1). Subjects were required to class themselves as strongly or moderately right or left-handed and also to report which hand was employed for writing, cutting with scissors and using a screw-driver. The results show that 67% (44) of right-handers demonstrated right-hand superiority whi足e 55% (22) of left-handers showed clear left-hand superiority. If all subjects who scored +1 or more are classed as right-handed and all those scoring 0 or less as left-handed, then success in terms of correct right or left identification from performance scores can be seen from the following table:

Questionnaire Classification	Dexterity test	Scissors
All	86%	85%
Strong handers	91%	91%
Moderate handers	75%	69%

The scissors test results in 43% of left-handers being better with the right hand, and this may be due to the design of scissors for right-handed individuals.

Provins and Cunliffe (1972a, b) selected male subjects on a more stringent basis than in either of the two studies by Benton. On a 13-item questionnaire scores were obtained for each subject which lay between -1 and +1, using the formula $\frac{R-L}{R+L+E}$ (where R, L and E refer to the number of 'right', 'left', and 'either' answers respectively). The 10 'left-handed' subjects scored between -0.39 and -1, while the 10 right-handed subjects scored between +0.45 and +1. Subjects were also matched for age.

On each of the 7 tests (see 1.3.2.1) differences between preferred and non-preferred hands were highly significant. In addition a mean standardised score for the motor tests was correlated with questionnaire indices of handedness for all subjects, giving a value of 0.7. Similar comparisons of questionnaire assessment and performance scores are not carried out for individual tests.

Fifty-four self-classified left-handers and sixty-nine self-classified right-handers were subjected by Satz et al (1967) to tests of manual preference and to a battery of performance tests (see 1.3.2.1). Manual preference scores were obtained from a simple 10-item questionnaire (details of response procedure are not revealed). The resultant scores were derived by subtracting number of left hand preferences from number of right hand preferences.

Results from the performance tests, compared to questionnaire scores were as follows:

	Right-hand	Left-hand	Right-hand	Left-hand
	self-classified sinistrals		self-classified dextrals	
1. Grip	177.9	183.2	206.8	172.6
2. Tapping	49.3	52.1	55.8	49.8
3. Dexterity	18.1	19.4	18.1	15.3

No difference in mean scores on tests 1 and 2 was found between groups, while on test 3 the overall mean performance for sinistrals was significantly higher than that for dextrals. Greater functional asymmetry was demonstrated for dextrals over all three tasks, with left-handers showing far greater likelihood of performing better with the non-preferred hand on all three tasks. On the handedness questionnaire left-handers were also more prone to show a majority of right-hand preferences, than were right-handers to show a majority of left hand preferences.

Satz et al conclude that the most appropriate measure of handedness available to them is a composite score, compiled from standardised scores of all four tests (performance plus questionnaire), which will take into account both the degree and direction of manual laterality. The mean composite score is calculated as z = -0.33 (but it must be remembered that this is not an unselected sample with respect to handedness self-classification: mean z scores would tend to be lower for an unselected group).

Such a composite score would disguise discrepancies between performance scores and preference scores in any individual and rests on the assumption that it is possible to amalgamate the two sets of scores statistically. It may be preferrable to leave overall assessment in terms of a logical addition. That is, an ambidextrous subject is one who shows no difference between hands on performance tests and who shows a given balance of right and left preferences on a questionnaire. A subject showing right manual dominance and left hand preference is not ambidextrous or even mixed handed in the accepted sense.

Annett (1970) related questionnaire responses to performance on a test of manual speed (peg moving). Subjects choosing 11 (out of 11) 'right' or 'either' answers averaged 0.84 ($\pm$0.70) peg difference score, while those choosing 12 (out of 12) 'left' responses to questionnaire items average -0.89 ($\pm$0.53). Annett concludes that Strong right and left handers (classified by questionnaire) emerge as equal and opposite on the performance test, although self-styled left-handers proved to be less consistent than self-styled right-handers. Confirming previous reports of inconsistency among self-classified left-handers, some individuals claiming sinistral tendencies were found to be more dextral on the manual speed test than some dextrals. This agrees with the results of Benton (1962) who makes a more radical suggestion, namely that experimental results indicate that the typological classification of left-handedness, whether made by S himself or by others is so broad as to be'almost meaningless from a practical standpoint.'

Provins and Cunliffe (1972b) modify further Annett's claim of 'equal and opposite' by commenting that there is often little right-left difference between the hands in the left-hander. They found, as did Benton, that left-handers, although succeeding, in general, better with the left hand, show a more extreme range of scores than right-handers. Left-handers succeeded better on 27 (of 70) tasks with the right hand while right-handers performed better with the left hand on only 17 occasions. Provins and Cunliffe, however, took self-classified right and left-handers who also happened to demonstrate clear right and left hand scores on a preference questionnaire, while Annett is comparing only preference-classified strong right and left handers (who perform no actions with the non-preferred hand). In other words, Annett's claim of 'equal and opposite' is based on a far more stringent selection of subjects than that of either Benton or Provins and Cunliffe.

1.4 Influences on handedness

Both genetic and environmental factors may influence the course of development in handedness; both learned and unlearned aspects are present as 'relatively inseparable co-functions' (Palmer, 1964). It may be that no simple genetic model can be expected to account for the varying degrees of handedness, the determination of which, because of its relatively continuous distribution, must rest upon polygenetic inheritance. The argument for consideration of a polygenetic inheritance among theories of the physical basis of handedness is also supported by Annett (1970).

While the two factors of genetic endowment and early training are generally assumed to be determiners of handedness (Falek, 1959), Annett (1972) puts forward three sorts of influence - genetic, cultural and accidental - which together may account for the distributions of hand preferences and skill. Accidental influences are demonstrated in the normal distribution of relative manual speed, while genetic and cultural factors in humans (unlike in animals) account for the shift of this distribution to the right.

1.4.1 Two genetic models of handedness (hand preference)

Studies of the genetics of handedness can be based on figures of right, mixed and left-handedness derived from preference questionnaires, and thus would tend to support certain theories of discrete handedness rather than any continuous normal distribution of handedness obtainable from performance test scores. Thus any successful genetic model might be seen to support certain preference measures of handedness by its agreement with the frequencies of right, left and mixed handers found empirically. Such a model must also account for the handedness of children produced by given parents whose handedness is known.

Genetic models of handedness may be hypothesised which are polygenetic in origin (compare with proposed models of intelligence) or which are based on single gene involvement.

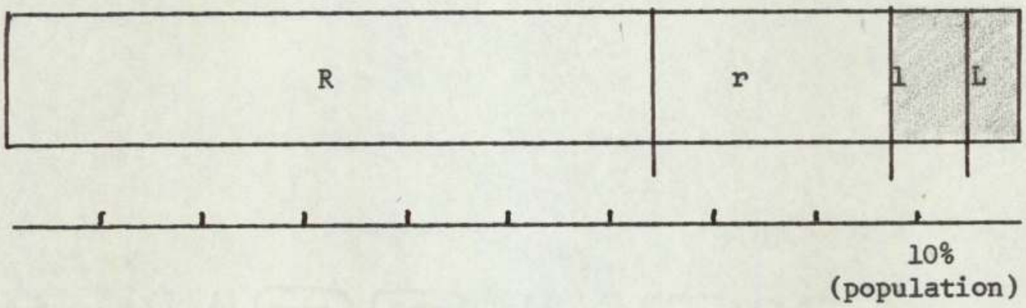
Annett (1964) describes a model of the inheritance of handedness and cerebral dominance. According to this model handedness is determined in normal individuals by two alleles, D (dominant - right-handed) and R (recessive - left-handed). Dominant and recessive homozygotes, DD and RR, represent consistent right and left-handers respectively, while heterozygotes, DR, may use either hand (but more usually the right for skilled activities.

Annett assumes the proportions of D and R in a population to be D = 0.8 and R = 0.2; thus:

DD (strong right-handed)	= 0.64 (64% of the population)
RD/DR (mixed handed)	= 0.32 (32% of the population)
RR (strong left-handed)	= 0.04 (4% of the population)

These expected proportions were found to be empirically verifiable (see Annett, 1967).

With reference to the relative strengths of D and R (4:1), one might expect one fifth of all mixed-handers to demonstrate overall left hand preference. The resultant distribution of right (R), mixed and left (L) handedness is shown in the diagram below. Mixed handers are represented as either 'r' (overall right hand preference) or 'l' (overall left-hand preference)



Criticism of this genetic model is provided by Levy and Nagylaki (1972), who claim grounds for choosing values for D and R appear to be subjective and based on minimized deviations of Annett's predicted fractions of left and right-handers from the observed proportions.

They (Levy and Nagylaki) claim also that Annett's model fails to account for known experimental findings with respect to the relationship between hand usage and cerebral dominance. For example, Annett claims that all strong left-handers (RR's) will be right cerebrally dominant for language, while in fact, left hemisphere damage will cause aphasia in approximately 35% of sinistrals (but note, as no indication is given of specific handedness measures to be used, these do not appear to be grounds for rejecting Annett's model outright).

The model put forward by Levy and Nagylaki rests on the interplay of two genes suggested by :

1. Which hemisphere is dominant? Alleles L (dominant-left hemispher)

and l (recessive-right hemisphere)

and

2. Is dominant hand contra or ipsi-lateral to this hemisphere? Alleles C (dominant-contralateral) and c (recessive-ipsilateral).

The resulting genotypes can be seen from the table below:

	DOMINANT HEMISPHERE FOR LANGUAGE	
	LEFT	RIGHT
Sinistral	cc;LL cc;lL	CC;ll Cc;ll
Dextral	CC;LL CC;lL Cc;LL Cc;Ll	cc;ll

Although the earlier model of handedness (Annett, 1964) had the advantage of supportive empirical evidence, Annett (1972) concedes that any simple gene hypothesis is unacceptable. Certain parental matings did not produce a child with the expected handedness (according to the earlier model) and, in fact, the sex of both parents and child appeared to be crucial variables in determining filial handedness (1967, 1970). A genetic model should therefore consider:

1. The origins of sex differences in handedness
2. The differing hereditabilities of mothers and fathers.

It may also be possible that genetic factors can only account for certain aspects of handedness (for example, right-handers who have left cerebral representation for language) and not others (for example, left-handers having right hemisphere language representation).

1.4.2 Observations of handedness in families

Since no completely adequate genetic model appears to be forthcoming, consideration of the inherited nature of handedness must rest, in part, on recognition of all the various possible influences on the handedness of the individual. These considerations will then provide an overall context in which all genetic models must be set.

Certain observations have been made with regard to the relationship between maternal, paternal and filial handedness, which must be taken into account by any genetic or cultural models of handedness. Annett (1972) discovered that, while in general a higher incidence of left-handedness can be expected when either parent is left-handed, mixed and left-handed children are more numerous in families with sinistral mothers than fathers.

In a large study of handedness in families Annett (1973) reanalysed data from earlier studies (Chamberlain, 1928; Rife, 1940) and carried out a further study of her own, inquiring into the handedness of individuals and of their families. Some interesting conclusions are reached, among which are:

(a) Left-handedness in the mother (and not in the father)is significantly ($p<0.001$) associated with left-handedness in male and female children, while paternal sinistrality on its own is significantly ($p<0.025$) related only to left-handedness in boys. In general, maternal sinistrality has a greater effect on filial left-handedness.
(b) The increased incidence of left-handedness among children of left-handed mothers is especially marked for daughters.
(c) The incidence of left-handedness in children of both sexes is highest when both parents are left-handed.
(d) There is a stronger association of handedness between female relatives (mothers, daughters and sisters) than between male relations.

Support for the greater influence of maternal left-handedness was found in a test of dichotic listening carried out by Bryden (1970). While paternal left-handers proved to be 64% right ear dominant (paired number presentation), maternal left-handers were only 45% right ear dominant. Assuming a positive relationship to exist between ear and hand dominance, (see White, 1969; McGlone & Davidson, 1973) these figures demonstrate a greater penetration of maternal influence on left-hand (ear) preference.

Falek (1959) found a significant increase in left-handers only amongst matings of right-handed fathers and left-handed mothers, but prefers to recognise cultural factors as the cause of this. Due to their own experiences, left-handed fathers are thought to be more concerned than left-handed mothers to change any sinistral tendencies in their children.

In a further study, Annett (1974) tested children of two left-handed parents together with their parents on a preference questionnaire and on the peg-moving task. The distribution of handedness scores, according to the questionnaire classification is found to be as follows (for the children): 5L, 15R, 25M (13 of whom were left-handed writers and 9 of whom were left-handed for most activities). The handedness of these children was considered by Annett to be most likely to demonstrate a distribution unbiased by the right shift which typifies that of the normal population. In fact, on a test of manual speed, the mean difference between the hands for the group was approximately equal to zero, thus lending support for this hypothesis.

1.4.3 Sex differences on tests of handedness

In addition to the influence of familial handedness, another factor which might affect handedness is that of sex. In general there are two common findings concerning male-female differences on motor or questionnaire tests of handedness. Either no significant differences are reported (Annett, 1967; Falek, 1959) or females tend to be distributed more towards the right-hand extreme of scores (Annett, 1972; Oldfield, 1971; Crovitz & Zener, 1962; Kovac 1973). Only rarely are females found to have a greater incidence of mixed or left-handedness (in children see Belmont & Birch, 1963).

Annett (1967) found no significant differences in a comparison of males and females on a 12-item questionnaire, although the proportion of males in the pure left-handed group slightly exceeded that of females. Negligible differences were also found in a further study (Annett, 1973). However, normal distributions for male and female hand difference on manual speed tasks show different degrees of shift to the right of zero (Annett, 1972). While the distance between the mean and the point of no difference between the hands is calculated to be 0.5 s.d. in schoolboys, the corresponding distance in schoolgirls is 1.10 s.d. On this occasion, preference questionnaires revealed ambiguous results. Among undergraduates there were slightly more males (66.6%) than females (65.1%) classed as right-handed, while among school-children there were far more right-handed females (75.8%) than males (61.6%).

Falek (1959) discovered only non-significant differences between numbers of left-handed mothers and fathers from a total population of 10,236 parents, classified by a simple questionnaire. 3.10% of the mothers and 3.88% of the fathers emerged as left-handed.

Crovitz & Zener (1962) demonstrate differences in the distribution of questionnaire scores for males and females. While for females the mode of the J-shaped distribution was the most extreme right hand score (14), the mode for male scores was far less extreme - 18 (on the scale 14-70).

394 male and 734 female psychology undergraduates returned completed forms of the Edinburgh Inventory of Handedness (Oldfield, 1971). Various findings with regard to sex differences on the test are reported. First, 25.9% of the males and 16.6% of the females claimed some tendency towards left-handedness ($p<0.001$). When compared for Laterality Quotients significant differences again emerged between male and female groups. If left-handedness is defined, for the purposes of test scores, as any L.Q. less than zero, then handedness frequencies are found to be:

	Right-handed	Left-handed
Males	360 (90%)	40 (10%)
Females	667 (94.08%)	42 (5.92%)

Differences between males and females are found to be significant ($p<0.02$). It may be that a dichotomy between positive and negative L.Q.s such as that employed by Oldfield is more conducive to the discovery of significant sex differences than a preference-defined classification such as that of Annett (1972). The difference between sexes found by Oldfield is spread throughout the left-handed segment of the L.Q. scale, and although numbers were small it is noted that the greatest male-female discrepancy is not apparent for the extreme left-handed scores but for the range -41 to -60. Thus the difference may lie mostly in the 'mixed' or 'ambidextrous' regions, especially as there is also a large increase in male right-handers with low positive L.Q.s (+11 to +30).

If one is studying a consistent-inconsistent distinction with respect to handedness then it appears that males may be more inconsistent than females - irrespective of left and right-handed tendencies (see Crovitz & Zener and some findings of Oldfield). This possibility appears to be the more interesting than any which deals with right and left-handedness as such, since the implications with regard to cerebral organisation may be of more relevance (see Chapter 3).

1.4.4 Environmental influences

Although Annett (1972) claims that no society favours the left hand it is believed (Goodglass & Quadfasel, 1959) that handedness is less strongly developed among primitive peoples, thus lending some support to theories emphasising training in manual skills.

Provins and Dalziel (1969) and Provins and Cunliffe (1972) stress 'the pre-eminent role of training in the differential performance of the two sides'. While not stating conclusively that any genetic influences on handedness can be overcome through appropriate training, the possibility is held out that the hands could become equally proficient with training in particular skills.

The case is presented of a strongly right-handed individual who taught himself to write better with his left hand. Some suspicion of brain dysfunction is present in that the subject was motivated to this change by intolerable tension in the muscles of his right arm when writing. Provins & Dalziel conclude, however, that the marked improvement with practice of the previously non-preferred hand may ultimately approach, if not equal, the standard achieved by the right hand. Elsewhere Provins (1967) claims that, in tasks involving little spatio-temporal organisation equal performance by both hands may be expected. Tasks such as tests of muscle strength may demonstrate this, while tests of totally untrained ability, although difficult to find, also show no direction of dominance. A tapping test performed by each big toe in turn produced no differences in rate of tapping.

Kovac (1973) believes that if genetic determination were to be the only factor in ontogenesis (development of the individual) then the ratio of right to left-handers would be 50:50 (an accidental distribution). However, environmental influences alone, he claims, account for the observed frequencies of handedness:

"The predominance of a right-hand preference of contemporary population is explained by the action of environmental factors. The influence of a right-handed civilization is effectively resisted only by about 4% of individuals and these may be regarded as stable left-handers. During the process of ontogenesis, practically half the individuals readjust themselves to right-handers in opposition to their genetic dispositions. Stabilization of handedness is presumed to be achieved only at the time of maturity." (p.236)

The argument expressed by Kovac would find little support elsewhere, due not least to the weak causal links relating the handedness of successive generations according to such a model.

Evidence also exists which minimises the role played by environmental factors in the determination of handedness. Annett (1974) studied children of two left-handed parents. While the 45 children observed tended to be representative of an accidentally distributed population on tests of manual speed, a further group of 5 children whose parents were probably pathological (ie 'unnatural') left-handers, presented the same right-handed superiority as did an unselected sample. Thus the experience of being raised by two left-handed parents is apparently not in itself a significant variable in the handedness of the children. Further studies on larger numbers of subjects could confirm the purely genetic influence of two left-handed parents.

Palmer (1964) states that it is difficult to find clear-cut evidence for an environmental influence on handedness. However, since man appears to possess no strong hand preference at birth, and since development of hand preference may be regarded as part of general motor and psychological development, then one might expect influences which operate over this general aspect of development to have a similar effect on the emergence of hand preference. Palmer believes that laterality development may be regarded as a response to environmental demands for skilled performance, and once 'set-in' becomes difficult to change. Arguments such as this, however, again fail to demonstrate origins of the dextral majority, although Palmer seeks to unite the above standpoint with the possibility of a poly-genetic explanation of the basis of handedness.

Finally, an interesting study by Oldfield (1969) sheds some light on the resistance of natural left-handers to a right-handed world. Oldfield carried out a study on musicians, in which comparisons were made of the frequencies of right and left-handers in this group (of 129) and in the normal population. It was hypothesised that the handicap of left-handedness would lead to a shortage of sinistral musicians - although at first sight many instruments appear to possess no definite right or left-handed modes of being played, most instruments ranging from recorder through violin to piano and percussion are undoubtedly geared to facilitate skilful playing by dextral musicians. It was the case, however, that no proportional shortage of left-handers emerged. All the left-handers had found different ways of overcoming handicaps, without necessarily resorting to right-handed techniques.

An unfavourable environment does not appear to deter or diminish the number of left-handers expected on the basis of normal population figures, and where musicians played their instruments in the conventional (or right-handed) fashion this did not appear to lead to changes to right-hand preferences in other activities.

2. CEREBRAL DOMINANCE

2. CEREBRAL DOMINANCE

2.1 Concept of cerebral dominance

Evidence of the specialisation of one hemisphere for particular cognitive functions arose from studies of individuals with uni-lateral brain lesions, notably originating in 1861 with clinical descriptions supplied by Broca. Jackson (1932) observed:

"The two brains cannot be mere duplicates if damage to one alone can make man speechless. For these processes (of speech), of which there are none higher, there must surely be one side which is leading."

Although the term 'cerebral dominance' usually refers to control of language functions, there are other situations where it can also arise. The definition of cerebral dominance is given by Goodglass & Quadfasel (1954) as the relationship of a cerebral function to one cerebral hemisphere. Touwen (1972) gives a similar description:

"The phenomenon by which one cerebral hemisphere plays the major role with regard to a specific function." (p.747)

while Zangwill (1962) mentions two possible meanings:

1. where functions are controlled asymetrically, and
2. where one hemisphere is in direct control over the other in general physiological functioning.

It is Zangwill's first meaning which is of interest here, and indeed Dimond (1972) refutes the second possibility; although the right hemisphere may have a negligible role to play in language processing it cannot be described as 'subordinate to' the left hemisphere in overall functioning. Dimond emphasises co-ordination between the two hemispheres on both a perceptual and conceptual level. He suggests that the 'double brain', which, with two hemispheres functioning differentially, was instrumental in giving man greater spatial awareness, also acted as a highly organised system with continuous communication between the two hemispheres.

This interplay is often minimised by studies such as that of Gazzaniga & Sperry (1967), who refer to surgical evidence that the subjective experience of each hemisphere is known to the other only indirectly through 'lower and peripheral effects'. In studies of commisurotomised patients (patients with deconnected hemispheres) Levy (1969) and Sperry (1968) emphasise the evidence for organisational differentiation of the hemispheres with respect to perceptual and cognitive functions, whereas in a similar study Kreuter, Kinsbourne and Treverthen (1972) demonstrate that a subject's performance is never freed from unitary sub-hemispheric control.

All the above studies support the view that at least on some level the activities of the two hemispheres are co-ordinated.

2.1.1 Right and left hemisphere functions

Speech and language functions are controlled almost entirely by the left hemisphere in most individuals, while the right hemisphere is involved in processing material of a visuo-spatial or spatio-temporal nature (Kershner & Jeng, 1972). For instance, Bradshaw, Geffen & Nettleton (1972) discovered that, while the left hemisphere was better at processing different names, physical (visual) differences were better handled by the right hemisphere.

The argument that the two hemispheres never act totally independently, and are not as separated in their functions as some would believe, is supported by evidence that comprehension of spoken or written language can be dealt with by either hemisphere (Benton, 1962). While the right hemisphere is totally incapable of 'speech' is is capable of perceptual understanding in the absence of linguistic expression. Verbal stimuli projected to a de-connected right hemisphere can stimulate the identification, by pointing, of a named object, although they cannot elicit a verbal response of the name.

Milner (1971) confirms that the right hemisphere does have a role to play in complex cognitive functions and urges that lateral contrasts should not be taken to extremes. For some time the left hemisphere was regarded as the centre of control for all such cognitive functions, with the right hemisphere being less important and involved only in elementary sensory and motor functions. Now indications from right-sided lesions are that:

"it has become increasingly evident that the right hemisphere plays a major role in many non-verbal cognitive functions and particularly in the perception of spatial relations." (p.272)

2.1.2 Contra and ipsilateral pathways

Both the eyes and the ears are connected to the two cerebral hemispheres by ipsilateral (same side, uncrossed) and contralateral (opposite side, crossed) pathways. The relative strengths and positions of crossed and uncrossed channels will determine the hemisphere to which visual or auditory stimuli in one visual field, or to one ear, are primarily projected. The situation is slightly more complex for visual than for auditory presentation.

2.1.2.1 The eye

Uncrossed fibres run from the outer half of each retina to the visual cortex on the same side, while a second group of nerve fibres, from the nasal half of the retina, cross over in the optic chiasma and pass to the contralateral hemisphere. The information sent by this latter channel does not conflict with the more direct input but merely reinforces it (Anon, 1969). However, two projections of the same object will be received by the right and left hemispheres as mirror-images of each other (See Orton, 1925).

The visual system can thus be seen to operate in such a way that each cerebral hemisphere receives information primarily from the opposite half of the visual field (Kimura, 1973; Kershner & Jeng, 1972) (see Figure 2.1).

2.1.2.2 The ear

Au auditory stimulus to either ear is, in general, projected to both cerebral hemispheres via crossed and uncrossed pathways. The contralateral (crossed) connections are, however, stronger than the ipsilateral (uncrossed) connections and, in a competing situation, it is believed that the input via the crossed channels 'inhibits or occludes' that sent by the uncrossed channels (Kimura, 1973). (see Figure 2.2)

2.1.3 Clinical and experimental studies of cerebral dominance

Studies of language disorders have yielded much information about the organisation of the brain. Geschwind (1972) lays great stress on this:

"Virtually everything we know of how the functions of language are organised in the human brain has been learned from abnormal conditions or under abnormal circumstances: brain damage, brain surgery, electrical stimulations of brains exposed during surgery and the effects of drugs on the brain." (p.76)

By studying both the side and site of lesions resulting in aphasia knowledge of the hemispheric location of language organisation can be inferred (Goodglass and Quadfasel, 1954; Geschwind, 1972) and by studying

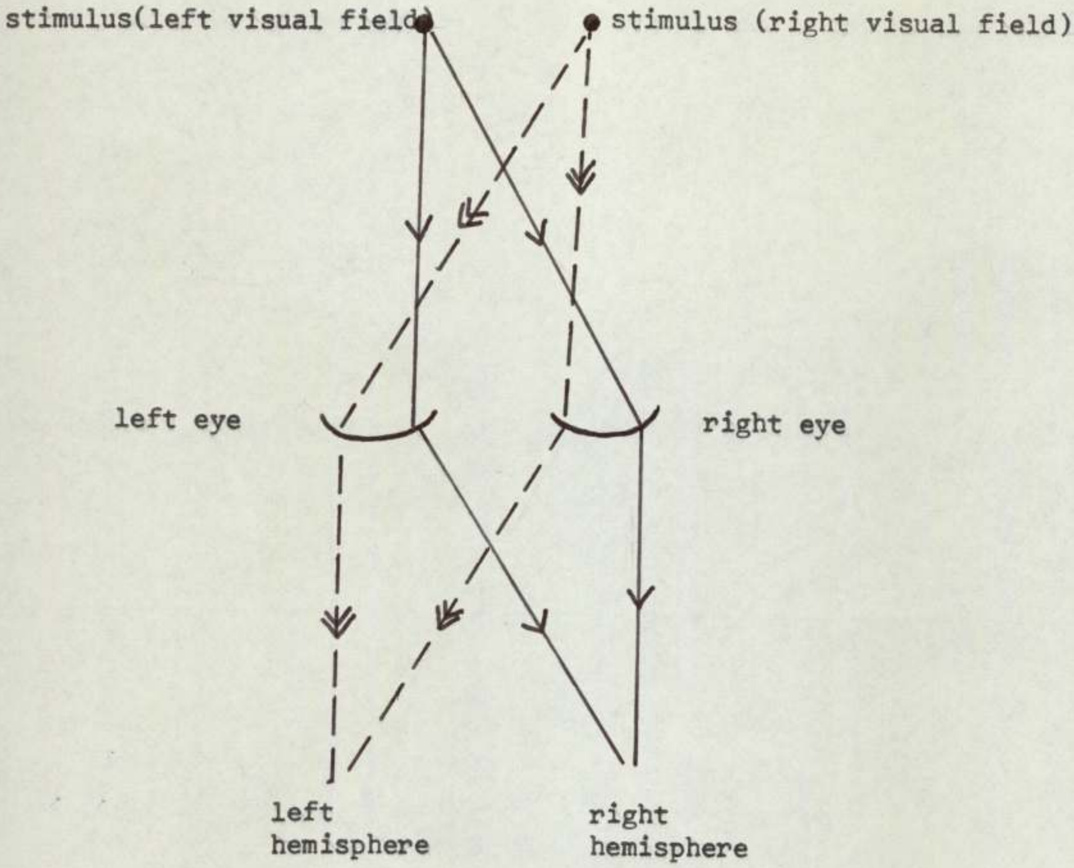


Figure 2.I. Projection of Visual Stimuli

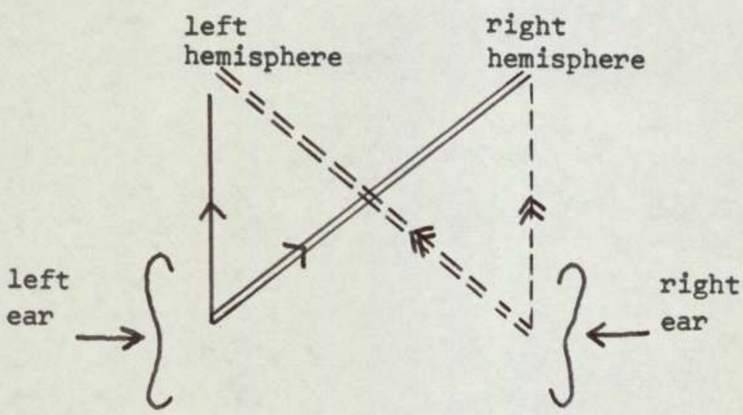


Figure 2.2. Auditory Pathways

hemispherectomized or commisurotomized patients, the functions of one hemisphere can be observed in isolation (Gazzaniga & Sperry, 1967; Levy, 1969). By presenting visual information very rapidly to left or right visual fields using a tachistoscope the processing capacities of the hemispheres contralateral to presentation can be analysed. Functional differences (usually in verbal and visuo-spatial tasks) are found to be reflected in perceptual asymmetries which favour the visual field opposite the predominant hemisphere (Durnford & Kimura, 1971). In most individuals the right visual field will demonstrate higher scores for verbal stimuli while the left visual field will often produce better results for visuo-spatial stimuli. This effect could, according to Umilta, Frost & Hyman (1972) be due either to longer processing time in the minor (for <u>this</u> task) hemisphere or to longer transmission time as stimuli are sent across to their major (for <u>this</u> task) hemisphere from the hemisphere to which they are directly presented.

The auditory system being predominantly crossed, speech sounds presented to one ear are presumed to be processed primarily by the opposite hemisphere. When different digits are delivered simultaneously to each ear (dichotic listening), the ear which gives the most accurate report will indicate the hemisphere which is dominant for the processing of verbal stimuli. Kimura (1973) believes that it is reasonable to suppose that speech sounds presented to the right ear would have readier access to the speech perception system of the left hemisphere and would thus produce superior recall to left ear presentation.

2.2 Development of cerebral dominance

Differing estimates of the rate of development of cerebral organisation compare closely with reports of the development of handedness. The term 'plasticity' is often used to refer to the equipotential nature of the two cerebral hemispheres in early life. In early childhood it is generally assumed that either hemisphere is potentially capable of controlling language functions, a capacity which gives way in later life to lateralisation of specific functions within one or other hemisphere (Lenneberg, 1967; Krashen, 1972; Marshall, 1972). The notion of development from a state of plasticity is described and supported in various ways.

Lashley (see Marshall, 1972) puts forward two general proposals which might account for the loss of plasticity as the child acquires language:

1. An accidental embryonic development and, deems Marchall, a more acceptable hypothesis,
2. Separate localisation of functions determined by integrative mechanisms which cannot co-exist in the same area of the brain.

Goodglass & Quadfasel (1954) suggest that after an initial phase of almost bilateral participation, a self-reinforcing process causes a slight lead in the language performance of one hemisphere to 'snowball into a nearly complete unilateral representation'. This initial state of plasticity is seen by Palmer (1964) as being potentially 'trainable'; that is, left hemisphere dominance for language is not necessarily a biological certainty in the majority of individuals.

Sperry (1968) is more sceptical about the effects of cerebral dominance on development. To begin with, he believes the mechanisms responsible for plasticity to be essentially unknown and unapproachable, while it is also uncertain whether the 'pre-programmed process of cerebral development' can be modified by function. Although the young brain is given a great ability to correct certain dysfunctions, any functional changes are at best represented not on a structural level but on a physiological level which is difficult to investigate. Sperry points to the important role played in the lateralisation of function by the Corpus Callosum which integrates the two hemispheres. Without this link (as in young agenisis patients) language development would continue bi-laterally, never becoming lateralised in only the right or left hemisphere.

Witelson & Pallie (1973) found structural differences between the right and left hemispheres of both adult and neo-natal brains. The area known as the Planum Temporale, which mediates language functions in adults was found to be significantly larger in the left than in the right hemisphere for both groups. No support is found for an environmental explanation of the predominance of left hemisphere speech lateralisation in adults (see Gazzaniga, 1970). Lateralisation is not thought to be the effect of a variable such as handedness or of language development (see Marshall, 1972) but instead, Witelson & Pallie suggest that:

"The anatomical data indicate that the human infant is born with, or develops very soon after birth, a larger area in the left hemisphere in a region known to be of significance for the language function. It is suggested that this anatomical asymmetry precedes any learning effects, since the postnatal age of the infants precluded little if any environmental experiences such as language acquisition or preferred hand usage." (p.644)

This evidence does not, however, contradict notions such as those of Krashen or Lenneberg that the development of lateralisation within the brain is closely linked, not necessarily in a causal relationship, with such factors as language development. The study of Witelson & Pallie merely suggests that the beginnings of left hemisphere specialisation for language are present at birth.

2.2.1 Age of complete lateralisation

The age at which cerebral dominance is thought to be complete varies to much the same extent as figures for handedness (see Chapter 1.2.1)

Lenneberg (1967 and see Marshall, 1972) suggests that not until puberty does the brain lose its power to successfully transfer control of function from one hemisphere to the other. By studying the recovery rate from childhood aphasia due to unilateral lesions, prognosis appears to be best in very early years and gradually deteriorates until, at puberty, language control cannot be taken over by the undamaged hemisphere. Marshall cites similar figures to support the notion that prognosis for recovery from childhood lesions is good compared to that for adults.

The'lateralisation by puberty' hypothesis of Lenneberg is refuted by Kreshan & Harshman (1972) who note that of 30 cases reported by Lenneberg (20 with disturbed speech) 29 sustained the brain injury before the age of 5. If it is accepted that prognosis for recovery is related to the onset of lesions rather than to the age at which recovery is complete, then, they claim, cerebral dominance would appear to be established well before puberty and probably at around 5 years. Lenneberg does, however, refer to other figures and to his own clinical experience in supporting the hypothesis that at least before ten years of age there is a good possibility of total or partial recovery from aphasia due to unilateral lesions. Krashen and Harshman's refutation does not appear to take into account all the evidence presented by Lenneberg. Krashen & Harshman also reanalyse data from dichotic listening experiments which had been thought to demonstrate that left hemisphere (right ear) superiority for auditory stimuli actually decreased during childhood. The R-L (right score minus left score) method of scoring is, however, shown to be negatively correlated with accuracy: that is, as older children achieve greater accuracy, so their R-L score decreases. When instead, a 'percentage of error' score is used, ear difference is found not to change significantly after 4 or 5 years of age (but note that figures for ages under 4 cannot be obtained and therefore the relationship of these specific results to the development of lateralisation of function is of a tenuous nature).

2.3 Functions of the major and minor hemishperes

The terms 'major' and'minor' are used here to refer to the cerebral hemispheres which mediate predominantly language and visuo-spatial functions respectively. 'Major' does not imply control or superiority over 'minor' and does not necessarily always refer to the left hemisphere.

2.3.1 Major hemisphere

From observations of a relatively small number of aphasics with left hemisphere damage, Broca advanced the now famous expression that "nous parlons avec l'hemisphere gauche!". The left hemisphere has since been verified as the centre for speech and language processes in most individuals (Geschwind, 1972; Benton, 1965; Gazzaniga & Sperry, 1967; Dimond, 1972 and others).

Although it is difficult to find clinical cases in which fine levels of language disturbance can be detected and measured, evidence exists that the left hemisphere subserves all language activity, including both elementary and higher functions (Benton, 1965). The question can then be raised (Krashen, 1972): does the language facility share properties and cortical mechanisms with other aspects of cognition?

2.3.1.1 Language functions

It is commonly suggested that all symbolic processing takes place in the left hemisphere during verbal activity (Lewin, 1974) and that during the processing of logic and speech functions of the right hemisphere are supressed (Bannatyne, 1966a & b).

Details of the dominance for language functions of the left hemisphere are presented by Marshall (1972), who cites evidence that the left frontal lobe plays a role in controlling the vocal tract in 'syllable-sized' units. This area of the left hemisphere is also involved in many other linguistic functions, including lexical selection and the 'decoding of phonological patterns from primary acoustic stimulation'. The left infero-parietal region is also believed to be involved in lexical selection and in the output to speech areas of non-vocal forms for 'linguistic elaboration'. Other more detailed associations of hemispheric locations with specific linguistic functions are reported which emerge from various studies of localised brain defects.

Dimond (1972) reports that the left hemisphere alone has the capacity to express itself through speech and further, that in patients with de-connected hemispheres, reading took place only in the right visual field (left hemisphere), while Benton (1965) refers to cases of writing disability resulting from left hemisphere lesions.

2.3.1.2 Other functions

If, as Krashen (1972) suggests, mental capacities underlying language are dependent on left hemisphere mechanisms, then abilties related to these capacities will also be mediated by the left hemisphere. For instance, temporal order perception appears to be a left hemisphere phenomenon which involves both speech and rhythm. Models of speech often stress the role of rhythm in speech production, but non-speech rhythmic patterns may also be processed by the speech hemisphere (Robinson & Solomon, 1974, although some other studies fail to confirm this result). In the experiment by Robinson & Solomon, subjects listened to 30 dichotic pairs of rhythmic pure-tone patterns. Patterns presented to the right ear were identified on significantly more occasions than patterns to the left ear.

In studies of commisurotomized patients Gazzaniga & Sperry (1967) found that, while the separated minor hemisphere was unable to compute simple arithmetic calculations (for example, multiplication or division by 2), the major hemisphere performed on a level with pre-operation standards. They conclude that like speech and writing,'calculation in these patients seems to be confined almost exclusively to the major hemisphere', a suggestion confirmed by Pohl, Butters and Goodglass (1972).

In addition to the temporal ordering capacity of the left hemisphere, it appears also to account for ordering of a spatial nature. Ajuriaguerra, Hecaen & Angelergues (1960) found ideo-motor apraxia (inability to perform familiar acts on verbal command or by imitation) to be associated with major hemisphere lesions. Left hemisphere damage can also result in body disorientation (Gerstmann's Syndrome) and patients may also suffer from finger agnosia, the inability to recognise and identify a touched finger.

2.3.2 Minor hemisphere

The implications of the term 'minor' are historically outlined by Benton (1972). From the observations of Gerstmann in 1920, the minor hemisphere became regarded on a three fold basis as:

1. The mediator of motion and sensation in the right hand side of the body.
2. Subordinate to the left hemisphere in subserving language functions.
3. Processing no distinctive functions, other than those shared with the left hemisphere - anything the right hemisphere could do the left could do better!

However, a movement of thought opposing the totally subserviant role of the right hemisphere had begun as early as 1874, when Hughlings Jackson suggested that the posterior area of the right hemisphere played a crucial part in visual recognition and memory. Other observations followed, some from ophthalmologists who noted an association between impairment in topographic memory and right hemisphere disease. In more recent times, distinctive functional properties, normally of a visual nature, have been ascribed to the right hemisphere by most contemporary workers in the field (see Paterson & Zangwill, 1944; Hecaen, de Ajuriaguerra & Massonet, 1951). The silent properties of the right hemisphere do not appear so silent "if only we can learn to understand their language!" (Benton, 1972). In particular Benton hypothesises that right hemisphere lesions to a greater extent than left lesions, may lead to impaired performance at certain types of perceptual and motor tasks.

The minor hemisphere, therefore, can be thought of as possessing distinctive functional properties. While emphasising the interplay between the two cerebral hemispheres, Dimond (1972) refers to this differential functioning:

"Although the left hemisphere may have the greater capacity for dealing with large quantities of concurrent information, nonetheless, for reasons which we cannot as yet specify, there are qualities of function which ensure that when given a choice the right wins out and registers its information more effectively than the other." (p.154)

2.3.2.1 Visual functions

Functions often described as visual (visuo-spatial, visuo-temporal, visuo-constructional etc)are amongst those most frequently associated with minor hemisphere control. Although more general terms such as non-verbal or perceptual (Milner, 1971) may better describe the totality of right hemisphere functions, most clinical and experimental work has revolved around the study of visual abilities and disabilities (Benton, 1972). The delineation of functions is extended by theoretical approaches which implicate the right hemisphere in <u>artistic</u> activities of a creative nature (Lewin, 1974, see also Bannatyne, 1966a).

From studies of aphasia Benton (1965) infers five areas of function subserved by the minor hemisphere, the first three of which are of a specifically visual nature:

1. Spatial perception and memory: following and remembering routes and maps, memory for designs (see White 1969 for a discussion of left visual field preference for geometric shapes).
2. Visuo-constructive abilities: block design, copying designs.
3. Visual perception: facial recognition
4. Aspects of auditory perception and memory: the identification of certain meaningful sounds; musical perception and recognition.
5. Motor ability: the ability of a subject to sustain a movement that he has been able to initiate on verbal command (eg keeping the eyes closed).

Dee & Fontenot (1973) state more specifically the relationship between hemispheric functioning and visual stimuli by suggesting that forms of low verbal association value are better recognised by the right hemisphere (random shapes were found to be recognised more accurately in the left visual field).

Durnford & Kimura (1971) point to the special function of the right hemisphere as the perception of visuo-spatial material. In particular, depth perception was studied by noting visual field preferences for judgement of the relative distance of two rods. Subjects were asked to decide whether a rod placed either to the right or to the left of a centrally placed rod was in fact nearer or further away than this central rod. Results indicated that, under conditions of binocular viewing, essential for obtaining field differences, the left visual field was superior to the right ($p<0.05$).

Other studies have looked at the role of the minor hemisphere in depth or 3-dimensional perception. Levy (1969) claims the right hemisphere to be superior to the left in its ability to visualise in 3-dimensions, while Milner (1971) reports right hemisphere superiority for tasks involving visualisation of spatial relations. Apart from a discussion of abilities such as facial recognition, dot location (see also Pohl et al 1972) and discrimination of slopes of lines, all of which appear to be functions mediated by the right hemisphere, Milner refers to another interesting incidental finding (Hermelin & O'Connor, 1971), namely that blind children can read Braille more efficiently with the left hand. Although Braille reading cannot be described literally as a visuo-spatial ability, the spatial nature of the task appears to render it under the control of the right hemisphere.

Further evidence for the dominance of the minor hemisphere for spatial tasks is found in the replication of 3-dimensional shapes (Gazzaniga & Sperry, 1967). When asked to reproduce simple objects graphically, the right hand performance of commissurotomized patients was inferior with respect to 'getting correct spatial representation'.

On further tests with commissurotomized subjects, Nebes (1972) discovered a left hand superiority in tests of a spatial, constructive nature. Subjects felt unseen individual shapes with a given hand and were required to choose, from a selection of items, the item which could be formed from these shapes. Nebes concludes that the functions of the right hemisphere reside mainly in 'the ability to visualise the total configuration of a stimulus from partial information'.

Control of body movement by the right hemisphere in such activities as skiing is reported by Ornstein (see Lewin, 1974) and by Pohl et al (1972), who also found a right hemisphere superiority for dot location and suggest that damage to the right hemisphere might result in geographic disorientation and in dressing apraxia (inability to put one's clothes on). Although reports exist which demonstrate right ear superiority for rhythm, most studies (see Benton, 1965) tend to support the hypothesis that the right hemisphere (left ear) is dominant for the perception of rhythm. Gregory, Harriman & Roberts (1972), with five right-handed subjects, presented stimuli alternately to each ear and required the subject to adjust the precise timing of one ear so as to make the rhythm appear completely regular. The stimulus to the right ear was significantly delayed in relation to the left, thus suggesting a more direct involvement of the right hemisphere in the perception of rhythmic stimuli.

2.3.2.2 Language involvement

Estimates of the degree of involvement of the right hemisphere in the mediation of language functions vary considerably. For instance, the minor hemisphere may be regarded as playing no part at all in the organisation of speech activity (Luria, 1973) or according to Benton

(1972) it may play a distinctly important role in the original learning of language.

Benton notes that, in aphasics with left hemisphere damage, automatic, interjectional and emotional aspects of speech remain, suggesting that dominance of the left hemisphere is of a relative rather than an absolute nature. Although the right hemisphere cannot account for the true propositional use of words it may nevertheless remain fundamental in these other aspects. In fact, occasionally, verbal engrams laid down in the right hemisphere may be invoked in intelligible sentential speech under unusual conditions of stress (in patients with left hemisphere lesions).

Under normal circumstances information which is fed to the right hemisphere and is understood is not, however, verbalisable (Gazzaniga & Sperry, 1967).

Other possible attributions of language ability to the right hemisphere include a 'high level contribution to the organisation and planning of the speech process' (Dimond, 1972) and a role in articulation, fluency of speech and word finding (Critchley, 1962). A general model put forward by Marshall (1972) suggests that both right and left hemispheres receive 'linguistic tokens' (thus suggesting the possibility of comprehension in the minor hemisphere) which are then processed and structured only in the left hemisphere. Such a model might well also account for such basic aspects of language behaviour as interjectional speech without grammatical organisation (see Benton, above) being controlled in part by the minor hemisphere.

2.4 Experimental indictors of cerebral dominance

2.4.1 Visual perception experiments

In general, verbal stimuli are found to be recognised better in the right visual field for tachistoscopic presentation. Such effects are believed to be due to cerebral dominance but other explanations have been offered which could also account for such field differences.

These alternative theories emphasise the role of pre and post-exposural scanning of stimuli. For example, letters are thought to be 'attended to' post-exposurally in a fashion similar to that involved in normal reading (see White, 1973; also Bryden, 1967). A number of factors emerge which must be controlled if the cause of hemifield stimulus-type interaction is to be ascertained.

It appears (White, 1969, 1973) that under bilateral viewing conditions (stimuli simultaneously presented to both visual fields) left field preferences for verbal stimuli can occur, while for unilateral presentation (left or right hemifield) the right field is superior. White (1973) lists a number of factors which may influence these results. These include the number of letters in the stimulus, the retinal locus of stimuli, the spacing of letters, exposure duration and report instructions.

In general both letters and words seem to be affected by the influence of cerebral dominance on perception, but we should be wary of attributing all perceptual laterality differences for different stimuli to hemispheric functioning alone. Two contending hypotheses are reiterated by White:

1. Traces of letter stimuli are attended to post-exposurally - in bilateral viewing conditions the left-most traces, as in reading, fade less rapidly.

2. Perceptual laterality effects are principally determined by functional differences between the cerebral heimspheres.

A scanning hypothesis has also been used to explain right field superiority for <u>unilateral</u> presentation of verbal stimuli (see Kershner & Jeng, 1972). In this instance, left to right scanning, as acquired through reading experience, is in discord with scanning towards the left-most element and in harmony with scanning from the fixation point (right visual field). When stimuli are not 'competing', therefore, right field preference occurs.

Kershner & Jeng attempted to eliminate the scanning hypothesis of visual field preference by using Chinese bi-lingual subjects whose predominant language (Chinese) did not involve learned reading habits of a left-to-right directional nature. Results indicate that, irrespective of eye dominance, verbal material was better reported in the right visual field under both successive (unilateral) <u>and</u> simultaneous (bilateral) modes of presentation. They suggest that reading habits represent a factor which, at least under bilateral viewing conditions, must be controlled for in order to demonstrate that cerebral dominance can determine the pattern of visual field preferences. In this instance the view is supported that right field superiority reflects the language specialisation of the left hemisphere.

The overriding influence of cerebral dominance on perception is demonstrated in the use of a different technique by Carmon & Nachshon (1973). They hoped to show that 'cerebral dominance in visual perception of verbal material can be demonstrated in situations where differential inputs in crossed and uncrossed sensory projections are delivered to both hemispheres simultaneously'. By projecting the two halves of a stimulus strategically in the same visual field the opposing hemisphere will receive information from both eyes and fuse this information to register a number. In this way hemispheric functions, rather than the transmission of material from eye to brain, are being tested directly in the synthesis of verbal material. In bilateral viewing conditions (involving four half-digits, two in each field) both English and Hebrew readers (possessing left-right and right-left reading habits respectively) demonstrated right field superiority.

Bryden (1966) suggests that the influence of pre or post-exposural scanning is less important for non-verbal stimuli, which are generally perceived more accurately in the left visual field. This may also be the case with single items (eg letters) which do not involve the perception of a sequence. If right field superiority is determined by cerebral dominance only when single letter material is used and by post-exposural scanning mechanisms when multi-letter material is used, then, Bryden claims, there should be little or no correlation between right field superiority on the two types of task. Although the right field proved superior under unilateral viewing conditions for both stimulus types the left-right difference was seven times greater for multiple-letter displays. He concedes, however, that cerebral dominance contributes to the immediate recognition of <u>all</u> verbal material and to left right differences in tachistoscopic recognition, albeit to differing degrees depending on stimulus type.

Verbal stimuli are therefore usually better recognised in the right visual field (Kimura, 1966; Milner, 1971; Carmon et al 1973; White, 1973) both with single letter presentation (Bryden, 1965; White, 1971) or letter-sequence presentation (McKeever et al 1971; Bryden, 1965, 1966). McKeever et al discovered that, even when given a 20 msec 'lead' the left visual field fails to produce a recognition score superior to that of the right visual field (using words as stimuli). Thus the hypothesis that words presented in the left visual field take longer to arrive at the right hemisphere and arrive with less intensity is put inconclusively to the test. At least the transmission time from receptor to hemispheric destination does not appear to be a determining variable in the differential field effects that were discovered.

One other aspect of left hemispheric functioning tapped by tachistoscopic experiments is recognition of familiar objects (see Milner, 1971) which, if it involves verbal recall, is better performed by the right visual field (Klatsky & Atkinson, 1971).

Superiority of the left visual field for recognition of certain non-verbal material has been found, complementing the right field effects for verbal stimuli.

The right hemisphere 'incorporates components of a system of spatial co-ordinates that facilitates the location of a point in space' (Kimura, 1973) and thus induces left field superiority for such tasks as dot enumeration (Kimura and McGlone et al, 1973). McGlone et al see such a test as a true measure of non-verbal cerebral dominance.

Recognition in the left visual field is also superior for geometric shapes, simple enumeration of forms (Kimura, 1966), facial recognition, perception of location of dots, discrimination of the slope of lines (Milner, 1971), and for letter stimuli which are spatially represented (Klatsky & Atkinson, 1971; Kimura, 1966).

The right hemisphere, therefore, appears to be involved in the recognition of objects which are primarily of a visuo-spatial nature and which do not reflect a sequential (or left-to-right) processing.

2.4.2 Dichotic listening experiments

Material presented to one ear will be more efficiently transmitted to the contralateral hemisphere. Demonstrating this greater efficiency, Netley (1972) found that, in hemispherectomised patients, more material was recalled in the ear contralateral to the remaining hemisphere when ears were compared on a dichotic listening task.

The dichotic listening task used to detect differences in aural perception between the two ears was devised by Donald Broadbent (1954). This technique involves the simultaneous presentation of two different spoken digits (or words), one to each ear. The subject is then asked to recall the numbers - perhaps three such sequences - which he has heard. Kimura (1973) found that most patients, with different types of brain damage, to whom the dichotic listening test was administered, reported words more accurately which were heard in the right ear. Since the left and right ears do not differ in their basic capacity for detecting sounds, the difference in perceptual recognition scores for each ear was thought to reflect asymmetrical cerebral functioning.

Kimura found further evidence that relative scores for right and left ears reflected specialisation of function within the brain. It was known that right temporal lobe damage could lead to perceptual deficits involving quality and pattern of tone. On a dichotic listening test it was discovered that melodic patterns were better recalled and matched, when presented under simultaneous conditions to the left ear (right hemisphere). Further effects reported by Kimura are that the left ear appears superior for the perception of vocal, non-speech sounds, such as coughing or laughing, while the right ear is superior for recall of nonsense syllables and nonsensical sounds (for instance, an unfamiliar foreign language).

Bryden (1970) set out to use the dichotic listening technique to throw light on the development of speech lateralisation. He took as subjects 234 children from 2nd, 4th and 6th grades and subjected each to 10 trials with three pairs of numbers. From the results subjects are classified as either right or left ear dominant. Among right handers the frequency of right ear superiority increased with grade level, whilst among left handers the frequency decreased. Overall both right-handed males and females (with presumed left hemisphere dominance for language) show a right ear superiority.

2.4.3 Sodium amytal injections

Limited at this time to clinical use, the controlled injection of sodium amytal into the carotid arteries of patients presents a unique method of measuring directly the involvement of each hemisphere in language activity (see Palmer, 1964; Quinn, 1972; Branch, Milner & Rassmussen, 1964).

The intra-carotid sodium amytal test for cerebral dominance was introduced in 1949 by Wada and has since been used on a clinical basis to determine the locus of speech representation when there is some doubt as to cerebral dominance. Branch et al took only left-handed, ambidextrous and right-handed subjects in whom there was some doubt as to the side of speech representation.

In such experiments as this the sodium amytal (an anaesthetic) is injected into the right or left carotid artery (on different days), thus anaesthetising the hemisphere on the opposite side. While the anaesthetic is effective the patient is required to indulge in certain simple language tests, such as naming objects and calling out the names of the days of the week in forward and reverse order. In this way the hemisphere specialising in the control of language functions can be identified by the temporary dysphasia produced in the patient.

Branch et al discovered that, of 119 patients tested, 77 demonstrated left speech representation, although it must be remembered that:

(a) the population sample was biased with respect to (1) handedness groups and (2) expectation of speech representation.

(b) 22 patients had only unilateral tests.

The tests are described as proven 'a safe and valid method of determining the dominant hemisphere for speech', although inherent medical risks will always remain. Empirical post-operative observations confirmed diagnosis of speech representation in all cases but one.

2.4.4 Head and eye turning

Bakan (1971), somewhat philosophically, regards the eyes as the 'gateway to the mind'. A relationship is proposed between CLEMS (conjugate - lateral eye movements), the asymmetrical functioning of the human brain, and the 'inherent duality in man's behaviour and experience'.

First it is established that the direction of joint eye movement to the right or left is consistent for each individual; on average 75% of our CLEMS are in one direction. Secondly, cerebral dominance will tend to be related contralaterally to CLEMS. An individual who has left hemisphere speech representation will be more likely to possess right CLEMS, and here Bakan presumes not only that the left hemisphere is dominant for language functions but that also most individuals with this pattern of cerebral functioning will think verbally rather than visually and will in general use their right hemisphere only in a subordinate fashion (see also Lewin, 1974).

Kinsbourne (1972) proposes a similar measure of cerebral dominance without making the same assumptions. He predicts that in most individuals, when they are indulging in verbal thought (awaiting a verbal stimulus), 'the verbal activation overflows into the left-sided orientation centre, driving attentional balance off centre and to the right'. Thus when one hemisphere is primarily active in thought the head and eyes should turn to the opposite side. (Note, however, that individuals will write, for practical reasons, with their head naturally turned slightly to the right.)

Experimental results conform to the expected trend. On the basis of head movements language processes were left lateralised in most right-handed subjects while spatial functions were more equally distributed, but nevertheless predominant in the right hemisphere.

2.5 Theories of hemispheric functioning

When looking at the interplay of the two cerebral hemispheres, there appear to be numerous descriptive techniques used in connection with differential functioning and processing properties. The 'verbal/ visual' opposition is found frequently among clinical and experimental accounts of hemispheric differences of function, while the underlying psychological processes involved in the processing capacities of each hemisphere are often described on a more abstract level in order to compare the opposite yet complimentary functions involved. It is necessary to investigate theoretical accounts of brain organisation in order to relate specific tasks to the control of one or other hemisphere.

2.5.1. Analytic - Gestalt

Cohen G. (1973) claims that, in general, the major hemisphere employs an analytic serial procedure, while the minor hemisphere processes visual stimuli in a wholistic gestalt (or parallel) fashion. 'Serial' is taken to signify the sequential processing of stimuli in a direction, while 'parallel' refers to recognition of a number of stimuli at one instant. (Both these terms are used specifically in the context of hemispheric processing.)

While verbally-mediated matching is necessarily of a serial nature, matching of physical characteristics may be regarded as a parallel process. As far as hemispheric specialisation is concerned a few counter-examples do arise: the perception of faces, although regarded by Cohen as a serial process (but not by others) is lateralised in the right hemisphere, as is memory for tunes. From a reaction-time experiment Cohen concludes that serial/parallel processing differences may be limited to linguistic material which can be analysed either verbally <u>or</u> visuo-spatially.

The left hemisphere can be thought of as analysing stimulus properties while the right hemisphere immediately abstracts the gestalt (Levy, 1969). Klatsky and Atkinson (1971) suggest that it is specifically the analytic and gestalt processing mechanisms of the left and right hemispheres which have suited them to the control of verbal and spatial functions respectively. They demonstrated that, in a memory scanning task, letter and picture test stimuli were spatially and verbally represented in the right and left hemispheres respectively. Although this may at first appear somewhat incongruous, it is perfectly in keeping with general theories of hemispheric functioning, since subjects were required either to visually match letter stimuli or to verbally code and match pictures with letter stimuli. Thus the mode of processing rather than the nature of the stimuli is of the paramount importance.

The notion that gestalt or analytic processing ability represents the determining factor in the control of functions by the two hemispheres is reiterated by Levy (1969). With regard to language and experimental evidence Levy claims that:

"It was as if the speaking hemisphere processed stimulus information in such a way that the stimulus could be described in language. Gestalt appreciation seemed to be actively counteracted by a strong analytic propensity in the language hemisphere." (p.615)

Taking an alternative viewpoint, Ornstein (see Lewin, 1974) sees the division of brain functions as the result of the development of speech and other 'higher human functions'. This division of function is again regarded as one involving gestalt and analytic processing, or more exactly, a situation where the left hemisphere generates sequential information processing and the right hemisphere deals with simultaneous processing on an intuitive level.

2.5.2 Matching - identification

Facial recognition tasks are better performed by the right hemisphere (Cohen, 1973; Kimura, 1973). The faster processing of facial stimuli by the minor hemisphere may, however, be dependent on the matching aspect of the task (Geffen et al 1972), and not necessarily on the type of stimulus used. Geffen et al discovered that, although stimuli having the same name were responded to more quickly when presented to the right visual field - a process of identification - matching was faster when physically identical stimuli were presented in the left visual field. In addition, the left field advantage in processing physical matches was even greater when the subjects did not know whether a name or a physical match would be required.

These findings are in agreement with those of Klatsky & Atkinson (see previous section) and point to the importance of the type of processing required - for instance, verbal stimuli which are primarily visually processed and matched will be processed by the right hemisphere.

In further support of this argument, Gibson, Pick, Osser & Hammond (1962) found words to be more accurately matched by the right hemisphere, and noted that subjects were often unable to give a verbal report of words they had correctly matched. It is suggested that this test is better thought of as a perceptual or spatial rather than a verbal one. It is further envisaged that in the early stages of the multi-stage process of word recognition 'much detailed spatial analysis' occurs. Thus the sequential interplay of both hemispheres may be a possibility with such tasks, the primary aspects of the task (eg matching or identification) determining the dominant hemisphere on any occasion.

2.5.3 Verbal association value

While the perception of verbal material demonstrates a well-established right visual field superiority, forms of low verbal association value are more easily recognised in the left visual field (Dee & Fontenot, 1973). Taylor (1972) describes further the relationship of associative processes to differential hemispheric functioning. Right hemisphere defects can lead to a difficulty in recognising shapes and objects from unconventional angles and in shape matching in general. Such defects are regarded as representative of the impaired processing of basic simple sensory stimuli, whereby apperceptive processes of a non-associative nature are disturbed. In left hemisphere defects, Taylor claims, there is a higher level failure to combine separate stimuli to form a complex whole. Here an associative process, such as that involved in matching objects by name, is being disturbed.

2.5.4 Similar-dissimilar

When two or more stimuli are judged to be 'same' or 'different', two separate processes are thought to be at work. Semmes (1968) expresses the belief that sensory and motor capacities are represented differently in the two hemispheres: in the left elementary capacities are represented focally favouring the integration of similar units, while in the right hemisphere elementary capacities are represented diffusely, favouring the integration of dissimilar units and hence 'specialisation for behaviours requiring multi-modal co-ordination such as the various spatial abilities'.

Atkinson & Egeth (1973) found no support for the idea that 'same' and 'different' judgements are differently lateralised. Subjects were required to say whether two lines presented one above the other in the same visual field were the same of different with respect to degree of orientation. Results indicated that the left visual field was significantly superior ($p<0.01$) for all such judgements. A further test, where a line was held in memory by the subject and compared with a line previously learnt also demonstrated right hemisphere superiority with the required level of significance reached for 'different' judgements only.

Davis & Schmit (1973) found the situation to be slightly more complex. With stimuli verbally processed (upper and lower case letters matched for name) 'same' judgements were more efficiently dealt with by the left hemisphere and 'different' judgements by the right hemisphere. However, when the same stimuli were matched purely on a visual level (upper case with upper case, etc.) the effect was reversed - 'same' judgements processed by the right hemisphere and 'different' judgements by the left hemisphere. It is tentatively suggested that in the case of 'different' judgements only, analysis is transferred to the other hemisphere before a decision is made; and further that the results are due to the differing capacities of each hemisphere to deal with work better carried out by the other. For instance, the right hemisphere can analyse and compare signals on the basis of visual information only, while the left hemisphere can carry out these operations both on the basis of visual information and verbal content.

2.5.5 Hierarchical-parallel

Since both speech and rhythm require the hierarchical organisation of temporal units and are better processed by the left hemisphere, it seems possible that the left hemisphere is better able to process data in hierarchical fashion (Robinson & Solomon, 1974).

Marshall (1972) speculates further that

"... individual tokens of linguistic and visuo-spatial stimuli are laid down in both hemispheres with a degree of diffusion proportional to some kind of frequency principle. The higher order coding of tokens then takes place in a single hemisphere - the left for natural classes of lingquistic objects, the right for visuo-spatial objects." (p.14)

Further, the neurological correlate of language must be highly responsive to serial order within a hierarchic system.

The nature of right hemisphere processing is not hierarchical in this sense since visuo-spatial objects are ordered 'in one place', where none affects the status of the others. Serial order combined with hierarchi structuring (ie the relating of items and the changing of their status by previous and succeeding items by systems of rules - see Chomsky, 1957, 1965) is thus a property only of the left hemisphere.

Hecaen & Angelergues (1963) summarise this distinction between hemispheric perceptual processes by associating an 'elementary and intuitive' level with the right hemisphere and a 'higher and categorial' level with the major hemisphere.

In conclusion, while a verbal/visual dichotomy serves as a sufficient differentiation of functions for most purposes, the exact nature of the verbal and visual tasks undertaken is also crucial. Thus visual tasks involving a sequencing categorial or analytic element may be subserved by the left hemisphere, while verbal tasks involving visual matches may be controlled by the right hemisphere.

3. HANDEDNESS AND CEREBRAL DOMINANCE

3. HANDEDNESS AND CEREBRAL DOMINANCE

3.1 General and theoretical relationship between handedness and cerebral dominance

3.1.1 General background

Although a relationship between handedness and cerebral dominance undoubtedly exists (Zangwill, 1962), the exact nature of such a relationship is by no means agreed. Many methods have been employed to relate these two variables (Krashen & Harshman, 1972), usually involving clinical observation and testing or experimental work with tachistoscopes and dichotic listening apparatus. In the experimental situation, handedness scores obtained from questionnaires or performance tests are related to cerebral dominance scores based on visual field or ear preference for verbal or non-verbal stimuli. Similar handedness measures can be used with aphasic patients to associate handedness with the language hemisphere.

It has been questioned (Sommers & Taylor, 1972) whether handedness is a reliable measure of speech and language representation in the brain, and indeed few would admit to the possible relationship being anything but complex (Touwen, 1972) especially with regard to left-handers, in whom the dominant hemisphere is essentially unpredictable (Zangwill, 1962; Benton et al 1962). While nearly all right-handers possess unilateral left cerebral dominance for language, in left handers the relationship is less precise. Although it has been suggested that the left-hander is the complete flip-over of the right-handers, with right cerebral dominance for language (see Levy, 1969) this neat mirror-image theory does not agree with the evidence (Levy, 1969; Levy & Nagylaki, 1972; Zangwill, 1962; and many others). It appears that in more than one half of the left-handed population the left hemisphere is dominant for speech (Touwen, 1972).

The question of degrees and differences of left-handedness appears to be in need of clarification if the ambiguous relationship between 'left-handedness' and cerebral dominance is to be untangled. In relation to this, the nature of laterality tests and classification procedures must be all-important.

Touwen envisages some inherent problems in the investigation of certain aspects of the relationship between handedness and cerebral dominance. In tachistoscopic studies of cerebral dominance, for instance, the role of ocular dominance in determining visual field preferences is often ignored (but see Kershner & Jeng, 1972). Ocular acuity dominance, rather than sighting dominance may be of some relevance to the manifestation of perceptual laterality differences, especially under conditions of minimal stimulation (for discussion see White, 1969). In the clinical situation, on the other hand, inferences of causal relationships between left-handedness and neurological disorders often appear to be based on tenuous grounds and further evidence is required in order to clarify the nature of this relationship.

3.1.2 Theoretical relationship between handedness and cerebral dominance

Levy & Nagylaki (1972) refer to Girard (1952) who described the left-hander as being one who 'speaks with the right hemisphere'.

Such a simple model of a contralateral relationship between preferred hand and dominant hemisphere may appear to be no longer acceptable. The acceptability of any model, however, rests to a very large extent upon the criterion of left-handedness invoked. If 'left-handers' are classed as such by possessing an overall superiority of the left hand (perhaps they perform more than half the items of a preference questionnaire with the left hand) then the picture is undoubtedly more complex than any simple model would suggest. If, on the other hand, only true or strong left-handers are taken, ignoring the more ambidextrous sinistrals, then the projected relationship between (strong) hand preference and cerebral dominance may be of this contralateral nature.

Annett (1964) proposes a simple genetic model of handedness from which she hypothesises the nature of the possible relationship between handedness and cerebral dominance. The suggestion is that:

1. Those individuals who are dominant homozygotes (DD) and thus consistent righthanders will have speech 'more highly developed in the left hemisphere'.
2. Recessive homozygotes (RR), who are consistent left-handers, will demonstrate right hemispheric dominance for speech and language (mirror-image of (1)).
3. Heterozygotes (DR), who may show hand preference but who are basically mixed-handers, may develop speech representation in either hemisphere. They will tend to be right-handers with left hemisphere dominance through control of the dominant gene, but this is by no means always the case.

Here, then, is an inference that 'genuine' left-handers may well be expected to possess right hemisphere specialisation for speech and language functions, but as stated, evidence for this rests very much on adequate measures of consistent left-handedness.

Further, Annett, commenting on left and mixed handedness, claims that ambidexterity can be seen as a correlate of 'uncertain cerebral representation' for speech. Due emphasis is again placed on items which distinguish the various types of right and left-hander. Commenting on the accepted finding that 'left-handers' are found to possess a great degree of left hemisphere dominance, she explains that 'the fact that more left than right-handers appear to violate the rule of contralateral representation is probably a function of the criterion used to separate the two groups'.

How are we to identify the consistent left-handed group? If, as Annett suggests, such a group is best represented by those individuals who perform none of (12) preference items with their right hand, and at least some, if not all, with their left hand, then the problem remains, of treating a continous distribution (of handedness) as if it were discrete. Thus any inferred relationship between handedness and cerebral dominance must at this stage remain to a large extent theoretical.

Benton et al (1962) present a similar view of this relationship. Suppositions are based on questionnaire or performance test results and also on much clinical experience. To begin with, they claim that the relationship between cerebral dominance and handedness is far from being clearly understood, especially when it appears that, even among right-handers, left cerebral dominance is not always invariable. The ratio of inferred left to right hemispheric dominance in aphasic sinistrals is calculated as 2:1, although the situation remains that 'the dominant hemisphere for sinistrals is essentially unpredictable'.

Benton et al conclude, in similar fashion to Annett, that in strong left-handers who do everything with their left hand we can expect the right hemisphere to be dominant for language, while in left-handers who demonstrate some right-hand preference and skill, left hemispheric dominance may well be the case. In self-confessed 'strong' and 'moderate' left-handers who are essentially ambidextrous, however, mixed dominance will be found (language represented in both hemispheres).

Newcombe & Ratcliff (1973), also on the basis of clinical experience, refer to the probable influence of left-handedness in the immediate family (FAML) on cerebral speech representation. They propose that:

1. Mixed-handers and non-right-handers with FAML are more likely to have language represented in the left hemisphere, while
2. Left-handers without FAML together with strong left-handers are the most unpredictable.

McKeever et al (1973) also refer, more generally, to the evidence that differences in cerebral organisation are related to handedness and to the family history of handedness. They claim that individuals with FAML will have a better chance of recovery from aphasia. The inference can be drawn that FAML will predispose towards more uncertain or bilateral speech representation, a suggestion not in line with the theory of Newcombe and Ratcliff.

Uncertainty, therefore, is most associated with the cerebral dominance of mixed handed or ambidextrous subjects (Benton, 1962: Bannatyne, 1966b), while in general, the left hemisphere may be regarded by some as dominant for speech and language functions regardless of handedness (Penfield & Roberts, 1959). The contention of Penfield & Roberts that brain function and handedness may be unrelated, except by disease, is by no means universally accepted. It appears that clarification of the exact relationship between handedness and cerebral dominance must await at least better identification and delineation of types of left-handedness.

3.2 Clinical evidence of the relationship between handedness and cerebral dominance

3.2.1 The problem of left-handers

In general, studies which attempt to relate cerebral dominance and handedness through the observation of aphasic patients conclude that, in comparison to right-handers, cerebral dominance is not as well specialised in left-handers or ambidexters (Benton, 1965, Annett 1964, Geschwind, 1972; Marshall, 1972; Palmer 1964 and others).

Although the relationship between the side of a lesion and the existence of language disturbance remains essentially unpredictable for left-handers in general, Annett (1964) claims that 'there are undoubted cases of aphasia resulting from lesions of the right hemisphere and in such cases it is almost always possible to find sinistral tendencies in the patient or his kin'.

Annett predicts that the chance of recovery from acute lesions are greater for sinistrals than for dextrals and also for dextrals with FAML than for dextrals without FAML.

Geschwind (1972) also finds that left-handed patients in general present milder disorders and, together with right-handers who have a strong pattern of FAML, will possess a better chance of recovery from aphasia.

Benton (1965) confirms that the situation in terms of severity of and recovery from aphasia is different for the left-hander. The bilateral speech representation most often present in sinistrals with ambidextrous tendencies can account for both the mildness of any aphasia resulting from unilateral lesions and for the greater probability of the presence of any aphasia in the first place.

In a patient with truly bilateral speech respresentation, aphasia may well occur whichever side the lesion is incurred. Benton presents a table adapted from the figures of Conrad (1949) which confirm the greater incidence of <u>some</u> aphasia in left-handers:

	RIGHT-HANDED			LEFT-HANDED		
Site of lesion	Total N	% Aphasic	Aphasics % right or left lesion	Total N	% Aphasic	Aphasics % right or left lesion
Left hemisphere	388	52	94	19	53	59
Right hemisphere	249	4	6	18	39	41
Totals	637	32%		37	46%	

Newcombe and Ratcliff (1973) believe that, although the prognosis for left-handed patients is favourable, overemphasis has been placed on the view that left-handers are more likely to develop (and recover from) aphasia. In the majority of left-handed patients with unilateral missile injury to the brain language was found to be represented predominantly in the left hemisphere. From a table representing incidence and recovery from aphasia it is noticeable that 30.2% of left-handers were dysphasic on admission compared to 33.7% of right-handers (no statistically significant difference). When compared for rate of recovery, 31.6% of left-handed dysphasics were adjudged to have recovered compared to 29.5% of right-handers (again no significant difference). It was noted, however, that left-handers with right-sided lesions were less efficient than both normal subjects and right-handed patients with right hemisphere lesions in all verbal tasks, thus indicating the greater involvement of the right hemisphere in language control in sinistrals.

Newcombe & Ratcliff suggest, from observation of a few cases, that FAML is associated with left hemisphere dominance for language and that 'unusual states of cerebral dominance are associated with some cases of non-familial left-handedness'. As stated, this view is in direct opposition to the suggestions of Annett and Geschwind if FAML is supposed to exert the same influence over all ranges of handedness. In this latter instance, familial strong left-handers would be the group most likely to possess right hemispheric dominance for language.

Chesher (1936) refers to a small group of patients with mixed motor preference whom he belives to possess unlateralised speech representation. He claims that he has 'yet to encounter a patient with mixed motor preference in whom the pathology was adequate and in the language zone of either hemisphere, who was not aphasic'. The group of mixed handers also tended to recover their linguistic stability more quickly than the right-handed or left-handed group.

In general, Chesher adheres to the view that language mechanisms reside in the cerebral hemisphere on the opposite side to the preferred hand.

Out of a total of 157 cases, however, only 3 left-handers were observed, and each of these possessed right hemispheric dominance for language. Although this number is exceedingly small, Chesher did go to lengths to include only pure left-handers in this group (subjects who performed 13 items with their left hand) and is probably detecting those individuals classed as consistent left-handers by others, and who would be expected to demonstrate right hemisphere speech lateralisation. (Note that Chesher's classification of left-handedness is even stricter than that of Annett (1964), since <u>all</u> items must be performed with the left hand, and no 'either' responses made.)

Many studies of left-handedness and aphasia appear to neglect the specificity in the choice of left-handers. Piercey (1964) in a comprehensive survey of the literature, supports the general finding that, among people who are 'generally regarded as left-handed', dysphasia more often results from a left than from a right hemisphere lesion. Piercey perhaps underestimates the wide range of left-handedness which includes many mixed-handed individuals.

Goodglass et al (1954) present data from 123 left-handed patients and conclude that the incidence of aphasia from brain lesions contralateral to the preferred hand is much greater in right-handers than in left-handers. Sinistrals tend to have more left representation for speech than right-handers have right representation. Results obtained from patients with unilateral lesions and with or without aphasia are presented below. A patient was considered to be left-handed if he performed most skilled acts (eating, cutting and handling tools) with the left hand and also considered himself to be left-handed.

	LEFT HEMISPHERE LANGUAGE	RIGHT HEMISPHERE LANGUAGE
Total left-handers 123 (of whom 35 were known to write with their right hand)	63 (53%)	58 (47%)

A table summarising data from 5 studies is referred to by Restorick (1973) and reproduced below. It can be clearly seen that although the chances of right hemisphere damage resulting in aphasia are much greater for left-handers, it is still left rather than right hemisphere damage which results in aphasia, whatever the handedness of the subject.

	LEFT HEMISPHERE DAMAGE				RIGHT HEMISPHERE DAMAGE			
	Right-handers		Left-handers		Right-handers		Left-handers	
	N	Aphasic	N	Aphasic	N	Aphasic	N	Aphasic
Conrad (1949)	338	175	19	10	249	11	8	7
Bingley (1958)	101	68	4	2	99	1	10	3
Penfield & Roberts (1959)	157	115	18	13	136	1	15	1
Russell & Espir (1961)	288	186	24	9	221	3	24	4
Hecaen & Ajuriaguerra (1963)	163	81	37	22	130	6	22	11
TOTAL	1047	625	102	56	895	16	89	26
	59.7%		54.9%		1.8%		29.3%	

Although the majority of 'left-handers' tend to possess left hemispheric dominance for language, the recovery rate from aphasia caused by left hemisphere lesions is greater in left-handers than in right-handers, suggesting that some bilateral speech representation exists. Luria (see Levy & Nagylaki, 1972) quoted rates of no aphasia or recovery from left hemisphere lesions to be 35% for right-handers and 65% for left-handers.

Further, Humphrey & Zangwill (1952) claim that a direct relationship between left-handedness and the dominant hemisphere does not exist. Although some studies have shown the inference from handedness to cerebral dominance to be justified in nearly all cases, pure right or left dominance for left-handers tends to be the exception rather than the rule. Referring to the view of Conrad, they state that:

"left-handedness differs from right-handedness in that it does not imply strict dominance of the contralateral hemisphere, but on the contrary shows all the signs of less advanced specialisation." (p.185)

From a study of 10 left-handed cases, 5 with right and 5 with left sided lesions, Humphrey & Zangwill found the incidence of dysphasic symptoms to be higher in the left-damaged group (see also Zangwill, 1962), although the hypothesis put forward is that cerebral dominance is not as well, if at all, specialised in left-handers or ambidexters.

3.2.2 Other clinical measures

Branch, Milner & Rassmussen (1964), using sodium amytal injection techniques, demonstrated that handedness was a relevant factor in predicting the side of representation of speech in the brain. Using patients, in whom there was some doubt as to cerebral dominance, the following results were obtained:

HANDEDNESS	NO. OF PATIENTS	SPEECH LATERALISATION LEFT	BILATERAL	RIGHT
Left	51	43%	8%	49%
Ambidextrous	20	60%	30%	10%
Right	48	90%	0%	10%

When left and ambidextrous patients were grouped together the proportions of left, bilateral and right speech lateralisation for this group became 48%, 14% and 38% respectively, and further, if cases of early brain injury (a possible cause of handedness) are ignored, the proportions of left speech representation for the group rises to 64%.

Warrington & Pratt (1973) administered E.C.T.'s to depresssive patients and tested immediately for temporary dysphasia. E.C.T.'s were administered to opposite hemispheres on successive days involving 30 patients who were free from any trace of cerebral disease. The results of a further 13 subjects with possible cerebral disease were also examined. It was discovered that with this small group (30 patients) neither the degree of sinistrality, as assessed by the Edinburgh Inventory, nor a family history of left-handedness were reliable predictors of language laterality.

After administering language tests, answering 4 simple questions involving the naming of objects, the results demonstrate that, of the 30 cases, 21 left-handers (70%) possessed left hemispheric dominance for speech while 7 (23%) possessed right dominance. Indications of bilateral representation are not given.

3.3 Experimental evidence of the relationship between handedness and cerebral dominance

3.3.1 Visual perception experiments

If perceptual asymmetry (superior performance in one visual field) represents a true reflection of hemispheric specialisation, then evidence is forthcoming which demonstrates handedness to be related to cerebral dominance. The nature of such a relationship hypothesised from tachistoscopic studies is no less complex than that inferred from clinical observations. Again this is due not least to the widely varying criteria of handedness employed to serve as independent variables in such studies. White (1969), reviewing the literature referring to studies of the relationship between handedness and laterality differences in perception (L.D.) concludes that:

"There is little question that handedness is related in some form to L.D. Exactly what form this is and by what intervening processes handedness becomes a determining factor of L.D. remains unclear, or at best, speculative." (p.399)

In tasks involving the unilateral recognition of verbal stimuli, results indicate that, as expected, left-handers show less right visual field (left hemisphere) preference. Bryden (1964), summarising results from other investigations, reports the following visual field effects:

	Number	Right field superior	Left field superior
Left-handers	33	16 (49%)	17 (51%)
Right-handers	124	91 (73%)	33 (27%)

Bryden himself (1965) carried out an experiment in which he investigated the relationship between tachistoscopic recognition, handedness and cerebral dominance (assessed by dichotic listening tests). Subjects were required to answer a 6-item handedness questionnaire by means of which 20 right-handed and 20 left-handed subjects were chosen with equal numbers of males and females in each handedness group. Right and left handedness was determined by all six actions being performed with the preferred hand.

The right-handed group were found to identify verbal stimuli (single letters) better in the right visual field, while in the left-handed group there was no overall field preference. A significant relationship emerged between handedness and left-right differences in accuracy, but only at the shorter of two exposure durations (20, 25 msec).

A further comparison between familial and non-familial left-handers showed that the former group were more left (field) dominant ($p<0.01$) thus demonstrating support for the argument that FAML will be a predisposing factor towards right hemispheric speech representation.

Zurif & Bryden (1969) (see also Touwen, 1972) also compared familial and non-familial left-handed groups, together with a group of right-handers. In general, right-handers were again more right field dominant for verbal presentation (2 letters) than left-handers. Together with results obtained from dichotic listening tests, Zurif & Bryden demonstrated that the results quite consistently pointed at the similarity between the perceptual asymmetry patterns of non-familial left-handers and right-handers; only the familial left-handers were unpredictable in terms of perceptual laterality.

Familial left-handers showed no consistent lateral dominance and it is suggested that the FAML variable could be crucial in discovering the hemispheric speech location of left-handers. It is possible that familial left-handers are characterised by greater hemispheric equipotentiality rather than being simply variable in their dominance.

McKeever et al (1973) found FAML to have a significant effect on the performance of right-handers in a tachistoscopic task (word recognition). Using the Edinburgh Inventory to classify subjects, three groups were arranged, 24 right-handers with FAML, 24 right-handers without FAML and 24 left-handers (14 with FAML). Results demonstrate that there was a significant difference between the two right-handed groups, the group with FAML showing a smaller right field preference, as did the left-handed group in general.

Certain evidence exists that right and left-handedness as such may not influence the extent of hemifield differences. Olson (1973) found no significant difference in field preference for three and four letter nouns, between 38 right-handed and 12 left-handed children between the ages of 7 and 11, while McGlone & Davidson (1973) also demonstrated that handedness alone might not be a determining factor in perceptual asymmetry. Seventy-nine right and left-handers were classified according to field superiority for dot enumeration. Left-handers might be expected to show less left field (right hemisphere) superiority for this task, an hypothesis not confirmed by the statistically non-significant results:

	LEFT FIELD SUPERIORITY	RIGHT FIELD SUPERIORITY	NO DIFFERENCE
Right-handers	21 (60%)	9 (26%)	5 (14%)
Left-handers	23 (52%)	13 (30%)	8 (18%)

The trend of results was, however, as expected, with fewer left-handed subjects (52%) than right-handed subjects (60%) demonstrating a left field superiority. If subjects are divided by sex, then it is found that males show significantly more right hemisphere superiority than females - a result not expected on the basis of evidence for more strong right-handers (right hemisphere for spatial functions) among females - see 1.4.3.

	LEFT FIELD SUPERIORITY	RIGHT FIELD SUPERIORITY	NO DIFFERENCE
Males	28 (68%)	6 (15%)	7 (17%)
Females	16 (42%)	16 (42%)	6 (16%)

Of the 36 left-handers, however, nearly half (17) were female and since female left-handers may tend to be more strongly left-handed than male left-handers (Crovitz & Zener, 1962), more defined left hemisphere dominance for this task could be anticipated than among male left-handers. A large percentage of females with right field superiority may consist of strong left-handers. Thus the significant sex-hemifield interaction may be due either to the greater dependence of males on right hemisphere dominance for spatial functions (McGlone & Davidson) or to the selection of the original groups according to criteria of handedness.

3.3.2 Dichotic listening experiments

Similar effects to those found in visual perception tasks are discovered in tests of dichotic listening (refer to Chapter 2.4.2). In general right ear preferences for verbally presented material occur for subjects unclassified by handedness (Kimura, 1973; Staz et al 1967).

With left-handers the expected left-right difference may not always appear. Bryden (1965) found right-handers to be significantly better in identifying numbers from the right ear than from the left ear, and although ear scores for left-handers did not differ significantly, the scores were better overall for the left ear and a significantly greater variance of scores than that of right-handers emerged.

Although a relationship with handedness similar to that found between tachistoscopic results and handedness was discovered, there was only a small, insignificant, correlation (0.19), between results on the listening and viewing tasks. This effect was also found by Zurif & Bryden (1969) who performed intercorrelations between left-right difference scores in the auditory and visual modalities, discovering correlation coefficients ranging from 0.01 to 0.18 under various conditions of presentation. In the dichotic listening situation almost identical results were found to those in the tachistoscopic task with respect to the influence of FAML. Non-familial left-handers proved to be significantly right ear dominant while the familial left-handers did not possess a score significantly greater for either ear.

In partial agreement with these results, Satz et al (1967) discovered that more FAML was to be found in subjects presenting ipsilateral tendencies of dominance (ear and hand) in a dichotic listening test. In general there was a statistically significantly smaller functional asymmetry between ears for the 54 self-classified left-handers and for left-handers classified by questionnaire and performance tests. Thirteen of the 33 test-classified strong left-handers demonstrated right cerebral speech dominance compared to 2 of the remaining 21 self-classified left-handers who were test-classified as ambidextrous or right-handed. The influence of FAML was noted for both right and left-handers and was compared with speech dominance:

	LEFT CEREBRAL DOMINANCE	RIGHT CEREBRAL DOMINANCE
Right-handed	27%	56%
Left-handed	57%	33%
	(incidence of FAML)	

Thus the incidence of FAML is nearly twice as great in subjects whose dominant hand is ipsilateral to their dominant (for speech) hemisphere. The influence of FAML may therefore rest in determining the laterality relationship (ipsi or contralateral) between dominant hand and hemisphere, rather than in predisposing to right hemispheric dominance alone (see Bryden above).

3.3.3 Other experiments

Kinsbourne (1972), employing measures of direction of head and eye turning as indicators of cerebral dominance (see Chapter 2.4.4) was led to the following tentative conclusions:

1. Right-handers: Language processes are left-lateralised and spatial skills more evenly distributed, but emphasised in the right hemisphere.

2. Left-handers: Dominance of right and left hemisphere for language is approximately equal, with spatial functions also being controlled with equal frequency by either hemisphere.

3.4 Conclusions

In general results demonstrate that only the relationship between right-handedness and left cerebral dominance for language is beyond question. While there is undoubtedly more right and mixed cerebral dominance amongst sinistrals, it appears that variables such as FAML play an as yet unspecified role in determining the exact relationship between preferred hand and speech dominance.

It is not even clear that subjects classified as 'strong' left-handers will, on a probabilistic basis, be much more likely than other sinistrals to possess strict right hemispheric dominance.

4. THE NATURE OF THE RELATIONSHIP BETWEEN HANDEDNESS, VERBAL AND SPATIAL ABILITIES

4. THE NATURE OF THE RELATIONSHIP BETWEEN HANDEDNESS, VERBAL AND SPATIAL ABILITIES

4.1 General models

Either standard test batteries or sub- tests of such batteries are often used in an attempt to relate handedness to general intellectual ability or to specific aspects of intellectual ability. The W.I.S.C. and W.A.I.S. IQ measures (for children and adults respectively) are among the most widely used at this time and can be employed to obtain separate Verbal and Performance scores for subjects (see Levy, 1969; Miller, 1971; Rourke & Telegdy, 1971; Wussler & Barclay, 1970; Newcombe & Ratcliff, 1973). Other general IQ measures are also employed, some of which contain few verbal elements and presume to test for basic underlying ability (see, for example, Berman, 1971).

Where specific hypotheses are put forward with regard to the relationship between handedness and facets of intellectual ability, then single tests, such as reading, vocabulary (Annett & Turner, 1974), and spelling (Bannatyne, 1966a) are used.

Where interest lies in the association of certain types of brain organisation (and dominance) and suppresssed or enhanced ability, then as previously stressed, the particular handedness measure used as an index of cerebral dominance is of great importance. These range from simple measures of learned and unlearned handedness (Bannatyne, 1968) through preference questionnaires (Annett & Turner, 1974; Newcombe & Ratcliff, 1973) to complex batteries of hand perference and performance tests (Rourke & Telegdy, 1971; Berman, 1971). Others (see Levy, 1969) appear to measure handedness on the basis of self-report of hand used for writing.

4.1.1 Verbal and performance IQ

Much discussion arose from the claim of Levy (1969) that left-handers were poorer on tests involving abilities normally mediated by the minor hemisphere. Mixed dominance, as it were, pushes out those processes normally subserved by the minor hemisphere, while not significantly affecting the language ability of the major hemisphere. Levy, taking 10 left-handed and 15 right-handed graduate science students, found the following results on the W.A.I.S.

	Left-handers	Right-handers	
Verbal IQ	142	138	(n.s.d.)
Performance IQ	117	130	($p<0.002$)

The difference in verbal-performance discrepancies (left-handers 25, right-handers 8) is also significant ($p<0.002$).

Miller (1971), using a different test battery, found limited support for Levy's hypothesis:

(NIIP tests of verbal and form relationships)

	Right-handed	Mixed-handed	
NIIP Verbal	153.3	153.6	(n.s.d.)
NIIP Form Relations	41.4	35.4	($p<0.025$)

The 29 right-handed and 23 mixed-handed subjects were classified by

Annett's (1967) questionnaire. Miller states that real differences in ability do exist between right and mixed-handers and probably reflect underlying differences in the asymmetrical organisation of functions within the brain.

Gibson (1973) refers to a much larger academic sample than that of Levy and finds no such differences. He cites W.A.I.S. results from Gibson J. & Light (1967):

	Left-handers	Right-handers
Number	13	132
Verbal IQ	127.4	128.2
Performance IQ	120.4	120.7

Newcombe and Ratcliff (1973) also examine the suggestion that a left-handed group of subjects will be impaired in non-verbal visuo-spatial skills. Using 823 inhabitants of Oxfordshire villages as subjects (obtained in conjunction with other geographic surveys) they, like Gibson, demonstrate no significant differences in skill between right, mixed and left-handers:

	Left-handers		Mixed-handers		Right-handers	
Sex	Male	Female	Male	Female	Male	Female
N	15	11	92	47	302	356
WAIS verbal	107.7	103.3	107.4	106.4	105.1	103.4
Performance	112.3	108.3	112.2	110.7	111.4	108.9

Wussler & Barclay (1970) using both WISC and ITPA tests to compare 25 lateralised and 25 mixed dominant reading retardates, found results in the direction expected by Levy but again these were not significant (and note the specialised population):

	Lateralised	Mixed
WISC verbal	100.38	98.27
Performance	100.30	93.64
ITPA	194.21	193.55

An alternative method of seeking differences in laterality groups to those described above is to take groups according to a criterion of intellectual performance and then compare these groups on laterality measures. Rourke & Telegdy (1971) compared three groups, each of 15 males, on the WISC. These groups comprised of children with high performance-low verbal scores (HP-LV), low performance-high verbal scores (LP-HV) and equal scores on both subtests (V=P). No significant differences were found between groups on a complex battery of handedness tests.

Berman (1971) used a similar laterality classification on 5 groups of children who were described as having either high, average or low IQ (on the basically non-verbal Columbia Mental Maturity Scale) and having or not having possible brain damage. (No high IQ groups with brain damage was included). A relationship between Cerebral Dominance, as measured by laterality tests, and IQ was confirmed with the high IQ (no brain damage) group scoring most highly lateralised and the low IQ (no brain damage) group showing least strong lateralisation.

The two divergent approaches to the study of relationships between handedness and intellectual abilities are described by Annett & Turner (1974) as represented by:

1. A normal population study - where the population is sub-divided into laterality groups, which are then compared on given tests of intellectual or perceptual ability.
2. A clinical population study - the continuum of scores on a test is sub-divided and subjects performing in the high or low regions of scores are compared on a handedness measure.

The normal approach (1.) which can be described as the experimental approach, may, according to Annett & Turner, yield few or conflicting results, while by studying regions of tests scores (2.) an increase in, for example, mixed handedness, can be detected on certain tests. They claim that:

"variations in ability are not characteristic of laterality groups in the general population, but anomalies of laterality are sometimes, but not always, detected in children selected for educational disability." (leading to a small increase in mixed or left-handed children) (p.38)

While no significant differences were found on draw-a-man, vocabulary, maze and reading tests by method (1.), significant differences ($p<0.05$) were found, for example, between handedness groups at the lower end of the reading scale. The proportion of left-handers with specific reading disability was more than twice that of right-handers.

It is to be noted at this stage that, logically, if method (2.) above, consistently furnishes significant differences in the number of R, M and L-handers scoring above or below a particular test score, then method (1.), if efficiently followed, should also lead to differences in test scores between laterality groups, where these differences are demonstrated either by a difference in means or by a difference in variance between groups. The reasons for the superior claims and results of method (2.) probably lie in the specificity in 'choice' of subjects and method (1.) may well require either:

(a) more accurate measures of handedness and control of other extraneous factors between subjects, or
(b) much larger population samples than employed, for instance by Levy (1969), or
(c) better defined notions of the particular type of intellectual or perceptual ability in which laterality differences are sought.

4.1.2 Theoretical relationships between handedness and ability

Two basic variations are apparent in hypotheses relating handedness and intellectual ability. First, the mixed or left-hander may be regarded as equal in verbal intelligence but inferior in visuo-spatial ability (see Levy, 1969; Berman, 1971). Secondly, the mixed or left-hander may be regarded in some ways inferior in verbal ability and superior in visuo-spatial ability (see Corballis & Beale, 1970; Bannatyne, 1966a).

Radical differences in the construction of such models may be due to the specific nature of the various abilities studied. For example the WAIS performance scale used by Levy and others, contains items not necessarily of a visuo-spatial nature, while the verbal scale also contains numerical items. Thus a common meaning of 'verbal' or 'visuo-spatial' may sometimes be lacking between authors who are supporting opposing hypotheses and using different test material.

Levy's model stresses the evolution of unilateral control of language expression within the brain. Language is accorded functional priority and in cases of mixed dominance will survive unimpaired to the detriment of visuo-spatial abilities. Levy describes this evolutionary process:

> "It is not illogical to suppose that during the evolution of the hominids Gestalt perception may have lateralised into the mute hemisphere as a consequence of an antagonism between functions of language and perception." (1969, p615)

Thus subjects with bilateral language representation are expected to perform poorly in tests of perceptual function. It is interesting to note that Levy's argument involves other assumptions. First it assumes that sex differences in handedness and intellectual ability will not confound the argument and secondly the minor hemisphere is regarded as being historically exactly that - minor - in its relationship to the other hemisphere.

Miller E. (1971), although agreeing with Levy's conclusion that bilateral language capacity interferes with minor hemisphere abilities, notes Levy's highly specialised choice of subjects, all of whom had high overall IQ's. Subjects were chosen who had succeeded academically and who might thus be expected to possess high verbal IQ's. Miller, although producing results similar to those of Levy, is sceptical about Levy's inferences and suggests that there may be a discrepancy between right and mixed-handers on a verbal scale hidden by the nature of a highly selected sample. Miller also presumes left-handers (according to Annett's 1964 model) to be in a similar position to right-handers, while it is mixed-handers with mixed dominance who are of real interest.

Models which stress not the inferior, but the superior ability of mixed-handers on certain visuo-spatial tasks or tests tend to be of a perceptual nature, rather than centring upon general conceptual or intellectual issues. Such models concentrate on theoretical reasons for the superior perception of verbal or visuo-spatial material in certain groups of individuals rather than working back from empirical findings on tests of intelligence.

An organism with completely mixed dominance might be expected to demonstrate total directional confusion. In Chapter 1.1.1 it was noted that animals lacking cerebral dominance were unable to discriminate between mirror-imaged stimuli. Corballis & Beale (1970) find 'reason to believe that symbolic thought processes, like certain bi-manual skills, might be hindered by complete symmetrization' - which would render (left-to-right) reading impossible. It appears that it is the directional or sequential aspects of visual perception which may be diminished in cases of mixed dominance.

Palmer (1964) refers to this notion that the absence of a complete laterality should lead to greater directional confusion than a strong right or left skill differential, while Tschirgi (1958) also claims that awareness of spatial position and directionality in space is dependent upon the asymmetry (strong lateralisation) of the perceiving system.

Tasks such as reading depend upon such directional perceptual abilities, which enable correct recognition of directional symbols arranged in a left-to-right sequence. Tests of visual perception which are of an inherently sequential nature (for instance, ordering of asymmetrically patterned shapes or blocks into a sequence) may also present problems for the mixed dominant individual.

At this stage, therefore, it is possible to suggest that the verbal performance dichotomies employed by those investigators using the WAIS and other similar measures will not reveal the basic differences in performance of right, mixed and left-handed individuals. The nature of each component of tests and subtests should be examined and the presence of sequential or directional factors taken into consideration. While verbal tests are more likely to be of an analytic, directional (major hemisphere) nature and performance tests are, on the whole, more likely to involve non-sequential (minor hemisphere) gestalt recognition, this need not be the case.

Models opposed to that of Levy would seek to demonstrate definite advantages of the more symmetrical perceiving system. Dimond (1972) discusses the more general nature of such advantages which take the form of a greater spatial awareness, while Corballis & Beale (1970) indicate the survival value of mixed-dominance when spatial stimuli are expected from all directions.

These advantages in dealing with symmetrical or multi-directional stimuli are incorporated into Bannatyne's (see 1966a, 1966b, 1968) Efficient, Well-balanced Brain Hypothesis, through which he interprets both the poor reading ability and the superior visuo-spatial ability of certain mixed dominant children (a clinical group of dyslexic children). Again the model of Bannatyne emphasises the directional nature of stimuli to be perceived and is concerned not with general intellectual abilities so much as with the fundamental perceptual abilities required to master tasks such as reading.

Bannatyne's hypothesis is that 'unlearned ambidexterity and/or left handedness is indicative of a brain with overall superior visuo-motor-praxic neurological functioning - one which balances the body well and does not distort visuo-spatial material'.

Reiterating the observations of Croballis & Beale (1970), and extending his hypothesis, Bannatyne continues elsewhere, that,

"In order to have good appreciation of spatial relationships one needs a fairly well co-ordinated motor system in terms of both hemispheres of the brain. One must also have acute three-dimensional vision in both visual fields and this involves the equal use of the visual areas of the brain in both hemispheres. This neurological state of affairs; ie the equality between the hemispheres in people with a reasonable or high degree of spatial ability, tends to make them ambidextrous and to make them scan the whole field of vision rapidly in all directions as is necessary in a three-dimensional world." (Reading calls for the discipline of scanning in one direction only.) (1966b, p.28)

In the context of the majority of the population it would appear that, while good visuo-spatial ability demands an equality of hemispheric dominance, in most people there seems to be some kind of control centre in the right hemisphere.

This type of model which looks behind the complex and multitudinous abilities involved in general 'verbal' and 'performance' tasks, appears to be stressing one underlying message which relates asymmetry on these different levels:

1. brain organisation
2. hand preference and dominance
3. perceptual abilities

In two opposing situation it might be found that:

(a) Equipotentiality of the two hemispheres will be reflected in symmetry of hand usage and preference and also in an ability to perceive symmetrical and three-dimensional material (ie gestalt recognition),

while,

(b) Asymmetry or lateralisation of brain function will result in strong hand preference and also in the ability to perceive stimuli ordered sequentially.

At this stage the discussion is centred around visual perception but similar views are expressed concerning the perception of ordered auditory stimuli (Bannatyne, 1968; Newton, 1974).

4.2 Handedness and language ability

Many relationships between language (reading) ability and handedness have been postulated or demonstrated. Although the issues concerning laterality and reading ability remain confused (Weintraub, 1968) the general trend is for mixed or left-handedness to be associated with impaired reading ability. No research clearly demonstrates any inferiority in reading ability on the part of right-handers.

Conclusions are rarely categorical in their assertions. While Cohen & Glass (1968) postulate that some relationship exists between consistent handedness and good reading ability requiring further investigation, Coleman & Deutsch (1964) point to inconclusive results. Although mixed and crossed lateral dominance and poor right-left discrimination have long been implicated in disorders of reading (see Harris, 1957; Vernon, 1957) the exact nature of the relationship of these factors to reading disability remains unclear.

In general, the difficulties confronting the investigator, who seeks to demonstrate the existence of a relationship between laterality and reading ability, can be broken down into two areas:

1. Widely varying test instruments
2. Extraneous variables involved in the investigation. (Cohen & Glass, 1968).

The first of these two problems concerns (a) the choice of a suitable handedness or laterality measure and (b) the selection of an appropriate test of reading aptitude or ability. While many different measures are employed by investigators, differences in conclusions drawn may be simply a product of this divergence.

Extraneous factors which should be controlled include IQ, age, home and school environment and physical characteristics such as eyesight and hearing. In general clinical and control subjects are taken from the same grade (and age range) and have IQ's deviating only slightly from

100 or from each other (see Cohen & Glass).

To the two main problem areas mentioned above can be added a third more general area of disagreement. Exactly what constitutes reading disability? For the purposes of the present discussion it appears that only a specific reading disability, often referred to as dyslexia, or specific dyslexia, is of great relevance. Laterality must be related to a reading disability which is relatively independent of 'IQ'. Bannatyne (1966b) describes dyslexia as 'one type of reading disability not caused by low intelligence per se'. Other similar descriptions are found elsewhere (Naidoo, 1972; Rabinovitch, 1968; Keeney, 1968) and often point to the lack of observable physical or emotional problems of a primary nature in dyslexic children. The primary reading disability appears to involve perceptual confusion, on a visual and/or auditory level. The inability to perceive objects or symbols in their correct orientation and sequence prevents such children from attaining, with any great fluency, a level of reading commensurate with their underlying intelligence. Does mixed dominance often result in this type of perceptual confusion, while consistent dominance allows easy acquisition of reading skills?

Apart from the nature of the association between handedness (and thus, by inference, cerebral dominance) and perceptual disabilities, the direction of the possible relationship is also disputed. This is to say, does lack of or late lateralisation cause dyslexia or does retarded linguistic development cause poor lateralisation. Krashen & Harshman (1972) pose this question and prefer to see external linguistic behaviour and internal lateralisation of language functions as parallel manifestations of 'crucial processes of linguistic development' normally taking place in the first five years of a child's life.

In general, laterality factors are seen as identifiers or concomitants of poor reading ability (Naidoo, 1972; Critchley, 1968; Rabinovitch, 1968). Tansley (1967) discusses the possible causes of dyslexia - poor linguistic background or school environment -and presents a list of identifying factors which includes both laterality and 'directionality'. Within this framework, however, reading disorders are often seen in terms of backwardness (low IQ concomitant with reading ability) rather than in terms of retardation (IQ relatively higher than reading ability).

In the general educational situation, laterality (left or mixed-handedness) has been used as an identifying factor in cases of reading disability. In special schools, proportions of left-handers may be higher than expected (Gordon, 1921). As early as 1899, Smedley discovered that dull pupils were, on average, more ambidextrous on tests of hand strength than bright pupils, a result replicated with a tapping test. Gordon quotes figures of 18.2% left-handedness among mentally defective children compared with 7.3% among controls. This general backwardness is related by Gordon to mirror-writing although specific reading disability and perceptual retardation are not referred to. In children with above average IQ suffering from 'specific developmental speech disorders' Ingram (1959) found a higher proportion of mixed-handers than expected. His findings with respect to hand preferences are summarised in the table below. Similar results were forthcoming with eye and foot preference scores.

	Clinical Group	Control Group
Right-handed	46.25%	78%
Not strongly lateralised	50%	14%
Left-handed	3.75%	8%

Ingram remarks, in terms reminiscent of Bannatyne's model (see 4.1.2), upon the general nature of language disorder observed in the clinical group, 50% of whom were mixed-handed:

"There is frequently disturbed appreciation of spatial relationships in the horizontal plane. This results in mistakes being made in recognising the identity and order of letters and small words in reading and in letters being incorrectly formed (often reversed) and placed in incorrect relationships with one another." (1959, p.463)

It is this perceptual confusion referred to by Ingram and Bannatyne, amongst others, which lies at the heart of any hypothesised relationship between reading ability and handedness.

4.2.1 Handedness and specific reading disability (Dyslexia)

The question posed by Liberman (1971) : is weak laterality associated with poor reading? must be answered in two parts. First it can be established to what extent handedness is an adequate indicator of cerebral lateralisation for language (see chapter 3). Secondly, the relationship between handedness and children's specific reading problems must be ascertained.

If we assume that the left-handed, mixed-handed or ambidextrous child is less likely to possess left cerebral representation for language, then it appears that, in many cases, the dyslexic child lacks this well-defined brain organisation.

4.2.1.1 Mixed-handedness as a factor in dyslexia

According to Goldberg & Schiffman (1972) the 'typical dyslexic subject' is likely to show signs of ambilaterality: of referrals approximately 65% showed some disturbance in laterality (of hand, eye or foot). Although most studies refer to ambilaterality or mixed-handedness, mention is made of the group of specifically left-handers. Perlo & Rak (1971) claim that among their adult dyslexic sample, 26% showed themselves to be left-handed - more than twice that expected in the normal population. Witelson & Rabinovitch (1972) tested children on dichotic listening apparatus and concluded that amongst those children with an auditory-linguistic deficit there was more right hemisphere speech representation, but not necessarily any greater lack of lateralisation. This also points to left-handedness as a possible factor in children with specific speech disorders.

Although Levy (1969) and Miller (1971) claim that the verbal IQ scores of left and mixed-handers did not differ significantly from those of right-handers, mixed (or left) handedness is often regarded as a concomitant of poor reading or language ability (Critchley, 1969: Levy, 1969: Hepworth, 1971). Seen in other terms, there is evidence for less left hemispheric language representation among dyslexics. Newton (1970) confirmed this relationship by comparing the EEG's of 25 dyslexic and 25 control children. Amongst other findings significant differences were found in the amount of alpha activity in the two hemispheres between the two groups. Results are seen as neurological confirmation of the 'necessity for resolution of cortical hemispheric dominance to facilitate the acquisition of language skills'.

Bannatyne (1968) studied the relationship between handedness and various auditory and vocal skills and discovered that both ambidextrous and left-handed subjects were more prone to confuse the direction of verbal stimuli, thus producing more mirror-writing than in right-handers. Naidoo (1961) found similar differences between groups. She found the greatest difference in performance on reading tests lay between right-handed and ambiguously-handed children. The differences between dextrals and sinistrals were less extreme.

Elsewhere Naidoo (1972) discovered dyslexic children to be more commonly ill-lateralised than strongly left-handed; in addition, among the group of primary reading retardates (children with IQ's greater than 90 and reading ages more than two years below mental age) significantly more male ambilateral subjects were found than in a control group. Also, more left-handedness was found in the families of dyslexic children. On the basis of much data analysed by factor analysis, Naidoo suggests that there may be two possible types of dyslexia: one characterised by speech and language delay and a second demonstrating atypical patterns of laterality. Mixed handedness may be <u>one</u> possible cause of specific reading disability.

The difficulty associated with the perception of directional material was pointed out many years ago by Orton (1925). He suggested that in people with incomplete dominance, incorrect memory images would be fed out from the brain either for the purposes of recognition (reading) or for production (writing). When a symmetrical functional relationship exists between the two hemispheres, the memory traces (of, eg letters) will be stored in both hemispheres as mirror-images of one another and, on activation, the stimulus may be fed out from <u>either</u> hemisphere, thus accounting for reversal of letters, words or other visual stimuli. In Orton's words incomplete dominance may lead to 'strephosymbolia' (twisted symbols) while strong left or right-handedness will facilitate the acquisition of perceptual skills involved in reading.

Dyslexic children, aged between 7 and 9, were found by Harris (1957) to demonstrate a significantly greater degree of mixed handedness than a control groups of similarly aged children. A similar study by Wussler & Barclay (1970) also showed that, although the intellectual performance of different laterality groups did not differ, mixed dominance could again be seen as one possible cause of dyslexia. From the data it is further suggested that:

"inadequate cerebral dominance and its associated concomitants of perceptual-motor immaturity or dysfunction .... and differential adequacy of psycholinguistic functioning may be an integral part of the dyslexic syndrome." (1970, p.424)

Thus, mixed dominance not only inhibits the perception of ordered material, but may also have a deleterious effect on psycholinguistic ability in general.

Clinical data collected at Aston university and involving both dyslexic and control children also points to the atypical laterality patterns in the former group. Laterality deviation scores were given to each individual on the basis of the number of hand, eye, foot and ear preferences which deviate from the overall laterality pattern. Thus a child scored 10 if all answers were right, or left, and scores were scaled such that 0 indicated no overall dominance. A table of the scores is seen below:

Score	1-2	3-4	5-6	7-8	9-10
Controls	6	18	20	8	10
Referrals	20	18	12	4	2

When scores are divided into two groups (1-6) and (7-10) significant (X^2) differences are found between referrals and controls ($p<0.005$). Dyslexic children are therefore on the whole less well lateralised than control children of the same age. This finding has since been reinforced with results from a study involving matched groups from school populations. Sixty dyslexic and sixty control children were compared on a number of measures. Again dyslexic children were significantly less well lateralised than the controls ($p<0.001$), but perhaps more interesting is the fact that for both groups, laterality scores correlated positively with reading age scores ($p<0.01$).

4.2.1.2 Handedness as a non-significant factor in dyslexia

Studies exist which report no laterality differences between groups of reading disabled and normal children. A study by Gates and Bond (1936) revealed that, although eye and hand dominance have little relation with reading difficulties, mixed dominant individuals were prone to make more reversals in writing, a finding rejected by Woody & Philips (1934), who found that right-handed pupils tended to make the most errors of reversal. Overall handedness and eyedness groups responded with approximately the same number of reversals.

Bettman, Stern, Whitsell & Gofman (1967) completed a study with 47 dyslexic and 58 control children aged between 7 and 14. Again no significant differences were found between groups on laterality tests. Both groups possessed a similar number of left-handed or ambidextrous children.

On performance (peg-board) tests of handedness Trieschmann (1968) could find no differences in the handedness characteristics of normal and reading problem groups, containing children aged 7-9 years with at least normal IQ.

The polarisation of results into those which support a specific relationship between handedness and reading ability and those which categorically deny such a relationship, obscures the fact that each study employed its own concept of handedness and reading disability. The overriding impression is that a relationship does exist, but that use of measures of abilities underlying reading would clarify the position further. For example, if it is the directional, perceptual aspects of reading rather than the conceptual factors (eg vocabulary and imagery) which pose difficulties for the mixed moninant individual then these aspects could be isolated for the purposes of testing.

4.2.2 Other laterality concomitants of language disability

Some authors find no relationship between hand/eye preferences and reading disability (Balow & Balow, 1964; Cohen & Glass, 1968) although visual defects per se (such as binocular inefficiency) are often postulated as possible causes of dyslexia (Witty & Kopel, 1936; Ludlam, Twaroski & Ludlam, 1973; Birnbaum & Birnbaum, 1968).

Crossed dominance of hand and eye is, however, seen by many as a possible contributory factor in the dyslexia syndrome (Berner & Berner, 1968; Blai, 1972), although Harris (1957) found a greater incidence of crossed laterality in normal subjects than in subjects with reading impairment.

Left-eyedness alone is also put forward as a concomitant of poor reading ability (Monroe, 1935) and possible reasons for this are suggested by Witty & Kopel (1936), who claim that the left-eyed individual might naturally tend to perceive things in a right-to-left direction and thus be in a disadvantageous position for the specifically left-to-right task of reading. However, no cross-cultural evidence (from countries with right-to-left script) is given in support of this claim.

Naidoo (1972), although detecting an increased incidence of left-handedness amongst cases of reading retardation, found no such increase in left-eyedness. She did, however, find a greater proportion of crossed lateral male subjects amongst spelling retardates (with reading age between 0 and 2 years below mental age).

With respect to tests of dichotic listening, there appears to be less right ear dominance among dyslexics, especially among older children (Satz et al 1967). Sommers & Taylor (1972) similarly found more left ear superiority on a dichotic word test in younger language-disturbed children (age 5-8 years) although no relationship was discovered between laterality tests and the dichotic listening results.

Finally, familial left-handedness was found in one study not to influence reading age (Allison, 1966). Three groups of children, right-handers, left-handers with FAML and left-handers without FAML produced no significant differences on tests of reading.

4.3 Handedness and visuo-spatial ability

Much has been said about the spatial abilities of left-handers and ambidexters. On an intellectual level Levy (1969) claims that left-handers are inferior to right-handers on a performance measure of intelligence. This claim is upheld by Gilbert (1973), who also refers to common assumptions that the left-hander presents performance deficits in mirror-tracing, spatial ability and tasks lacking field dependence. Gilbert hypothesised that it would be weak left-handers, being more variable in speech laterality, rather than strong left-handers, who would perform least well on a task involving memorisation and recognition of faces. This hypothesis was upheld.

Thus on one particular spatial task inferiority can be demonstrated on the part of the mixed lateral individual. It is to be noted, however, that the standard deviation of scores was larger for weak left-handers (3.79) than for strong left-handers (2.07) or right-handers (3.47). Thus there remains the possibility that of those subjects recording high scores there may be the expected number of mixed lateral individuals present. This point is elucidated by McGlone & Davidson (1973).

McGlone & Davidson (1973) also point out that Levy and others did not obtain measures of individual speech laterality and did not examine relevant sex differences. They found some evidence in support of Levy although not all left-handers performed poorer than right-handers on spatial tests (of dot enumeration). The situation found to be most disruptive to spatial performance was that in which neural asymmetry of functions was completely reversed to the normal brain organisation (ie in strong left-handers). This contradicts the findings of Gilbert, above, if facial recognition and dot enumeration are seen as facets of the same underlying ability. The group of subjects found to perform consistently most poorly on the dot enumeration test was that of female left-handers (with higher left ear dichotic listening scores).

McGlone and Davidson suggest that, although their results are not readily explicable with respect to neural competition (mixed laterality as such did not produce poor results) an explanation may lie in the possibility that the left hemisphere is, in all cases, simply less efficient than the right with regard to non-verbal functions.

4.3.1 Superior spatial abilities of left (and mixed)-handers

Trieschmann (1968), unlike Zangwill (1962) and Gilbert (1973), found ambilaterality unrelated to perceptual retardation or impaired spatial awareness. In two groups of children, one with reading problems and a control group, perceptual errors (symbol transformations) were found to be higher for problem readers, regardless of hand differentiation.

Kershner & Jeng (1972) also reject the notion that to be well-lateralised necessarily entails the possession of significantly better spatial ability. In normal 7 year old children mixed dominance was associated with good complex visuo-spatial abilities. In addition, crossed lateral right-handed subjects were found to recall overlapping geometric shapes, presented by tachistoscope with greater accuracy than consistent lateral subjects.

Some of the most convincing support for Bannatyne's theories (see 4.1.2) is found in two studies by Kershner (1971, 1972) involving both normal and mentally retarded children. First looking at intellectually normal children aged 7 years, Kershner (1971) found that those children exhibiting mixed lateral dominance were superior in complex visuo-spatial abilities, involving short-term memory and reversible visual imagery, to children showing consistent lateral preferences (consistent hand preferences and consistent hand, eye, ear and foot dominance). The task employed demanded good gestalt recognition, memory and recall. The child was required to observe a T-shaped path with a schoolhouse and car which could be rotated and moved in various directions (the T could also be rotated). Memory for the conservation of this complex spatial relationship was tested in another room.

In a later study (1972) Kershner reproduced this result with teachable mentally retarded children. More mixed-handed and crossed-lateral children had success in reproducing the conceptual spatial relations than did lateralised children. Unlike authors who stress the relationship between consistent laterality and intellectual growth (see Berman, 1971) Kershner views things in a different perspective and suggests that his results support the developmental importance of <u>bilateral</u> sensory and motor functioning. It thus appears that the definition of 'intellectual growth' (ie at its simplest level, does it refer to verbal or non-verbal intelligence?) is the determining factor in hypotheses concerning the relevance of laterality to intellectual development and performance.

Wussler & Barclay (1970), studying reading-disabled children, found that, when they were compared with respect to laterality (mixed dominance) no differences were revealed in intellectual functioning (WISC scores) within the group. An experiment by McGlannon (see Wussler & Barclay) demonstrated that on the WISC test (in particular the Blocks Design sub-test) both mixed and well-lateralised dyslexic subjects performed well.

Reference to the superior skill of left-handers is cited by Gardner (1973). One of the earliest records of the possible incidence of left-handedness (2.7%) is found in the Old Testament, Judges 20, vv15-16:

"And the children of Benjamin were numbered at that time out of the cities twenty and six thousand men that drew sword, beside the inhabitants of Gibeah which were numbered seven hundred chosen men. Among all this people there were seven hundred chosen men left-handed; every one could sling stones at an hair breadth, and not miss."

The suggestion here is that, unlike other biblical inferences of the particular qualities of left-handers, the sinistral individual is unusually skilful in certain spatial situations.

Bannatyne's model (see 4.1.2) also seeks to demonstrate the possibility of left-handers or ambidexters possessing certain superior spatial abilities. In fact he demonstrated (1968) that unlearned right-handedness was negatively correlated with a test involving selection of designs while this same test yielded a highly positive correlation with unlearned left-handedness. In general Bannatyne would expect ambidexters to be more artistic (as opposed to Critchley, 1970) and to be good at tasks where multi-directional scanning is required. This hypothesis is supported by Harnad (see Bakan, 1971), who demonstrated that left-movers (see 2.4.4) who are less likely to possess left cerebral dominance, are in general more creative and artistic, showing more visual imagery in problem solving. (Note, however, that Bakan's notion of cerebral dominance refers to 'total physiological functioning' rather than specifically to dominance for language functions.)The notion that the left-hander (ambidexter) is more artistically inclined than the right-hander is furthered by Peteron & Lansky (1974), who studied the handedness of a large group of architects. Their findings were twofold: first, of a total of 484 architecture students, 79 (16.3%) were left-handed and of 17 staff 7 (41.7%) were left-handed or ambidextrous, and secondly left-handers proved to be significantly superior to right-handers in the design of mazes. With regard to the first finding, it was also claimed that, on the whole, the percentage of left-handers increased with grade level:

Year	1	2	3	4	5	6
% left-handed	10.8	15.7	19.7	23.7	14.6	18.0

The implication here is that greater proficiency in architectural studies is reflected by a greater incidence of left-handedness (which will include a large proportion of mixed laterals).

Hepworth (1971) and Newton & Thomson (1974) also associate poor dominance with superior artistic and spatial ability and point to the fact that parents in spatial occupations (engineers, dentists, architects, etc.) tend to have more genetically dyslexic, mixed-handed and spatially gifted children.

4.3.2 Inferior spatial abilities of mixed (left)-handers

Again with reference to the model of Bannatyne (1966b, 1968), it might be expected that visuo-spatial abilities requiring the perception of uni-directional material (for example reading alphabetic script) would be performed less well by the individual possessing mixed cerebral dominance. On this basis, one would not necessarily expect lack of dominance to lead to difficulties of a spatio-constructional nature, as suggested by Critchley (1970). Indeed, to refer to one instance, the writer has observed a four year old autistic child who, while possessing no spoken language, could use either hand or both hands for most activities - including drawing and painting - and who could copy exactly complex spatial designs either drawn or constructed three-dimensionally.

The problem for the left-hander or ambidexter is more likely to be of the nature described by Gerhardt (1959). The left-hander, while perceiving things accurately in gestalt or three-dimensional form, may possess difficulty in perceiving the direction or order of symbols or objects. A left-hander may comment (Gerhardt): "Even though I have no difficulty in perceiving the forms of my environment, I can be confused or retarded when seeing them in a special order, direction or sequence."

A number of experimenters do, however, like Critchley, suggest that the mixed dominant individual is likely to possess poor general visuo-spatial ability In general these results originate from experiments which have concerned themselves with specific, isolated tasks and not from theories which envisage a broader, more general deficit. Zangwill (1962), however, suggests a range of deficits associated with mixed and left-handedness: poor drawing, copying and spatial ability and right-left discrimination. Although these deficits are found in dyslexics, Zangwill maintains that they occur in abundance only in ambilateral dyslexics and not in right-handed dyslexics, whom he would class as'pure' cases.

Little evidence of this 'pureness' can be found in accounts of other authors.

Nebes (1971) took 10 left-handed and 10 right-handed graduates together with 16 left-handed and 16 right-handed undergraduates and subjected them to a test in which they were required to make an inter-modal match between an arc and the circle of which the arc was a segment. An arc was felt, unseen, by the subject and matched to one of a number of circles which the subject could see before him. Left-handers proved to be inferior regardless of the hand used for the experiment. Initially, self-opinion of handedness was used as a criterion of inclusion into the experimental groups and thus the type of right or left-hander referred to remains unclear (there may have been more mixed dominant right-handers). The particular aspect of the task which poses problems for the left-hander is also unclear - for example, was it the inter-modal matching or the perception of the part-whole relationship (as they claim) which was related to self-assessed handedness?

Gilbert (1973), while reporting findings showing deficits in mirror-tracing, spatial ability, speed and flexibility of closure and increased field-dependence for left-handers, suggests that the weak left-hander possesses 'impoverished gestalt perception' - an hypothesis directly opposed to the notions involved in Bannatyne's model. This being the case, one must ask whether a facial recognition task, such as that used by Gilbert, is representative of wholistic perceptual tasks in general. Indeed, such a task is seen by Cohen (1973) to require an analytic (left hemisphere) procedure for accurate performance. In this case, the time allowed for recognition and remembering together with type of recall - verbal or otherwise - may be crucial in determining the performance of weak left-handers. (Gilbert gave his subjects no time limit for recognition of 8 faces previously shown for 25 sec. from a set of 40 faces).

4.4 Relationship between visuo-spatial and linguistic ability

Language functions and visuo-spatial functions are, to a great extent, controlled by opposite hemispheres. Functional integrity - separation of these two processes into two hemispheres - is more likely to be intact in those individuals with strong hand preference, while in mixed handers functional differentiation of the hemispheres is less clear. When two nerve fields, controlling different functions, interact, one set of functions may be impaired (Levy, 1969; Marshall, 1971), but as stressed, it is not always clear whether it is language or spatial ability which will suffer in the individual with mixed laterality.

Annett (1964) suggests that heterozygotes (mixed-handers) are poorer in verbal IQ and that cerebral functions are shifted at the expense of speech, while Levy (1969) states categorically that it is spatial ability (measurable by performance IQ) which is impared in the left or mixed-hander, while verbal IQ remains at the same level as for right-handers.

An exploration of the nature of visuo-spatial ability and facets of linguistic ability may shed light on their interrelationship in the individual and on the appearance of apparently conflicting evidence with regard to the mixed-dominant individual.

Spatial functions, although controlled by the 'minor' hemisphere, appear to share, to some extent, the major hemisphere with language functions (see Bannatyne, 1966a; and Kinsbourne, 1972). Few tachistoscopic studies of non-verbal abilities show as clear a field preference as do tests of verbal perception, and this further supports Bannatyne's view, expressed in his distinction between the 'verbal brain' and the 'spatial brain':

"Thus it can be seen that while the verbal brain, so to speak, involves only one hemisphere, is primarily auditory and one-handed, the spatial brain is mainly visual in nature and uses both hemispheres, both visual fields and both hands." (p.2)

Further, Bannatyne defines visuo-spatial ability as 'the ability to manipulate objects and their interrelationships intelligibly in three-dimensional space.'

Verbal ability differs from spatial ability primarily in its involvement with sequencing and analytic procedures. Marshall (1972) exemplifies the inherent differences between verbal and spatial thought by using models of (a) a language grammar and (b) a picture grammar. Linguistic stimuli are processed in the context of past and future verbal stimuli - thus the status of linguistic tokens is affected by other linguistic items (words gain a specific meaning only in the context of sentences). The status of visuo-spatial tokens, however, is unaffected by other visuo-spatial objects. Thus the ordering is not hierarchical in the same sense as we talk about language being hierarchical in nature.

Both verbal and spatial abilities contribute to intelligence. In reading, where specialisations of both hemispheres are involved it is thought that a method combining phonic (auditory, left hemisphere) and gestalt (visual, right hemisphere) may represent the optimal approach where individual children inherently favour either approach but not both (Wepman, 1962; Hannatyne, 1967).

Many studies have concentrated on this relationship between linguistic and visual factors of reading (Smith, 1971; Rozin, Poritsky & Sotsky, 1971; Gibson E. 1965, 1969) and often it is the directional aspect of reading which is regarded as the most crucial perceptual ability required for fluent reading. Corballis, Miller & Morgan (1971) demonstrated that, on the visual level, directionality is perceptually more salient than left-right symmetry. Reaction times to sequential stimuli (→ →) or (← ←) were significantly shorter than those to mirror-imaged stimuli (→ ←) or (← →). Explanations are given which relate these findings to experience in reading.

Another study by Kolers (1972) demonstrates the importance of direction in reading. Kolers discovered the left-to-right nature of reading to be a more important factor than meaning in ease and speed of reading. A meaningful message written right-to-left was read more easily as a nonsense message written left-to-right than in the unusual direction, in which it made sense.

Studies of dysphasia, which might be expected to demonstrate the independence of verbal from non-verbal abilities, may fail to produce clear evidence. Piercey (1964), while suggesting an overlap of dysphasia and general intellectual impairment, points to the possible reasons for failure on non-verbal tests. A patient may inadequately comprehend instructions or perform poorly on tests (including Ravens Matrices), in which success is aided by implicit verbalisation of the intellectual operation leading to a solution. The attempt to devise a test which does not depend on verbal mediation may, according to Piercey, be fruitless.

4.4.1 Spatial abilities and dyslexia

By definition, the dyslexic child has a problem with reading. Modern interpretations are that this is a relatively isolated disability. Apart from noting that ambidexterity is often linked to the directional confusion of the dyslexic, it is interesting to discover the level of non-directional spatial ability in the dyslexic population as a whole. If an understanding can be arrived at concerning the types of perceptual ability impaired and those conserved, then the primary nature of the disorder will be clarified and possible links with handedness and cerebral dominance elucidated.

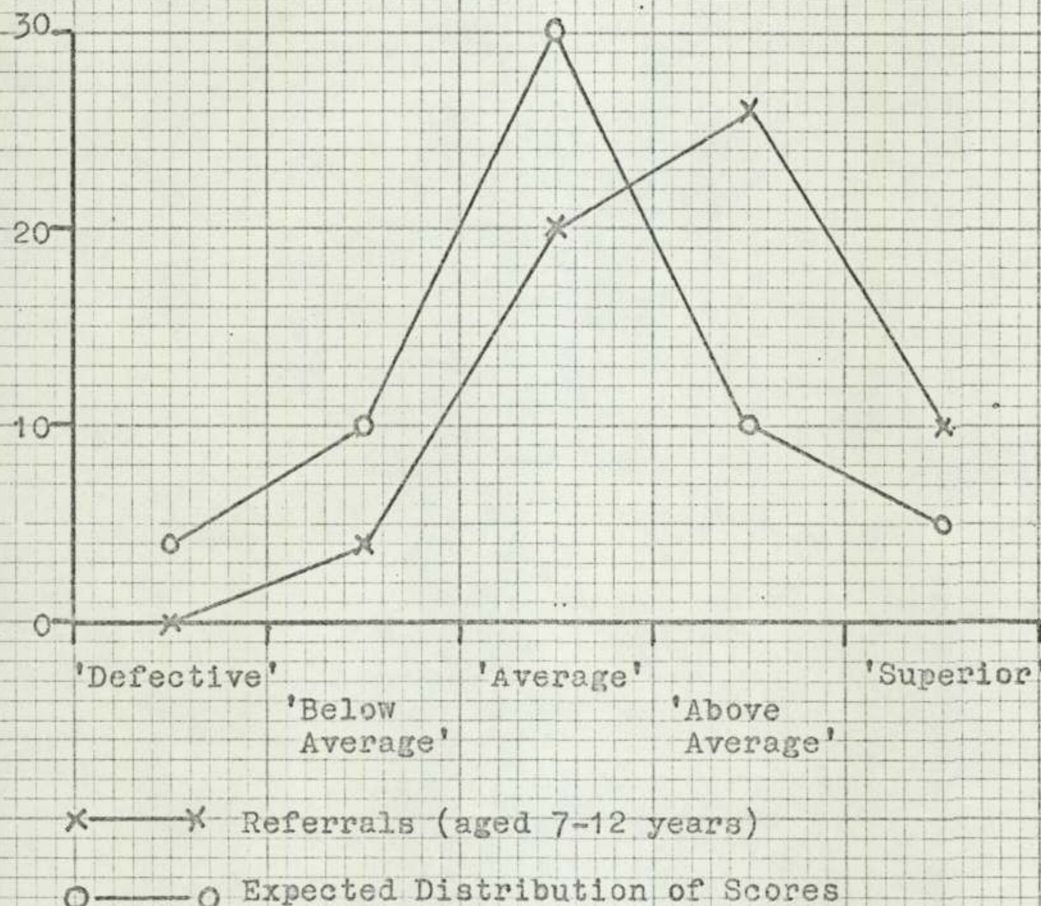
One major link between dyslexia and visual perception is provided by the observation that lateral images (left-to-right) are often reversed while vertical images are rarely confused or up-turned (see Orton, 1925 and Anon 1969). When symbols are misplaced or reversed, this does not necessarily indicate a general spatial disability, but the true picture is perhaps that it is demonstrative of one facet of spatial impairment, namely disturbance of orientation in a left-right direction or of left-right discrimination (Lovell & Gorton, 1968). Krise (1949) proposes an alternative hypothesis - that reversals in reading are due to the similarity of symbols and the lack of familiarity between the various symbols and their background. Such an argument fails, however, to account for the specific left-right nature of errors. For example, why should 'b' and 'd' be frequently reversed while 'n' and 'u' are rarely confused?

Bannatyne's (1966b) arguments, mentioned in previous sections, support the notion that a dyslexic is likely to possess superior spatial abilities where the particular direction of the material or stimuli is not of importance. Evidence for this hypothesis is difficult to acquire since it is hard to define what would constitute 'superior' ability in a child severely disabled in writing and reading - abilities involved in the majority of IQ assessments. However, Camp (1973) could find no deficit in the performance on Ravens Matrices of severely disabled readers. Children averaged scores around the 50th percentile (for normal population).

Clinical work at Aston University has shown that dyslexic children perform, on average, better than normal on the Ravens Matrices - a test of visual perception relatively independent of directional stimuli. The performance of dyslexic referrals, aged 7-12 years, on the coloured Matrices can be seen from the graph (Fig.4.1). The expected distribution for the number of children (60) is also shown.

Perlo & Rak (1971) report that adult dyslexics often show good appreciation of visuo-spatial shapes, while Sladen (1971) observes that dyslexics often possess 'compensatory' abilities and suggests good map-reading as one such ability. This observational evidence is further supported by Guthrie, Golberg & Finucci (1972) who demonstrated that memory for geometric forms was not related to visual memory for letters, although tests of visual sequential memory were significantly correlated with several measures of reading.

Performance on tasks requiring recognition of numbers and shapes did



Classification of Referrals on Ravens Coloured Matrices

Figure 4.I.

not significantly differ between poor and good readers, (Vellutino, Steger & Kandel, 1972) although poor readers performed less well on tests of verbal recall. With regard to the perceptual abilities of the group of poor readers, Vellutino et al claim that:

"Poor readers are able to process visual representations as well as normals but find it difficult to integrate and/or retrieve the verbal equivalences of such input." (p.113)

4.4.2 Dyslexia as a visual sequencing disorder

At least one type of reading disorder appears to be characterised by (a) mixed laterality and (b) a sequencing disability (Naidoo, 1972). The model of Bannatyne and evidence cited in the two previous sections would suggest that there is also a direct connection between mixed laterality and sequencing (dis)ability.

Certain visual memory items and visual abilities may remain unrelated or even negatively related to reading ability (eg good map-reading related to severe dyslexia). Visual abilities involving similar sequencing processes to those demanded in the reading situation may, however, be positively related to reading ability. A dyslexic child may therefore possess good artistic, spatial and spatio-constructional ability but be unable to sequence visually, either from memory or by copying. Dyslexia is often seen as a sequencing or blending disability both on a visual and auditory level (Naidoo, 1972; Bannatyne, 1966b; Gardner, 1973).

Clinical results from the University of Aston show that reading ability and visual sequential memory are positively related. One hundred and twenty children (60 control and 60 dyslexic) completed a battery of tests and produced correlations of 0.59 and 0.69 between reading age and two tests (pictorial and symbolic) of visual sequential memory.

Although dyslexia can be seen as a deficit in cross-modal integration (auditory-visual or phoneme-grapheme disturbance, see Belmont & Birch 1963) it can be shown that reading retardates often possess a disability in one modality or on one level. Blank & Bridger (1966) demonstrated that retarded readers who found difficulty in sequencing visual material appeared to have no such difficulty with complex visuo-spatial (dot) patterns. It is the sequencing aspect of the reading task which presents the real problem, whether this be on a visual or temporal (auditory) plane.

In other areas of language study, linguistic deficits are often explained as sequencing disorders, ranging from sub-types of aphasia to every-day slips of the tongue (Boomer & Laver, 1968). These sequencing difficulties appear to persist in children who may have been subjected to either phonic (and sequencing) or gestalt (whole word) learning approaches to reading at school (North Surrey Dyslexic Society Review, 1969). The successful learning of English by certain children may depend on the integration of these two approaches. The prime difficulty, however, appears to be in the directional nature of the task itself. Results from Blank & Bridger's study (above) confirm what has been found with respect to the two types of script found in Japan (see Makita, 1967). With Kanji - pictographic script, where each symbol represents an event - there appears to be little incidence of dyslexia, while Kana - phonetic script - appears less resistant to dyslexia, although still only producing one-tenth the incidence of dyslexia in Western countries. Makita notes that, in Kana, no figures stand in mirror-relationships to one another. Any reading problem with Kanji would seem to be related to individual differences in learning ability (at the end of the 6th grade almost 1,000 complex symbols have to be mastered).

The difference between scripts is envisaged by Makita as one between 'total perception' of a figure representing an event (Kanji) and 'partial perception' of sequentially ordered phonemes (Kana). (See Gibson E. 1969, for discussion of perception of distinctive features in reading). It is this partial perception of distinctive features in a particular orientation and sequence which the so-called visual dyslexic lacks or has difficulty with.

4.5 Sex differences in spatial and verbal ability

Evidence exists that males tend, on the whole, to be less strongly right-handed than females (see 1.4.3). It may even be the case that males are overall more ambidextrous or mixed-handed, while females exist in greater proportions at both ends of the handedness continuum, although this is not universally accepted.

It can also be suggested that strongly-handed individuals are in the most advantageous position for the acquisition of good, fluent language skills (see Chapter 4), while individuals exhibiting degrees of mixed-handedness may possess certain good visuo-spatial skills.

If the above hypotheses were to prove acceptable, then certain sex differences in tests of spatial and language ability are to be anticipated. While males might be found to show lower verbal ability than females, they may also tend to demonstrate superior facets of spatial ability. Evidence for any such trends will depend to a very large extent on the handedness measures employed and on the specific types of verbal and spatial ability under scrutiny.

4.5.1 Sex differences in spatial ability

Bannatyne (1966a) describes the typical dyslexic as male, verbally inferior, but spatially superior. The relationship between sex and spatial ability can be taken out of this context of dyslexia in order to discover the extent of the association. In a comprehensive study, involving almost equal numbers of males and females from a normal population sample, Newcombe & Ratcliff (1973) found significant sex differences on the WAIS performance IQ measure. The groups (409 men and 414 women) were subdivided into left, mixed and right-handers, by a preference questionnaire of 7 items. Within each sub-group males performed better than females on the performance scale:

	RIGHT-HANDED		MIXED-HANDED		LEFT-HANDED	
	MALES (302)	FEMALES (356)	MALES (92)	FEMALES (47)	MALES (15)	FEMALES (11)
WAIS Performance	111.4	108.9	112.2	110.7	112.3	108.3

Over all groups the average for males was 111.5 compared to 109.1 for females.

Although the WAIS performance test is not a genuine test of visuo-spatial ability it does contain non-verbal and spatial sub-components and good results can be regarded as indicative of a tendency towards superior spatial ability. The particular population sample used here may, however, have been biased, in that males tended to be superior on the verbal scale also. No evidence exists elsewhere for a general significant sex difference on both scales of the WAIS or WISC.

Kershner (1971) found no significant sex differences on a test of ability to conserve spatial relations (see 4.3.1). However, although he employed equal numbers (80) of males and females, no indication is given of the handedness composition of each group. Altogether there were 139 right-handers, only 10 mixed-handers and 11 left-handers. The unexpectedly low number of mixed-handers, if it is not simply a product of the handedness measure used, may well have dissolved any sex differences in ability, especially as mixed-handedness may be more predominant feature of male groups.

McGlone & Davidson (1973) produced more positive results. They found that, compared to males, females showed poorer spatial ability and a higher incidence of right-field superiority of a dot enumeration test. More males were found above the median and more females below the median on a Spatial Relations Test and on the WAIS Blocks Design Test. The left-handed female appeared to be especially poor on such tests of spatial ability.

Finally, differences in spatial ability are noted by the authors of the Minnesota Paper Form Board Test (Likert & Quasha, 1948), a measure of visual perception of complex shapes (free of verbal mediation). The test, which was found to have predictive value for achievement in mechanics, art, design and inspection situations, was standardised over various population samples with the result that males 'consistently excelled' females in score, although such a difference was not statistically significant.

4.5.2 Sex differences in verbal ability

The supposition that females will demonstrate greater overall verbal ability is strengthened by results produced in the standardisation of the Modern Languages Aptitude Test (Carroll & Sapon, 1959). Females tended to score higher than males on both the longer and shorter versions of the test, but Carroll suggests that the relationship may be complex,for example with regard to performance on sub-tests.

In general, evidence for the superior verbal ability of females is found most frequently in indirect fashion, by studying the lower end of the scale of verbal ability. In studies of dyslexia or primary childhood language disability, the incidence of males often exceeds that of females in this respect.

Amongst children with developmental dyslexia Critchley (1971) estimates the sex ratio to be approximately 4 or 5 boys to one girl. This figure appears typical of many others calculated from similar populations. Amongst adult dyslexics with normal IQ Perlo & Rak (1971) claim that about 80% are men, while other figures of Hallgren (see Sladen, 1971) show a 77% male incidence in childhood dyslexia. Sladen reports sex ratios ranging from 10:1 down to 3:1 with an average near 4:1.

Annett & Turner (1974) studied the lower end of the reading scale and produced two sets of figures. First, amongst those children with a reading score of less than 80 there were 8 males and 5 females. Secondly, amongst those children with a specific reading deficit (reading score more than 30 points below vocabulary score) there were 12 males and 4 females (75% males).

From studies of infants showing minor brain dysfunction, Kalverboer, Touwen & Prechtl (1972) discovered more neurological signs among males. These signs are thought to correlate with later learning difficulties. Further to this, Ingram (1959) found with older children a ratio of 58 males to 22 females (72.5% males) when studying 'specific developmental disorders of speech'. More recently Rose (1973), describing a school for language-handicapped children, again claims a 4:1 ratio amongst such children, aged 8-16 years with IQ's within the normal range. With younger children (7 years) with marked speech defects Sheridan (1973) found a ratio of 144 males to 71 females(67%).

Although figures from cases of reading or language disabled children do not confirm the higher verbal ability of females, they do give an indication of the lower verbal ability of males at the lower end of the scale. If the distribution of verbal ability scores is spread over the same range of points for both sexes (equal variances) then males are shown to be poorer overall. Such an assumption is not, however, made by those authors dealing only with clinical populations.

4.6 Conclusions

Although left-handedness has long been implicated in disorders of speech and reading, it appears that mixed-handedness, accurately assessed, is a factor more closely associated with perceptual confusion. Left-handedness taken as overall superiority of the left hand or as left hand for writing, will encompass many mixed-handed or ambidextrous individuals.

Thus, as an index of mixed cerebral dominance, carefully classified mixed-handedness may provide a reasonably accurate measure. The confusion over the suitability of either preference questionnaires or performance tests suggests that a method combining both types of test will be the best predictor of mixed-handedness and dominance.

Mixed dominance (sometimes referred to as incomplete lateralisation) can be linked theoretically, experimentally or clinically to poor ability in tasks which are inherently directional or sequential in nature. These tasks include reading and writing but could also be extended to cover spatial tasks which possess similar, directional, analytic features.

Mixed dominance has also been associated with good or superior abilities in situations which lack directional features or which contain multi-directional stimuli. In general, tasks such as modelling, map-reading or spatial pursuits requiring good ability to abstract the visual gestalt from a situation, may be performed well by the mixed-hander.

The relationship of directional to non-directional spatial tasks, covered in 4.4 is significant in that it serves to distinguish the types of ability which, under certain conditions, can remain relatively independent from one another. The dyslexic with a sequencing problem can remain proficient in certain spatial tasks. Impairment of either 'verbal' or 'spatial' abilities may therefore be selective.

Either a 'clinical' or a 'normal' population study (see Annett & Turner, 1974) can be employed in order to detect the level of abilities in the mixed-hander. Experiments in the next three chapters will attempt to demonstrate similar approaches in the context of the above discussion.

Throughout any studies relating cerebral dominance to differential abilities sex factors remain very important for a number of reasons. Sex differences in handedness must be taken into account when studying the relationship between cerebral dominance and ability. In a 'clinical' study the presence of more mixed-handers in a certain ability group may be due to a large proportion of males in the population sample, while, in an experimental situation, males and females must be studied separately in order to determine whether the relationship between handedness and ability is similar for both groups or whether it is sex-linked.

Sex differences also provide a supportive link between cerebral dominance and ability. For example, dyslexics are usually male, and males tend to be more ambidextrous than females. A non-causal relationship between ambidexterity (or mixed-handedness) and dyslexia is thus suggested. Such inferences which look beyond sex factors, are at best sceptical, but nevertheless strengthen the connections in the complex network of relationships between laterality and ability.

On a more basic level sex differences can be studied in isolation with respect to one other variable. For example, on different measures of handedness, are there consistent trends in male-female differences, and will the greater consistency in hand preference of males be reflected in greater inconsistency between performance on different tests of handedness?

In proceeding from the literature, it is necessary to indicate the writer's general acceptance of Bannatyne's model (see chapter 4). It is this model which clearly undermines Levy's (1969) claim concerning the deficit in minor hemisphere tasks in the mixed dominant individual. Bannatyne prefers to look at the overall picture of brain organisation and suggests that first, it is the directional aspect of functioning which is impaired in mixed-handers and secondly, some tasks believed to be non-directional and mediated by the minor hemisphere may be performed better by the mixed-hander.

5. LATERALITY SURVEY

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5. LATERALITY SURVEY

5.1 Introduction

Laterality questionnaires can be employed to provide much information about the handedness of large population samples. Many different questionnaires have been compiled which can be sent through the post and analysed upon return (for example, see Annett 1967, Oldfield, 1971).

In Chapter 1 a discussion of questionnaire items demonstrated that the rationale for including specific items remained very much in the hands of the individual investigator. For example, although some researchers do not include items such as dealing cards and unscrewing a jar, which are performed frequently with the non-dominant hand, at least one of these items would appear to be necessary in order to detect and rank some individuals who have mixed-handed tendencies. In the writer's experience, both items may correlate with superior hand strength. The predominant right-hander in whom the left hand is stronger (on a dynomometer test) is likely to both unscrew jars and deal cards with his or her left hand.

A combination of items involving such features as dexterity, practice, strength and gross arm-shoulder movement (Palmer, 1964) provides, at this time, a heterogeneous measure of handedness and is less likely to fail to spot any kind of mixed-hander.

A good questionnaire should, at least, discriminate between the subject's self-classification and the questionnaire assessment of handedness. It is widely accepted that, while subjects in general consider their writing hand to indicate true manual dominance, left-handers in particular overestimate their degree of left-handedness (see, for example Humphrey & Zangwill, 1952; Benton, 1962). The use of every-day objects designed for right-handers may help to create a more 'mixed-handed' left-hander, but it does appear that strong left-handers (probably less than 4% of the population) will adapt to these situations and continue to use the left hand.

Some investigators have attempted to link a laterality quotient or handedness assessment to low or high ability groups (see Berman, 1971; Annett & Turner, 1974) with the result that low IQ or low attainment on certain measures, normally of a verbal nature, is associated with mixed or left-handedness. However, studies involving the assessment of large population samples by laterality questionnaire have rarely sought or found differences in handedness between different groups of individuals (see Oldfield, 1971; Annett, 1967). Annett compared frequencies of Right, Mixed and Left-handers within various population samples with proportions expected on the basis of a binomial distribution of handedness. Among various University samples and a sample of Enlisted Men, no handedness distribution differed significantly from that expected according to the binomial model.

Techniques which aim to discover handedness differences by classificatory measurement, among poor or superior ability groups, can readily be extended to investigate the handedness of population sample which are constructed according to more general principles of performance. For instance, in determining the handedness of dentists in relation to the general population, a relationship may be postulated between, say, left-handedness and fine motor-control and spatial ability, which are presumed to be at a high level in such an occupation. In fact Barsley (1970) refers to figures which demonstrate a high incidence of left-handedness among dentists, compared to figures for other professions:

Dentists	14% left handed
Doctors	9%
Violinists	8%
Pianists	10%

(figures from Christiaens et al 1962)

Evidence cited in Chapter 4 suggests that mixed-handedness might be more prevalent amongst individuals with good visuo-spatial or artistic ability, while strong handedness is found in greater abundance in individuals possessing good analytic, linguistic ability. The present investigation is concerned with this hypothesis.

In a School of Art and Architecture courses are found which involve most facets of spatial ability: Furniture design, Architecture, Town Planning, Fabric design, Three Dimensional Art etc. It can be presumed that individuals pursuing such courses, both to degree and diploma level will, in general, possess a good ability to perceive and manipulate items in three-dimensional space. Their 'intelligence' will be of a 'performance' rather than of a 'verbal' nature. Although some students will conceivably drop out of their courses at various stages due to under-achievement, to have reached the relatively high level expected on entry to courses suggests that students, in general, possess a superior spatial ability.

Peterson & Lansky (1974) sought to determine the level of left-handedness among architects and to discover whether those architecture students who are left-handed show more 'spatial flexibility' than right-handed students (see Chapter 4). From a simple 5-point self-assessment scale, where a score of 4 or 5 indicated some degree of left-handedness, it was found that, on average, 16.3% of architects were left-handed, compared to an expected normal population average of around 10%. It should be noted that all subjects were male, and that this may have accounted for some of the increased incidence of self-confessed sinistrality.

Peterson & Lansky suggest support for the notion that right-hemisphere dominance, associated with left-handedness, is also a concomitant of greater spatial competence. This conclusion appears rather fragile however, due to the nature of the handedness assessment employed. The concensus among other investigators would be that only very few of the 16.3% 'left-handers' would possess strict right hemisphere dominance for language. Nevertheless, the fact remains that a figure of 16.3% self-confessed left-handers is remarkably high for such a large population (484), and it appears that the sex factor (all were males) could not account completely for this. Oldfield's (1971) incidence of general left-handedness in males was approximately 10% (population of 400 undergraduates). If it is possible to contrast the figures of Oldfield with those of Peterson & Lansky, the different proportions of left-handers would produce a χ^2 equal to 7.89 ($p<0.01$). Even remembering the different assessment procedures employed by each investigator, it is likely that practically all of Peterson & Lansky's left-handers would have scored a negative IQ on Oldfield's Inventory.

The writer carried out a minor pilot survey of second year Architecture students, among whom Peterson and Lansky found an incidence of left-handedness of 15.7%. Individuals were asked questions concerning their writing hand, the hand most used for other activities, their preferred foot and eye and the presence of familial left-handedness.

The small group of 34 (5 females) produced 7 left-handers with respect to the first two questions above. This incidence of left-handedness (21%) while found in a very small population, was thought large enough to warrant further investigation. Especially interesting was that, of these 7 left-handers, only one showed completely consistent dominance - eye, hand and foot. In addition, 7 individuals were left-footed (of whom only 4 were left-handed), and 9 individuals reported a left-handed member of their immediate family. These findings indicated that inconsistent laterality rather than strong left-sideness might be a concomitant of good spatial ability.

If a School of Art and Architecture is presumed to provide subjects with superior spatial ability, then large numbers of individuals possessing good linguistic ability are likely to be found in foreign language departments of universities.

Some foreign language students may be nationals of the country whose language they are studying and some may be the type of student who does not respond well to the grammatical, analytic approach to language learning, but who prefers the approach where learning is achieved by analogy (see Rivers 1964 for discussion). In general, however, the teaching of syntax and sematics by analytic techniques still represents a very important tool in the teaching of foreign language and, ultimately, linguistic success in more than one language may depend on the ability to extract syntactic and semantic rules and reapply them to new situations.

A study of subjects with good linguistic ability could therefore centre around students of foreign languages. Again, it is in general assumed that students at <u>any</u> stage of a language course will have a linguistic ability superior to that found in the normal population. Although no studies can be found which examine the incidence of left or mixed-handedness amongst language students, the notion that there will be a low incidence of left or mixed-handed individuals is suggested by figures demonstrating more mixed-handedness amongst children with <u>poor</u> verbal ability (see Chapter 4).

In a study of the EEG patterns of Linguists and Artists, Newton (see Newton & Thomson, 1974) demonstrated the existence of certain differences in cerebral functioning. Comparisons were made between three groups of subjects: artists, linguists and engineers, and both inter and intra-hemispheric EEG activity. Preliminary analysis suggested that the linguists demonstrated differences in brain activity between the two hemispheres, while artists and engineers revealed more inconsistent patterns of hand laterality and a greater equivalence of electrical activity between the hemispheres. This equivalence of alpha rhythms is attributed to a more equipotential functional relationship between the hemispheres. Linguists, on the other hand, are believed to show clearer indications of possessing a dominant hemisphere.

As reported in Chapter 4, the relationship between crossed laterality (eye and hand) and verbal ability is unclear. Although often postulated as a possible cause of dyslexia, there is little evidence for this. Harris (1957) in fact found more crossed laterality in an unselected sample than in a population of reading disabled children.

In any study of laterality among different ability groups, it is necessary to take account of such factors as crossed laterality, eyedness and footedness in order to establish whether it is, as hypothesised, a difference in the incidence of mixed handedness which best distinguishes the groups or whether other factors also play a part.

In addition populations should be compared on handedness scores for males and females separately. It must be ascertained that any differences in the incidence of mixed handedness are due not to different proportions of males in each population but to the differences between the populations as a whole.

The present study sets out to examine handedness differences between various population samples, with the hypothesis that strong handedness will be more prevalent in samples whose members demonstrate good linguistic ability, while mixed handedness will be found more in those samples drawn from a spatially-gifted population. Further, with regard to footedness and eyedness it was hypothesised that more inconsistency or general left-sidedness would be shown by artists and that this group would also demonstrate less eye-hand-foot consistency.

5.2 Method

5.2.1 Laterality questionnaire

A questionnaire was devised which would supply as much information as possible concerning the subject's laterality but which was also short and easy to follow. All the questions were arranged on a single sheet of paper and designed such that misunderstanding was unlikely to arise.

General information: The subject's name (anonymity was permitted) age, sex, course of study and 'A' level achievements.

Handedness self-classification: The subject was asked, 'How would you classify yourself?' and was presented with five alternatives:

*Strongly right-handed

*Right-handed but left hand for some things

*Ambidextrous

*Left-handed but right hand for some things

*Strongly left-handed

Handedness items: The subject was required to answer the question 'Which hand would you use for the following activities?' by ticking in the appropriate column (Left, Right or Either) for each activity. The items selected for this battery were:

1. Write
2. Knife (cutting)
3. Clean teeth
4. Comb hair
5. Play tennis (cricket/golf)
6. Paint and draw
7. Throw a ball
8. Throw a punch
9. Stir a drink

10. Use scissors

11. Deal cards

12. Play instruments (guitar)

13. Hammer a nail

As indicated previously, there is no adequate overall rationale for choosing a certain set of items. The above items were chosen on a number of grounds. Items 1, 2, 3, 4, 7, 9 and 13 appear on many other questionnaires and seem to be fairly standard activities by which handedness is assessed. Item 5 may produce different answers for different sports from one individual. Racket and bat play involves both dexterity and strength and thus may be a good indicator of tendencies in handedness. Item 6 (see Oldfield, 1971) is often omitted from questionnaires as redundant, since it will tend to correlate highly with item 1. Some individuals may, however, choose to use different hands for the very fine motor control necessary for writing and for painting. It is these individuals who could often be of great interest in studies of ambidexterity. Item 8 was included as a measure of gross hand-arm-shoulder control and strength - a feature considered important by Palmer (1964). Item 10, while possessing an inherent cultural bias, since scissors are made primarily for right-handers, is useful in detecting strong from moderate left-handers. A strong left-hander may compensate for the right-handed bias of the tool and adapt it to left hand usage. Similarly for item 12, strong left - handers may adapt to the left-handed playing of musical instruments which are designed for right-handers. Such a task also involves both fine arm, hand and finger control. Item 11 will tend to spot individuals with mixed-handed tendencies (see Annett 1970) and is included for this reason.

Other items: One question was included on foot laterality ('Which foot do you kick with?'), and two questions on eye preference and dominance.

Subjects were asked which eye they used to look through a telescope and which was their 'pointing' eye. Instructions were given as follows:

"To determine your 'pointing' eye, keep both eyes open and point with outstretched arm at a small, distant object. With your finger still pointing at the object, cover each eye in turn with the other hand. The eye through which you see your finger still pointing at the object is your 'pointing eye'."

Finally subjects were asked whether any members of their immediate family were left-handed (mother, father, brother, sister).

5.2.2 Classification of subjects

Handedness:

A Laterality Quotient score was employed. This was calculated as $\frac{R - L}{R + L + E} \times 100$ where R, L and E refer to the number of 'Right', 'Left' and 'Either' responses respectively. Subjects could then be classified according to the following scale.

L.Q.	Classification
+90.1 - +100	SR (strongly right-handed)
+50.1 - +90	R (right-handed)
-50 - +50	A (ambidextrous)
-50.1 - -90	L (left-handed)
-90.1 - -100	SL (strongly-left-handed)

For certain comparisons a more general classification of right and left-handedness was established by the sign of laterality quotient. Thus a positive L.Q. indicated 'general' right-handedness, while a negative L.Q. indicated 'general' left-handedness.

Eyedness:

A subject was classified as 'left' ('right') eyed if he or she answered with two 'left' (right) or one 'left' ('right') and one 'either' response. Otherwise a 'mixed' classification was used.

Crossed laterality:

This was determined by taking into account handedness and eyedness. A subject whose general handedness (determined by sign of L.Q.) and eyedness were contralateral would be classed as 'crossed'. Otherwise a subject was a 'consistent' lateral (same side for handedness and eyedness) or a 'mixed' lateral (where mixed eyedness was found with right or left handedness).

Eye-hand-foot:

A subject was classed as 'consistent' for eye, hand and foot preferences only if a right classification or a left classification was found for all three modalities.

5.2.3 Population samples

Artists and Architects were obtained from the Birmingham College of Art and Design.

Linguists were obtained from the Foreign Languages Departments of

Birmingham University.

Engineers were obtained from the Engineering Departments of Aston University. This population sample was chosen basically as a control group. It was considered that engineering students would demonstrate both the analytic and spatial skills displayed by linguists and artists, although their work is to a large extent non-verbal in nature.

5.2.4 Procedure

Questionnaires were sent, together with an accompanying letter to individuals from the three populations under consideration. The letter contained brief information concerning the nature of the survey and stressed the need for responses from individuals belonging to every handedness category. Letters and envelopes displayed the name of the recipient wherever this was possible. The procedure for Artists, Linguists and Engineers was very similar, but for the purposes of further comparison, is set out below for each group.

Artists:

Approximately 750 letters and questionnaires were to be circulated by the Registrar at enrolment. All years of courses were thus included and subjects would be given the correspondence individually. Instructions were included concerning the return of completed questionnaires. These were to be placed in a specially-marked box in the Registry office which was centrally placed in the College. A similar procedure was adopted for a smaller sample of Artists (50) at Sutton Coldfield College of Further Education. Some post-graduates were included in the survey.

Linguists:

Questionnaires were sent individually through the internal mail to all students within the Departments of Foreign Languages at Birmingham University. Close co-operation was obtained with the Registry Division and completed questionnaires were to be returned to the secretarial office of the particular foreign language being studied by the student. Approximately 550 letters and questionnaires were sent.

Engineers:

Questionnaires and letters were handed out individually to first year students at registration. All other years were contacted via the departmental offices after names had been obtained from the Registry Division of the University. For each Engineering Department instructions were included to return completed questionnaires to departmental offices, where secretaries were willing to supervise collection. The total number of questionnaires sent (to all years) was approximately 1,200.

5.3 Results

5.3.1 Questionnaire return

A certain percentage of the questionnaires failed to reach their destination for various reasons.

Approximately 300 of those questionnaires destined for Artists were misrouted by the Registrar to College Annexes in North and South Birmingham where collection points had not been arranged.

Of those questionnaires sent to Engineers it was presume that approximately 400 had not found a recipient due both to exam failure and drop-out on the part of students from the previous academic year (the Registrar did not have up-to-date information of individuals at the time of the survey) and to absence on industrial training - again a factor not always predictable from general course lists. Thus two-thirds of questionnaires sent to Engineers were presume to have reached their destination.

No such problems arose with Linguists. The Registrar provided completely up-to-date information such that it was possible to assume that nearly all the questionnaires would be received.

The number of returns for each group can be seen from the table below:

	Number sent and received	Number returned	%
Artists	500	184	36.8
Engineers	800	268	34.5
Linguists	550	226	41.1
Total	1850	678	36.6

5.3.2 Costitution of groups

The average ages of individuals within each of the population samples were as follows:

	Males	Females	
Artists	22.9	20.7	years
Engineers	21.7	20.1	
Linguists	20.0	19.7	
Total	21.8	20.0	

The numbers of males and females can be seen from the following table:

	Males	Females	Total
Artists	117	67	184
Engineers	263	5	268
Linguists	60	166	226

While it is not surprising that only 5 female Engineers were found (this being the total number of female Engineers within the University), the trends amongst Artists and Linguists are less easily explained. Career and vocational prospects for Artists and Linguists would appear to be comparable, as would the practical suitability of work to either sex. Some evidence from Chapter 4 suggests that males may possess a higher spatial but lower verbal IQ than females. Such a factor may account for the above differences in sex ratios between Artists and Linguists, although alternative explanations favouring the greater emphasis on linguistic pursuits in girls' schools cannot be entirely dismissed. Educational opportunities geared to career prospects certainly account for the almost totally male engineering population.

5.3.3 Handedness

(a) Self-classification

Numbers of individuals self-classified as Strong Right (SR), Right (R), Ambidextrous (A), Left (L), and Strong Left (L) can be seen in Table 5.1.

(b) Test-classification

Table 5.2 shows the numbers of Artists, Engineers and Linguists falling into the five handedness categories. Ambidexterity is subdivided into right and left-handed segments, dependent upon the sign of the laterality

	SL	L	A	R	SR
Artists	6	16	3	75	84
Engineers	5	24	0	82	157
Linguists	8	10	1	45	162
Total	19	50	4	202	403

Table 5.1 Handedness self-classification of Artists, Engineers and Linguists

	SL	L	A		R	SR
			A(L)	A(R)		
Artists	2	13	4	13	84	68
Engineers	2	17	6½	18½	99	125
Linguists	5	6	4	8	70	133
Total	9	36	14½	39½	253	326

Table 5.2 Handedness test-classification of Artists, Engineers and Linguists

quotient. Thus scores between 0.1 and 50 count as Ambidextrous Right-handed while scores from -0.1 to -50 are classed as Ambidextrous Left-handed. One individual scored exactly 0 and accounts for the '½' score among Ambidextrous Engineers.

The relationship between self and test-classified handedness is presented by a series of graphs (see figures 5.1 - 5.4) which show numbers of test and self-classified individuals in each handedness category for the three population samples and for the whole group. Within each ambidextrous rating the number of test-classified Right (R) and Left (L) ambidextrous individuals is given.

(c) Strength of handedness

For the purposes of comparison, between groups, of the numbers of consistent and inconsistent handers, individuals were categorised as either 'Strong' or 'Weak' with regard to handedness:

'Strong' = S_L or SR

'Weak' = R, A or L

Table 5.3 reveals the number of Strong and Weak handers in each population sample. Subjects are further subdivided by sex. To further demonstrate the strength of handedness, the average L.Q. for each group was determined (a) with negative L.Q.'s scored as negative and (b) without regard to the direction of handedness, i.e. $|L.Q.|$ (Table 5.4).

A χ^2 analysis was carried out on the data presented in Table 5.3 in order to detect differences in the distribution of Strong and Weak handers between the various population samples. A summary of the findings

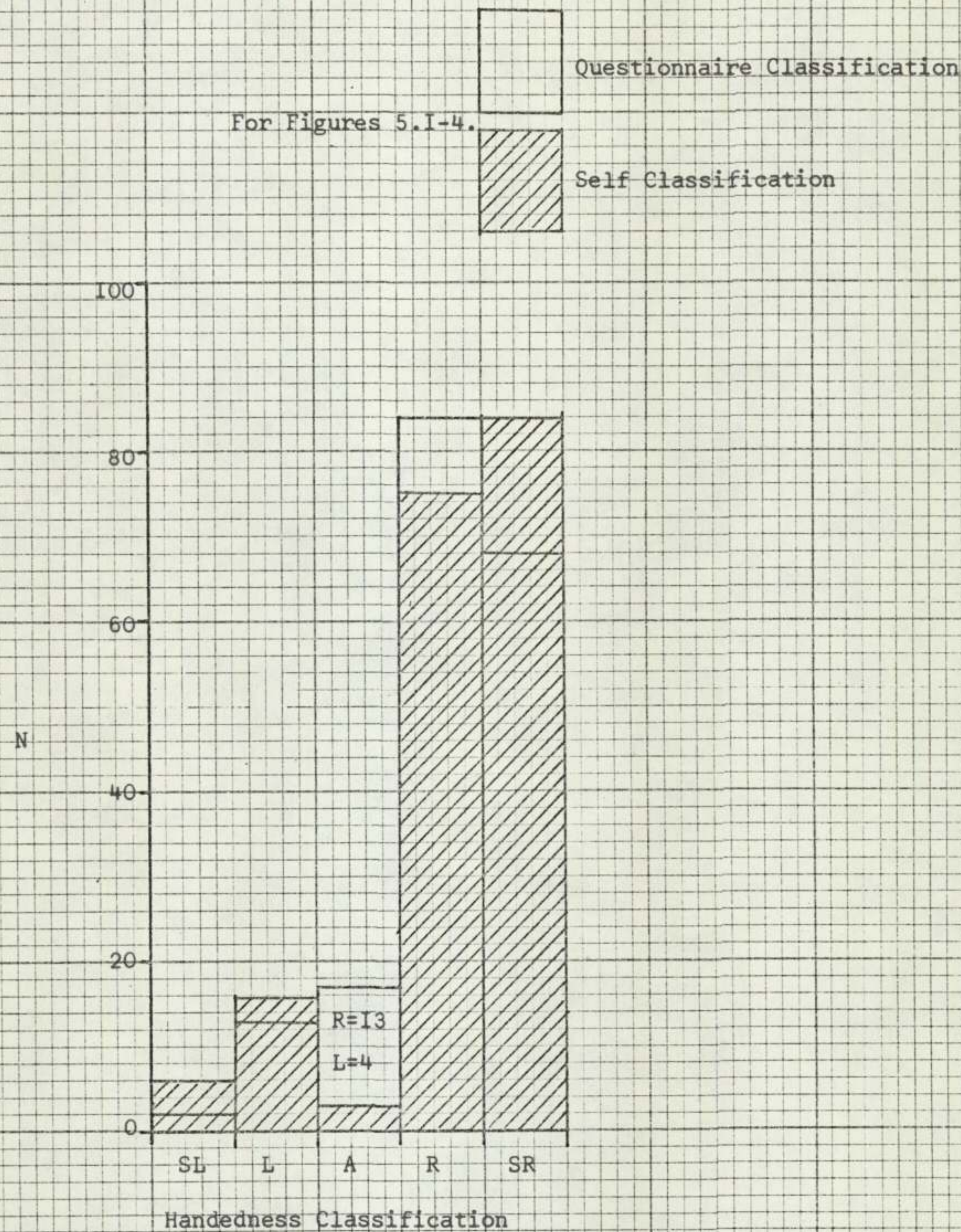


Figure 5.I. <u>Handedness of Artists</u>

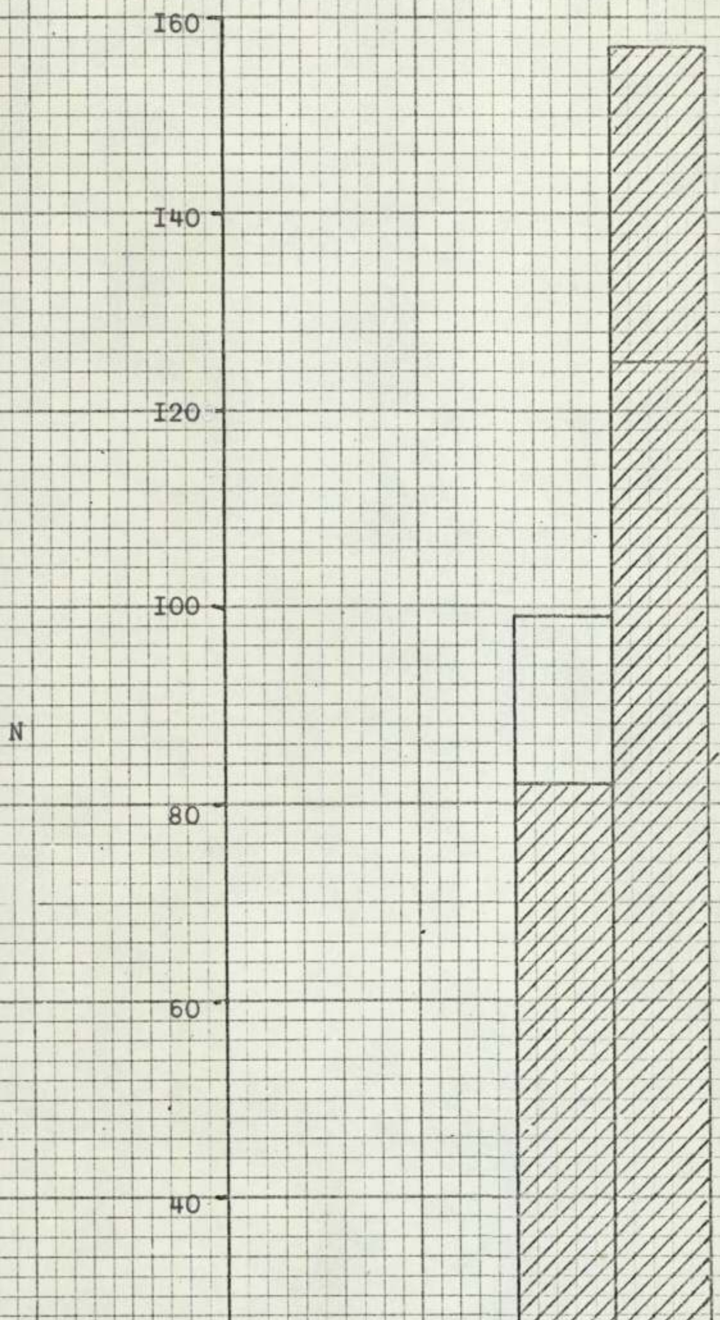


Figure 5.2. Handedness of Engineers

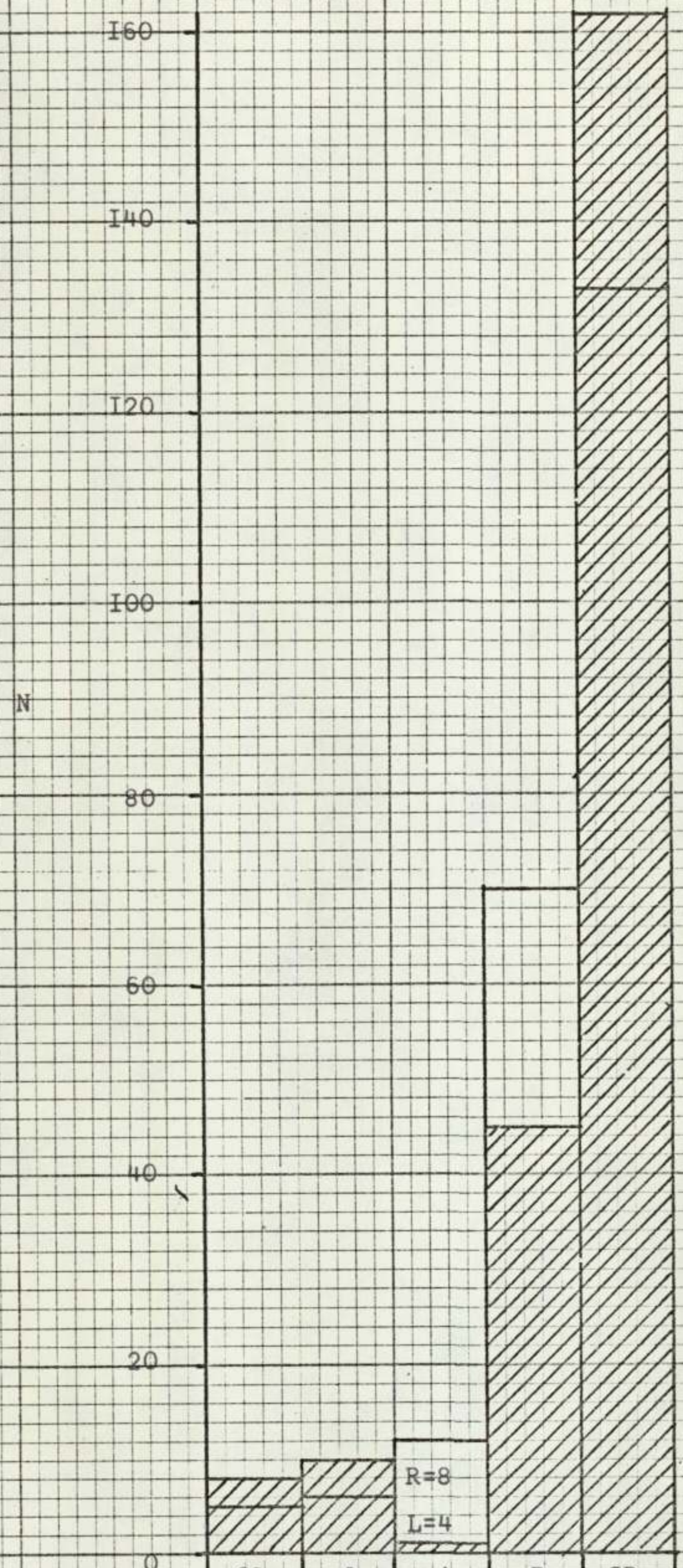


Figure 5.3. Handedness of Linguists

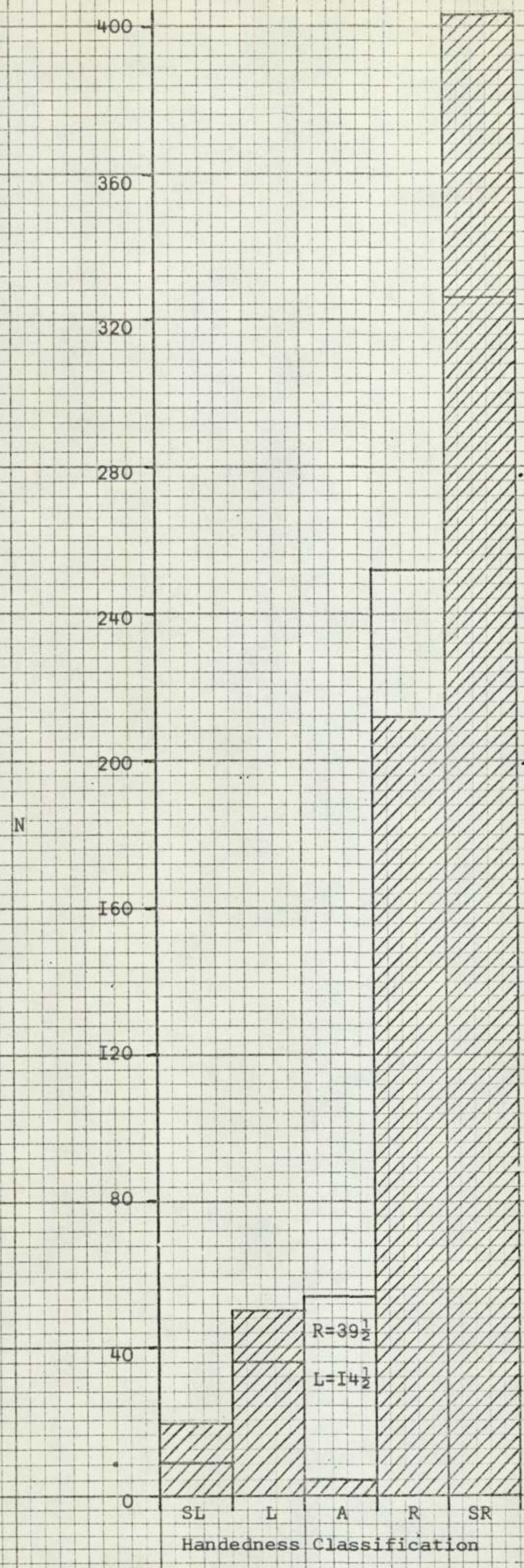


Figure 5.4.

Handedness of Total Population

		Strong	Weak	% Weak
Artists	Male	37	80	68.4
	Female	33	34	50.7
	Total	70	114	62.0
Engineers	Male	123	140	53.2
	Female	4	1	20
	Total	127	141	52.6
Linguists	Male	30	30	50
	Female	108	58	34.9
	Total	138	88	38.9

Table 5.3 Numbers of 'Strong' and 'Weak' handers among Artists, Engineers and Linguists

		L.Q.	|L.Q.|
Artists	Male	65.5	75.6
	Female	66.2	82.9
	Total	65.8	78.4
Engineers	Male	69.9	80.8
	Female	67.7	86.2
	Total	69.9	80.9
Linguists	Male	61.9	82.7
	Female	83.0	88.9
	Total	77.4	87.2

Table 5.4 Average Laterality Quotients of Artists, Engineers and Linguists

is presented in Table 5.5. The number of female Engineers precluded an anlysis comparing them with other female groups. In this and all subsequent χ^2 analyses artists, engineers and linguists will be represented by 'Art', 'Eng' and 'Ling' respectively. In the case of 2 x 2 contingency tables the χ^2 test corrected for continuity was employed and where the direction of results is clearly predicted one-tailed probabilities are given.

(d) Left-handedness

Data was also analysed for proportions of left-handers in the three samples. Percentages of left-handers are presented in Table 5.6. For the total population the proportion of left-handers is as follows:

	Right-handed	Left-handed	Total	% left-handed
Males	394.5	45.5	440	10.34
Females	224	14	238	5.88
Total	618.5	59.5	678	8.78

The summary of the χ^2 analysis carried out on the data is presented in Table 5.7. Only those results which provided significant differences between groups are given here.

5.3.4 Foot preference

The proportion of 'L', 'E' and 'R' classifications for foot preference are presented in Table 5.8. A χ^2 analysis comparing numbers of 'L', 'E' and 'R' individuals for given groups is summarised in Table 5.9.

SEX	GROUPS	χ^2	df	p <	DIRECTION*
All	Art, Eng, Ling.	22.18	2	0.001	Art > Eng > Ling
Males	Art, Eng, Ling.	8.86	2	0.02	Art > Eng > Ling
Females	Art, Ling	4.35	1	0.025	Art > Ling
All	Art, Eng	3.50	1	0.05	Art > Eng
All	Art, Ling	20.59	1	0.0005	Art > Ling
All	Eng, Ling	8.68	1	0.005	Eng > Ling
Males	Art, Eng	7.01	1	0.005	Art > Eng
Males	Art, Ling	4.94	1	0.025	Art > Ling
Males	Eng, Ling	0.10	1	n.s.	Eng > Ling
	Art Males, Females	4.89	1	0.025	Males > Females
	Ling Males, Females	3.60	1	0.05	Males > Females
	All Males, Females	18.75	1	0.0005	Males > Females
	Art Males, Ling Females	29.39	1	0.0005	Art > Ling

* a > b : a is more 'weak'-handed than b

Table 5.5 χ^2 Analysis of handedness distributions amongst Artists, Engineers and Linguists

		Right-handed	Left-handed	Total	% Left-handed
Artists	Male	105	12	117	10.3
	Female	60	7	67	10.4
	Total	165	19	184	10.3
Engineers	Male	238.5	24.5	263	9.3
	Female	4	1	5	(20)
	Total	242.5	25.5	268	9.5
Linguists	Male	51	9	60	15
	Female	160	6	166	3.6
	Total	211	15	226	6.6

Table 5.6 Left-handedness in Artists, Engineers and Linguists
(Figures in percentages, numbers in brackets)

	χ^2	df	p<	DIRECTION*
Art, Ling Females	3.03	1	0.05	Art >Ling
Ling Male, Female	7.48	1	0.005	Male >Female
All Male, Female	3.30	1	0.05	Male >Female

* a > b : a possesses more left-handers than b

Table 5.7 χ^2 analysis of numbers of left-handers

		Right	Either	Left
Artists	Male	55	48	14
	Female	33	24	10
	Total	88(47.9%)	72(39.1%)	24(13.0%)
Engineers	Male	148	94	21
	Female	4	0	1
	Total	152(56.7%)	94(35.1%)	22(8.2%)
Linguists	Male	35	19	6
	Female	120	40	6
	Total	155(68.6%)	59(26.1%)	12(5.3%)

Table 5.8 Distribution of Footedness amongst Artists, Engineers and Linguists

SEX	GROUPS	χ^2	df	p <	DIRECTION*
All	Art, Eng, Ling	20.50	4	0.001	Ling > Eng > Art
Males	Art, Eng, Ling	3.98	4	n.s.	Ling > Eng > Art
Females	Art, Ling	15.15	2	0.001	Ling > Art
All	Art, Eng	4.64	2	n.s.	Eng > Art
All	Art, Ling	19.79	2	0.001	Ling > Art
All	Eng, Ling	7.52	2	0.05	Ling > Eng
	Art Male, Female	0.63	2	n.s.	Female > Male
	Ling Male, Female	5.52	2	n.s.	Female > Male
	All Male, Female	9.03	2	0.02	Female > Male

* a > b: a contains more 'Right-footed' individuals than b

Table 5.9 χ^2 Analysis of distributions of Foot preference

5.3.5 Eye preference and dominance

Table 5.10 presents the number of Right, Left and Either-eyed individuals. A summary of the χ^2 analysis is found in Table 5.11. Three female linguists failed to complete both eye preference items and their results are not included in Tables 5.10 and 5.14.

5.3.6 Eye-hand-foot consistency

Table 5.12 presents figures for consistent and inconsistent individuals and in Table 5.13 a summarised χ^2 analysis is shown.

5.3.7 Crossed laterality

Table 5.14 presents the number of consistent, crossed and mixed lateral subjects in each population sample. A χ^2 analysis yielded no significant results and is not shown here.

5.3.8 Familial left-handedness

Numbers of individuals with FAML are presented in Table 5.15. A χ^2 analysis yielded no significant results for male and female groups taken separately. The four significant comparisons found are presented in Table 5.16.

5.4 Discussion

If the total population (678) is considered only on the basis of males and females, then sex differences in laterality appear to be very prominent. In terms of handedness, females in general tend not only to be more consistent than males ($p<0.0005$) but also more right-handed ($p<0.0\ 5$). Similar results are found with respect to footedness, where again females demonstrate more right-sidedness ($p<0.02$), and with eye-

		Right	Either	Left
Artists	Male	89	15	13
	Female	39	8	20
	Total	128(69.6%)	23(12.5%)	33(17.9%)
Engineers	Male	167	43	53
	Female	3	0	2
	Total	170(63.4%)	43(16.0%)	55(20.5%)
Linguists	Male	41	4	15
	Female	119	18	26
	Total	160(71.7%)	22(9.9%)	41(18.4%)

Table 5.10 Distribution of Eyedness amongst Artists, Engineers and Linguists

SEX	GROUPS	χ^2	df	p <	DIRECTION*
All	Art, Eng, Ling	5.48	4	n.s.	Ling > Art > Eng
Male	Art, Eng, Ling	10.44	4	0.05	Art > Ling > Eng
Female	Art, Ling	6.13	2	0.05	Ling > Art
Male	Art, Eng	6.39	2	0.05	Art > Eng
Male	Art, Ling	6.51	2	0.05	Art > Ling
Male	Eng, Ling	3.85	2	n.s.	Ling > Eng
	Art Male, Female	10.36	2	0.01	Male > Female
	Ling Male, Female	2.95	2	n.s.	Female > Male
	All Male, Female	1.4	2	n.s.	Male > Female

* a > b: a contains more 'Right-eyed' individuals than b

Table 5.11 χ^2 Analysis of distribution of Eye preference and dominance

		Consistent	Inconsistent	Total	% Inconsistent
Artists	Male	46	71	117	60.7
	Female	29	38	67	56.7
	Total	75	109	184	59.2
Engineers	Male	101	162	263	61.6
	Female	4	1	5	(20)
	Total	105	163	268	60.8
Linguists	Male	28	32	60	53.3
	Female	90	76	166	45.8
	Total	118	108	226	47.8

Table 5.12 Consistency of Eye-Hand-Foot preferences among Artists, Engineers and Linguists

SEX	GROUPS	χ^2	df	p <	DIRECTION*
All	Art, Eng, Ling	9.53	2	0.01	Eng > Art > Ling
Male	Art, Eng, Ling	1.37	2	n.s.	Eng > Art > Ling
Female	Art, Ling	1.87	1	n.s.	Art > Ling
All	Art, Eng	0.06	1	n.s.	(Eng > Art)
All	Art, Ling	4.89	1	0.025	Art > Ling
All	Eng, Ling	7.90	1	0.005	Eng > Ling
	Art Male, Female	0.14	1	n.s.	Male > Female
	Ling Male, Female	0.73	1	n.s.	Male > Female
	All Male, Female	8.41	1	0.005	Male > Female

* a > b: a contains more inconsistent individuals than b

Table 5.13 χ^2 Analysis of numbers of Consistent and Inconsistent laterals

		Consistent	Mixed	Crossed
Artists	Male	86	14	17
	Female	42	9	16
	Total	128(69.6%)	23(12.5%)	33(17.9%)
Engineers	Male	173	42	48
	Female	4	0	1
	Total	177(66.0%)	42(15.7%)	49(18.3%)
Linguists	Male	45	4	11
	Female	113	18	32
	Total	158(70.9%)	22(9.9%)	43(19.3%)

Table 5.14 Relationship of Eye to Hand dominance in Artists, Engineers and Linguists

		No FAML	FAML	Total	% FAML
Artists	Male	87	30	117	25.6
	Female	53	14	67	20.9
	Total	140	44	184	23.9
Engineers	Male	176	87	263	33.1
	Female	3	2	5	(40.0)
	Total	179	89	268	33.2
Linguists	Male	44	16	60	26.7
	Female	136	30	166	18.1
	Total	180	46	226	20.4

Table 5.15 Familial left-handedness in Artists, Engineers and Linguists

SEX	GROUPS	χ^2	df	2-tailed p<	DIRECTION*
All	Art, Eng, Ling	11.22	2	0.01	Eng > Art > Ling
All	Art, Eng	4.10	1	0.05	Eng > Art
All	Eng, Ling	9.52	1	0.01	Eng > Ling
	All Males, Females	8.89	1	0.01	Males > Females

* a > b: a possesses more FAML than b

Table 5.16 χ^2 Analysis of Incidence of FAML hand-foot consistency, in which females show greater unilateral preference for all three modalities ($p<0.005$).

Females also show less likelihood of having left-handedness present in members of their immediate family ($p<0.01$). This may be due in part to the general association between left-handedness in children and in parents, together with the finding that a greater proportion of males than females were left-handed. Other more complex reasons for the increase in FAML amongst males are beyond the scope of the present study.

It is only with regard to eyedness and crossed laterality that male-female differences are insignificant. It is noticeable that these two areas also fail to demonstrate clear or expected differences between the population samples of Artists, Engineers and Linguists.

In order to ascertain the influence of these general sex differences on the results of specific measures and to present a structured discussion of results, handedness and other laterality items are looked at seaparately below.

Handedness: The general hypothesis is confirmed. Artists tend to be less consistent in hand preference than Engineers of Linguists. Differences in numbers of consistently-handed individuals are also significant for Artists and Engineers, for Artists and Linguists and for Engineers and Linguists taken separately. (See Table 5.3)

The highly significant overall difference between males and females

(χ^2 = 18.75) suggests that confirmation of the hypothesis might be weakened when sex differences between Artists, Engineers and Linguists are taken into account. This is not, however, the case. Significant differences were also found between males (Artists, Engineers and Linguists) and between females (Artists and Linguists), all, in the expected direction. Although one comparison of numbers of consistent handers (male Engineers and Linguists) proved insignificant, but in the expected direction, differences between Artists and Linguists were significant for males, females and for males and females together. Artists are significantly less consistent in hand preference than Linguists.

The above findings are mirrored by the average Laterality Quotients obtained in the population samples. A discussion of Laterality Quotients also highlights one possible reason for failing to uncover either sex differences in handedness or differences in handedness between selected population samples. If L.Q.'s are totalled with regard to the sign of each L.Q. (i.e. a left-handed score is included as a negative score), the resultant averages appear to demonstrate strength of handedness, whereas in fact the size of this average is more likely to be determined by the number of left-handers present in the sample.

If, on the other hand, the sign of individual L.Q.'s is ignored in such calculations, then a true measure of the strength or consistency of hand preference is obtained. To use the present results as an example, it would appear at first instance that male Linguists possess the lowest L.Q. (61.9 compared to Artists 65.5, Engineers 69.9). The reason for this is, however, the high proportion of left-handed male linguists (15%) and when the sign of L.Q.'s is ignored the average L.Q.'s are in the expected direction:

Male Artists	75.6
Male Engineers	80.8
Male Linguists	82.7

Results for females were also in this expected direction, but considerably higher, in each case, than those of males.

It was not found, as in the study by Peterson & Lansky (1974), that the sample of Artists and Architects contained an exceptionally high number of specifically left-handers. Even with regard to self-classification, the present population of Artists produced only 12% self-confessed left-handers. On the basis of test classification this proportion dropped to 10.3% (males 10.3%, females 10.4%). Although the incidence of left-handedness in males did not differ significantly between groups, there was a significant difference between female Artists (10.4%) and female Linguists (3.6%), suggesting that left-handedness may be a factor with respect to good spatial ability. The findings concerning left-handedness are, however, not as conclusive as those which look at consistency in hand usage.

A point of real interest is raised when figures demonstrating the incidence of left-handedness are compared with those obtained by Oldfield (1971). Although overall percentages of left-handedness are remarkably similar between the present study and that of Oldfield, the nature of the population samples does appear to be important.

If the figures for left-handers are broken down into figures for Artists and Linguists (females) it looks convincingly as if the present study has produced an accurate overall incidence of left-handedness while also uncovering a possible difference in the sub-groups which go towards producing this figure:

	Oldfield (1971)		Present Study	
	N	% left-handed	N	% left-handed
Males	400	10.00%	440	10.34%
Females	709	5.92%	238	5.88% - 10.4% Artists
				3.6% Linguists

($\chi^2 = 3.03$; $p<0.05$)

Mixed dominance (associated with deviation from consistent handedness) is present to a greater degree in Artists than in Linguists. Engineering students registered a strength of hand preference between that of the other two groups.

Thus, in those individuals who are predisposed to artistic and spatial ability, there is a greater degree of mixed dominance than in those individuals who tend to be proficient in verbal or linguistic ability. As Bannatyne (1966a) proposes, it is probably the mixed dominant individual who, specifically through his particular pattern of cortical functioning, is in an advantageous position for coping with tasks of a gestalt, multi-directional nature. The individual who is likely to possess strict left or right hemispheric dominance for language will be in a perceptually more salient position for adapting to the analytic, directional tasks exemplified by reading and language learning.

While it has been demonstrated that sex differences in handedness do not confound the results between population samples, it is interesting to note that the largest χ^2 to be found between any two groups was that between the number of consistently handed Male Artists and Female Linguists ($\chi^2 = 29.39$; $p<0.0005$). This exceptionally large value is almost certainly an aggregate of inherent handedness differences both between sexes and between Artists and Linguists.

Finally, a few points can be made concerning the subjects' self-classification of handedness.

First, as predicted, left-handed subjects in general tended to overestimate their strength of their left-handedness. Right-handers also overestimated their strengthof handedness, but this was only apparent for those subjects self-classified as <u>strong</u> right-handers. Secondly, for <u>all</u> population samples, the relationship between self and test-classification was identical. Apart from the overestimation of left-handedness and strong right-handedness, ambidexterity was virtually never used as a self-classification, and moderate right-handers produced more test than self-classified individuals. This last point confirms Oldfields' observation that moderate right-handers tend to underestimate their degree of departure from strong right-handedness and do not readily admit left-handed tendencies. The similarity demonstrated by the three population samples in the relationship between self and test-classified handedness also indicates that each group was approaching the task of filling in the questionnaire in the same manner, and that in each case the results may accurately reflect a true measure of handedness.

Other laterality results:

Artists replied with more 'Either' responses to the question on foot preference than either Engineers or Linguists. Although this trend was exaggerated by general sex differences, the expected direction of results was also found within the male group (although not significant) and with female Artists and Linguists ($p<0.001$). Limited support for handedness results is revealed. Inconsistency (and left preference) in footedness is found more in Artists than in Engineers and more in Engineers than in Linguists.

No such support is indicated by figures demonstrating eye preference. Despite a limited number of significant differences between groups in the distribution of eye preferences, no clear direction is apparent from the results. Further to this, a comparison of the number of crossed lateral subjects also revealed no differences. Although not unexpected, this result proves interesting in the light of reports which indicate a relationship between crossed laterality and linguistic disorders (see Chapter 4). Overall proportions of crossed lateral individuals are so close as to suggest that an accurate estimate of crossed laterality in the general population has been obtained in each sample. (Artists 17.9%, Engineers 18.3%, Linguists 19.3% crossed lateral.) The confusing results on measures of eye preference probably distort figures of eye-hand-foot consistency. Although there are significantly more consistent individuals amongst Artists and Engineers than amongst Linguists, this result is almost certainly a product of differences between males and females. Females were more consistent than males ($p<0.005$). When compared separately, both female and male Artists and Linguists provide results in the expected direction, although neither of these are significant.

5.5 Conclusion

Although noticeable differences in the distribution of handedness have been found between Artists and Linguists, it is possible only with caution to compare these results with distributions from the general population. The main reason for this is that other surveys reporting incidences of Right, Left and Mixed-handers have based criteria for inclusion into the categories on different principles or scoring techniques. They may also have often employed populations biased in what might be described as either a 'verbal' or a 'spatial' direction. The largest closed population sample available for the present study was that of Engineers, and for the purposes of the survey, this provided an adequate 'control' group, at least for male individuals.

The most convincing support for the hypothesis that mixed dominance is associated closely with superior spatial ability comes from the comparison of consistent and inconsistent handers within the three population samples. Differences in test-classified handedness reflect similar differences in self-classified handedness, although, as mentioned, the relationship between self and test-classified handedness is by no means a perfect one.

While left-handedness as such remains a much studied factor in comparisons of various ability groups, and may be found in greater proportions amongst Artists and Architects, it is in a comparison of consistency of handedness that the most noticeable and significant differences are revealed. It appears to be mixed cerebral dominance, rather than, as Peterson & Lansky (1973) suggest, right dominance, which is associated with the pursuit of a spatial or artistic career.

The present experiment relied upon criteria of handedness obtained from a single multi-item questionnaire. Before attempting to relate handedness variables to ability factors in the experimental situation, a further analysis of various handedness measures will be undertaken. While supplying valuable information for the selection of handedness groups, the experiment and analysis described in Chapter 6 are intended to provide a clearer understanding of the interrelationships between scores on different handedness measures.

6. INTERRELATIONSHIP OF HANDEDNESS MEASURES

6.1 Introduction

6.2 Method
6.2.1 Subjects
6.2.2 Apparatus
6.2.3 Design
6.2.4 Procedure

6.3 Results
6.3.1 Laterality questionnaires
6.3.2 Performance tests
6.3.3 Interest correlations
6.3.4 Sex differences
6.3.5 Item analysis of laterality questionnaires

6.4 Discussion

6.5 Concluding remarks

6. INTERRELATIONSHIP OF HANDEDNESS MEASURES

6.1 Introduction

When handedness assessments are sought for populations smaller than those referred to in Chapter 5, more detailed measures may be employed.

Not only may a variety of laterality questionnaires present different profiles of an individual's handedness, but all questionnaires in general deal only with manual preference over a number of tasks. They do not encompass immediate measures of relative hand skill on any one task. Subjects filling in a laterality questionnaire may often suggest to the investigator that they are unable to answer each question as they would wish. Frequently individuals may want to state that the left hand could perform a given action satisfactorily if they were forced to use it. This feeling of potential competence with the non-preferred hand is not given expression on the questionnaire.

Thus, if time permits, a measure or battery of tests more comprehensive than a single questionnaire may do greater justice to a subject's overall handedness.

Questionnaires and performance tests remain on two different levels of measurement and it is not clearly valid to merge scores obtained on each to arrive at an overall handedness score (see Satz et al, 1967). This does not, however, prevent the two types of measure being employed side by side to demonstrate both equally important aspects of handedness.

Surprisingly little research has concerned itself with the exact relationship between questionnaire and performance measures of handedness. A certain measure of validity could, for example, have been ascribed to questionnaires which most accurately predict or reflect relative hand performance on a comprehensive battery of motor tests. As it is, laterality questionnaires are seldom validated in any respect other than in the context of expected proportions of, say, right, mixed and left-handers or of observation of reported activities (Raczkowski et al, 1974).

Relationships between questionnaire and performance test scores have, to some extent, been revealed. Studies by Annett (1970, 1972), Benton et al (1962), Provins and Cunliffe (1972 a, b) and Satz et al (1967) go some way towards theories of handedness encompassing both performance and questionnaire aspects, but nevertheless leave many facets of the interrelationships untouched. The lack of clarity is illuminated by Newcombe and Ratcliff (1974), who claim, though with minimal apparent justification, that there seems to be little or no correlation between performance and questionnaire measures of handedness. A brief observation of the four studies referred to above would cast doubt upon this claim. Benton et al and,more particularly Annett (1970), demonstrated that, in general, dexterity scores ranged from strong right hand superiority to strong left hand superiority in keeping with the preference defined classification of subjects, while Provins and Cunliffe found a significant correlation between a single questionnaire and a handedness score from seven performance tests. (See Chapter 1.3.2.3 for discussion)

The present experiment attempts to reveal the extent of the relationship between various aspects of handedness. The interrelationships between different questionnaires, between different performance tests and between the two types of measure are revealed.

Apart from a clarification of handedness assessment, the investigation aimed to set up distributions of scores for the various handedness measures such that these 'standardised' scores could be employed in the future to select subjects for a further experiment. Once an estimate of the population distribution of handedness is obtained, this distribution can be segmented, according to various criteria, into Right, Mixed and Left-handed scores for both questionnaire and performance tests. Right, Mixed and Left-handed subjects can then be sought on the basis of these stringent handedness classifications.

Three of the most widely used and quoted questionnaires employed by investigators are those of Annett (1967), Harris (1957) and Oldfield (1971). At first glance these measures would appear to be very similar. The expected close relationship between their rankings of individuals might be modified slightly, however, after a closer observation of

(a) the items used,

(b) the procedure employed, and

(c) the scoring technique adopted.

Only four items are shared in common by the three questionnaires (hereafter referred to as A, H and O respectively), these being:

1. throw a ball
2. brush teeth
3. use scissors
4. write

Few of the remaining items are shared between any two questionnaires.

Those in common are:

A, H	A, O	O, H
Hammer a nail	Use a broom	Knife (without
	Strike a match	Fork)

The items found only in a single questionnaire are:

A	O	H
Hold Racket	Draw	Wind Watch
Thread Needle	Use Spoon	Comb Hair
Deal Cards	Open Lid	Open Door
Unscrew Lid		Hold Eraser
Shovel Sand		

A diagram representing the number of items shared by the three questionnaires is shown below. It is clear that unless a very small number of handedness items (e.g. 4) yields a true handedness assessment and ranks subjects in comparable fashion to some other small battery of questions, then the measures of Annett, Harris and Oldfield may not correlate as highly as expected. The total number of different items presented by the three questionnaires is 20.

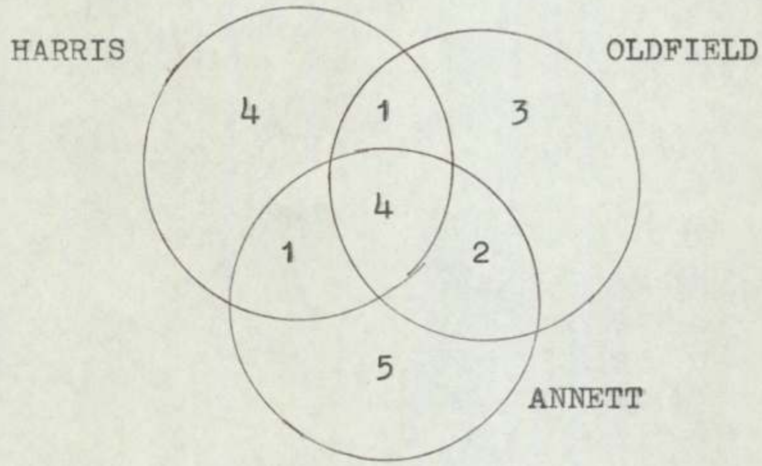


Figure 6.1 Number of handedness items shared by three questionnaires.

Procedurally the three questionnaires also differ. Harris requires subjects (often children) to mime the activities listed so that the investigator can, by observation, fill in the questionnaire himself. There may be less chance of incorrect responses in this situation than with either of the other questionnaires, which were designed to be filled in by the subject without the necessity of any actions being overtly performed. Any advantages in procedure with the Harris questionnaire may, however, be eradicated by the inclusion of two items which offer a dubious contribution to handedness assessment. 'Opening a door' almost certainly depends on the situation of the door, the location of the handle and the outward or inward motion of the door, while winding a watch will only rarely be performed by the left hand even in sinistrals.

Items on both the Annett and Harris questionnaires appear to be fairly random in their order of presentation. Observation of completed Oldfield questionnaires, however, suggests that items seem to be ordered with respect to their significance. Items which are more likely to be performed with either hand and which may require more thought on the part of the subject, are placed towards the bottom of the list (e.g. opening a lid, using a spoon). This apparent ordering of items together with the more appealing visual format of Oldfield's response sheet may well lead subjects to report less accurately their true manual preference.

Although the three authors employ different scoring techniques, scores from the questionnaires can be compared if a laterality quotient (LQ) similar to that used by Oldfield is determined for scores from each. Harris' scores ranging from 0 to +100 can be converted into scores from -100 to +100, while responses on Annett's questionnaire can be used to calculate a L.Q. by the formula 100 x (R-L)/(R+L+E) where R, L and E denote the number of Right, Left and Either responses respectively.

It must be remembered that the Right, Mixed, Left classification used by Annett was not based on L.Q. scores but on the inclusion or omission of L(R) responses from a predominantly R(L) score. Thus in this study, the questionnaire items and procedure are as indicated by Annett (1967) while an additional scoring method has been employed for the purposes of ranking individuals according to their handedness.

Apart from their relationships with performance measures of handedness the success of questionnaires may be judged according to other criteria. For instance, does a questionnaire discriminate between as many individuals as possible? Although a large proportion of scores can be expected at the extreme right hand end of the scale, some questionnaires may discriminate more finely than others both amongst this majority of right-handers and between individuals with other handedness tendencies. One measure of this success may be the percentage of individuals performing items with their non-dominant hand. A good questionnaire will include genuine handedness items (i.e. items not obviously biased by practice or by the nature of the task) which are often performed with the non-dominant hand in individuals with mixed-handed tendencies. The present experiment sought to confirm that the questionnaire with the greatest sum of items showing preference of the non-dominant hand, would most highly correlate with performance items.

Batteries of performance tests are rarely used with large populations due mainly to the time-consuming nature of the exercise. Although

Provins & Cunliffe (1972 a,b) employed a battery of seven tests (see 1.3.2.1) a smaller number would be adequate for quicker assessment. Some of the tests used by Provins & Cunliffe involved a great deal of practice with the preferred hand and thus may have exaggerated any trends in handedness (see especially handwriting and throwing darts).

The three tests which are common to the studies of Provins & Cunliffe and of Satz et al (1967) may represent the shortest adequate battery encompassing most aspects of handedness:

(a) Dexterity: A peg-board test of some description (varies from one investigation to another) will give a measure of fine motor control involving arm, hand and finger co-ordination. The preferred hand will have had practice in similar tasks and some account of this should be taken when arranging sequences of trials. Some sub-routines of the pegboard situation - grasping, reaching and releasing movements - may be more highly developed in the preferred side, although according to Provins & Cunliffe, the overall movement remains relatively unpracticed.

(b) Tapping: A short test involving hand or finger tapping can supply a measure of arm-hand-finger co-ordination and speed, where good performance demands an automatic, reflex-like sequence of tapping. This temporal sequence of events is likely to produce clear differences between preferred and non-preferred hand, due partly to the rapid alternation of antagonistic muscle groups practiced in other tasks (Provins & Cunliffe).

(c) Hand Strength: A Dynamometer test assesses the relative grip strength of hands. Hand strength is certainly an important feature of any handedness assessment and is involved in many of the items selected for questionnaires (e.g. unscrewing a jar, opening a box lid, using a racket and shovelling with a spade). This task, unlike the tapping test, is not dependent on the temporal organisation of muscle activity but involves instead the 'discrimination, selection and maximum contraction of muscles which contribute to the required movement' (Provins and Cunliffe).

Provins (1967) suggests that only low correlations may be anticipated between performance on different motor tests. One of the reasons for this assumption may be that great emphasis is placed on the role of training in performance on such tasks. It is tacitly assumed that equal practice may mean equal performance, and thus those activities more practised with both hands may produce widely diverging results from those in which the preferred hand has had significantly more practice than the other.

The performance tests above, however, remain relatively unpractised by the majority of individuals, unless one chooses to emphasise the positive transfer from every-day tasks of a similar nature. The real argument here remains one centred around the relative roles of experience and inherited handedness characteristics. Evidence from experimental work in the Ergonomics Unit at Aston University (Ellis, 1974) has shown that, on a pegboard task at least, over a very large number of trials, performance of the non-preferred hand may to some extent approach that of the preferred hand, but is unlikely to ever equal it.

The present experiment tests the hypothesis that significant correlations will exist between all measures of handedness, reflecting the inherent trend in most individuals to use one hand more frequently, and more skillfully than the other for all activities which do not possess an intrinsic handedness bias (as in scissor cutting).

It was hypothesised, however, that questionnaires would correlate more highly with each other than would performance test scores. Questionnaires cover a wider range of activities, many of which are held in common between different measures, and pick out dominant trends in handedness more clearly, due to the classificatory nature of responses.

With respect to sex differences it was expected, as in the previous investigation (see Chapter 5), that males would prove less consistent in hand usage. This might be reflected in three ways (for males):

1. Lower L.Q. on questionnaires (calculated without regard to sign of L.Q.)
2. Lower relative hand superiority on performance tests
3. Lower correlations between different tests of all kinds.

The main concern of the experiment was to study the strength of the relationship specifically between Laterality questionnaires and Performance tests. Assuming the three performance tests to be more or less representative of a general performance measure of handedness, it was intended to discover which questionnaire most accurately predicted the rankings on the performance battery, and to suggest reasons for this.

6.2 Method

6.2.1 Subjects

One hundred and forty-four university students were used as subjects

(72 male, 72 female). The average age of subjects was 21.9 years (males 22.6, females 21.2). The majority of subjects were psychology students, selected on the basis that:

1. Relatively equal numbers of males and females could be found for purposes of handedness comparisons between the sexes, and
2. Such undergraduates have been found to possess a handendess distribution almost identical to both that found in the general student population and that expected in the normal population (see Annett, 1967).

It was desirous to obtain subjects who would come from a population relatively unbiased in its handedness distribution, and, by implication, a population which was not polarised in terms of a verbal or spatial ability (see Chapter 5). The exact source of subjects can be seen from the table below:

	Males	Females
Psychology	49	47
Engineering	15	-
Pharmacy and Domestic Science	-	10
Others	8	15
Total	72	72

6.2.2 Apparatus

Laterality questionnaires: Three questionnaires were employed each following the format and instructions used by the authors. Objects were placed near the subject which could be used to determine his or her preferred hand for the relevant activities. These objects included a broom, a pack of cards, a jar with an unscrewable lid, a needle and thread, an eraser, a pair of scissors, a box of matches and a box with a lid.

The questionnaires used were those of Harris (1957), Annett (1967) and Oldfield (1971 - the Edinburgh Inventory).

Performance items:

1. Purdue Pegboard: the standard Purdue Pegboard (Purdue Research Foundation) was used, ignoring the more complicated constructional procedures. Pegs were to be placed in the right or left-hand column with the subject's right or left hand respectively, over a number of trials.
2. Dynamometer: A simple adjustable-grip dynamometer was employed.
3. Tapping: The subject manipulated a standard morse key attached to an electric counter and timer. A solid sponge block was used as an arm support.

6.2.3 Design

Handedness questionnaires (Q1, Q2 and Q3) and Performance tests (P1, P2 and P3) were administered alternately to subjects in order to eliminate, as far as possible, both transfer between similar types of test and cumulative manual fatigue from successive performance tests. Thus 72 (6x3x2x2x1x1) possible orders of test emerged, where subjects began with either a questionnaire or a performance test. It was decided to employ 72 male and 72 female subjects (total 144), where each of the test orders was accounted for by one male and one female.

6.2.4 Procedure

The experiment took place in a small room with a large table and adjustable chair.

The nature of the experiment was explained to the subject before-hand. This was thought necessary in order to obtain the most favourable conditions for true manual performance. It was stressed that each test should be treated, as far as was possible, in isolation. For questionnaires in particular it was important that responses should not be made on the basis of replies to previous questionnaires. On performance tests subjects were to be given feedback after each trial of each test, and it was explained that each hand on each trial should attempt to perform optimally.

Questionnaires: For both Annett and Oldfield questionnaires instructions were read by the subject who then completed the items in his or her own time. Objects were available if the subject wished to test hypotheses about his preferred hand for a specific activity (this was left entirely optional). Subjects were required to mime the ten activities stated in the Harris questionnaire and responses were noted by the experimenter on a response form.

Performance items: Subjects commenced with either right or left hand for the first trial of each task. It was arranged that half the subjects would begin each test with their right hand, irrespective of their confessed manual preference.

Purdue Pegboard: One practice trial was conducted with each hand followed by 5 trials with each hand alternately. One trial consisted of placing as many pins as possible in either the right or left-hand column over a period of 30 seconds. The first two trials with either hand were to be discounted in an assessment of manual dominance. This further reduced the effects of practice in similar manipulative tasks on superior hand performance. Subjects were not informed of this procedure.

Dynamometer: Three trials were conducted with each hand, after the instrument had been adjusted to maximum comfort. No actual practice was allowed due to the marked fatigue effects over a short number of trials.

Tapping: A short practice was allowed with each hand. Subjects were instructed to lightly grasp the key with thumb and first two fingers and not to let go of the key at any time. A solid sponge block provided arm support and further ensured a uniform approach to the task. Subjects commenced trials on instruction and continued until the counter automatically switched off after 10 seconds. Three trials were conducted with each hand alternately.

6.3 Results

6.3.1 Laterality questionnaires

Scores on the three questionnaires (Annett, Harris, Oldfield) produced typically J-shaped distributions which are presented, for males and females combined, in Figure 6.2.

Questionnaires produced Laterality Quotients ranging from -100

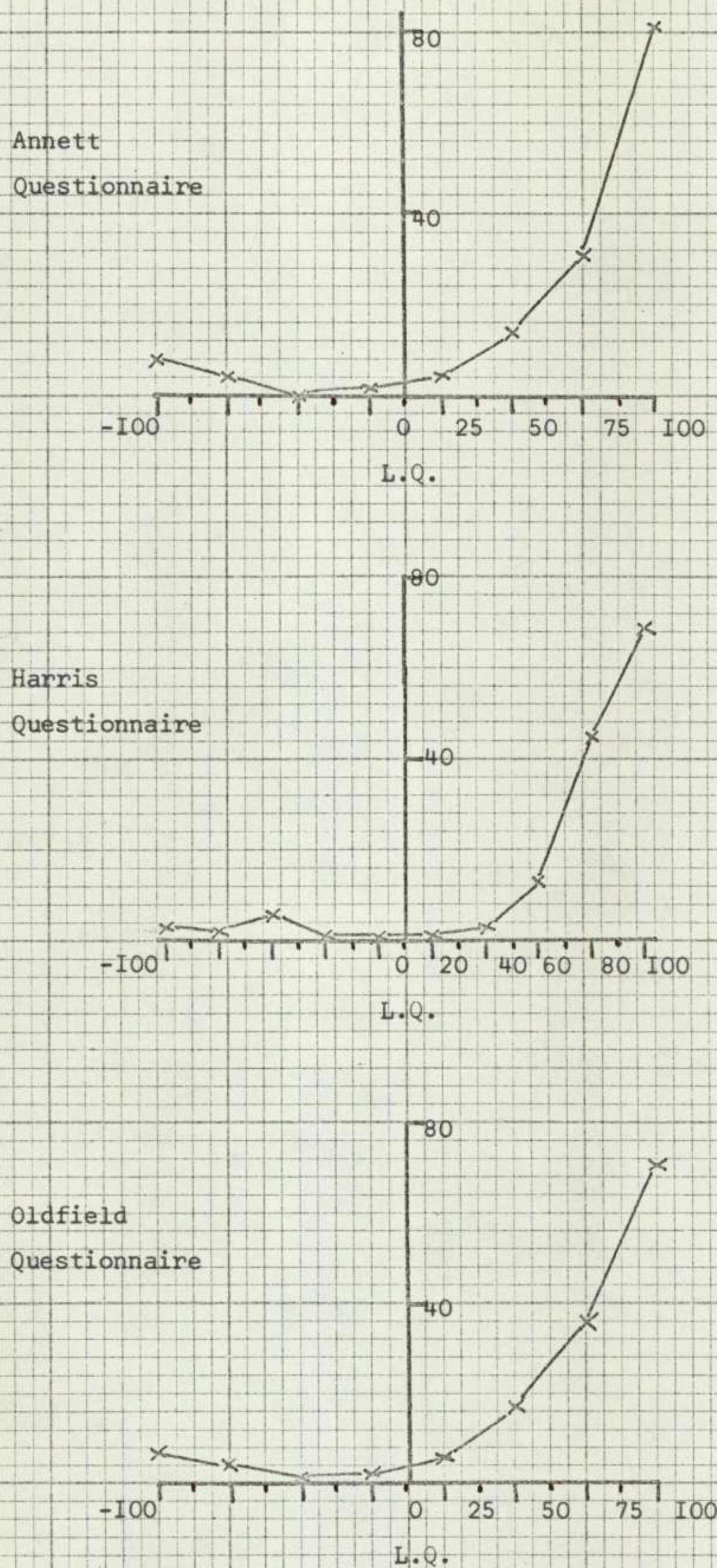


Figure 6.2. Handedness Distributions for Questionnaires

(strong left-handed) to +100 (strong right-handed), and average L.Q.'s are shown in Table 6.1 for males and females separately. Table 6.2 demonstrates average L.Q.s where the sign of each L.Q. is ignored. This represents a measure of strength of hand preference (see 5.3.3).

6.3.2 Performance tests

Relatively normal distributions were produced by all three tests after scores had been calculated on the basis of percentage relative superiority of either hand. This method has advantages over simple right-left difference scores since account is taken of overall level of performance. Thus, for instance, female inferiority on the test of hand strength is not reflected in such scores.

For each task scores were calculated according to the formula $\frac{R - L}{R + L} \times 100$ where R and L stand for:

(a) Purdue Pegboard - R = total number of pins placed in holes over last three trials with the right hand.

L = total number of pins placed in holes over last three trials with the left hand.

(b) Dynamometer - R = total Kilograms over three trials with the right hand.

L = total Kilograms over three trials with the left hand.

(c) Tapping task - R = total number of taps with right hand over three 10 sec. trials.

L = total number of taps with left hand over three 10 sec. trials.

	Males	Females
Annett Q.	65.6	65.1
Harris Q.	69.0	68.1
Oldfield Q.	62.5	60.7

Table 6.1 Average L.Q.'s produced by the three Questionnaires

	Males	Females
Annett Q.	76.7	81.9
Harris Q.	77.1	82.8
Oldfield Q.	71.9	78.4

Table 6.2 Average L.Q.'s (disregarding sign of L.Q.) produced by the three Questionnaires

A summary of scores from the three performance tests is found in Table 6.3 while Figure 6.3 illustrates the distributions of individual test scores. In Table 6.3 both average scores ($\bar{x}$) and average scores disregarding sign ($|\bar{x}|$) are presented, for males, females and males and females together.

In order to compare and combine scores on performance tests, the scores for each test were converted to z scores, such that the point of no difference between hands was represented by a z score of:

Purdue: -0.804

Dynamometer: -0.565

Tapping: -0.889

z scores were averaged for each individual over the three tests so as to obtain an index of overall manual dominance. The combined z score representing the equivalent of total ambidexterity in all three tasks became:

$\bar{z} = -0.753$

6.3.3 Intertest correlations

Spearman's Rank Correlation Coefficients were computed for all possible combinations of test scores. This operation was performed for males and females separately and for the total population. A summary of the analysis is presented in Table 6.4.

In addition, each questionnaire and a simple average score from all three questionnaires were compared with the average z scores for performance tests. This represented a measure of the relationship

	Males			Females			Total		
	$\bar{x}$	s.d.	$\lvert\bar{x}\rvert$	$\bar{x}$	s.d.	$\lvert\bar{x}\rvert$	$\bar{x}$	s.d.	$\lvert\bar{x}\rvert$
Purdue	2.72	3.72	3.75	3.38	3.89	4.39	3.05	3.78	4.07
Dynamometer	1.89	4.42	3.66	3.41	4.88	4.89	2.65	4.69	4.27
Tapping	4.44	4.59	5.08	4.83	5.80	6.28	4.64	5.22	5.68

Table 6.3 Performance test scores $(\frac{R-L}{R+L} \times 100)$

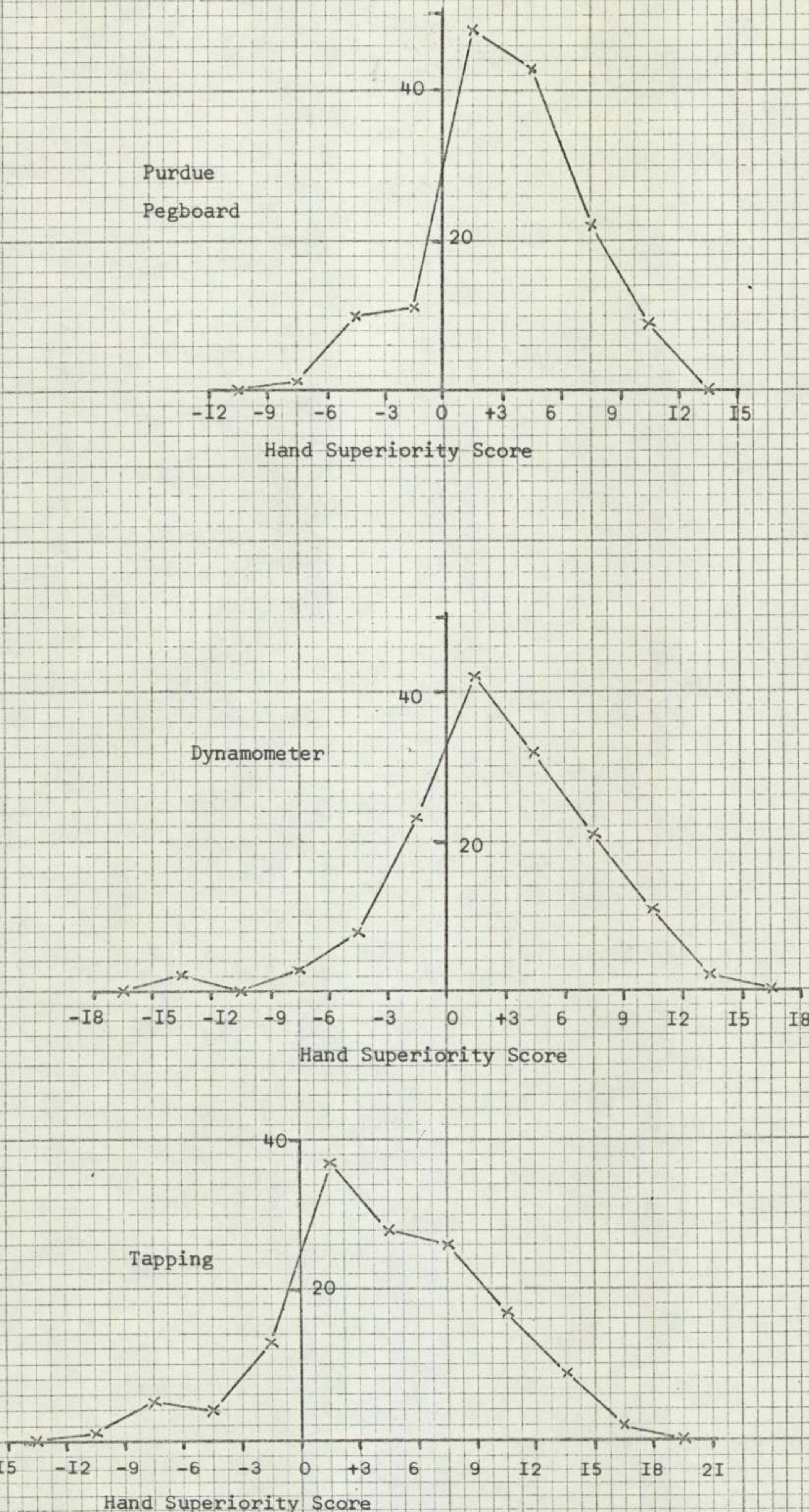


Figure 6.3. Distributions of Performance Test Scores

		Annett Q.	Harris Q.
Harris	m	0.67***	
	f	0.78***	
	total	0.73***	
Oldfield	m	0.79***	0.69***
	f	0.73***	0.71***
	total	0.76***	0.70***

		Purdue	Dynamometer
Dynamometer	m	0.29*	
	f	0.37**	
	total	0.35***	
Tapping	m	0.23+	0.23+
	f	0.53***	0.45***
	total	0.38***	0.35***

		Purdue	Dynamometer	Tapping
Annett Q	m	0.36**	0.32**	0.31**
	f	0.52***	0.48***	0.41***
	total	0.45***	0.40***	0.36***
Harris	m	0.36**	0.35**	0.16 n.s.
	f	0.48***	0.47***	0.46***
	total	0.43***	0.42***	0.33***
Oldfield	m	0.29*	0.24++	0.33**
	f	0.37**	0.38**	0.45***
	total	0.34***	0.31***	0.40***

Table 6.4 Intercorrelations between 6 questionnaires and performance tests (Spearman's Rank Correlation Coefficients)

one-tailed probabilities
*** $p<0.0005$
** $p<0.005$
* $p<0.01$
++ $p<0.025$
+ $p<0.05$
n.s. not significant

between questionnaires and an overall performance criterion (see Table 6.5).

Figures 6.4 and 6.5 suggest the nature of the relationship between
(a) Annett and Oldfield Questionnaire distributions, and
(b) the distributions of the three performance tests respectively.

6.3.4 Sex differences

Questionnaires: Differences between male and female scores on questionnaires are reflected by average L.Q.s only when the sign of the L.Q. is ignored in the calculations. Males appear to possess less consistent manual preference (of right or left side). The numbers of specifically left-handers (over three questionnaires) were similar for males (6) and females (7).

χ^2 tests were performed on the numbers of consistently-handed and inconsistently-handed males and females. Ranges of scores representing inconsistency in hand preference varied slightly for different questionnaires, and are expounded in Table 6.6 - 6.9, which present a summary of the analysis.

A note is necessary here concerning the classification employed by Annett (1967) for her questionnaire. Annett presents a preference defined classification whereby a subject is classed as 'Mixed' when at least one 'Right' and one 'Left' response are recorded. Otherwise a subject is 'Right' ('right' + 'either' responses) or 'Left' ('left' + 'either' responses). On this basis the distribution of handedness amongst males and females in the present study would demonstrate an

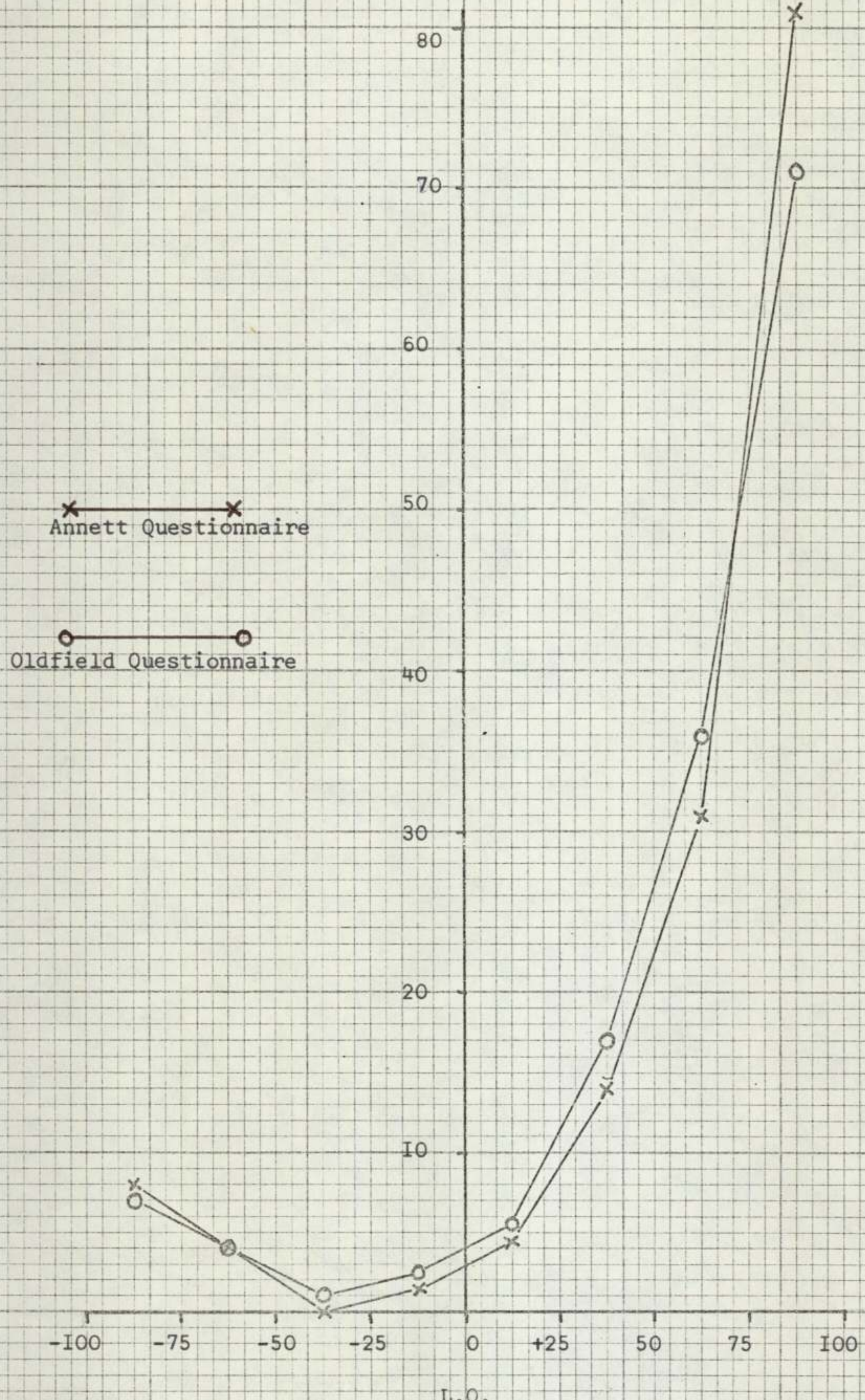


Figure 6.4. Relationship between Annett and Oldfield Questionnaires

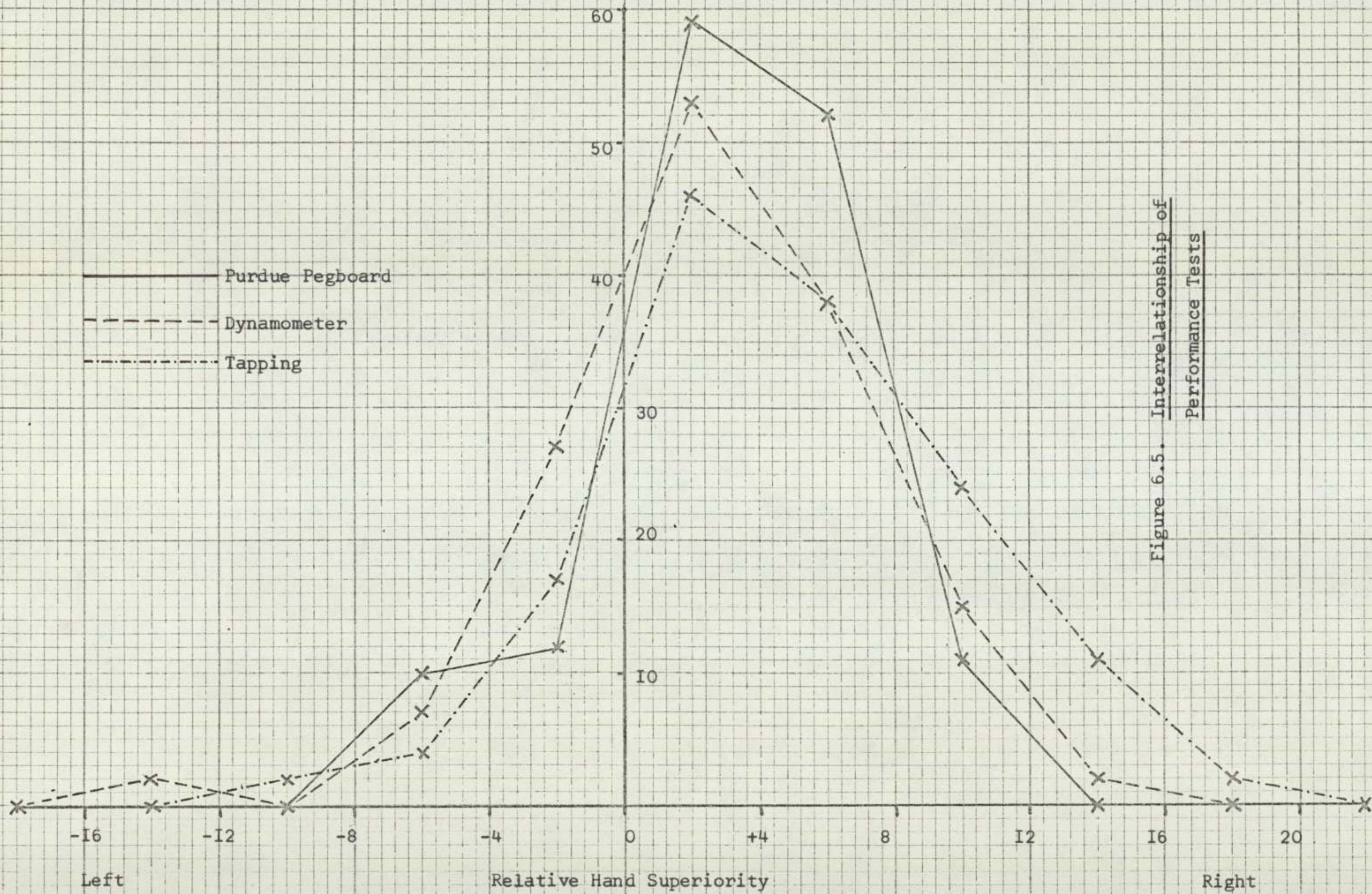


Figure 6.5. Interrelationship of Performance Tests

	Males	Females	Total
Annett Q	0.45***	0.59***	0.52***
Harris Q.	0.37**	0.59***	0.50***
Oldfield Q.	0.38**	0.47***	0.43***
Av(A+H+O)	0.41***	0.59***	0.50***

Table 6.5 Correlations between questionnaires and average z scores

one-tailed probabilities

*** p<0.0005

** p<0.005

	Number Inconsistent (50- -75)	Number Consistent
Males	17	55
Females	7	65

$\chi^2 = 4.05$ ($p < 0.025$)

Table 6.6 A comparison of the handedness of males and females (Annett Questionnaire)

	Number Inconsistent (60- -60)	Number Consistent
Males	17	55
Females	8	64

$\chi^2 = 3.01$ ($p < 0.05$)

Table 6.7 A comparison of the handedness of males and females (Harris Questionnaire)

	Number Inconsistent (50- -75)	Number Consistent
Males	21	51
Females	9	63

$\chi^2 = 5.09$ ($p < 0.025$)

Table 6.8 A comparison of the handedness of males and females (Oldfield Questionnaire)

	Number Inconsistent (65- -65)	Number Consistent
Males	21	51
Females	11	61

$\chi^2 = 3.25$ ($p < 0.05$)

Table 6.9 A comparison of the handedness of males and females (scores averaged over three questionnaires) equal number of male and female 'Mixed'-handers and a greater number of female 'Left'-handers:

	'Right'	'Mixed'	'Left'
Male	45	26	1
Female	40	26	6

The average L.Q. scores of the 26 males classed here as 'Mixed' is 32.4 while that of the 26 females is higher - 57.0 (Mann-Whitney U-test $p<0.044$). Hence the male 'Mixed'-handers possess significantly less right-sided preference than the females. When compared for strength of handedness, the male group again possesses a lower L.Q. (55.46) compared to females (62.42) although this difference is not significant.

Sex differences in manual preference are demonstrated by a further graph(Figure 6.6). Those areas of the distribution where males outnumber females and where females outnumber males are denoted by different types of shading, which show more males in the centre of the distribution and more females at the extremes.

Performance tests: Males consistently scored lower than females in all three tests whether scores were regarded with or without sign (see Table 6.3).

Differences on the Purdue Test were insignificant, while a

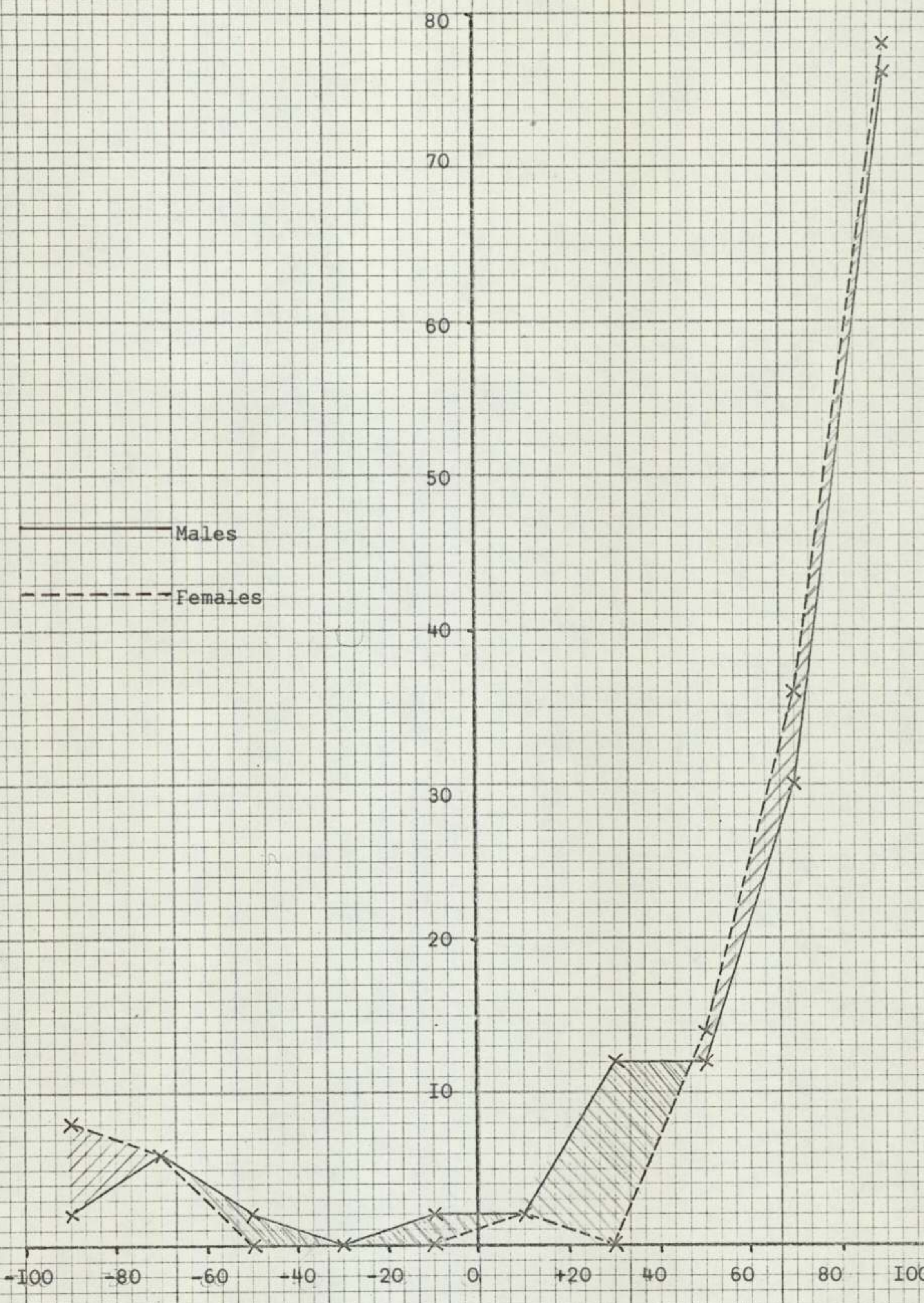


Figure 6.6. Male and Female Distributions of Average L.Q.'s

variety of significant differences were discovered on the other two tests and also on the composite z score from all three tests. This data is presented in Tables 6.10 - 6.13. For χ^2 tests scores were subdivided into 'strong' and 'weak' handedness categories with various ranges of scores.

Figure 6.7 demonstrates the sex differences in composite z scores. The distribution is presented for size of score irrespective of sign. Thus it can be seen that males cluster more around the zero $\bar{z}$ score while females are found more in the extreme ranges of score (a finding reflected in the higher deviations for females in all three tests - see Table 6.3).

Test Intercorrelations: 14 of the 15 interest correlations produced higher r_s's for females than for males ($p<0.001$; binomial test). Mean correlation coefficients for the three types of handedness comparison are presented in Table 6.14, while table 6.15 contains details of the male-female differences for individual test comparisons. Differences with a probability greater than 0.10 are not shown.

6.3.5 Item analysis of laterality questionnaires

An analysis of items performed by the overall non-preferred hand was carried out over the three questionnaires and involved, in all, 20 items. The percentages of right-handers performing activities with their left hand are given in Table 6.16. Table 6.17 presents a similar analysis for left-handers. The figures for left-handers appear to be determined by the right hand bias in scissors and in

	Average	s.d.
Males	1.892	4.42
Females	3.406	4.88

t = 1.951 p 0.05 (one-tailed)

Table 6.10 Sex differences in Dynamometer scores

	Strong	Weak (scores -6 to +5)
Males	16	56
Females	32	40

$\chi^2 = 7.03$ $(p<0.005)$

Table 6.11 Numbers of strong and weak handers on dynamometer test

	Strong	Weak (scores -6 to +11)
Males	6	66
Females	19	53

$\chi^2 = 6.97$ $(p<0.005)$

Table 6.12 Numbers of strong and weak handers on tapping test

	Strong	Weak (scores -1 to +1)
Males	8	64
Females	19	53

$\chi^2 = 4.56$ $(p<0.025)$

Table 6.13 Numbers of strong and weak handers as assessed by composite z score

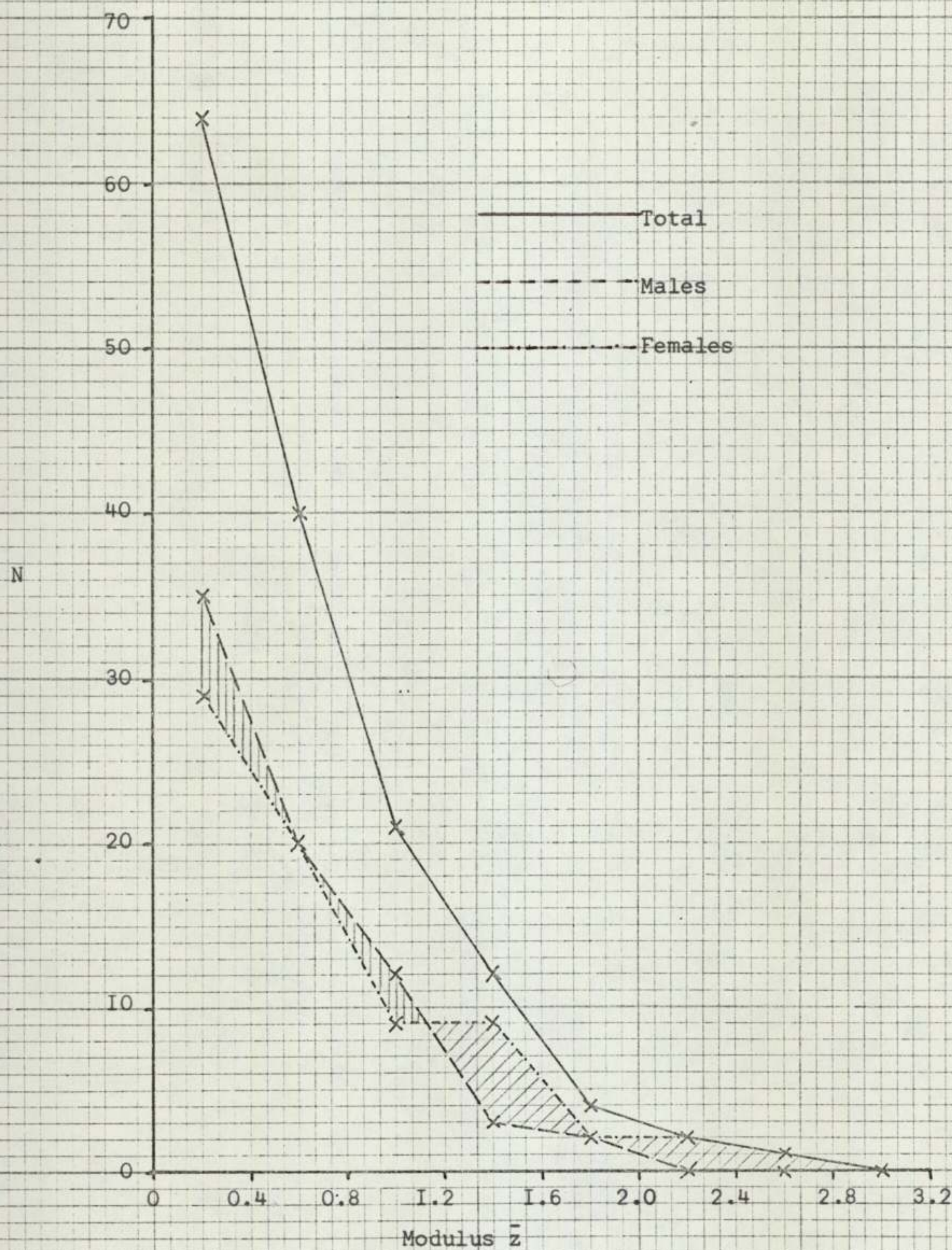


Figure 6.7. Average z scores(ignoring sign) for Performance Tests

	Male	Female	Total
Q x Q	0.72	0.74	0.73
P x P	0.25	0.45	0.36
Q x P	0.30	0.45	0.38

Table 6.14 Average correlation coefficients for comparisons of questionnaires (Q) and performance test (P) scores

	Male r_s	Female r_s	Significance of Difference
Annett Q x Harris Q	0.671	0.783	$0.10<p<0.05$
Harris Q x Tapping	0.162	0.461	$p<0.025$
Tapping x Purdue	0.232	0.531	$p<0.019$
Tapping x Dynamometer	0.225	0.454	$0.10<p<0.05$
Harris Q x $\bar{z}$ scores	0.370	0.587	$p<0.05$
Average Q x $\bar{z}$ scores	0.405	0.586	$0.10<p<0.05$

Table 6.15 Differences in Male - Female correlation coefficients (using technique described by Blalock, 1960)

Deal cards	16.8%	Open door	1.5%
Unscrew lid	14.5%	Write	1.5%
Thread needle	10.0%	Draw	1.5%
Shovel (spade)	7.6%	Throw ball	1.5%
Sweep (broom)	6.9%	Scissors	0%
Open box	6.2%	Racket	0%
Rub out	4.6%	Hammer	0%
Spoon	3.8%	Knife	0%
Clean teeth	3.8%	Watch	0%
Strike match	2.3%	Comb hair	0%

Table 6.16 Activities performed by the left hand in right-handers (total number of right-handers = 131)

Wind watch	69.2% (N=9)
Scissors	38.5% (N=5)
Throw ball	7.7% (N=1)
Shovel (spade)	7.7%
Racket	7.7%
All other activities	0%

Table 6.17 Activities performed by the right hand in left-handers (total number of left-handers = 13)

winding a watch and thus represent an effect of a different nature to that for right-handers.

A further sex difference is evident from the above figures. The total number of items deviating from the dominant manual trend is higher for males:

	Males	Females
Left-handers	11	6
Right-handers	60	48
Total	71	54

6.4 Discussion

The analysis of results carried out here can be seen as a reply to Benton's demand for an assessment of the extent of any relationship between the two aspects of handedness (Benton, 1962):

"The relationship between hand preference (either as verbally reported or as actually observed) and the relative dexterity with which skilled acts are performed by each of the hands has not been systematically investigated. There is every reason to assume that in general there is a positive association between the two types of definition of handedness. However, the crucial question of degree remains open."

p.323

Benton's attempt to establish this degree of association, together with more recent attempts (see Provins & Cunliffe, 1972a, 1972b; Satz et al 1967) appears to have revealed only superficially the relationship between performance and preference measures of handedness. The above experiments revolve around the association between one questionnaire or self-report of handedness and one or more performance test. In none of the accounts are detailed statistical analyses presented of the intercorrelation of measures.

In addition to the doubt cast upon the close relationship between the two types of handedness measure by Newcombe & Ratcliff (1974), Oldfield (1971) also claims that the generally small right-left differences in performance tests do not correspond with the gross disparity between the two hands manifest in well-established tasks. The grounds for this claim are based on the suggestion that in every-day tasks, where one hand is generally used to the exclusion of the other, the relative proficiency of the preferred hand is much larger than that demonstrated in novel performance items. While this may, to some extent, be the case, it appears tenuous to claim such a superiority when measures of non-preferred hand skill have and perhaps could not been taken into account. For instance, how could the relative superiority of the preferred hand at dealing cards, threading a needle, sweeping with a broom or opening a box be measured (all items commonly found on questionnaires)?

In the present study significant correlation coefficients were produced in comparisons of handedness measures. This held both for male and female scores and for scores from the total population sample. The only result (of 45 individual comparisons) to prove insignificant at the 5% level was that comparing male scores for tapping with Harris L.Q.'s. This finding was in keeping with the trend for male correlations to be lower in general than female correlations.

As expected, the highest correlations were discovered amongst comparisons of questionnaire scores (average overall $r_s = 0.729$) while correlations of questionnaire with performance test scores (average $r_s = 0.381$) and between performance test scores (average $r_s = 0.364$) remained lower. All correlations for males and females together were significant at the highest level considered ($p<0.0005$).

The three preference questionnaires produced the expected J-shaped distributions, and ranked individuals in comparable fashion. The highest correlation was found between the Annett and Oldfield questionnaires (0.755) and this was probably due in part to the greater number of items shared in common (6) and to the mode of response - written instructions with subjects filling in the questionnaires.

Distributions of performance test scores were roughly bell-shaped, but displayed some evidence of a second mode towards the left hand extreme. Previous findings also present the possibility of a bimodal distribution for performance test scores (see Oldfield, 1971), and this may correspond to the smaller tail of the J-shaped distribution of preference scores.

In a comparison of average scores on the three performance tests it is possible that the larger discrepancy between hands on the tapping test (see Table 6.3) is due to the practised nature of sub-routines common to this test and many every day activities. Provins & Cunliffe (1972a) suggest that the effect of practice should also be present, although to a lesser degree, in the pegboard task, but this, as reflected by hand superiority, was not as apparent here. The size of hand superiority was, however, in the most likely direction, with tapping showing the greatest right hand superiority and hand strength the least. Observation of the pegboard task suggested that eye dominance may have affected performance, crossed lateral subjects showing less discrepancy between hands, independent of hand strength and preference on other tasks. It was decided to investigate this at a later stage.

Provins & Cunliffe's study (1972a) provided correlations between preferred hand scores and between non-preferred hand scores over a series of motor tests, but gave no indication of the relationship between relative hand superiority on the tasks. Thus a relationship between level of performance on different tests is proven while disappointingly no indication is given of their relative capabilities to discriminate as handedness measures.

Of the correlations between preference questionnaire scores and performance test scores the highest was found between the Annett Questionnaires and the Purdue Pegboard. This finding was confirmed for all three groups (males, females and males plus females).

The lowest correlations were:

1. For males: Harris Questionnaire and Tapping Test.
2. For females: Oldfield Questionnaire and Purdue Pegboard.
3. For males plus females: Oldfield Questionnaire and Dynamometer.

The question to be answered by the comparison of preference and performance measures concerns the validity of handedness questionnaires. Exactly what is a measure of validity for questionnaires? The contention here is that one such notion of validity, and the most important, is inextricably bound up with the predictive validity of questionnaires in performance tests which do not directly measure any of the specific questionnaire activities, but which presume to give an accurate, albeit summarised, account of relative hand dominance in tasks involving sub-routines common to those every-day activities selected by questionnaires.

Other notions of validity concerning (a) the observation of activities found in a questionnaire and (b) the conformity of preference score distributions with expected frequencies of handedness in the population are also important but are set on a different level of investigation. (a) is really providing a guide of the subject's memory and an estimate of how accurately the questionnaire is completed, while (b) rests largely on the justification of and reasons for expected proportions of, say, right and left-handers.

While the present notion of validity is confounded by the necessarily constricted nature of performance tests, it does attempt to bridge the gap between the two types of measurement, which, if they are to remain conversant, must both presume to be measuring the same underlying variable. It is, however, only in performance tests that relative hand superiority is directly measured, and questionnaires, while appearing to give such a measure, must be shown to do so by studying their relationship with performance tests.

The relationship between reported and actual hand usage for various activities may be a vital factor in the predictive validity of questionnaires. Raczkowski et al (1974) claim that it is 'unsafe to assume that a subject who says he uses one or other hand for a particular task, actually does so'. Benton et al (1962) also suggest that there is very little empirical evidence bearing on the validity of the assumption that using the right hand for given activities means that it is used so consistently. The Harris Questionnaire may overcome such difficulties by employing direct observation of a subjects hand preference. The present investigation attempted to compensate for lack of observation of Annett and Oldfield items by allowing subjects to manipulate relevant objects, if desired, in the completion of the questionnaires.

Whilst the Purdue Pegboard appears to be the performance test most closely related, in terms of handedness scores, to questionnaires, it is the Annett questionnaire which 'predicts' most accurately the relative hand performance on the whole battery of performance tests. When correlated with the average z score from performance tests Annett's questionnaire provided higher coefficients than either of the other preference measures.

The correlation coefficient for the Harris questionnaire is surprisingly higher than that for Oldfield's. It was expected that, on the basis of the item analysis and careful construction of the Edinburgh Inventory and on the basis of the dubious nature of at least two of the Harris items, these results would have been in the opposite direction. However, other reasons for the results are not difficult to find.

First, careful observation of activities in the Harris Questionnaire satisfied the experimenter that an accurate assessment of handedness was being made, at least on the basis of the items presented.

Secondly, as stated, the visual format of the Oldfield questionnaire together with the apparent ordering of items may have lead to a distortion of true handedness tendencies.

Thirdly, while a 5-choice response pattern (present only in Oldfield's inventory) may appear to offer finer discrimination, it was often observed to lead to greater confusion on the part of the subject. The use of three possible responses may offer as wide a choice as is practically necessary.

A report published since the completion of the present investigation (McMeekan & Lishman, 1975) describes further the relationship between the Annett and Oldfield questionnaires and sheds some light on the results presented here. While the Annett questionnaire remains easy to comprehend, McMeekan & Lishman found subjects often unable to grasp the instructions of the Edinburgh Inventory. Often single +'s were placed in all columns where double +'s may have been more appropriate. More interesting was the discovery that, while there was little change in subjects' rankings on a retest of the Annett Questionnaire, some subjects differed by as much as 100 points (e.g. L.Q. -50 to L.Q. +50) on a retest of the Oldfield Inventory. Only 5 subjects (of 73) retained the same quantitative (number of +'s) and qualitative (right or left) response pattern on the latter test. In general, lack of observation of reported activities lead to lower reliability coefficients than expected.

While the Oldfield Inventory was found by McMeekan and Lishman to result in a wider dispersion of scores (as found in the present erperiment - see 6.3.1), they put forward the further suggestion that the items of the EHI are 'superior for displaying inconsistencies in hand preference', a suggestion to be categorically refuted on the basis of the item analysis carried out here. A lower L.Q. does not necessarily show more inconsistency in hand preference, but may instead demonstrate inadequacies of the procedural content of the Oldfield questionnaire. It appears that subjects, without giving 'non-preferred' responses to items, placed more +'s in both columns, denoting an equal preference which may not have been the case.

While Oldfield's Inventory shows lower overall L.Q's than that of Annett, this effect is only present at the right-hand extreme of the handedness scale (see Fig.6.4).

One possible reason for assuming Annett's (1967) questionnaire to be the best 'predictor' of hand performance rests in an analysis of item responses. Raczkowski et al (1974) state clearly that a 'good' questionnaire should include a number of items which a 'fair number of left-handers perform with the right hand.' Put more concisely for the purposes of the present investigation, the hypothesis is that the questionnaire which contains the highest sum of individual item responses indicating non-preferred hand usage will 'predict' more accurately the ranking of relative hand scores of subjects on the battery of performance tests.

The total number of left hand responses by (overall) right-handers for each questionnaire is presented below: (scores for left-handers are omitted due to the particular nature of non-preferred hand usage in such individuals).

	Annett Q.	Harris Q.	Oldfield Q.
Males	46	11	21
Females	39	7	12
Total	85	18	33

The Annett questionnaire thus includes many more items which discriminate finely between the large number of right-handers in the population sample, and it is noticeable that amongst males in particular, the Annett questionnaire correlates more highly with average z scores - 0.447 compared to 0.370 (Harris) and 0.379 (Oldfield). A χ^2 value of 40.22 ($p<0.001$) was found in a comparison of total numbers of left-handed responses by right-handers between the three questionnaires. Annett (1970) presented an analysis of item responses which demonstrated the following percentages of left hand responses to questions:

Dealing cards	17.02%	Sweeping	13.49%
Unscrewing jar	16.50%	Threading Needle	13.10%
Shovelling	13.53%	Writing	10.06%

Raczkowski et al (1974) also reported a high proportion of left-handers using the right hand to deal cards (19%).

The present item analysis produced similar results to those of Annett (see table 6.16), while showing not the number of left hand responses in general, but the number of left hand responses made by right-handed subjects only. Compared with Annett's ranking of left hand responses above, the five items with the highest percentage of non-preferred' responses were:

1. Dealing cards 16.8%
2. Unscrewing jar 14.5%
3. Threading needle 10.0%
4. Shovelling 7.6%
5. Sweeping 6.9%

These items, all of which appear on the Annett questionnaire, but only one of which (sweeping) is found on the Oldfield inventory, and none of which are featured in the Harris questionnaire, represent those activities which are most likely to discriminate amongst right-handers. The Harris and Oldfield questionnaires must rely on a preponderance of 'Either' responses for the purposes of classification, and as previously suggested, may thus be less reliable since some subjects may be prone to make 'Either' responses incorrectly.

Both Annett (1970) and Oldfield (1971) claim that the 'Hammering' item is a good overall indicator of handedness, and this is borne out by the present results, where out of twenty activities only three were never performed with the overall non-preferred hand, in right or left-handers. These three activities were:

1. combing hair
2. cutting with knife
3. hammering nail

Both questionnaires and performance tests produced the expected handedness differences between males and females. From the results of questionnaires it can be seen that males were to be found in greater abundance towards the centres of the distributions with females in excess at the right hand extreme, and to a certain extent, at the left hand extreme also. In performance tests similar findings were revealed, although in the Purdue task such sex differences were not statistically significant. Most noticeable was the distribution of average z scores for the three tests. Here males were clustered more around the mean (zero) score with females demonstrating greater overall hand differences in performance. A further sex difference was indicated by the item analysis, where males claimed more non-preferred hand usage in individual items.

Perhaps the most significant result of all with respect to sex differences in handedness was found in the size of correlation coefficients between tests. In 14 of the 15 test comparisons female r_s's were higher than those for males. Thus an indication is given that the inconsistency in male handedness within tests is extended to performance between tests. The impression is created that differences in handedness between males and females are best described in terms of general inconsistency in all aspects of handedness.

6.5 Concluding remarks

Oldfield (1971) refers to the benefits of a carefully constructed laterality questionnaire:

"A measure of hand laterality, then, simply applied and widely used would be of considerable value. In the absence of any firmly based knowledge of the underlying mechanism of handedness, the only way of providing such a measure is to adopt a set of inventory items and a scoring and computational convention, and apply these to an adequate sample of individuals. The resulting frequency distribution is then available as a meaningful background for the quantitive assessment of further individuals." (p.99)

Although it is essential to construct questionnaires according to carefully pre-set criteria Oldfield perhaps places undue confidence in questionnaires as the only 'real' test of handedness. Any laterality measure is, to a certain extent, arbitrary, due partly to the lack of knowledge of the underlying mechanisms of handedness, and there is no adequate reason for rejecting carefully chosen performance measures as an equally important facet of handedness.

A relationship between various measures of handedness has been demonstrated. Such a relationship does not however justify the amalgamation of L.Q. scores and $\bar{z}$ scores as suggested by Satz et al (1967). While recognising the reflection in scores of a common underlying handedness variable, the two levels of assessment - preference questionnaire and performance test - should be regarded as complementary functions in the description of a subject's handedness. For instance, a strong right-handed individual could, for certain purposes, be classed as one who obtains an L.Q. of +90 to +100 and a $\bar{z}$ score of +1.5 or above. The interpretation of a high positive L.Q. with a negative $\bar{z}$ score would present greater problems. In general, such scores (rare as they are) might indicate a consistency of handedness which has been exaggerated by cultural processes, but which is uncovered by performance test scores.

Annett's questionnaire has been demonstrated to be the best 'predictor' of performance test scores, and whilst the specific items employed in this questionnaire may be a determining factor in this respect, observation of the proscribed activities (as with the Harris test) may have improved the relationship between this and performance test scores.

The experiment to be reported in Chapter 7 employs the results of the present investigation in order to select subjects for 'Right', 'Mixed' and 'Left'-handed groups. It was thought best at this stage not to employ just one questionnaire (the Annett Q.) but to continue using an average L.Q. score obtained from all three questionnaires. Although suggestions have been made above concerning the suitability and validity of the questionnaires under consideration, the diversity of items and procedures amongst the questionnaires precludes any totally definitive judgement on the overall superiority of any one, especially in the knowledge that the correlation coefficients obtained between each of the questionnaires and $\bar{z}$ scores did not differ to a statistically significant degree. If in future investigations a single questionnaires is to be employed, it is however recommended that the Annett questionnaire together with a L.Q. scoring technique and, where possible, observation of reported preferences, may furnish the most adequate measure.

7. ABILITY DIFFERENCES BETWEEN HANDEDNESS GROUPS

7. ABILITY DIFFERENCES BETWEEN HANDEDNESS GROUPS

7.1 Introduction

In studies of reading disability or dyslexia handedness has often emerged as an insignificant factor. The precision of the handedness measurement and the choice of categories of reading disability have both contributed to the lack of significant findings. When both handedness and level of reading ability (in relation to general intelligence) are strictly controlled, in studies such as that of Naidoo (1971), results relating the two variables do emerge.

A further contributory factor in the confusion of results has been the attention given to left-handedness in particular as a possible concomitant or even cause of dyslexia (see for example Perlo & Rak, 1971). This emphasis on left-handers has been extended to studies of verbal and non-verbal abilities in the general population, especially by Levy (1969) and the aftermath of studies seeking to confirm or refute her figures (see Chapter 4).

As has already been suggested by reference to such studies as those of Bannatyne (1968), Tschirgi (1958) and Naidoo (1971) and in particular to the findings presented in Chapter 5, it appears far more likely and theoretically plausible that mixed rather than left-handedness will be associated with the various aspects of perception and intelligence under consideration. Especially at the lower levels of spatial development and perception, mixed dominance may be a pre-requisite for efficient functioning (see Kershner, 1971, 1972).

A further deficit in the study of Levy is found in the composition of the two groups (right and left-handers). No indication is given of the numbers of males and females in the groups and no apparent account has been taken of possible sex differences in handedness and ability. Sex differences are often found in cases of reading disability and in scores of general ability (see Newcombe & Ratcliff, 1974), and it is by no means clear whether, when laterality factors are controlled, such differences are eliminated. In the context of the present investigation, for instance, it has already been ascertained that males are less consistent in handedness than females and that, to some extent, inconsistent handedness is associated with superior spatial ability. Thus male superiority in spatial tasks, if it exists, may be due either to the general increased incidence of mixed handedness or to some sex-linked factor which ensures that male mixed-handers will perform at a higher level than female mixed-handers. In any case, Levy's model of the left (or mixed)-hander with inferior spatial ability cannot be reconciled with the idea of a spatially competent, mixed dominant reading retardate.

Results which support the notion that mixed dominance will be associated with a good spatial ability where direction and sequencing are not involved, present various findings with respect to sex differences. Kershner (1971, 1972) in two studies, found no sex differences on a complex spatial task, while McGlone & Davidson (1973) found a difference in performance between males and females even when handedness was taken into account. Most disruptive to performance on a test of spatial relations and on the WAIS Blocks Design test was the

Bettman, Stern, Whitsell & Gofman (1967), in summing up the situation for studies of developmental dyslexia are, in fact, accurately describing the state of affairs in more general areas of performance and ability, when they claim that handedness has remained undetected as a factor of reading disability due to the liklihood that left-handedness as such does not exist in higher proportions. Instead attention should be given to a study of inconsistency in handedness.

Investigations which study independent laterality groups and compare these groups on a measure or series of tests do not frequently find significant differences between right, left and mixed handers (see Annett & Turner, 1974). It is against the background of such studies (for example Newcombe & Ratcliff, 1974; Wussler & Barclay, 1970 and Gibson, 1973) that the results of Levy appear most prominent, but even then criticisms of choice and number of subjects and handedness measure diminish the impact of the results.

Using correlational techniques, Berman (1971) does lend considerable support to Levy, although a single measure of intelligence was used differing from that employed by Levy. Such techniques to some extent bridge the gap between the 'clinical' and 'normal' population approaches delineated by Annett and Turner (1974) and expounded in Chapter 4. In the present experiment an independent groups design is supplemented by a correlational analysis which takes into account within group variation in laterality.

situation where neural asymmetry of functions was completely reversed to the normal brain organisation, this effect being especially prominent in left-handed females. A discussion of the possibility of superior spatial abilities in males is presented in Chapter 4.

The main concern of the present experiment was to investigate the spatial and linguistic abilities of different handedness groups in the light of the inconclusive findings from previous studies. Of major concern was the choice of handedness measures and of suitable tests. While the work carried out in Chapter 6 facilitated the formation of groups carefully selected according to handedness criteria, the choice of suitable ability tests presented a greater problem.

It was intended to employ both visual and verbal tests, which could be analysed into components containing either sequential or non-sequential, gestalt elements. Thus the general 'verbal-performance' opposition describing WISC or WAIS tests was of little use here. Some reasons are discussed below for the rejection of this general distinction and for the need for a closer scrutiny of 'verbal' and 'spatial' tests.

In clinical work it is often not, as might be expected, the case that intelligent dyslexic children show a relative deficit in overall verbal IQ on the WISC. The abilities supressed in such children are frequently not those measured by the verbal scale. While a dyslexic child will, in general, possess a sequencing difficulty which is most apparent in the perception and graphic reproduction of words (see Naidoo, 1971), the basically conceptual and informational content of the WISC verbal scale may draw on the good underlying ability of the dyslexic child, as will the performance scale, and will often give no or little indication of the child's difficulty. Performance on individual WISC subtests may, however, be indicative of the specific problems of the child. For instance, a child may be especially poor at coding, a test included in the Performance Scale, but which measures factors underlying verbal ability.

Other measures, especially of a visual nature, will, however, demonstrate a relationship with reading ability and disability. While Benton (1962a) shows that deficiency in visual form perception is not an important correlate of developmental dyslexia, Wussler & Barclay (1970) found reading-disabled chilren to be significantly inferior on the visual sequential memory subtest of the ITPA to a group of equally intelligent normal readers.

Perhaps more interesting is the significant relationship found between reading scores of a group of normal children and a test of visual sequential memory by Guthrie & Goldberg (1972), who also found only very low correlations between this test and tests of visual discrimination. A Blocks test was also found tocorrelate signifícatly with the reading ability of 81 normal children. In this case the Blocks test scores correlated with visual sequential memory scores ($r = 0.39$; $p<0.01$).

This analysis supports the view that in a Blocks test (such as the

WAIS Blocks test) a sequencing element (placing blocks in order) and an orientation element (placing blocks the right way round) are present, which simulate components of the perceptual basis of analytic verbal tasks.

Thus a pattern of visual ability emerges amongst dyslexics which can be envisaged extending to all individuals with inconsistent laterality. At its simplest level this pattern may involve poor visual sequential memory, average blocks design (see Wussler & Barclay, 1970) and good spatial ability in tasks with gestalt rather than directional features (see for example the use of Ravens Matrices, Chapter 4). WISC and WAIS subtests tend not to be clearly representative of these facets of spatial ability and indeed the WAIS Blocks Design test produces correlation coefficients ranging from 0.39 to 0.77 (all significant) with all other verbal and performance tests thus not demonstrating any of the unrelatedness between tests alluded to by Guthrie & Goldberg (1972).

The present investigation is not concerned with verbal-performance differences in handedness groups, as was that of Levy, since for the purposes of the theoretical context adhered to here, such a battery of tests represents none of the specific differences to be expected between mixed and consistent handers. The Blocks Design test (WAIS) was, however, employed for two reasons. First it is one of the tests most commonly featured in ability profiles of dyslexics or of different handedness groups. Secondly it was intended to discover whether this test would be unrelated to a further spatial test and whether it would also be unrelated or positively related to strength of handedness.

A further measure was devised to assess visual perception and memory in a situation where verbalisation would be virtually impossible due to the complexity of the task (as in tests used by Kershner, 1971, 1972). This task was intended to include no prominent directional, sequential or orientational aspect and to be, to a greater extent than the Blocks test, three-dimensional (the Blocks Test, although appearing three-dimensional, is in reality a two-dimensional problem). It was hypothesised that mixed handers would score higher than consistent handers on this test.

A parallel between the use of the above two tests is drawn in the choice of verbal measures. A battery of three sub-tests combined to yield a measure of foreign language aptitude was employed. This test, unlike the verbal scale of the WAIS, involves analysis and manipulation on a perceptual level of linguistic items. It was hypothesised that the overall score would relate positively with hand strength. There were reservations about this hypothesis since, although the test was not intended to relate directly to actual foreign language ability or experience, these factors had to be taken into account. To compensate for any bias in individual scores due to foreign language experience the subtest scores were compared between groups in relation to total scores. In particular it was hypothesised that on the first subtest, which involved the auditory and visual sequencing of phonemes, scores relative to total performance would relate positively to hand strength, while a negative relation with hand strength would pertain with relative scores on the third subtest, which demanded memory of whole words and associations between words. This test contained on a verbal level similar operations to those found in the second spatial test. In fact, Caroll & Sapon (1959) found that these two subtests correlated only mildly (average r = 0.23) and hypothesised that the tests involved diverging facets of language ability.

The experiment had two aims, (1) the demonstration of certain ability differences between handedness groups, and (2) the clarification of all problems and factors relevant to a study of ability differences in independent laterality groups. If differences in handedness distributions are consistently found in low and high ability groups and yet differences in ability not found in independent handedness groups (see Annett & Turner, 1974), there should be explanations for this otherwise apparently logically contradictory state of affairs. Apart from size of groups, other factors which should be taken into account include (a) sex, (b) eye dominance, and (c) familial left-handedness.

An additional laterality measure employed in the present investigation for which the above factors were also important, was that of tachistoscopic field preference for verbal and for spatial stimuli. A discussion of tachistoscopic techniques and of the relationship between field preference and handedness was presented in Chapters 2 and 3 (2.4 and 3.3).

It was decided to present (a) letter strings and (b) overlapping geometric shapes as indices of verbal and spatial dominance respectively. Although most investigators agree that cerebral dominance is not the only factor affecting field preference, there is every indication (from arguments of White, 1973) that cerebral dominance is the major contributory factor and will ensure that different handedness groups yield different field superiority scores. While, in general, right-handers, and to a large extent mixed-handers, demonstrate clear right field (left hemisphere) dominance for verbal stimuli (Kershner & Jeng, 1972; Bryden, 1964, 1965), left-handers tend to show no clear difference between hemifields. The tendency to scan from left to right possibly ensures a right field bias from the outset and thus it may not be surprising that left field dominance, although expected, is rarely found amonst sinistrals. Zurif & Bryden (1969), for instance, found that only familial left-handers demonstrated any degree of left field preference while non-familial left-handers showed clear right field preference for letters. This finding is duplicated by Bryden (1965), while McKeever et al (1973) found letter recognition to be superior in the right visual field for all handedness groups (including familial left-handers).

With regard to eye dominance (see White, 1969 and Kimura, 1966) only negligible effects pertain in size of hemifield difference although Kershner & Jeng (1972) found crossed lateral subjects to be inferior in total recall on a verbal task but superior on a spatial task involving recognition of overlapping shapes.

In general, spatial stimuli demonstrate little hemifield difference (see Kimura, 1966), although Dee & Fontenot (1973) and others suggest that right hemisphere (left visual field) superiority can be obtained with dot enumeration and other tasks. While pre and post-exposural scanning tendencies may still play a role, it is to be expected that under ideal circumstances left field superiority would be found in right-handers and right field superiority in left-handers.

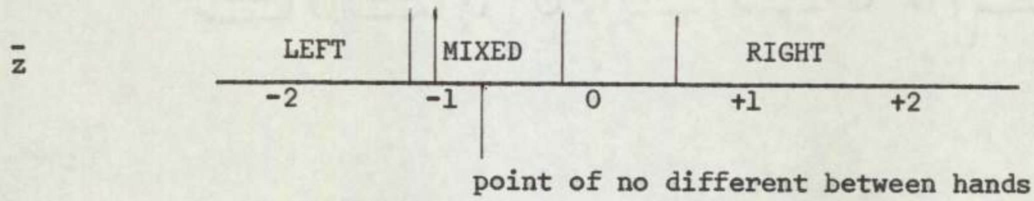
The present experiment sought to lend support to the relationship between handedness and cerebral dominance by the use of tachistoscopic techniques. Tachistoscopic scores could also be employed in order to clarify further the ability differences found between left, mixed and right-handers.

7.2 Method

7.2.1 Selection of subjects

Forty-eight subjects - 24 male and 24 female university undergraduates - were selected on the basis of scores over the range of six questionnaire and performance measures of handedness (see Chapter 6). Average ages of subjects were males : 22.9 years and females : 22.1 years. The distributions for questionnaire scores and performance test scores from the 144 subjects in the previous experiment were segmented separately to yield left, mixed and right-handed groups. Thus the same classification was employed for males and for females and was based on the distributions of scores for 72 males and 72 females combined. This procedure ensured as far as possible that the handedness groups chosen for the present experiment were including males and females with equal direction and magnitude of handedness.

The ranges of scores which counted as 'left', 'mixed' and 'right' are demonstrated in Figre. 7.1 below - for L.Q. and $\bar{z}$ separately. It must be stressed here, as previously, that exact cut-off points for handedness groups are to a large extent arbitrary, and are determined in part by the availability of more individuals towards the right hand end of the L.Q. scale and by taking into account the point of no difference between hands on the $\bar{z}$ scale.



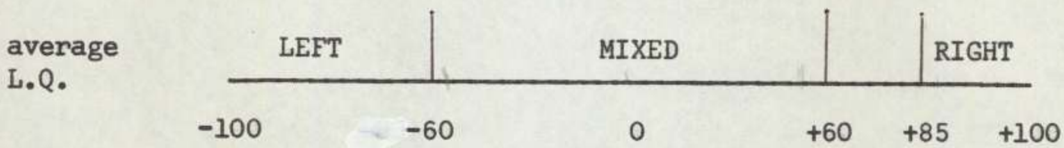


Figure 7.1 Classification of handedness on the basis of performance test scores ($\bar{z}$) and questionnaire scores (L.Q.)

For instance, approximately 42% of the 144 subjects whose scores contributed to the distribution lie in the narrow range of L.Q. scores over +85, which accounts for only 7.5% of the total spread of scores.

The only point at which it was really feasible to implement a gap between handedness groups was between mixed and right-handers and this is shown in both modes of classification. While this feature, together with the different cut-off scores for sinistrals and dextrals may suggest that the group of left-handers would be less strong in their handedness than the right-handers, certain points must be taken into consideration: first, far fewer left-handers exist in the extreme ranges of score. Secondly, cultural influences on handedness preclude the notion that left and right-handers are equal and opposite if they obtain the same size L.Q. but with differing signs. Thirdly, the discrete groups here can be amalgamated to take into account the individual laterality scores in correlations with ability measures, thus avoiding any inferences of 'equal and opposite' for right and left-handers.

The three handedness groups were selected from all subjects who volunteered. These groups each consisting of 16 subjects were arranged as follows:

Left-handers:	$\bar{z}$ score less than -1.1	and L.Q. score less than -60
Mixed-handers:	$\bar{z}$ score -0.15 to -1	and L.Q. score -60 to +60
Right-handers:	$\bar{z}$ score above +0.5	and L.Q. score above +85

The above classification ensures that, in the case of right-handers, the equivalent of just one 'Left' response on each questionnaire would rule them out of the 'Right-handed' experimental group.

Particular attention had to be given to finding mixed-handed females and left-handed males, who did not respond in great numbers to original advertisements. Approximately 80 subjects, who had been selected as possibilities for inclusion into groups were tested before the 48 experimental subjects were finalised.

7.2.2 Design

For the purposes of test order it was considered necessary to separate the two tachistoscopic tasks so as to avoid fatigue. Four groups of test emerged:

Tachistoscopic Verbal

Tachistoscopic Spatial

Verbal

Spatial

This presented 8 (4x2x1x1) possibilities of test order and within each handedness group each test order was accounted for by one subject. Altogether there were 6 independent groups selected on the basis of sex and handedness.

7.2.3 Material and procedure

The complete session including laterality tests lasted approximately two hours for each subject. Subjects were allowed a short break following the battery of handedness tests if they so desired, while subjects who failed to satisfy the handedness criteria in this initial part of the experiment were dismissed and paid accordingly. The testing took place in a small self-contained room.

Tachistoscopic presentation:

A two-field (Cambridge) tachistoscope was employed for presentation of verbal and non-verbal stimuli.

The verbal stimuli consisted of 24 arrangements of three letter arrays (Lettraset 706). Letter strings, although contested by Bryden (1965) as an accurate measure of cerebral dominance are justified as such elsewhere (see White, 1973). The arrays were composed from the consonants b, d, f, g, h, m, p, r, s, v, w and z and were arranged such that the degree of presentation ranged from 1° 30' for the letter nearest the fixation point to 2° 48' for the letter farthest from the fixation point.

Each letter occurred twice in each of the three positions and each array appeared once in each hemifield with at least ten presentations before a repeat of any array. It was also arranged that approximately half the arrays occurred first in the left hemifield and half in the right. The number and size of 'runs' in one hemifield of successive presentations was kept identical for both fields although runs occurred in different positions in the order of presentations for left and right hemifields.

The subject was allowed both to familiarise himself with the alphabet in the style of print to be used for presentations and to practise with one presentation in each hemifield until he or she was sure of the letters.

A 20 msec exposure time was used (see Bryden, 1965 and White, 1973) and subjects were required to trigger the exposure when they were satisfied that they were fixating on a centrally placed point. This technique is advocated by White (1969) as the most advantageous in ensuring correct fixation before presentation.

For spatial stimuli a series of geometric shapes were presented in overlapping fashion, two at a time. The shapes used were a square, circle, pentagon, hexagon, rhombus and two triangles, one with apex up and one with apex down. The two shapes together were presented at an angle of presentation of 1^{o} - 3^{o} to the right or left of fixation and the general conditions applying to order of presentation, practice and exposure time were as with the verbal stimuli.

In this case there were 21 combinations of shapes, with each possible combination occurring once in each field. Kershner & Jeng (1972), in presenting this type of stimulus, claim that there is no 'verbal mediation' involved in recall. In the present experiment subjects were asked to recall the shapes that they had seen by calling out the numbers of the shapes from a selection card. While this did not rule out verbal mediation, it did remove the need for a verbal label for the stimuli and compared with the situation in which the physical matching of words has been found to favour the non-dominant hemisphere (see 2.5.2)

For both types of tachistoscopic stimuli one error was recorded for each letter or each shape incorrect, although correct positioning of letters in the sequence was not required.

Houses test:

A simple street map was attached to strong cardand a further copy made. The subject and the experimenter then each had one'map' and in addition, 4 houses and 4 hotels taken from a Monopoly set. Using the houses and hotels in conjunction with a map, the experimenter then produced a street design, involving from two to

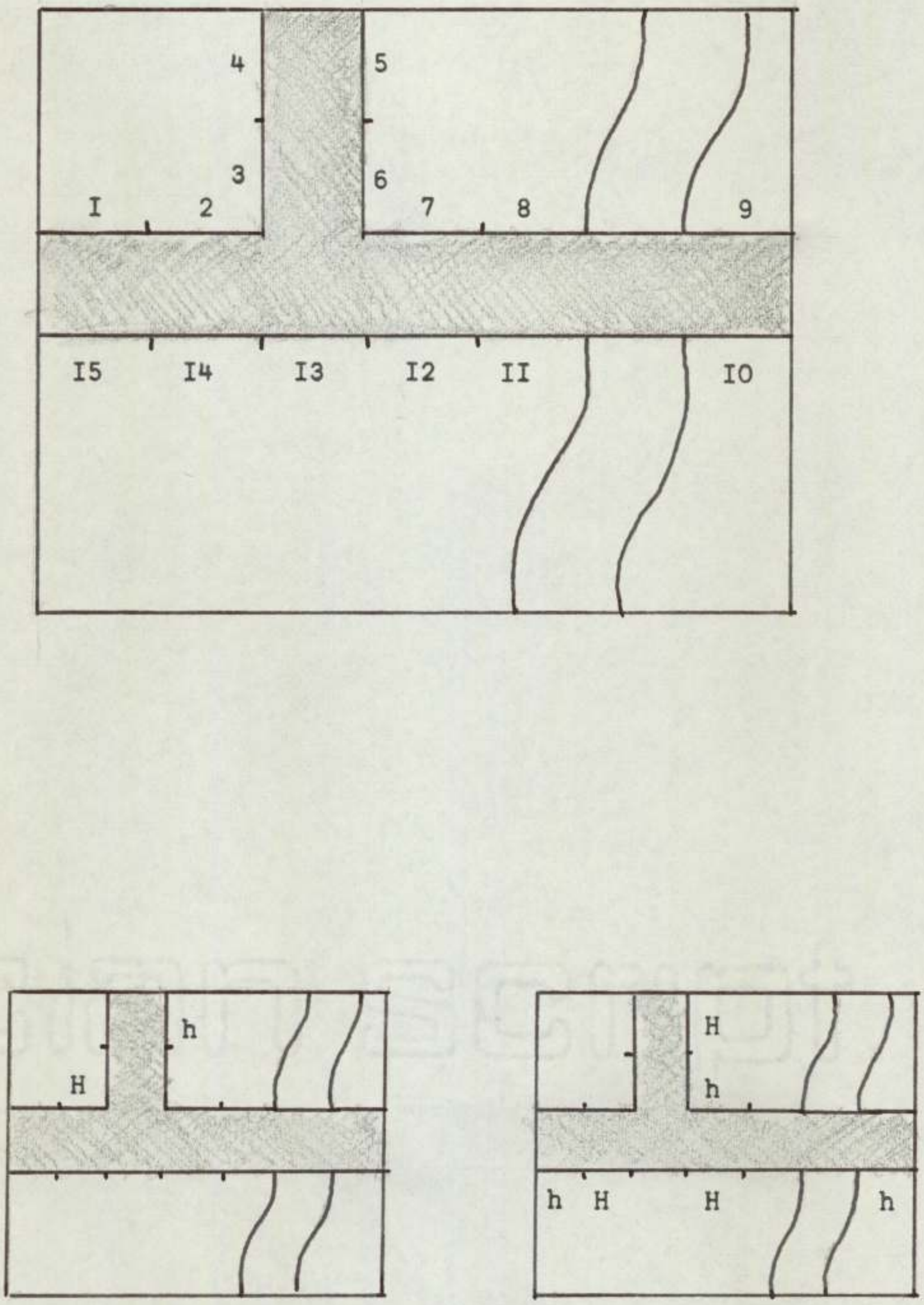


Figure 7.2. Positions for Buildings in Houses Test
(top map, actual size)

and two examples of presentations of
of houses(h) and hotels(H)

eight buildings, for 3 seconds, allowing the subject up to 30 seconds to reconstruct the design from memory. To score as correct (2 points) a building had to be of the right type (house/hotel) and in the right position. Orientation of the building (side or front-on to the road) was not vital although it was stressed that all buildings were in fact side-on to the road. The positioning of the incorrect building in the correct position scored one point only. Positions on the map were easily and clearly defined by the provision of a side-street and a river.

Altogether, 16 displays were constructed, feed-back being given in all cases. Two examples of items from the test are shown in Figure 7.2 opposite, together with a 'map' showing the 15 possible positions for buildings.

Blocks test:

The Blocks Design test from the WAIS was used as the second spatial test. Instructions and scoring techniques were followed exactly from the WAIS manual.

MLAT (Modern Language Aptitude Test, Carroll & Sapon, 1959).

The shortened version of the MLAT was employed which took approximately 35-40 minutes to administer. This involved three subtests, MLAT 3, 4 and 5.

Subtest 3 : this involved the auditory and visual sequencing of letters to form the auditory equivalent of a real word. For this real word a synonym had to be chosen from five alternatives. This test relied to a great extent upon speed.

Subtest 4 : a test of word function, involving semantics and syntax. Words fulfilling similar functions were to be identified by the subjects.

Subtest 5 : a set of 24 short Kurdish words were learnt in association with their English equivalents. After short practice the English equivalentsof a random series of the Kurdish words were selected from a choice of 5 (for each Kurdish word). This test is designed to test the 'rote memory aspect' of the learning of foreign languages.

Examples of questions from the above three subtests can be seen below, together with the relevant instructions:

Subtest 3 : (spelling clues)

"Each item below has a group of words. The word at the top of the group is not spelled in the usual way. Instead, it is spelled approximately as it is pronounced. Your task is to recognise the disguised word from the spelling. In order to show that you recognise the disguised word look for one of the five words beneath it that corresponds most nearly in meaning with the disguised word."

Ex.1 mblm

A. Blame
B. Ambulance
C. Blemish
D. Symbol ✓
E. Flower

Ex.2 kmplikashn

A. Framework
B. Creation
C. Sympathy
D. Case for a gun
E. Intricate involvement ✓

Subtest 4 : (words in sentences)

"..... look over all the choices to find the one which functions most nearly like the word or phrase in the key sentence."

Ex.1 Jill fell down AND Jack came tumbling after.

Now you may wait out there or you may come back on Friday if you wish.
A: Now; B: out; C: or ✓; D: on; E: if

Ex.2 She played the piano EXTREMELY well.

Promptly on the dot of five, he came up the stairs, quite flushed with excitement and breathing very heavily.
A: Promptly; B: quite; C: flushed; D: very ✓; E: heavily

Subtest 5 : (paired associates)

"...... memorise the Kurdish-English vocabulary below ..... you will be given 2 minutes to study the vocabulary ..... after 2 minutes further practice (filling in English equivalents with the aid of the vocabulary) ...... you will be given the Kurdish words and 5 choices in English."

Ex.1 mep

A. in
B. on ✓
C. mat
D. enter
E. art

Ex.2 ngoz

A. enter
B. lady
C. that
D. dark ✓
E. on

7.3 Results

7.3.1 Group handedness scores

Within group handedness scores are presented here in order to compare the average scores for males and females, and the average scores for right and left handers. The average handedness scores are shown for males and females separately in Table 7.1. Average Laterality Quotients (L.Q.), average z scores ($\bar{z}$) for performance tests and deviation of $\bar{z}$ scores from $\bar{z}$ = -0.75 (point of no difference between hands) are presented for left, mixed and right-handed groups. While right-handers in general were slightly more strongly handed than left-

		L.Q.	$\bar{z}$	$\lvert\bar{z} + 0.75\rvert$
Males	Left	-83.1	-2.00	1.25
	Mixed	+30.0	-0.66	0.09
	Right	+93.3	+1.00	1.75
Females	Left	-84.9	-1.97	1.22
	Mixed	+28.6	-0.56	0.19
	Right	+92.9	+0.94	1.69

Table 7.1 Handedness scores for Experimental Groups

handers, males and females in each handedness group produced very similar handedness scores.

7.3.2 Tachistoscopic tests

If tachistoscopic measures were to accurately reflect cerebral dominance for language and nothing else, then the following trend in field preferences would be expected:

	Left-handers	Mixed-handers	Right-handers
Verbal stimuli	Left field sup.	(Right field sup.)	Right field sup.
Spatial stimuli	Right field sup.	(Left field sup.)	Left field sup.

Although results should be interpreted in this context, previous results have suggested that, in general, right hemifield superiority is the case for letters, while non-verbal stimuli very seldom produce clear hemifield differences.

For both verbal and spatial stimuli, results were analysed by means of t-tests in which right and left field scores were compared (see Tables 7.2 and 7.3). These tests were carried out over male and female scores combined in each handedness category. Although right-handers (verbal stimuli) and left-handers (spatial stimuli) demonstrated significant hemifield differences in the expected direction, it was noted that in the case of right-handed males, field differences in verbal scores were insignificant, while amongst left-handed females field differences in spatial scores were insignificant. Hence, while right-handed females produced the expected right field superiority in verbal scores, males did not, and conversely, while left-handed males demonstrated significantly greater right field superiority for

	Left-handers		Mixed-handers		Right-handers	
	lvf	rvf	lvf	rvf	lvf	rvf
Males	18.8	15.4	16.0	11.5	18.5	15.6
Females	11.8	9.3	13.4	11.1	22.6	14.0
Total	15.3	12.4+	14.7	11.3+	20.6	14.8*

+ n.s. * t = 3.34, $p<0.005$ (one-tailed)

Table 7.2 Numbers of errors in right and left visual fields (rvf and lvf) for verbal stimuli

	Left-handers		Mixed-handers		Right-handers	
	lvf	rvf	lvf	rvf	lvf	rvf
Males	7.5	5.0	7.5	6.6	7.0	6.1
Females	7.0	6.4	8.9	8.3	7.0	6.1
Total	7.2	5.7*	8.2	7.5+	7.0	6.1+

+ n.s. * t = 1.80, $p<0.05$ (one-tailed)

Table 7.3 Numbers of errors in right and left visual fields (rvf and lvf) for spatial stimuli.

shapes, females did not. In general, all results demonstrated some degree of right field preference, a finding almost certainly biased by the effects of pre and post-exposural scanning tendencies. The use of a different type of spatial stimulus (e.g. dot enumeration) may well have overcome the effects due to these factors, which were not ruled out with the presentation of two geometric shapes.

A further method of comparing handedness groups is by means of a classification of scores into groups of right or left field superiority. Table 7.4 demonstrates numbers of left, mixed and right-handers showing right field superiority for letters, while Table 7.5 presents a similar set of data for spatial stimuli. Again it can be seen that results are in the expected direction, with left-handers showing significantly less right field preference for letters than mixed and right-handers combined ($\chi^2 = 2.73$, $p<0.05$ one-tailed). In fact exactly half the left-handers demonstrated right field preference for letters. In these two tables subjects showing equal field preference are scored with the left field superior group.

Finally, in order to compare the pattern of verbal-spatial scores within individuals, numbers of subjects demonstrating opposite preferences for verbal and spatial stimuli were calculated (Table 7.6). Right field preference for letters with left field preference for shapes would be considered typical of the hypothesised brain functioning in right-handed individuals, with the opposite pattern of field preferences mirroring typical left-handed performance.

Figures in general were too small for analysis by statistical methods

	Left Field Sup.	Right Field Sup.
Left-handers	8	8
Mixed-handers	3	13
Right-handers	4	12

Table 7.4 Numbers of subjects showing left field superiority for verbal stimuli

	Left Field Sup.	Right Field Sup.
Left-handers	5	11
Mixed-handers	5	11
Right-handers	7	9

Table 7.5 Numbers of subjects showing left field superiority for spatial stimuli

		Letters rvf sup. Shapes lvf sup.	Letters lvf sup. Shapes rvf sup.
Males	Left	0	4
	Mixed	3	1
	Right	4	2
Females	Left	4	3
	Mixed	2	2
	Right	2	0
Total	Left	4	7
	Mixed	5	3
	Right	6	2

Table 7.6 Patterns of field preference (rvf, lvf)

although in a comparison of male left and mixed plus right-handers a significant difference was obtained (p = 0.035, Fisher E.P.):

	Letters Right Field Shapes Left Field	Letters Left Field Shapes Right Field
Male left-handers	0	4
Male Mixed, Right-handers	7	3

In order to score in one or other of the above categories, either letters or shapes had to show a definite field preference with the other stimuli (letters or shapes) demonstrating opposite preference or no field difference.

While cerebral dominance, as indexed by handedness, does appear to affect tachistoscopic scores in the predicted direction, other factors obviously play a role in determining hemifield preferences. Apart from the scanning tendencies already mentioned variables such as eye dominance and familial left-handedness will be discussed at a later stage as these also may have influenced tachistoscopic performance.

7.3.3 Houses test

Results on the Houses test, expressed in terms of errors, can be seen in Table 7.7. Lower scores indicate superior performance and thus mixed-handers, were, overall, better than left-handers who in turn scored higher than right-handers. A two-way analysis of variance was carried out on these scores and is summarised in Table 7.8.

Both sex differences alone and handedness alone produce a significant effect on scores, while there is also apparently an interaction between

	Left-handers	Mixed-handers	Right-handers	Total
Males	12.63	13.63	23.00	16.42
Females	25.25	17.13	21.13	21.17
Total	18.94	15.38	22.06	

Table 7.7 Scores on Houses Test (errors)

Source	SS	df	MS	F	p<
Rows (sex)	270.75	1	270.75	5.41	0.05
Cols (Handedness)	358.29	2	179.15	3.58	0.05
Interaction	429.85	2	214.93	4.29	0.025
Error	2103.03	42	50.07		
Totals	3161.92	47			

Table 7.8 Analysis of Variance for Houses scores

	L.Q. x Houses	$\bar{z}$ x Houses
Male r_s	-0.46*	-0.37*
Female r_s	-0.14	-0.24
Total r_s	-0.28^{+}	-0.30^{+}

$^{+}$ $p<0.05$ * $p<0.025$

Table 7.9 Correlations between houses scores and handedness scores sex groups and handedness. Thus the magnitude and direction of the effects of handedness classification differ for males and females.

A post-hoc analysis revealed a significant difference between mixed and right-handers ($p<0.05$, Tukey's method), while a planned comparison between mixed-handers and consistent-handers (right and left) also produced a significant difference ($t = 2.115$, $p<0.025$ one-tailed). Right and left-handed scores produced a combined average of 20.50 errors, while mixed-handers scored 15.38.

Results of the correlational analysis carried out between individual handedness socres and houses scores are given in Table 7.9. From these results it is clear that males exhibit the expected trend in houses scores to a greater extent than females. Correlation co-efficients were computed using error scores for houses and then multiplied by -1 in order to yield a measure of association between strength of handedness and higher scores on the houses tests.

7.3.4 Blocks design test

Results on the WAIS Blocks Design Test are presented in Table 7.10. A Kruskal Wallis Analysis of Variance (employed due to the skewed nature of scores) demonstrated no significant differences between sexes or between handedness groups. The moderate interaction between sex and handedness can be seen from the difference in correlation coefficients for males and females between Blocks and handedness scores (see Table 7.11). Overall, virtually no association was found between the two sets of scores (Blocks and handedness).

	Left-handers	Mixed-handers	Right-handers	Total
Males	45.88	43.25	44.38	44.50
Females	43.88	45.50	44.50	44.63
Total	44.88	44.38	44.44	

Table 7.10 Scores on the WAIS Blocks Design test

	L.Q. x Blocks	$\bar{z}$ x Blocks
Male r_s	+0.13	+0.14
Female r_s	-0.15	-0.21
Total r_s	-0.01	-0.03

Table 7.11 Correlations between Blocks scores and handedness scores

7.3.5 Modern Languages Aptitude Test (MLAT)

Scores over the three subtests (3,4 and 5) of the MLAT are presented in Table 7.12. Although ostensibly a measure of potential or underlying foreign language ability, scores were, not too unexpectedly, found to correlate with foreign language experience as assessed on a 4-point scale by qualifications in foreign languages. Overall, a correlation coefficient of +0.42 ($p<0.01$) was obtained between MLAT scores and experience (males $r = +0.37$, females $r = +0.43$).

An analysis of variance, which failed to demonstrate significant differences between sexes (although this approached significance, $0.05<p<0.10$) or between handedness groups, is shown in Table 7.13.

In an unpredicted manner almost identical to the Blocks situation, male handedness scores tended to correlate positively while female scores correlated negatively with MLAT scores (Table 7.14). In the comparison between $\bar{z}$ scores and MLAT scores, male and female correlation coefficients differed significantly ($p = 0.05$).

Two MLAT subtests (3 and 5) were then further analysed to detect differences between handedness groups in performance on these subtests relative to total MLAT score. For this purpose, individual scores on subtests 3 and 5 were divided by total score and then multiplied by 100. Resultant scores can be found in Table 7.15, while analyses of variance are shown in Table 7.16 and 7.17.

From the analysis it can be seen that a further interaction between sex and handedness is revealed, especially with respect to subtest 3

	Left-handers	Mixed-handers	Right-handers	Total
Males	56.50	52.75	58.63	55.96
Females	63.38	65.00	57.00	62.46
Total	60.94	58.88	57.82	

Table 7.12 Scores on the MLAT

Source	SS	df	MS	F	p <
Rows (sex)	507.00	1	507.00	2.66	0.10
Cols (handedness)	80.79	2	40.40	0.21	
Interaction	418.88	2	209.44	1.10	
Errors	8015.25	42	190.80		
Totals	9021.92	47			

Table 7.13 Analysis of Variance for MLAT scores

	L.Q. x MLAT	$\bar{z}$ x MLAT
Male r_s	+0.15	+0.13
Female r_s	-0.12	-0.35
Total r_s	+0.03	-0.08

Table 7.14 Correlation between MLAT scores and handedness scores

	MLAT Subtest 3			MLAT Subtest 5		
	Left	Mixed	Right	Left	Mixed	Right
Males	39.5	30.5	42.9	19.5	29.6	24.4
Females	41.3	42.3	30.1	21.5	24.0	28.1
Total	40.4	36.4	36.5	20.5	26.8	26.3

Table 7.15 Scores of MLAT subtests relative to total MLAT score

SOURCE	SS	df	MS	F	p<
Rows (sex)	0.75	1	0.75	0.01	
Cols (handedness)	161.50	2	82.75	1.08	
Interaction	1214.00	2	607.00	7.95	0.01
Errors	3208.75	42	76.40		
Totals	4589	47			

Table 7.16 Analysis of Variance for relative MLAT 3 scores

SOURCE	SS	df	MS	F	p<
Rows (sex)	0.02	1	0.02	0.00	
Cols (handedness)	390.54	2	195.27	5.25	0.01
Interaction	198.79	2	99.40	2.67	0.10
Errors	1562.63	42	37.21		
Totals	2151.98	47			

Table 7.17 Analysis of Variance for realtive MLAT 5 scores

relative scores. Again this effect can be recognised in the different sign of correlation coefficients associating handedness scores and test scores (Table 7.18).

The predicted trend between handedness and subtest scores is reflected in male results only, in terms of the correlations presented in Table 7.18. On MLAT 3 scores both L.Q. and $\bar{z}$ correlations with scores show, as predicted, a significant positive association between strength of handedness and relative superiority on a verbal test employing sequencing procedures. From MLAT 5 scores a significant handedness difference is produced by the analysis of variance, in which left-handers were inferior on relative subtest scores to both mixed and right-handers. Again there is the predicted negative correlation between strength of handedness and performance on a test of memory for whole words, but only in the case of males. This correlation is significant in the case of $\bar{z}$ scores but not quite significant at the 0.05 level with respect to L.Q. scores.

Females do not conform to expected trends at all and three of the four correlation coefficients differ significantly ($p<0.05$) between males and females.

7.3.6 Intercorrelation of test scores

Houses test scores demonstrated no significant association with scores on the other two tests, and while some negative associations may have been expected the reasoning nature of the Blocks and MLAT tests may have accounted for this finding. Only the houses test could purport to approach a test of visual perception per se, relatively independent of 'intelligence'. The expected association

	MLAT 3 Relative Scores		MLAT 5 Relative Scores	
	x L.Q.	x $\bar{z}$	z L.Q.	x $\bar{z}$
Male r_s	+0.54*	+0.55*	-0.32	-0.38^{+}
Females r_s	-0.35	-0.18	+0.07	+0.26
Significance of male female difference p=	0.002	0.010	0.371	0.031

* $p<0.01$ $^{+}$ $p<0.05$

Table 7.18 Correlations between relative MLAT subtest scores and handedness

	Blocks x Houses (r_s)	MLAT x Houses (r)	MLAT x Blocks (r_s)
Males	+0.05	+0.04	+0.64*
Females	-0.11	+0.02	$+0.45^{+}$
Total	-0.02	-0.05	+0.48*

* $p<0.01$ $^{+}$ $p<0.025$

Table 7.19 Correlations between scores on the three tests between MLAT scores and Blocks scores was found with the strength of the association slightly greater for males (Table 7.19). In Table 7.19 correlations with houses scores were again multiplied by -1 to indicate comparison of success in two tasks.

7.3.7 Effects of Familial left-handedness (FAML) on performance

The effects of FAML were considered for all three test scores and for performance on tachistoscopic tasks. It was noted that more females (14) than males (8) indicated the presence of FAML - a difference not significant on a χ^2 test.

With respect to tachistoscopic performance, although groups were probably too small to demonstrate significant differences between subjects with and without FAML, a consistent pattern did emerge. Simply expressed, FAML in a subject seemed to induce a performance more closely related to that expected on the basis of his or her individual handedness. Thus, for example, amongst left-handers, FAML subjects demonstrated only a very slight right hemifield preference for letters in comparison to that shown by non-FAML left-handers. Results for mixed-handers were less predictable but for right and left-handers both verbal and spatial scores follow the above pattern, In Table 7.20 scores of right and left-handers are given in terms of hemifield difference, where a positive score indicates right field preference.

While FAML subjects proved superior on Blocks and MLAT tests, their scores were slightly lower than non-FAML subjects for the houses test. Scores were compared for all three handedness groups together

	Letters		Shapes	
	FAML	non-FAML	FAML	non-FAML
Left-handers	+1.83(12)	+6.25(4)	+1.67	+1.00
Right-handers	+5.25(4)	+5.08(14)	-2.00	+1.83*

* t = -2.35 p<0.05 (two-tailed)

Table 7.20 Effects of FAML on tachistoscopic performance (numbers of subjects in brackets)

	Houses(errors)		Blocks		MLAT	
	FAML	non-FAML	FAML	non-FAML	FAML	non-FAML
Left-handers	9.50	9.38	45.08	44.25	61.50	59.225
Mixed-handers	8.12	7.40	44.00	44.60	66.00	54.60
Right-handers	12.13	10.67	47.25	43.50*	69.00	54.08
Total	9.60	9.21	45.25	43.50	69.00	54.08 *

* p<0.05 (two-tailed)

Table 7.21 Effects of FAML on test scores and separately, since it cannot be ruled out that the effects of FAML differ for right and left-handed subjects (Table 7.21).

7.3.8 Effects of eye dominance on performance

Initially, a comparison was made between consistent (same eye and hand dominance) and inconsistent individuals on Purdue Pegboard scores, since in Chapter 6, it had been suspected that eye dominance might have an effect on hand superiority. On a score of relative hand superiority the consistent and inconsistent individuals from the right and left handed groups in the present experiment differed significantly. Ipsi-lateral eye and hand dominance lead to greater hand superiority even though handedness as such was almost identical in strength between the two eye-hand groups (Table 7.22).

As with FAML, eye dominance affected tachistoscopic performance consistently rather than significantly. As expected, consistent laterality enhanced the score in the direction expected by handedness (Table 7.23). Only in the case of letter scores for consistent right-handers do hemifield differences reach a significant level ($t = 4.09$, $p<0.005$).

Inconsistent laterals proved slightly superior on MLAT and Blocks tests, with virtually no difference between groups on the houses test. None of the these differences was significant and they are not presented here. It suffices to note that in a simple eye-hand consistency measure and a complex measure of hand preference and dominance, two distinct and different influences are at work. There is no evidence that inconsistency between modalities and within modalities (handedness) are related in a similar way to performance on the present tests.

7.4 General discussion

Performance over the test measures by males confirmed the trends expected on the basis of handedness differences in ability. The results of females, however, confused the overall effect and constantly gave evidence of interactions with those of males and handedness. If mixed-handed superiority on a task (over right and left-handers combined) is denoted by + and inferiority by - then the expected and actual directions in results can be seen in Table 7.24 below, where scores are calculated as simple averages:

		Houses	Blocks	MLAT	MLAT 3	MALT 5
					(relative scores)	
Expected		+	-	-	-	+
Actual	Males	+	-	-	-	+
	Females	+	+	+	+	-
	Total	+	-	-	-	+

Table 7.24 Direction of results from 5 test measures (mixed-hand superiority denoted by +)

Thus, even taking into account the female scores, the overall pattern of results is as expected. The probability of obtaining the predicted series of +'s and -'s in the above table was equal to 0.03 (Binomial Test). Having taken foreign language experience into account, males produced some form of significant result on the Houses Test and on both the MLAT relative subtest scores.

Although the laterality survey carried out in Chapter 5 suggested a significant relationship between handedness and facets of spatial and linguistic ability, it was not intended to categorically relate mixed-handedness and superior spatial ability. The findings demonstrated rather that among Artists there was significantly more mixed handedness than among Linguists. The present experiment has shown that, upon choosing a relevant test of spatial ability (the Houses test), it can in fact be demonstrated that mixed-handedness is significantly related to good performance. This extension from the classificatory techniques of Chapter 5 did not prove as successful in relating consistent handedness to good verbal ability. In keeping with the general pattern, males did demonstrate such a trend although female mixed-handers performed well on the MLAT in comparison to right and left-handers.

The two subtests of the MLAT (3 and 5), in their relationship with handedness again revealed some statistical supportive evidence for male but not for female scores. Mixed-handedness was related in males to relative superiority on subtest 5 and inferiority on subtest 3. In particular, on a verbal test, which involved an obvious auditory and visual sequencing component (subtest 3), the expected correlation coefficients for males emerged. On subtest 5 left-handers' relative scores were significantly lower (Table 7.18) for both males and females. Although this appears to conform to the hypothesis that strong handedness will relate negatively to relative success in this task, it is only in males that mixed-handers score higher than both left and right-handers.

The factors which may have caused the differences between males and females must next be considered, bearing in mind that handedness as an index of cerebral dominance might nevertheless reflect different patterns of cerebral organisation in males and females (Marshall, 1973, for instance, suggests that males may possess more equipotentiality with respect to spatial functions irrespective of handedness).

The possibility that overall differences in intelligence between males and females contributed to the results remains remote. If all three tests are regarded as contributing in some way to intelligence then it is found that:

(a) on the Houses test males are significantly better,

(b) on the Blocks test performance between sexes is equal, and

(c) on the MLAT females are superior ($p<0.10$).

It must be remembered that many authors may indeed consider the verbally-biased MLAT to be the best indicator of 'intelligence', but this cannot be substantiated here.

Before going on to consider the effects of FAML and eye dominance on sex differences and interactions, the possibility - and in the writer's opinion the most plausible in the circumstances - will be entertained that the nature of mixed or left-handedness in males and females may be intrinsically different. By this is not meant the appearance of handedness in performance tests or questionnaires but the relationship between mixed or left-handedness and cerebral functioning, or more overtly the relationship between this type of handedness and performance on tests of ability.

The interaction of developmental, genetic and environmental factors could not only lead to the emergence of more mixed-handedness in males but also, conceivably, to diverging patterns of cerebral dominance between males and females with similar handedness tendencies. The evidence from the present experiment is to some extent compatible with such notions.

To re-iterate the grounds for investigating the performance differences between male and female groups of the same handendess it is the consistency of sex x handedness interactions which promotes the initial concern. A significant interaction on the Houses test ($p<0.025$) may well have been mirrored by a similar interaction on the Blocks test had the range of scores been greater. As it was, the rank order of Blocks scores was:

1. Mixed
2. Right, and
3. Left for females and,

1. Left
2. Right, and
3. Mixed for males,

thus suggesting a difference in performance of left and mixed-handers between sexes. Both MLAT 3 and MLAT 5(both relative to total score) relate to handedness in different ways for males and females. For subtest 3 this is reflected in the Analysis of Variance by a significant interaction effect ($p<0.01$), while for subtest 5 the difference is disclosed by correlation coefficients for males and females which differ significantly ($p<0.05$) and in sign.

If only right-handed groups are considered over the three main test scores, it can be seen that male and female results are extremely similar:

	Houses(errors)	Blocks	MLAT
Female R.	23.00	44.38	58.63
Male R.	21.13	44.50	57.00

While those for left-handers show considerable differences (significant for houses test, $p<0.10$ for MLAT):

	Houses(errors)	Blocks	MLAT
Female L	25.25	43.88	65.38
Male L.	12.63	45.88	56.50

Could, then, the nature of left-handedness in males and females be a key to the interaction between sex and handedness? For both males and females, left-handers were slightly less strongly handed than right-handers (L.Q. and $\bar{z}$, see Table 7.1) and so the problem might be reinterpreted thus: do left-handers perform similarly to right-handers, do they exhibit the same results as mixed-handers, or are they different in nature to both right and mixed-handers in terms of scores? Bearing in mind the comments of McGlone & Davidson (1973) that left-handed females were especially poor spatially, it it interesting that on the Houses test both left and mixed-handed males perform well in relation to right-handers, whilst for females left-handers are the worst of all six male and female groups and are significantly worse than male left-handers. Male left-handed performance on this test is comparable to that of male mixed-handers, while female left-handers are shown to score similarly to female right-handers. Again on the Blocks test amongst females left-handers were the worst group, while amongst males they were the best.

While not irrefutably supporting McGlone and Davidson's remarks, it may be true to say that female left-handers are a 'special case'. This claim is further enhanced by comparisons of tachistoscopic scores. Although male and female sinistrals show equal proportions of FAML and equal distributions of eye dominance there is a difference in numbers of individuals with specific patterns of verbal-spatial scores:

	Letters rvf sup. Shapes lvf sup. (Right-handed brain)	Letters lvf sup. Shapes rvf sup. (Left-handed brain)
Male L.	0	4
Female L.	4	3

Consequently, controlling for Hand preference and dominance, eye dominance and incidence of FAML, tachistoscopic differences still emerge between male and female left-handers. Although the above figures are small, the Fisher E.P. of 0.1 suggests that the scores may reflect a real difference in performance on the part of male and female sinistrals.

If MLAT scores are considered in the light of sex differences and interactions then it can be seen that mixed handers contribute greatly to such effects. On total MLAT scores male mixed-handers perform worst of all 6 groups while, together with female left-handers, female mixed-handers perform best (Table 7.12).

Again on MLAT subtest 3 relative scores, female mixed-handers are the group which score most unpredictably, recording a significantly higher score than male mixed-handers.

Overall, however, it is with left-handers that the greatest impression of different profiles for males and females remains. In general, female left-handers show greater definition in patterns of cerebral dominance and more 'right-handed' brain organisation. They are inferior spatially but certainly not linguistically. Male left-handers, on the other hand, show definite signs of a 'left-handed' brain organisation (right cerebral dominance for letters and left cerebral dominance for shapes), prove spatially superior and to a certain extent linguistically inferior (in comparison with the other groups and with MLAT norms).

Familial left-handedness occurred more in females than in males and the total group of FAML subjects performed significantly better on the MLAT than the non-FAML subjects. While amongst left-handers the incidence of FAML is identical for males and females, it is in mixed-handers that females show more FAML (5/8) compared to males (1/8). FAML might conceivably account for the difference in performance on the MLAT of male and female mixed-handers. This is shown to be more likely when foreign language experience is found to be almost identical between the two mixed-handed groups. At this stage, however, no definite comments can really be made concerning the influence of FAML,more so due to the confusion already noted in the literature, where the direction of FAML effects, especially in tachistoscopic work, is contested (see 3.1.3 and Newcombe & Ratcliff 1974).

The effects of eye dominance on overall performance are also limited in terms of interpretation. While male and female left-handers possess the same degree of right-eyedness, only 4 male right-handers are consistent in hand-eye dominance compared to 7 females. This could almost certainly account for the different contributions of males and females to hemifield functioning for letters (see Table 7.2).

7.5 Conclusion

Clearly it is more difficult to establish the relationship between handedness and ability in the experimental situation than in the less explanatory situation of surveys or clinical studies where numbers of left, right and mixed-handers are compared in given ability ranges.

It may still be possible, however, especially with the use of measures such as the Houses test employed here, to establish differences in ability between laterality groups. Certainly such results as those produced by Levy (1969) can be held in question not only on the grounds that the handedness classification was inadequate but also, more significantly, because the WAIS verbal and performance measures involved were not specific enough to relate aspects of functioning to cerebral dominance. Levy's suggestion that the left or mixed-hander is spatially inferior is neither compatible with the present results (and the present study involved more mixed and left-handers than Levy's) nor with work in the area of dyslexia.

The results of the present experiment lend considerable support to the positive relationship between mixed handedness and ability in certain visuo-spatial tasks, and to the negative relationship between mixed handedness and linguistic tests involving the visual or auditory sequencing of items.

Mixed-handedness was significantly associated with superior performance on the Houses test, while on MLAT subtest 3 in particular, strong handedness implied a higher score relative to total MLAT score.

Through the sex differences and interactions with handedness found in the Houses test and MLAT test, it has been suggested that the nature of left-handedness and its relationship to cerebral dominance and ability may be different for males and females. Thus, in addition to pursuing research into mixed-handedness, a further study involving larger numbers of male and female left-handers equally matched in hand preference and other laterality factors would clarify the nature of ability differences between sinistrals of either sex.

8. FINAL DISCUSSION

8. FINAL DISCUSSION

8.1 Symmetry and asymmetry

The basis for assuming a relationship between handedness, cerebral dominance and certain facets of ability rests not only in observation or in experimentation but arises also from purely logical consideration. While the three investigations reported here lend considerable support to such a relationship, they remain no more impressive than the logical framework suggested by other authors. Corballis & Beale (1970), through studies of animals and humans, but also through reasoning, claim that,

"there are logical as well as empirical grounds for supposing that left-right confusion is indeed a consequence of bilateral symmetry ....

...... the fact that men usually can distinguish left from right was merely evidence that asymmetry existed somewhere in the nervous system .... (p.451)

.... Symmetries that are so prevalent in living organisms probably result mainly from lack of directional biases in the physical environment. But with the evolution of functions that are not tied to the immediate environment, there need no longer be any pressure toward symmetry: in fact, symmetry may often be a disadvantage. However, even man is more obviously symmetrical than he is asymmetrical, and even man occasionally confuses left and right." (p.462)

The 'left-right confusion' referred to above is a concomitant of the poor uni-directional and sequencing skills frequently mentioned here and elsewhere.

The logical contention is then that, with complete symmetry of cortical functioning and of hand preference, awareness of left and right, of a direction, is theoretically as well as practically impossible. The present investigation has attempted to demonstrate that, although individuals with perfect symmetry of function might never be found, symmetry is related by degree to modes of perceptual and intellectual functioning.

Some generalisation must be allowed. For instance, in claiming that an Art student is making use of good non-directional spatial skills it is not possible to substantiate this with any degree of scientific rigour. It is presumed that, in concentrating more on non-verbal learning, at which the students are considered superior, individuals are not confronted with an abundance of definite left-to-right analytic procedures. Artists will tend to succeed by envisaging whole events rather than by attending to linguistic detail.

En passant, an interesting observation with respect to Art students in the first investigation was that a great number had obtained 'A' levels in Art and English together. Very few students had acquired a foreign language 'A' level. This state of affairs might be explained by later discussions with mixed-handed subjects who invariably described their mode of reading as conceptual and image-forming rather than a directional attack on letters, words and sentences. Asked to describe how they read a page of a book, many stated that they never looked at each word in order but saw the page in large 'chunks', forming associations of images on a probabilistic basis. Thus many such students may have succeeded in the largely literary world of English 'A' level, while still floundering with the grammatical build-up approaches to foreign languages.

Although the tachistoscopic procedures of the third experiment failed to demonstrate adequately the link between <u>mixed</u>-handedness and lack of cerebral dominance, this was probably due to the influence of other factors already mentioned. Table 7.6 in fact does show a fairly equal distribution of 'right and left-handed brains' amongst mixed-handers, but the inadequacies of any measures of cerebral dominance, other than perhaps direct clinical assessments, leave the relationship between handedness and cerebral dominance in some experimental doubt. If, as seems most likely, strong right and left-handed individuals possess left and right cerebral dominance for language respectively, then the inference that the truly ambidextrous or mixed-handed individual would be most likely to show no dominance is a reasonable hypothesis.

The hypothesis that the mixed-hander (lacking cerebral dominance) will be relatively superior on tasks of a gestalt, spatial nature is supported by both the handedness investigation of Chapter 5 and, with reservations about female groups, by the experiment reported in Chapter 7. While the profile of male performance in this latter experiment is in concordance with the above hypothesis, the nature of female performance, despite some suggestions for this, remains somewhat puzzling.

It appears to be those abilities normally subserved by the minor hemisphere (see Chapter 2.3.2 and 2.5) which may be enhanced in mixed-handers. Thus it is possible that some minor hemisphere tasks of a spatial nature are better performed when those functions are most likely to be subserved by <u>both</u> hemispheres. This, together with the possibility that, in males, visuo-spatial functions are represented bilaterally to a greater degree anyway, could go some way to explaining the sex differences of Chapter 7. The suggestion that spatial abilities are subserved by both hemispheres more in males than in females is mirrored by the finding that on the tachistoscopic task involving spatial stimuli(Table 7.3) females (average hemifield differences 0.7) consistently showed less field preference than males (average hemifield difference 1.1). Thus, after taking into account the right field bias, females were more likely to possess right hemisphere dominance for spatial functions.

Other possible reasons for the interaction effects between sex and handedness have been dealt with in Chapter 7.4 and the next section will concern itself with the sex differences found in handedness alone.

8.2 Overview of sex differences in laterality

In each of the three studies some evidence was forthcoming which consistently revealed sex differences in handedness. While laterality differences sought between males and females have often remained on the level of comparisons of numbers of left and right-handers, closer scrutiny shows that no studies find significant differences between the incidences of strong left-handedness in males and females (where strong left-handedness refers to, for example, left hand preference for all items of a questionnaire, or a Laterality Quotient below a given score).

The general hypothesis involved the greater incidence of males towards the centre of handedness distributions, whether this be to the right or left of the point on the distribution indicating no overall manual preference (questionnaires) or dominance (performance tests).

It was apparent that, in the laterality survey of Artists, Engineers and Linguists, the results were often exaggerated by male-female differences which were similar for both Artists and Linguists (there being too few female Engineers for conmparison). Although the predicted relationships between mixed-handedness and course of study arose when males and females were studied separately, the different numbers of males and females in each sample was having an obvious effect on total group results. Females were more consistent in their hand preference than males and this trend was further reflected in other laterality measures.

The comparison of handedness measures in Chapter 6 yielded further proof that it was in terms of mixed-handedness that sex differences could best be described. The overall greater inconsistency, not only within preference and performance measures but also between various tests added a further dimension to the results of the survey.

The final experiment, comparing handedness groups over three tests of ability, emphasised sex differences in further ways. First, although ostensibly merely an observation, some difficulty was met in finding subjects for (a) the female mixed-handed group and (b) the male left-handed group. Again this raises the likelihood that females in the centre of the handedness distribution and males at the extreme left end exist in relatively smaller numbers than individual s with similar handedness of the opposite sex.

Secondly, the Houses test, although producing an interaction effect between sex and handedness (see Chapter 7.4) did uncover both (a) a simple sex difference in spatial ability with handedness controlled and (b) a positive relationship between mixed-handedness and spatial ability for both males and females, although correlations were significant only for males. Female mixed-handers performed well in comparison to right and left-handed groups, although female left-handers showed tendencies at variance with those of male left-handers.

8.3 Laterality implications for dyslexia

Clinical work at Aston University (see for instance Newton & Thomson, 1974) has not only demonstrated a relationship between dyslexia and inconsistent laterality, but has also produced numerous cases of dyslexia where a strong genetic component appears to relate reading problems in the child to similar past or present problems in the parent or parents. In most cases one or both parents also display evidence of inconsistency in handedness and very often a spatial ability which is revealed in their occupation or interests (see Hepworth, 1971; Bannatyne, 1966b). Where the father has had severe reading problems, traces of which often remain, it is very common to find him pursuing a career as, for example, an architect, doctor, engineer or dentist - in other words a career where spatial ability rather than clerical or verbal ability is of great importance.

Thus, in the patterns of ability and handedness in adults and children many similarities can be seen. Although as an adult an early reading problem may have been corrected, the cause or difficulties underlying the original problem will still influence the abilities utilised in occupations. A dyslexic will only rarely grow up to become extremely proficient in linguistic-type tasks which involve the visual and auditory sequencing with which originally so many difficulties were encountered. On the other hand, the spatial competence which accompanies so many cases of dyslexia will persist and continue to influence interests, opportunities and careers.

Since it has been argued (see Chapter 1.2) that hand preference does not change significantly after the age of 8 or 9 years, the mixed-handed children of that age who are diagnosed as dyslexic (it is not usually until the age of 8 or 9 that persistent failure results in specialist diagnosis) are unlikely to suddenly or even eventually become strong handers however delayed their psychomotor development is thought to be. Remediation must therefore take into account that such children are not, and probably never will be, in an advantageous position for the easy acquisition of directional perceptual skills involved in reading.

If some children have not developed to the stage where asymmetry of the perceiving system allows easy retention and acquisition of directional skills necessary to reading, then the point has been reached where mixed-handedness and failure in reading may be seen to go hand-in-hand. If, furthermore, mixed-handedness (and cerebral dominance) is a biological variant and not simply a reflection of late maturation, then remedial teaching must attack the cause of the failure <u>in the material</u> and not in the child. The directional and sequential nature of the written word must be explicitly or implicitly 'manipulated' so that at-risk children are not always expected to automatically and immediately grasp symbols arranged in an orientation, a sequence and a direction.

The present investigation has related spatial ability and facets of linguistic ability to handedness variables in adults. The fact that the expected relationships in Chapter 7 occurred more frequently for males than for females may correspond with the greater incidence (approximately 4:1) of dyslexia in males. It was, after all, in observation of dyslexic children that motivation for the present study was borne. It is hoped that results such as those presented here will strengthen the body of opinion which submits to a constitutional basis for dyslexia - a claim that some otherwise intelligent children, through no fault of their own, are left with enormous disadvantages in our verbally-biased society and educational system.

It is most likely that the mixed-handed boy of around ten years who appears at a clinic armed with a detailed diagram of the cross-section of an internal combustion engine, which he has drawn himself, will gain no easy foothold in the educational system with which to do justice to the obvious talents he possesses. As Professor A. Tropp (1975) has stated, the exam system in this country is ruthlessly exploiting the linguistically able children and is leaving behind the large minority of intelligent children with reading problems. The fact that 'O' level English, very often the hardest of all exams for such a child, is frequently required for admission to courses in Art or related subjects, speaks for itself. Dyslexic children are therefore at a real disadvantage and it is partly through studies which will provide reasons for an intelligent person's failure in written language, that educational support will be found for such children.

In conclusion, through being at 'biological variance' with their counterparts in the basically unnatural mechanical task of reading, many children are not enabled to succeed in tasks of a spatial nature, for which their intelligence fully equips them.

8.4 Future research

Ideally an extension of the present work with younger subjects can be envisaged. However, although an attempt to link levels of ability to handedness in children is obviously desirable, it appears to have been beset with many difficulties (judging from the confusion in the literature). For instance, it is considerably more difficult to find groups of children in which handedness is easily controlled. Each child, especially under the age of 8, may be at a different stage of development in hand preference and this developmental factor should really be taken into account when considering the relationship between observed handedness and ability. The use of young children in performance tests of handedness also appears to be somewhat limited (in the literature only simple measures can be found - see Chapter 1.3.1.2) although the effects of practice would undoubtedly be less than for adults.

The study of handedness and abilities in adults is less satisfactory since the benefits of any such study are primarily intended for children. It is, however, in adults that the permanent effects of the interaction between individual approaches to the task of reading and the task itself are observed. If a link can be maintained between the development of handedness and abilities in children and in adults then extreme relevance can be seen in sometimes studying adults alone.

Whether with children or with adults, certain improvements in the methods of the present investigation are certainly possible. Most noticeable are the factors which could ideally have been controlled in the experiment of Chapter 7. For instance, although handedness was, in the writer's opinion, well controlled and groups well matched by sex and handedness, larger samples, in which more equal numbers of crossed and consistent laterals (hand and eye) and subjects with and without FAML could be present, would have been preferable. It is not clear whether such groups could easily be formed, since to control for laterality factors other than handedness would impose very great restrictions on inclusion into sub-groups. In actuality it appears that groups independently arranged according to laterality criteria are no easy proposition and other means (factor analysis or further less explanatory correlational measures) may be better suited to some situations where adequate independent groups cannot be formed.

It is possible (in the writer's opinion) to uphold the present experiment (Chapter 7) on the grounds that handedness, the most easily accessible and measurable index of cerebral dominance was controlled far more stringently than in previous studies. Handedness alone must be carefully related to the ability levels in question before extensive studies look towards all other laterality variables in similar detail.

8.5 Recapitulation

In terms of overall handedness distributions man is unique in his strong asymmetry of hand preference. There is much disparity, however, in methods of assessing and classifying this hand preference.

Clinical and experimental indicators of cerebral dominance provide a general, but not too accurate, picture of the localisation of functions within the human brain. Most common is the situation where the left hemisphere subserves language functions while the right (and possibly left) hemisphere controls visuo-spatial functions.

The degree of ambiguity in assessment of handedness and cerebral dominance leaves one with no precise means of ascertaining the exact relationship between them. A relationship is shown to exist, however, through clinical studies of unilateral brain lesions and by tachistoscopic or dichotic listening techniques.

It appears that:

1. Strong right-handers will almost certainly possess left cerebral dominance for language with a tendency to show right cerebral dominance for spatial functions.
2. Strong left-handers, perhaps especially those with familial left-handedness, will be most likely to show the opposite trends (right cerebral dominance for language)
3. Mixed-handers, although tending to possess left cerebral dominance for language, will be most likely to demonstrate non-resolution of cerebral dominance, and to be unpredictable in terms of cerebral dominance.

Investigations relating specific ability levels to handedness must ultimately be studying the association between good or poor abilities and patterns of cerebral dominance. Here, two models must be reconciled:

1. Left (mixed) handers are poor spatially, average verbally (on WAIS/WISC type tests, see Levy 1969), and
2. Left (mixed) handed children and adults are often poor on basic linguistic tasks (such as reading) and good at certain spatial tasks.

The reason suggested for the apparent incongruity of these two models is the diverging concepts of 'verbal' and 'spatial'. For instance, the 'verbal' scale of the WISC involves little linguistic analysis or perceptual skill. On the basis of clinical work, model 2 is accepted and model 1 re-interpreted.

Mixed handers (note - left-handers are not included since the present investigation represents only strong left-handers as left-handers) are supposed to be superior in perceptual, visuo-spatial tasks of a non-directional nature while often presenting difficulties with the sequencing of linguistic items and the perception of items arranged in an orientation sequence and direction. In reading, for example, letters must be perceived in their correct orientation in their correct sequence, and in the correct direction (left to right).

The experimental sections (Chapters 5, 6, 7) involve three investigations: First, subjects with greater spatial skills showed significantly more mixed-handedness and left-footedness than linguistically gifted subjects. Thus, at least in numbers of mixed-handers succeeding artistically, there is evidence that refutes Levy's claim that left or mixed-handers are poor spatially. Agreement is found with the observation that dyslexics and parents of dyslexics displaying mixed-handed tendencies progress to occupations involving high degrees of spatial ability.

It is postulated that symmetry of cortical functioning, most likely in mixed-handers, is positively related to visuo-spatial ability, while strong asymmetry is associated with easy acquisition and good deployment of linguistic-type skills.

Secondly, an in-depth study of handedness was carried out in order to investigate various handedness measures and their inter-relationships. Distributions were produced for 3 questionnaires and 3 performance tests over 144 subjects and it was demonstrated that the questionnaire with the most 'left' responses, consistently displayed better correspondence with performance test rankings.

Using the handedness distributions mentioned above, 6 groups were formed according to strict handedness criteria and were employed in an independent groups design. In particular, mixed-handedness was again shown to relate to spatial ability of a non-directional nature (Houses test) where whole events were reconstructed from memory. A Blocks Design test was unrelated to handedness, and it was suggested that this test may not be the best example of visuo-spatial ability in the present context.

On a test of linguistic ability mixed-handedness was positively related, in males, to whole word memory and negatively related, in males, to a test involving the visual and auditory sequencing of letters and phonemes. (Both findings as predicted)

Females, due mainly to the performance of left-handers, scored on these tests at variance with males. It is suggested that male left-handers may possess cerebral dominance of a similar nature to mixed-handers while female left-handers possess more defined specialisation of function.

Overall, the literature and experimental sections indicate:

1. A relationship between mixed-handedness and good spatial ability, where the perception of directional and sequential material is not involved.
2. A relationship between strong-handedness and linguistic ability (basically not the conceptual and information verbal ability measured by the WAIS).
3. Sex differences in handedness (more male mixed-handers) and in ability (males superior spatially, females verbally).

The present work parallels clinical observation and evidence in the field of dyslexia and supports the notion that mixed-handedness in children, while delaying or preventing easy acquisition of linguistic (reading) skills, may facilitate the manipulation of spatial items where the ordering and orientation of such items is not of prime importance.

APPENDICES

Terminology

Chapter 5 : 5.1 Laterality questionnaire
5.2 Letter accompanying questionnaire

Chapter 6 : 6.1 Laterality questionnaire (Annett)
6.2 Laterality questionnaire (Harris)
6.3 Laterality questionnaire (Oldfield)

Chapter 7 : 7.1 Tachistoscopic stimuli (letters) : examples of right and left field stimuli
7.2 Tachistoscopic stimuli (shapes) : examples of right and left field stimuli plus selection card of 7 shapes
7.3 Instructions for Houses test
7.4 Vocabulary for MLAT subtest 5
7.5 Eye dominance, FAML and foreign language experience in laterality groups.

TERMINOLOGY

See Cohen and Glass (1968) for a similar list of definitions

Handedness:	The preference of one hand or the superior skill of one hand for given activities. While a general definition is perhaps not possible, 'handedness' is taken to embrace all specific and general aspects of hand preference and skill.
Preference and Dominance:	Although 'dominance' was originally a term employed by neurologists, it is not uncommon to read now of hand or eye dominance. The expressions 'preferred hand' or 'dominant hand' are often interchangeable, although 'preference' will refer more to subjective measures and 'dominance' more to objective measures of hand or eye superiority. For instance, a test of visual acuity will demonstrate a <u>dominant</u> eye, while observation of the eye used to look through a telescope may result in a <u>preferred</u> eye.
Laterality:	As defined by Touwen (1972), 'laterality' is the phenomenon by which ......"the performance of tasks, afferent or efferent, succeeds better on one side than the other." Laterality is often taken to by synonymous with handedness, but includes also foot, eye and ear preferences.

Crossed laterality: - where preferences in at least two different modalities are contralateral (on opposite sides). This term normally applies to eye and hand preferences but again could apply to any modalities.

Mixed laterality: - refers to lack of strong preference or inconsistency of preference in one or more modalities. It is often used to denote combinations of right and left answers on handedness questionnaires (as opposed to 'ambidexterity' which may involve equal skill with both hands on a number of items).

Cerebral Dominance: (sometimes 'Brainedness') - refers to the greater involvement of one cerebral hemisphere in a particular function. Normally (and here) 'Cerebral Dominance', used without further qualification, implies the attribution of greater involvement in language functions to one hemisphere (usually the left).

Equipotentiality: The equal possibility of either hemisphere playing the greater role in the processing of language stimuli. This term is often used in the context of lack of cerebral dominance at birth, but is taken here to involve lack of dominance at any age.

LATERALITY QUESTIONNAIRE

Name .... Date .... Age ...... Sex ....

Course of Study .... 'A Levels' ....

(a) How would you classify yourself?
(tick in appropriate place)

Strongly Right-handed	
Right-handed but left hand for some things	
Ambidextrous	
Left-handed but right hand for some things	
Strongly left-handed	

(b) Which hand would you use for the following activities? Tick in the appropriate column.

	LEFT	RIGHT	EITHER
I. WRITE			
2. KNIFE(cutting)			
3. CLEAN TEETH			
4. COMB HAIR			
5. PLAY TENNIS/CRICKET/GOLF			
6. PAINT & DRAW			
7. THROW BALL			
8. THROW PUNCH			
9. STIR DRINK			
IO. USE SCISSORS			
II. DEAL CARDS			
I2. PLAY INSTRUMENT(GUITAR)			
I3. HAMMER NAIL			

(c) Which foot do you kick with?
(tick in appropriate space)

LEFT	RIGHT	EITHER

(d) Which eye do you use for (a)looking through telescope
(b)pointing *

	LEFT	RIGHT	EITHER
(a)			
(b)			

* To determine your 'pointing eye', keep both eyes open and point with outstretched arm at a small, distant object. With your fingers still pointing at the object, cover each eye in turn with the other hand. The eye through which you see your finger still pointing directly at the object is your 'pointing eye'.

(e) Are any members of your family left-handed?

MOTHER	FATHER	BROTHER/SISTER

THE UNIVERSITY
OF ASTON
IN BIRMINGHAM

College House, Gosta Green, Birmingham B4 7ET
Tel: 021.359 3611 Ex 227

Applied Psychology Department
Head of Department: Professor W T Singleton MA, DSc

October 1973

Dear ,

Your help is required in a worthwhile project!

I am a research student in the Department of Applied Psychology at Aston University. My area of research is Child Language and Reading Disorders.

In order to carry out this research I must study the relationships between factors involved in reading failure. Two of the factors I am looking at are Handedness (which hand, eye and foot you use for various activities) and Ability in certain areas(e.g. what type of course you are doing). Insight into the relationship between these factors can be crucial in understanding a phenomenon which has wide educational implications.

Information is urgently required from both Right-handed, Left-handed and Ambidextrous people, and I would be grateful if you could fill in and return the enclosed questionnaire.

It is essential that I receive replies from individuals such as yourself if I am to complete this study.

If you are able to find time to fill in the short questionnaire, please replace it in the envelope provided and return it to a secretary in your DEPARTMENTAL OFFICE, as follows:

All correspondence will be dealt with in the strictest confidence.

Thank you for your co-operation,

David Bate

Telex 336997

LATERALITY QUESTIONNAIRE (A)

Please indicate which hand you habitually use for each of the following activities by writing R(for right), L(for left), E(for either).

Which hand do you use:

I. to write a letter legibly? ....

2. to throw a ball to hit a target? ....

3. to hold a racket in tennis, squash or badminton? ....

4. to hold a match whilst striking it? ....

5. to cut with scissors? ....

6. to guide a thread through the eye of a needle (or guide needle onto thread)? ....

7. at the top of a broom while sweeping? ....

8. at the top of a shovel when moving sand? ....

9. to deal playing cards? ....

IO. to hammer a nail into wood? ....

II. to hold a toothbrush, while cleaning your teeth? ....

I2. to unscrew the lid of a jar? ....

L.Q. [ ] Leave this space blank

LATERALITY QUESTIONNAIRE (H)

Hand Preferences

I. Throw a ball ....

2. Wind a watch ....

3. Hammer a nail ....

4. Brush teeth ....

5. Comb hair ....

6. Turn door knob ....

7. Hold eraser ....

8. Use scissors ....

9. Cut with knife ....

IO. Write ....

L.Q. | |

LATERALITY QUESTIONNAIRE (O)

Please indicate your preferences in the use of hands in the following activities by putting + in the appropriate column. Where 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 really indifferent put + in both columns.

Some of the activities require both hands. In these cases the part of the task, or object, for which 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
I. Writing		
2. Drawing		
3. Throwing		
4. Scissors		
5. Toothbrush		
6. Knife(without fork)		
7. Spoon		
8. Broom(upper hand)		
9. Striking match(match)		
IO. Opening box(lid)		

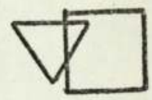
L.Q. [ ] Leave this space blank

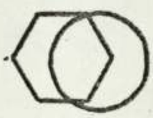
7.1 Tachistoscopic stimuli (letters) (examples of right and left field stimuli)

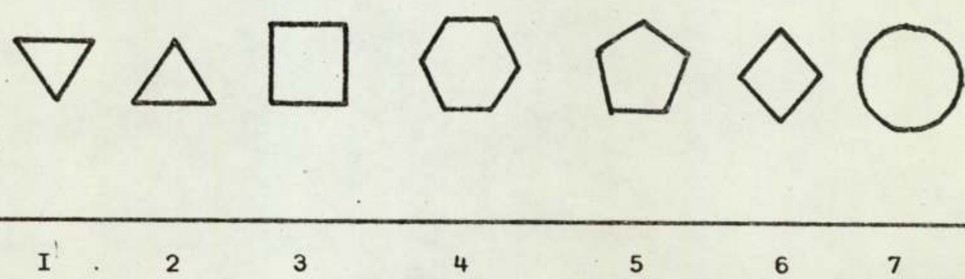
w f v

h d g

7.2 Tachistoscopic stimuli (shapes) (examples of right and left field stimuli plus selection card of 7 shapes)







7.3 INSTRUCTIONS FOR HOUSES TEST

"You will be shown a series of maps involving houses and hotels. Each map will be presented for three seconds and then you will have up to thirty seconds to reconstruct, from memory, the map which you have just seen. When you are sure that your map resembles as closely as possible the map which was presented you may say 'finished' and then you will be told whether your attempt was correct or not."

7.4 Vocabulary for MLAT Subtest 5

Kurdish	-	English
hij	-	draw
naq	-	that
sidqu	-	news
nente	-	lady
ja	-	day
n goz	-	dark
tsep	-	enter
lohong	-	ask
mupa	-	anger
nung	-	frog
chomco	-	body
roo	-	art
kete	-	camel
chie	-	few
y ong	-	hawk
hui	-	fall
xozo	-	easy
mep	-	on
lah	-	wolf
wener	-	book
mi	-	touch
jate	-	sun
e	-	bowl
hon	-	cold

Numbers of Left, Mixed and Right Eye Dominant Subjects in Laterality Groups

Eye Dominance (based on two sighting tasks)

	Left	Mixed	Right	R-L
Male Left-handers	4	2	2	-2
Mixed	2	2	4	+2
Right	2	2	4	+2
Female Left-handers	5	0	3	-2
Mixed	I	3	4	+3
Right	I	0	7	+6

Incidence of FAML in Laterality Groups

Handedness Groups

	Male			Female			Total		
	L	M	R	L	M	R	L	M	R
FAML +	6	I	I	6	5	3	I2	6	4
FAML -	2	7	7	2	3	5	4	I0	I2

Total: $\chi^2 = 8.73$ ($p < 0.025$)

Foreign Language Experience in Laterality Groups

Subjects were given
I point for an 'O' Level in a Foreign Language
2 points for an 'A' Level in a Foreign Language
3 points for University Level studies

Below are Average Group Scores together with Total MLAT scores

Handedness Groups

	Male			Female			Total		
	L	M	R	L	M	R	L	M	R
Experience	I.I3	0.88	0.50	I.75	I.00	I.25	I.44	0.94	0.88
MLAT	56.5	52.8	58.6	65.4	65.0	57.0	60.9	58.9	57.8

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